BACHELOR'S THESIS

Analysis of the Economic Viability of the Use of Renewable Energy in the Community Service Centre of Prek Hou

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To my family, for the help, support and unconditional love that they have always showed me.

To my friends, who bring me joy.

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And to Pour un Sourire d’Enfant (PSE), which has given me the chance to help them with their project in Cambodia.

ABSTRACT

This Bachelor's Thesis is based on the field of Development Cooperation projects. It is a study of the economic viability of the use of renewable energy for the independent generation of electricity in a school in Cambodia, so as to analyse if the use of sustainable technology is profitable.

In this context, a deep study regarding the current energy generation and electricity situation has been done, as well as the possibilities given by the country's legislation. In addition, the use of solar PV panels has been considered for the electricity generation and an energy system has been calculated for the educational centre. Furthermore, in order to analyse the viability of the project, the Levelized Cost of Energy (LCOE) calculation has been carried out as well as the Learning Curve calculation so as to study how the prices of solar PV panel will develop in the next years.

This research studies the viability of the transition to the use of sustainable energy technologies in education centres in the country, focusing in the Community Service Centre of Prek Hou, as well as to make an analysis of the policies that should encourage this transition.

TABLE OF CONTENTS

1. Introduction 5
   1.1. Literature review 6
2. Community Service Centre of Prek Hou 7
   2.1. General context of Cambodia 7
   2.2. Location 8
   2.3. Climatology 9
   2.4. Topography 10
3. Cambodian Electricity Situation 10
   3.1. The structure of energy authorities 12
4. Renewable Energy Sources 12
   4.1. Hydropower 12
   4.2. Biomass 12
   4.3. Solar power 13
   4.4. Wind power 13
5. Energy Policies 13
   5.1. Barriers for distributed renewable energy technology 15
6. Solar PV Panels Installation 15
   6.1. Electric power consumption 16
   6.2. Available solar irradiation 17
   6.3. Number of PV panels' calculation 18
   6.4. Battery size 19
   6.5. Charge controller 20
   6.6. DC/AC inverter 20
7. Levelized Cost of Energy (LCOE) 21
   7.1. LCOE calculation 21
8. Learning Effects 23
   8.1. Solar PV Learning Curve calculation 24
9. Renewable Energy Policies in ASEAN Countries 26
10. Conclusion 28

References 29

List of Figures

Figure 1: The 17 Goals of the 2030 Agenda for Sustainable Development. Source: un.org......... 5
Figure 2: Cambodia. Source: mapsoftheworld.com.. 7
Figure 3: Community Service Centre of Prek Hou's location. Source: Google Maps.................... 8
Figure 4: PSE Takh Mao Summer Camp 2019. Source: psncamboya.org 9
Figure 5: Cambodian Electricity Generation Rate. Source: Asian Development Bank (ADB) 11
Figure 6: Cambodia's Electric Power Consumption per Capita. Source: data.worldbank.org 11
Figure 7: Situation of Electrification in Cambodia (City + Rural as in December 2019). Source: eac.gov.kh 14
Figure 8: Off-grid Solar PV System Diagram. Source: guides.co 16
Figure 9: PV Learning Curve 2021-2025. Source: Author's Calculation 25
Figure 10: Evolution of the installed Solar PV Capacity. Source: irena.org................................ 27

List of Tables

Table 1: Average Temperature per month. Source: climatestotravel.com 9
Table 2: Average rainfall per month Source: climatestotravel.com 9
Table 3: Average of daily sunshine hours per month. Source: climatestotravel.com 10
Table 4: Solar Map Data. Source: globalsolaratlas.info 10
Table 5: Centre's electricity consumption. Source: Author's elaboration 17
Table 6: Solar electricity generation and irradiation of Ta Khmau. Source: globalsolaratlas.info 18
Table 7: Initial Investment Cost Calculation. Source: Alibaba.com... 22
Table 8: NREL LCOE Calculator Input Data. Source: Author's data 22
Table 9: Cumulative PV capacity from 2015. Source: GlobalData 25

1. Introduction

This Bachelor's thesis is focused on the field of development cooperation projects, making an analysis of the viability of the use of renewable energy in a school in Krong Ta Khmau, Cambodia, and the study of the energy situation of the country.

The motivation of this thesis is to study the transition to a more sustainable energy generation system by studying if the use of renewable energy in an education centre could be profitable from an economic perspective. Nowadays, countries are urged to achieve sustainable development in order to assure a social, economic and environmentally friendly future. The United Nations (UN), has proposed the "2030 Agenda for Sustainable Development" which has set 17 goals which are focused on the wellbeing of the people, the planet and the prosperity of the nations. [1]

Figure 1: The 17 Goals of the 2030 Agenda for Sustainable Development. Source: un.org

Within the 17 goals proposed by the UN, the followings can be found: quality education, affordable and clean energy and sustainable cities and communities. Therefore, this paper aims to develop a renewable energy project for a school in a developing country in order to encourage the generation of electricity by using sustainable energy sources.

A lot of works have been completed regarding the use of renewable energy in developing countries, so as to accomplish the affordable and clean energy goal. Most of them, are focused on the electrification of rural areas where the national grids of these countries cannot reach them, so sustainable energy projects are developed in order to provide electricity independently. However, this paper aims to transform the way an educational centre, which already has access to electricity through the national grid, gets its energy in order to make a transition to a more independent, environmentally friendly and secure energy generation system. Also, an economic study of the project will be made so as to analyse that this transition is viable and if it implies savings regarding the school's costs for its current electricity.

In this context, the study of the implementation of renewable energy technologies in the Community Centre of Prek Hou, in Krong Ta Khmau, is proposed. The high prices of electricity paid in Cambodia and the growing consumption of this type of energy urge the development of technologies which will help the country accomplish this growing electricity demand and make it more affordable, by using the country's sustainable energy sources potential.

1.1. Literature review

The analysis of the profitability of the adaption of renewable energy technologies for small buildings is a field of study that has been reviewed in similar projects. This research conducted a literature review in order to identify the economic analysis made in similar projects so as to learn what were the methodologies used.

There are numerous of Solar Home System (SHS) projects in Cambodia as the electric national grid hasn't arrived to some rural areas. Han Phoumin (in September 2015), from Economic Research Institute for ASEAN, focused his studies on the use of solar PV panels for rural households. He investigated the renewable energy polices present in Cambodia and compared the price of using a diesel generator with the cost of building SHS in these areas. The methodology used to analyse the costs of the transition to a more sustainable electricity generation system was calculating the Levelized Cost of Energy (LCOE) in two scenarios, with and without government subsidies from the Rural Electrification Fund. [2]

From the Thammasat University, in Thailand, Chhunheng Lao (in May 2017) made a techno-economic analysis of hybrid systems for rural electrification in Cambodia. He considered using a diesel generator, solar PV panels and a battery system as the optimal solution so as to supply electricity to remote villages of the countryside. In order to analyse the economics of the project, using a simulation software, he ran different scenarios and analysed the Cost of Electricity (COE) as well the Net Present Cost (NPC) of the project. [3]

From the Kyoto University, in Japan, a group of researchers (in November 2019) elaborated a discussion paper of the LCOE analysis of grid connected PV systems of utility scale across selected ASEAN countries. The paper focuses on assessing the LCOE of solar PV energy projects until 2040. In order to study how the costs of the components of the energy system decrease, the Learning Curve method is used. They have elaborated different learning curves for each territory based on local data. Therefore, a comparison of how the cost of energy decreases based on the learning curve calculation for the cumulative output capacity for the upcoming years in Indonesia, Malaysia and Thailand is done. [4]

A Learning Curve analysis in residential buildings in Thailand with photovoltaic systems has been made by a group of researchers (in September 2011) from the Naresuan University, in Thailand. The paper studies how the cost of PV technologies varies through time based on the cumulative output capacity of the technology. The aim of the research is to determine, using the learning curve calculations, when would the grid parity point take place for the residential sector based on the predicted price reductions. Hence, the results of the research would encourage the development of renewable energy polices so as to promote the use of this technologies as they become more competitive. [5]

A group of researchers (in August 2019), elaborated a study of the economics of solar PV self-consumption in Thailand. The focus on three different scenarios which were: no compensation for electricity, net metering and net billing. The economic analysis of the project was done using the System Advisor Model (SAM) which focuses on the LCOE calculation and Net Present Value (NPV) among other methods. After running the simulations for the different possibilities, the optimal one is chosen and the analysis is concluded with policy recommendations for the development of the PV sector. [6]

2. Community Service Centre of Prek Hou

2.1. General context of Cambodia

Cambodia is a country on the Indochinese mainland of South East Asia. The country has a population of 16.25 million people (2018) and 23% of those live in urban areas. As most developing countries, Cambodia is experiencing a rapid increase of population, which has now a rate of 1.48% per year, which makes the demand of energy higher and the need to develop new sustainable energy sources very important.

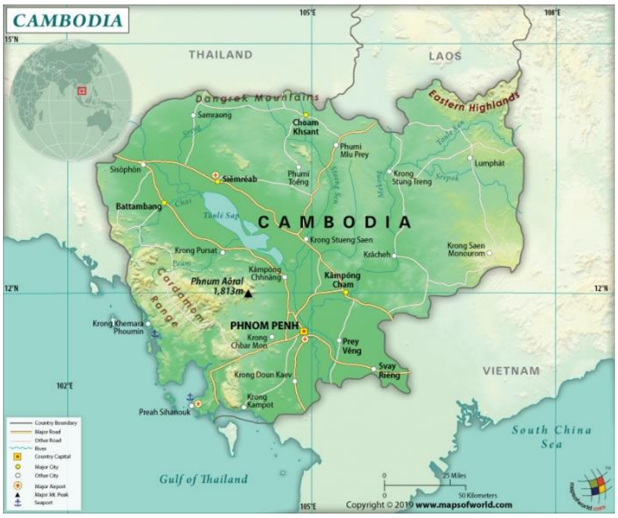

Figure 2: Cambodia. Source: mapsoftheworld.com

During the 20th Century, Cambodia experienced the turmoil of war, occupation by the Japanese, post-war independence and political instability. From 1975 to 1979, the control of the country was taken by the Khmer Rouge, a rural communist guerrilla movement, which carried out the Cambodian genocide in which 2 million people died of starvation and murder [7]. The country is still recovering from this humanitarian disaster. Hence, Cambodia has had difficulties developing its energy sector during the subsequent years after this catastrophe as it had to overcome from the terrible state in which the country as a whole was left.

Over the past two decades, Cambodia has undergone a significant transition driven by the increase of exports and tourism. Its economy has sustained an average growth rate of 8% between 1998 and 2018, making it one of the fastest growing economies in the world. In 2018, Cambodia's GDP per capita was 1,510 US$. In addition, the country is urbanizing rapidly but from a low level, as 77% of population still lived in rural areas in 2017.

According to estimates, the poverty rate was 13.5% in 2014 compared to 47.8% in 2007. About 90% of the poor live in rural areas and the vast majority of people who escaped poverty did so by a very low margin since 4.5 million people remain nearly-poor, vulnerable to fall into poverty when exposed to economic shocks. [8]

Cambodia has made great progress in educating its children, as the number of children enrolled in preschool programmes has more than doubled. The number of children enrolled in primary education has reached 97% in school year 2017/2018. However, children are failing to acquire learning standards appropriate to their age and by the time they are 17 years old, 55% of adolescents will have dropped out of school. [9]

The Community Service Centre of Prek Hou has proved to be very successful in terms of avoiding children to drop out from school. The education centre has started external education activities to support children and their families in their education and personal development, having very high rates of participation. Since the centre was inaugurated, reports show that children are in better health due to regular support for nutrition and hygiene. [10]

2.2. Location

The Community Service Centre of Prek Hou, also known as Takhmao Children Support Centre, is located in Prek Hou Lech Village in Krong Ta Khmau, the capital city of Kandal Province, in central Cambodia. It is 11km south from Cambodia's capital city, Phnom Penh.

The coordinates of the community service centre are: 11°27'18.8"N 104°56'00.8"E.

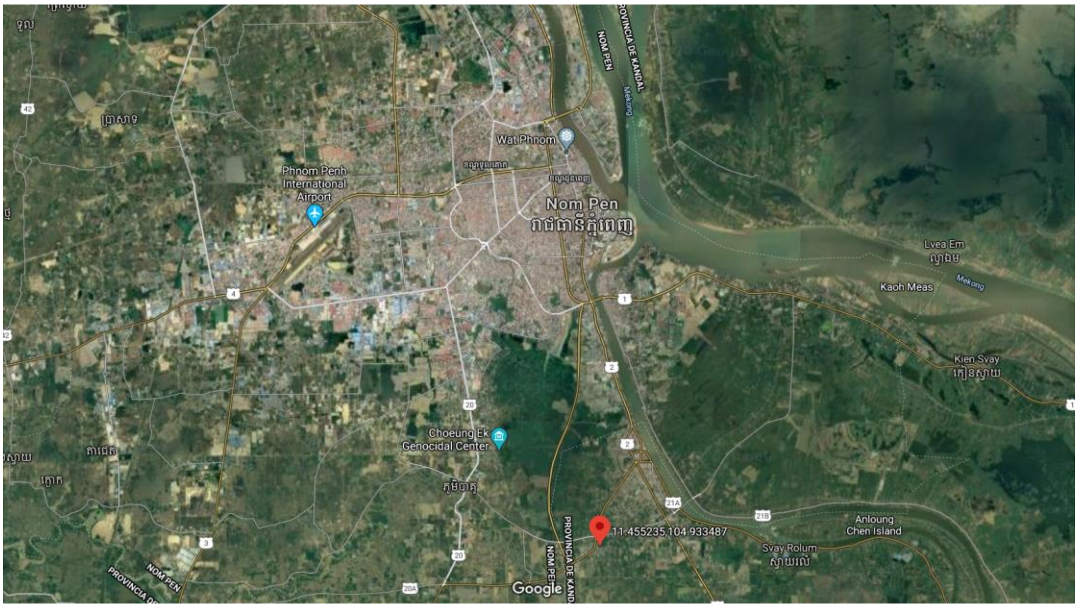

Figure 3: Community Service Centre of Prek Hou's location. Source: Google Maps

Prek Hou Lech Village is a neighbourhood which belongs to Krong Ta Khmau, one of Cambodia's largest cities. One of the main tasks of the children who come to Takhmao Children Support Centre, apart from fishing and agriculture, is going to the dumpsite searching for recycled material to be sold. This situation, with the problematic of alcoholism, drug addiction and unemployment of the children's parents, creates in this neighbourhood a very dangerous environment for the infants to grow in.

In 2014, the NGO Smalls Steps Project, partnering with the NGO Pour un Sourire d'Enfant (PSE), established the Community Service Centre of Prek Hou, which aims to provide education, nursery and nutrition to the children living in Prek Hou Lech Village. The centre provides education to around 70 children ranging from 0 to 6 years old during the year. However, during the School Continuity Program organized by PSE, the centre hosts up to 200 infants during the summer camp. The community helped by this education centre, mainly lives in a village that surrounds the dump in flimsy wood and thatched huts, with limited access to water and sanitation. [10]

Figure 4: PSE Takh Mao Summer Camp 2019. Source: psncamboya.org

2.3. Climatology

Cambodia has a tropical climate, having hot temperatures during all the year, with a rainy season that lasts from May to mid-November due to the south-west monsoon and a dry season from mid-November to April.

The coolest month is December, while the hottest months are April and May; in the rainy season, the temperature is a bit lower, but the humidity is higher.

The day time temperature is 30ºC in November and December, and it begins to rise in January reaching its highest value in April, with an average of 35ºC but with peaks of 40ºC. However, it slightly decreases during the months belonging to the rainy season.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (ºC)	22	23	24	25	25	25	25	25	24	24	23	22
Max (ºC)	32	33	35	35	34	34	33	33	32	31	30	30

Table 1: Average Temperature per month. Source: climatestotravel.com

There is average rainfall per year is 1,400 mm, with a minimum in January when the rain is practically inexistent and a maximum in October, when the rainfall reaches 250 mm. The last part of the monsoon period is the one that registers the largest amount of rain, presenting a high risk of flooding.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec. (mm)	7	10	40	75	135	155	170	160	225	255	125	45
Days	1	1	3	6	14	15	16	16	19	17	9	4

Table 2: Average rainfall per month Source: climatestotravel.com

The amount of sunshine is high from December to February, but also in March and April, despite the thunderstorms. However, from June to October the cloudiness brought by the monsoon decreases the sunshine hours. [11]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	8	8	9	8	7	6	5	6	4	7	7	8

Table 3: Average of daily sunshine hours per month. Source: climatestotravel.com

Also, the following data regarding the annual solar irradiation in Ta Khmau is available:

Direct normal irradiation	DNI	1,433	kWh/m²
Global horizontal irradiation	GHI	1,943	kWh/m²
Diffuse horizontal irradiation	DIF	899	kWh/m²
Global tilted irradiation at optimum angle	GTI_opta	1,986	kWh/m²
Air temperature	TEMP	28,4	°C
Optimum tilt of PV modules	OPTA	14	°
Terrain elevation	ELE	11	m

Table 4: Solar Map Data. Source: globalsolaratlas.info

2.4. Topography

What is known as the heart of Cambodia, occupying three-quarters of the country, is the large basin of Tonle Sap Lake and the Mekong River. Located in the centre of the country, it consists of plains with elevations generally less than 91 metres above the sea level, this is due to low-lying central alluvial plain that is surrounded by uplands and low mountains.

Kandal Province is located in the middle south of the country and consists of the typical plain wet area of Cambodia, covering rice fields and other agricultural plantations. The average altitude of the province is less than 10 m above sea level. The province also features two of the biggest rivers of the country. [12]

3. Cambodian Electricity Situation

The electricity generation sector in Cambodia is provided by different sources such as heavy fuel oil (HFO), diesel, coal, hydropower, wind and solar energy. However, the most used sources of power are diesel and HFO. Also, hydropower energy is one of the mainly used power producer and it will become one of the most important sources of energy in the country in the long-term supply.

Cambodia is a country which has been highly dependent on electricity imports from its neighbouring countries, such as Laos, Vietnam and Thailand. In 2015, electricity imports represented 1.9% of the total energy supply. However, this imports' dependency has been decreasing during the past years and it is expected to do so in the years to come due to the development of Cambodia's energy generation capacity.

The electrification rate in Cambodia remains low. Nearly 5 million Cambodians have no access to grid electricity and rely on wood and other traditional fuels of energy. The high electricity tariff in the country makes the access unaffordable to the poor and constraints economic competitiveness. The villages not connected to the national grid, often get their electricity using diesel generators, which are very polluting and have a high cost.

Before 2010, Cambodia's power generation capacity was close to entirely based on diesel generators. From 2011 to 2017, there were significant changes to Cambodia's generation capacity. The total installed capacity has substantially increased and has become more diversified, with hydro, coal, and solar projects being licensed. At the end of 2017, the Electricity Authority of Cambodia (EAC) reported that the total domestic installed capacity was 1,878 MW, of which 980 MW (52%) was hydropower, 564 MW (30%) was coal-fired, 295 MW (16%) was diesel, 29 MW (less than 2%) was biomass, and 10 MW (less than 1%) was solar.

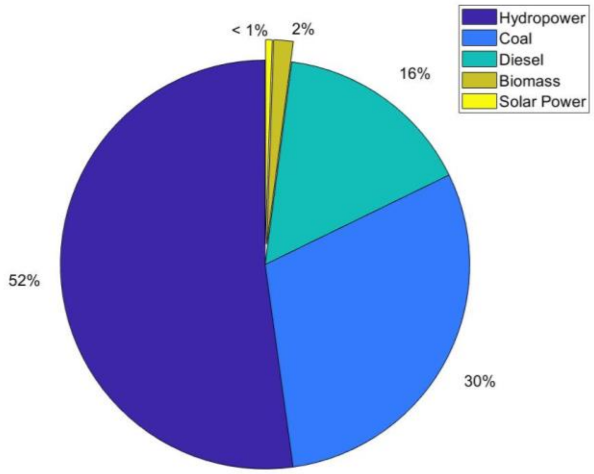

Figure 5: Cambodian Electricity Generation Rate. Source: Asian Development Bank (ADB)

From 2011 to 2015, Cambodia has experienced an average annual growth of electricity demand of 18%. An annual growth rate of 8.8% electricity demand has been estimated until 2030, when it may reach an energy demand of 18,000 GWh. The peak demand of electricity of the country is concentrated in Phnom Penh, which has a population of more than 2 million people and where businesses and industries are concentrated.

The electric power consumption per capita has experienced a dramatic increase during the last two decades. Total electricity consumption in 2016 was 400 kWh per capita, up from 270 kWh per capita in 2014. However, this annual average per capita consumption was just 38% of Asian average of 1,040 KWh and only 13% of the global average of 3,110 kWh. [13]

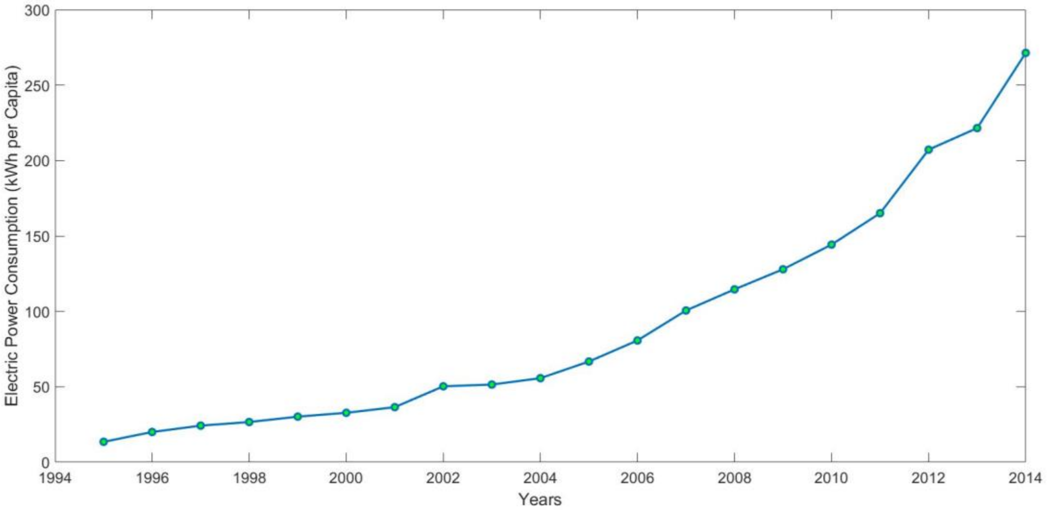

Figure 6: Cambodia's Electric Power Consumption per Capita. Source: data.worldbank.org

3.1. The structure of energy authorities

The main institutions as part of the Electricity Industry in Cambodia are: Ministry of Industry, Mines and Energy (MIME), Ministry of Economic and Finance (MEF), Electricité du Cambodge (EDC), the Electricity Authority of Cambodia (EAC), Provincial Electrical Utilities and the private sector.

The Ministry of Industry, Mines and Energy has the responsibility for policy formulation, strategic planning and technical standards of the power sector.

The Electricity Authority of Cambodia (EAC) is the regulatory agency that was established according to the Electricity Law (2001). The EAC is responsible for regulating the provision of electric power services in the country. Therefore, it grants licenses, approves and enforces performance standards as well as determines tariffs, rates and charges for electricity.

Electricité du Cambodge (EDC) is owned and controlled by the MIME and the MEF and was established in 1996. This state-owned company has the responsibility to develop, generate, transmit and distribute electric power throughout Cambodia as well as to facilitate the import and export of electricity to and from neighbouring countries. [14]

4. Renewable Energy Sources

Renewable energy in Cambodia consists of hydro, biomass and solar/PV. Wind energy has difficulties on being installed since the country lacks sufficient wind conditions for this type of technology. Hydropower will continue to increase as a major producer of electric energy as it’s very affordable and secure. [13]

4.1. Hydropower

Cambodia’s hydropower potential is estimated to be 10,000 MW. Around 50% of hydropower resources are located on the Mekong River, 40% on the tributaries of the Mekong River, and 10% in the southwestern coastal highlands. Only 980 MW of the total hydropower capacity of Cambodia has been built, 400 MW of capacity are being constructed and 90 MW of capacity are in the feasibility study stages.

Hydropower generation has wide variations between the dry and wet seasons, with reduced electricity generation during the hottest months of the year. [13]

4.2. Biomass

Cambodia has a considerable wide variety of biomass energy sources, which are: rubber plantation forests, fast-growing tropical trees, and agricultural residues. The country’s large-scale processing mills could use these products for power generation. The Ministry of Agriculture, Forestry and Fisheries, estimates that the theoretical potential of agricultural residues of the country is about 15,000 GWh per year.

In 2016, Cambodia had five biomass generation power plants in operation which represented nearly 18 MW of capacity installed and produced 42 GWh of energy that year. [13]

4.3. Solar power

Cambodia has one of the highest solar resources in the Greater Mekong Subregion, with an average solar irradiance of 1,400- 1,800 KWh per square meter per year throughout the entire country and it has an estimated technical potential of over 8,000 MW.

The middle of Cambodia, including the capital Phnom Penh, responsible for approximately 70% of the entire national electricity demand, has the peak solar resource measures over 1,900 KWh per square meter per year. Solar power is also a good option for remote rural households that currently do not have access to the national grid. By the end of 2017, Cambodia had installed over 60,000 Solar House Systems as part of the SHS program of the Rural Electrification Fund (REF).

Since 2015, the government has been urged to explore solar power as a generation option because of the rapid reduction in global prices for renewable technologies such as the ones involving solar power. Cambodia's excellent solar potential and the country's ratification of the Paris Agreement negotiated at the 2015 United Nation Climate Change conference have been key to the initiation of the development of this kind of technology in the country.

In 2017, the Asian Development Bank (ADB) developed a preliminary national solar photovoltaic (PV) grid integration study. The study's results showed that with currently available technologies, up to 350 MW could be added to the grid by 2030, with no additional technical upgrades required for the existing transmission system. Solar generation can complement hydropower by helping to meet daytime peak demand and improving hydropower storage performance during the dry season. The study found that the development of solar power technologies will result in savings from avoided thermal generation and imports. [13]

4.4. Wind power

Some wind assessments indicate that parts of the country have wind resources of medium intensity that are appropriate for utility-scale wind turbines. Average wind speeds range from 6 to 9 m/s per year in the southern regions of Tonle Sap Lake and along the coast, this only represents 3%- 5% of Cambodia's land area. Considering the ability of the grid to absorb the load of theoretical wind potential, the technical Cambodia's wind potential is estimated to range from 18 MW to 72 MW. [13]

5. Energy Policies

Cambodia has the potential for non-hydro renewable energy, such as biomass, wind and solar. However, these types of energy are not utilised optimally yet due to the barriers such as higher up-front costs and no clear target for renewable energy in the energy mix.

The Government of Cambodia has set up the Cambodian Energy Policy, which aims to provide an adequate energy supply throughout the country at an affordable price; to ensure a reliable and secure electricity supply; to encourage the development of energy sources needed to supply all sectors of the Cambodian economy; and to encourage the efficient use of energy.

The government has also set up policy targets: by 2020, 100% of villages in the country should have access to electricity, and by 2030, at least 70% of total households should have access to quality grid-supplied electricity.

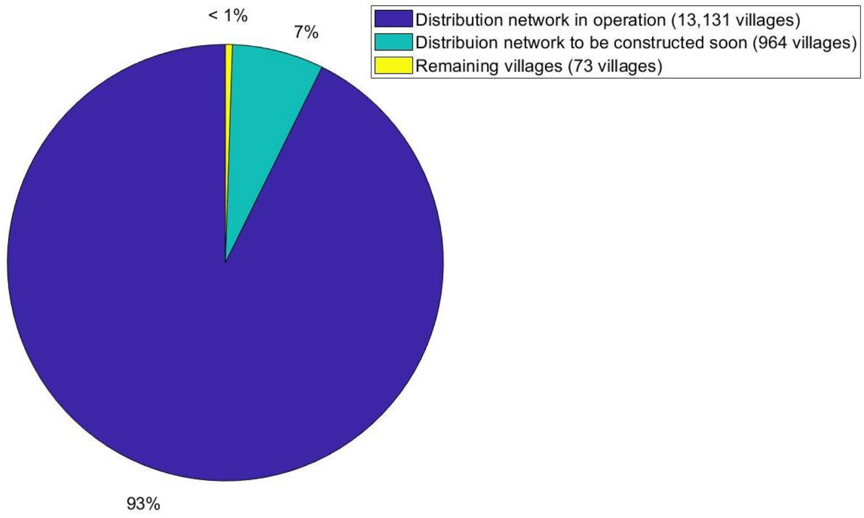

Figure 7: Situation of Electrification in Cambodia (City + Rural as in December 2019). Source: eac.gov.kh

The Electricity Law (2001) provides the governing framework for the electricity power supply and services throughout Cambodia. This law covers all activities related to the supply of electricity, provision of services and use of electricity and other associated activities in the power sector.

The National Policy on Rural Electrification by renewable energy has the aim of providing clean, reliable, safe and reasonably priced electricity in rural areas based on primarily renewable energy. Also, the Development Plan 2008-2021 projects that 2,770 MW will be constructed in 2020, of which 2,241 MW will be supplied by hydropower.

The National Climate Change Strategic Plan 2014-2023 promotes the use renewable energy to mitigate greenhouse gas emissions. Under the Intended National Determined Contribution (INDC), Cambodia has proposed the reduction of 16% of its greenhouse gas emissions, conditioned to international support. The priorities of the INDC are: national grid connected renewable energy generation and off-grid electricity, such as solar home systems.

In 2013, Prime Minister Hun Sen launched the Cambodian Climate Change Strategic Plan 2014-2023, the National Policy of Green Growth 2013-2030 and the National Strategic Plan for Green Growth 2013-2030, these propose policy actions in the energy sector that can support greener, more inclusive growth, increasing renewable energy deployment and facilitating loans for sustainable energy projects. [15]

5.1. Barriers for distributed renewable energy technology

The regulatory environment has not been supportive of renewable generation by small households, as the unclear legal status of excess generation does not allow to sell it to the national grid and there are not clear policies for net metering agreements.

Also, renewable energy targets are defined as numerical goals established by governments to achieve a specific amount of renewable energy production and consumption in the entire energy mix. Even though Cambodia has issued polices and regulations in the energy sector, the government has not yet set a national target for renewable energy utilisation. [15]

The on-grid renewable energy regulatory environment is unclear as, legally, a license from EAC is required to generate and supply electricity. In practice, the government does not require a license for organisations installing small-scale renewable generation where the electricity generated is only consumed by the organization itself and any excess electricity is not sent to the grid. The economic case for installing sustainable energy relies also in obtaining financial return from electricity generated. However, large offices and schools have been deterred from investing due to the lack of formal legality and not being able to monetize the excess of energy generated.

Hitherto, EDC has not generally recognized the value of distributed electricity provided to the grid as there is no feed-in tariff (FiT). However, there have been a few individual net metering arrangements for selected facilities such as the Don Bosco solar equipped school in Sihanoukville. These types of arrangements mean selected organisations are paid the retail price for electricity they provide to the grid, although a general regularisation policy of this type of agreements still needs to be done.

In addition, there are currently taxation issues regarding renewable energy technology products. Solar panels and equipment are still subject to VAT and a 7% import duty, which makes it more expensive to develop this kind of technology compared to others. Therefore, financial and fiscal incentives are needed to improve access to capital and lower financial costs. [16]

6. Solar PV Panels Installation

After considering the different renewable energy technologies available for the electricity generation of the Community Service Centre of Prek Hou as well as the climatology conditions, the best option for the education centre is to use solar PV panels for the renewable energy transition project. The objective of this project is to make the centre energetically independent, so an off-grid system will be designed for the project.

This is considered to be the most suitable and reliable option as Cambodia has an excellent solar potential. The sunshine hours' average is 8 per day during the entire year. Also, the Ta Khmau's daily average solar irradiation is 5.3 KWh/m^2, which is significantly higher than some of the most solar energy pioneering nations. The global industry for solar energy has matured during the last decade and the price per watt of solar panels has decreased. Furthermore, the installation process of solar panels can be easily done and can be built over time and be expanded to increase the volume of electricity generated.

The installation of wind energy technology, such as the installation of wind turbines, has been discarded due to the low wind velocity of the region, which make it inviable. Also, the fact that the wind energy technologies are not sufficient in Cambodia is proved by the lack of them in the region.

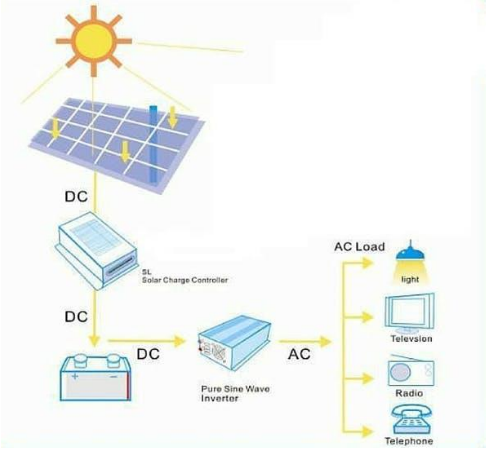

Figure 8: Off-grid Solar PV System Diagram. Source: guides.co

6.1. Electric power consumption

As the information about the exact electric power consumption of the Community Service Centre of Prek Hou is not available, a close estimation has been made in order to obtain the regarding information.

There are two methods that can be used so as to estimate the electric power load of the education centre: the top-down and the bottom-up approach. The top-down approach consists of doing an estimation of the aggregated electric load of the centre and then split it on the different electric components present in the location. However, the bottom-up approach is based on starting the estimation on a granular level listing the electric devices present in the centre and go upwards to aggregate the load of each of them to finally obtain the total electricity demand. [17]

The bottom-up approach has been selected to study the electric power load of the centre. Hence, based on the indications of one of the centre's workers, who provided a list of the electric devices that the school has in use as well as the approximate hours of usage each device is used in a day, an estimation of the amount of the electric power consumption has been made from this data. The centre is opened from 6 am until 6 pm during every day of the week but Sundays. After following the instructions given by one of the centre's workers and the author's experience in the location, the following daily usage hours of the electrical devices has been made.

Building	Device	Power Consumption (W)	Quantity (units)	Final Power Consumption (W)	Daily Usage (hours)	Energy (Wh)
Classroom building						5,054
	LCD TV (24")	50	1	50	6	300
	Small fan	45	2	90	6	540

	Ceiling fan	75	2	150	10	1,500
	Laptop	60	2	120	6	720
	Speaker	80	2	160	5	800
	White fluorescent light tube	36	3	108	8	864
	Cell phone charger	5	2	10	3	30
Porch						6,480
	Ceiling fans	75	6	450	8	3,600
	White fluorescent light tube	36	10	360	8	2,880
Toilet/showers						336
	CFL light bulb	14	6	84	4	336

Table 5: Centre's electricity consumption. Source: Author's elaboration

With this data the daily total estimated consumption is obtained:

$$Daily\ estimated\ consumption\ (Dec) = 11.870\ KWh/day$$

After calculating the daily estimated consumption of the centre, the yearly consumption is obtained, considering that the centre is used every day of the week but on Sundays:

$$Yearly\ estimated\ consumption = 3{,}715.31\ KWh/year$$

This estimated consumption is usually oversized, considering that this consumption represents the 75% of the installation's consumption, calculating the 100% demanded: [18]

$$Total\ energy/Necessary\ consumption\ (Ten) = \frac{Dec}{0.75} = 15.827\ KWh/day$$

6.2. Available solar irradiation

In order to determine the number of PV panels for the project, a study of the available solar irradiation has to be made so as to know how much electricity can be generated.

Using the Global Solar Atlas' tool, the global solar irradiation of Ta Khmau has been obtained as well as what would the average daily electricity production be of a 3 Wp sized system, with crystalline silicon PV panels.

Month	E_d	E_m	H_d	H_m
January	12.95	401.34	4.32	134
February	14.24	398.79	4.75	133
March	13.97	432.99	4.29	133
April	13.17	395.18	3.97	119
May	12.13	375.88	4.13	128
June	11.14	334.21	3.77	113
July	10.86	336.64	3.29	102

August	11.66	361.35	3.58	111
September	11.26	337.83	3.13	94
October	11.68	362	3.35	104
November	12.22	366.46	3.93	118
December	12.92	400.43	4.65	144
Yearly average	12.30	374.09	3.90	118.51
Total for year	4,503.1		1,443	

Table 6: Solar electricity generation and irradiation of Ta Khmau. Source: globalsolaratlas.info

E_d Average daily electricity production from the given system (KWh/day)

E_m Average monthly electricity production from the given system (KWh)

H_d Average daily sum of global irradiation per square metre received ((KWh/m^2)/day)

H_m Average sum of the global irradiation per square metre received (KWh/m^2)

The month in which the irradiation is the least favourable is in September, when it has a daily average of 3.13 KWh/m^2. Hence, the system will be designed in order to cover the electricity demand in the least favourable solar conditions, so as to guarantee that the electricity consumption of the centre is covered throughout the year.

The Peak Sun Hours (PSH) refer to the number of equivalent hours that the sun should shine at an intensity of 1000 W/m^2 in order to obtain the total solar irradiation of a day. Therefore, using the selected daily average solar irradiation and dividing it by 1 kW/m^2, the quantity of peak sun hours is obtained: [18]

$$PSH = \frac{Daily\ solar\ irradiation}{1\ kW/m^2}$$

$$PSH = 3.13$$

6.3. Number of PV panels' calculation

The number of PV panels needed in order to accomplish the electricity demand of the location is calculated using:

- The energy produced by a PV panel
- The total electricity consumption of the centre

To calculate the electricity produced, the Panel's Maximum Power (P_{pmp}) has to be determined with the technical data provided by the manufacturer:

$$P_{pmp} = I_{pmp} * V_{pmp}$$

I_{pmp} Intensity of electrical current at maximum power

V_{pmp} Voltage at maximum power

A solar PV panel can a produce a certain amount of energy per day which can be calculated with the following expression:

$$E_{panel} = P_{pmp} * PSH * \eta$$

P_{pmp} Panel's maximum power

PSH Peak Sun Hours

η PV panel's efficiency

In order to proceed with the calculation, the technical sheet of the solar PV panel that will be used for the system is needed, as well as the least favourable solar irradiation conditions, which have been determined previously. [18]

The selected solar PV panel is the Polycrystalline Solar Module PLM-270P-60 Series of 275 W, which is recommended by the manufacturer in order to provide electricity for basic consumptions.

The Community Service Centre of Prek Hou is used 6 days per week, as on Sundays the centre is closed. Therefore, in order to determine the number of PV modules needed the following equation is used: [18]

$$N_{md} = \frac{6}{7} * \frac{E}{P_{pmp} * PSH * \eta}$$

E Daily energy demand of the centre $= 15.827\ KWh/day$

$\mathrm{P_{pmp}}$ Maximum power of the selected PV module $= 275\ \mathrm{W} = 0.275\ \mathrm{KW}$

PSH Peak sun hours $= 3.13$

η Work efficiency $= 0.8$

Number of solar PV modules for the centre:

$$N_{md} = \frac{6}{7} * \frac{15.827}{0.275 * 3.13 * 0.8} = 19.7$$

$$N_{md} = 20$$

In order to provide the centre energy for its electricity demand, 20 modules of 275 W each are needed. As a 75% efficiency of the system has been estimated, the number of solar PV panels will not be over dimensioned.

With the selected modules 275 Watts peak (Wp), the following total peak power is obtained for the system:

$$P_{system} = 20 * 275 = 5{,}500\ Wp$$

6.4. Battery size

In order to make the community service centre electrically independent for the national grid, a battery bank has to be installed in order to provide electricity when the weather conditions are unfavourable for electricity generation.

The number of days' worth of energy determined which the centre should be completely electrically independent is 2, as the centre is not used during the night time and the average sunlight hours in the region is very high.

The battery used for the electricity storage of the centre is the Bluesun FCD-200, which has a voltage of 12V, an Ampere-hour rating of 200 AH and a 50% depth of discharge is considered for this battery system.

The number of batteries needed for the centre can be calculated using the following equation: [19]

$$N_{batteries} = \frac{E_d * n_d}{V_{battery} * AH * DOD}$$

E_d Daily estimated consumption $= 11.87$ KWh

n_d Number of days of backup power required $= 2$

V_b Voltage of the battery system $= 12$ V

AH Ampere-hour rating $= 200$ AH

DOD Depth of discharge of the battery system $= 50\% = 0.5$

$$N_{batteries} = \frac{11870 * 2}{12 * 200 * 0.5} = 19.78$$

$$N_{batteries} = 20$$

6.5. Charge controller

A charge controller has a lot of similarities with a voltage regulator. Its function is to regulate the current and voltage that the solar panel emits and is transported into the batteries. Usually, 12 V panels are set to around 16 to 20 V, so if there isn’t a voltage regulation, the batteries may be damaged from overcharging. Therefore, the charge controller protects against overly high voltage, over current and short circuit. Hence, it is an electronic device that prolongs the lifespan of the system if it is used properly and helps reduce the system’s cost. [19]

In order to prevent that the charge regulator operates constantly at 100% of its capacity, the selected regulator should be able to handle slightly larger currents than the previously calculated, especially in regions with high temperatures such as Cambodia. Hence, the selected charge controller for the centre is the Bluesun MPPT Solar Charge Controller BSM-SCH-20A, which supports a maximum current of 20A, and will be installed according to the best combinations.

6.6. DC/AC inverter

An inverter is used to convert the DC power in a battery to 240 V AC electricity.

To determine the inverter size, the maximum wattage of the community service centre which is calculated adding up the wattage of the devices that could be run at the same time. Hence, adding up the power of the electrical devices in the centre:

$$P_{max} = 1{,}582\ W$$

The chosen AC/DC inverter for the system is SSTH-DS-2000W, which supports the maximum power.

7. Levelized Cost of Energy (LCOE)

The method of Levelized Cost of Energy (LCOE) makes it possible to determine the cost of the energy generated. The basic form of this method is to sum all accumulated costs for building and operating a renewable energy project and compare it to the sum of the annual power generation.

The calculation of the LCOE is based on the net present value method, in which the expenses for investments and payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date. The cash value of all expending is divided by the cash value of the power generation. The idea of this method is that the energy generated corresponds to the earnings from the sale of this energy. The cash value will depend on the time displaced in the future, so the farther these earnings are displaced the lower is their cash value.

The annual total expenditures over the entire operational lifetime are included in the investment expenditures and operating costs accumulating over the operational lifetime. For calculating the LCOE for new plants, the following applies:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

LCOE	Levelized Cost of Energy ($/KWh)
I_0	Investment expenditures ($)
A_t	Annual Total costs in year t ($)
$M_{t,el}$	Produced quantity of electricity in the respective year (kWh)
i	Real interest rate (%)
n	Economic operational lifetime (years)
t	Year of lifetime (1, 2… n)

The annual total costs are composed of fixed and variable costs for the operation of the plant, maintenance, service, repairs and insurance payments. The LCOE is a calculation based on costs and not a calculation of the level of feed-in tariffs. It can only be calculated by using additional influence parameters. The calculation of the feed-in tariffs makes the calculation of the LCOE more difficult due to the tax laws, the rules that affect private use and realized operator earnings. Also, the LCOE does not take into account the significance of the electricity that is produced by the energy system in a specific hour of the year. [20]

7.1. LCOE calculation

In this chapter the Levelized Cost of Energy of the designed energy system is calculated. In order to it, the National Renewable Energy Laboratory (NREL) provides an LCOE calculator, which the US Department of Energy (DOE) has sponsored this tool's distributed generation data. This calculator determines the LCOE using the following equation: [21]

$$LCOE = \frac{I_c * CRF + OM_{Fc}}{8{,}760 * CF} + OM_{VC}$$

I_c	Investment Cost ($/kW)
CRF	Capital Recovery Factor
OM_{Fc}	Fixed Operation and Maintenance Cost ($/kW-year)
8,760	Number of hours in a year
CF	Capacity Factor
OM_{VC}	Variable Operation and Maintenance Cost ($/kWh)

So as to begin with the analysis, the Initial Investment Cost needed for the elements of the renewable energy system is calculated using Alibaba.com, which is the largest Chinese e-commerce platform that has a wide variety of products and the most competitive prices of the market.

Element	Price ($)	Quantity	Cost ($)
Solar Panel PLM-270P-60 Series of 275 W	60	20	1,200
Battery Bluesun FCD-200	185	20	3,700
Bluesun MPPT Solar Charge Controller BSM-SCH-20A	55	5	275
DC/AC Inverter SSTH-DS-2000W	219	1	219
Installation and Shipping Costs	700	1	700
		Total	**6,094**

Table 7: Initial Investment Cost Calculation. Source: Alibaba.com

Hence, the total investment cost for energy system is 6,094 $. As the solar PV capacity is 5.5 kW, the capital cost is 1,108 $/kW.

Also, in the economic analysis, the annual operation and maintenance cost of the energy system has to be considered as well. Investing in the maintenance of the equipment is very important so as to keep the equipment clean and to ensure that all components are operating as intended. The estimated average annual maintenance and operating cost of the equipment is 275$. Also, the lifespan of the batteries used is 10 years, while the solar PV panels are expected to last for a total of 25 years. Hence, two battery replacements that have a cost of 3,700 $ each are taken into account in the maintenance cost as well. Therefore, the considered fixed operation and maintenance cost is 103.81 $/kW-year. Also, a variable operation and maintenance cost of the energy system in case of damaged equipment is considered as 0.002 $/kWh.

The input data used for the LCOE calculation is:

Financial	
Period	25 years
Discount Rate	2%
Renewable Energy System Cost and Performance	
Investment Cost	1,108 $/kW
Capacity Factor	10%
Fixed O&M Cost	103.81 $/kW-year
Variable O&M Cost	0.002 $/kWh

Table 8: NREL LCOE Calculator Input Data. Source: Author's data

The obtained LCOE using NREL's Calculator for the above indicated input data is: 0.185 $/kWh.

The results obtained in the LCOE calculation, show us that making a renewable energy system based on solar panels so as to make the community service centre energetically independent, is more expensive than buying the electricity directly from the grid. The price of buying electricity from the national grid in Ta Khmau, for residences which consume more than 50 kWh per month is 720 Riel/kWh [22], which is 0.17 $/KWh. However, the designed energy system has a Levelized Cost of Energy of 0.185 $/kWh.

This result demonstrates that, even though the price of electricity in Cambodia is high compared to the countries of its surroundings, the lack of favourable renewable energy policies that intend to favour the transition to more environmentally friendly and energetically independent systems may prevent the households to decide switching to these technologies.

8. Learning Effects

The costs of the technology used, develop through time due to technological breakthroughs and innovations made. The cost curve is used to conceptualize the costs of the production of the technology as well as the market prices at which it is sold.

There is a diffusion phenomenon which occurs when a new technological solution competes with existing solutions and may be able to completely replace the old technology in use. However, the exact pattern and speed of innovation is not linear since no innovation spreads instantly. The temporal pattern of diffusion is S-shaped, with slow growth at the beginning, followed by strong growth at the middle which finishes with market saturation. Therefore, a simple and representative S-shaped diffusion and substitution curve is commonly used. It is described by the following equation: [23]

$$Y(t) = \frac{K}{1 + e^{-\beta(t-t_0)}}$$

K	Upper limit
t_0	Growth reversal, turning point at K/2 (here the growth rate reaches its maximum)
β	Diffusion or growth rate (steepness of the S-curve) definition

The Learning Curve analysis is the technique used to estimate the cost curves of the technologies' prices. It describes what is the relationship between cumulative output and per unit cost of a technology. As an expansion in the cumulative production capacity takes place, the producer acquires the knowledge needed to streamline the manufacturing process, causing a decrease of the cost per unit of output. This type of relationship between quantity and cost was developed by Wright's model of Technological Learning Effects (1936), which is defined by the following equation:

$$C(t) = C(0)Y(t)^{-b}$$

$C(t)$	Investment cost of for a unit at a time point t

$C(0)$ Investment cost of the first unit

$\mathrm{Y(t)}$ Cumulative output at time point t

b Measures the magnitude of the learning rate

In order to obtain a linear function of the cumulative output with the negative slope of -b, the previous equation is transformed using logarithms:

$$logC(t) = logC(0) - b\, logY(t)$$

This model reflects the decreasing investment costs $logC(0)$ as the output or the installed capacity of any technology $logY(t)$ increases. This model can be applied to the solar PV panels, in which the PV module prices (EUR/W) are declining as the cumulative capacity (MW) of the panels increases.

In a further step, the model can be standardized in the form of any time T:

$$C(t) = C(T)\left(\frac{Y(t)}{Y(T)}\right)^{-b}$$

$\mathrm{C(T)}$ Investment cost of a unit at time T

$\mathrm{Y(T)}$ Cumulative output at time T

The installed output of a technology at the time t can be understood as output. The coefficient -b describes the "learning effect" in this formulation and can be used to calculate the learning rate:

$$LR = 1 - 2^{-b}$$

The learning rate corresponds to a constant percentage, which is accompanied by a doubling of the accumulated output. [24]

8.1. Solar PV Learning Curve calculation

The calculation of the Learning Effects of the solar PV panels’ industry and how it affects the price per Watt of this technology for the renewable energy project in the community service centre is studied in this chapter.

Usual industry processes have b values which range from 0.15 to 0.5, which corresponds to a Learning Curve (LC) of 90% to 70%, respectively [25]. The LC assumed for the solar PV industry is 80%, thus the Learning Rate is 20%. This means that every time the cumulative produced quantity doubles, the manufacturing costs fall by 32.19%.

$$LR = 1 - 2^{-b}$$

LR Learning Rate $= 20\% = 0.2$

b Learning Rate Coefficient

$$0.2 = 1 - 2^{-b}$$

$$b = 0.3219$$

The Learning curve for the next five years for the solar PV panels is studied. Therefore, the initial timepoint is 2020 and a comparison of the price after 5 years will be done. Since the technology used for the project is imported from China, the current price per watt of the solar PV panels in that country will be considered. Nowadays, the price of this technology is 0.35$/W in Alibaba, the Chinese e-commerce giant.

The cumulative solar PV capacity data has been obtained from the statistics made by GlobalData, which shows the predictions of how the PV capacity will increase in the next five years:

Year	Y(t) (GW)
2020	382
2021	456.2
2022	531.3
2023	602.5
2024	673
2025	732.3

Table 9: Cumulative PV capacity from 2015. Source: GlobalData

In order to obtain a linear Learning Curve, the Technological Learning Effects standardized for a timepoint T, which corresponds to 2020, is used for the calculation:

$$C(t) = C(T)\left(\frac{Y(t)}{Y(T)}\right)^{-b}$$

$\mathrm{b} = 0.3219$

$\mathrm{Y(T)} = 382\ \mathrm{GW}$

$\mathrm{C(T)} = 0.35\ \$/\mathrm{W}$

Hence, introducing the cumulative solar PV capacity data in the function, the following Learning Curve for the years 2021 to 2025 is obtained using MATLAB:

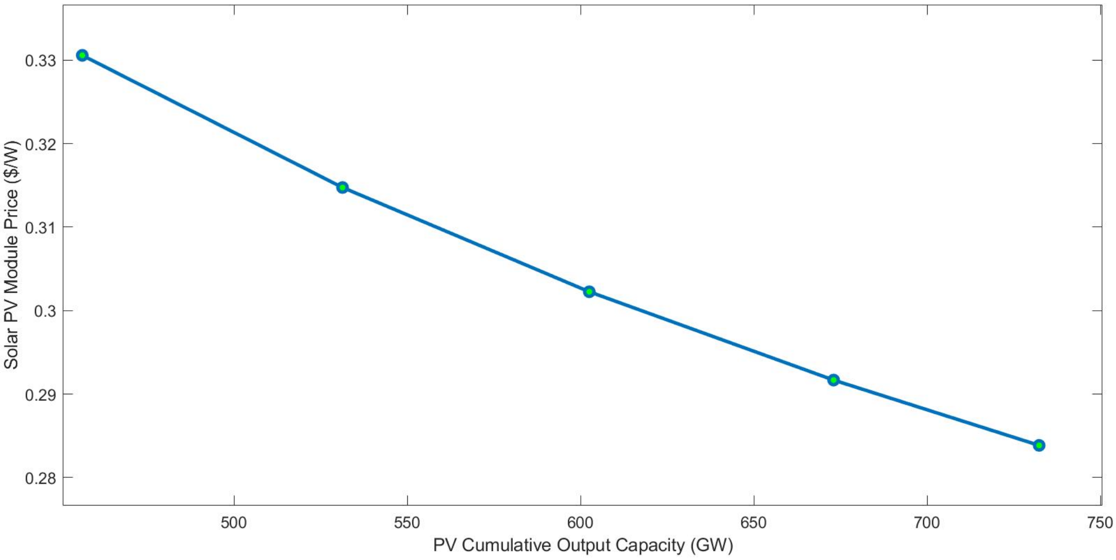

Figure 9: PV Learning Curve 2021-2025. Source: Author's Calculation

According to the forecasts based on the PV cumulative output capacity database provided by GlobalData, we would expect decreasing prices of the solar PV panels in the years to come due to the increase of the world's solar PV Capacity. In 2025, with an output capacity of 732.3 GW, the cost of the solar panels is expected to be 0.2839 $/W which is an 18.89% price reduction compared to 2020.

The fact that a price reduction of the PV panels is expected for the future, based on the previous calculations, would affect the LCOE of the project. This is due to the cost decrease that the project would have as the price of the solar PV panels goes down. Therefore, if the project were to take place in 2025 instead of in 2020, there would be a price reduction of 18.89% in the panel's costs, which would lead to a decrease of the LCOE of the project, which currently is 0.185 $/kWh. Hence, if the expected panel's price predictions based on the Learning Curve calculations are accomplished, the energy system's LCOE would experience a decline that would make the project viable.

9. Renewable Energy Policies in ASEAN Countries

As the solar PV system designed for the Community Service Centre of Prek Hou provides electricity with a higher cost than the national grid, a study of the different policies existing in Cambodia's neighbouring countries is done. This analysis aims to examine the different policies that promote the use of renewable energy technologies so as to make solar home systems profitable.

Among the Association of Southeast Asian Nations (ASEAN), Thailand is the leader when it comes to solar power adoption. It was one of the first ASEAN countries a form Feed-in-tariff (FiT) incentive policy in order to favour the growth of solar power in 2007. The program consists on adding additional payment to renewable energy generators on top of the usual prices that the producers would receive due to the sale of electricity to the grid. Hence, Thailand approved the Small and Very Small Power Purchase Agreement Act, which regulated the connection of small producers to the national grid and the sale of the electricity they produce at a higher price so as to make the renewable energy investment profitable. Also, Ministry of Energy of Thailand approved the Action Plan on Science and Technology Innovation for Renewable Energy Development (2012-2016), which allocated 11.3 million dollars for solar energy development.

Indonesia is also a clear example of how renewable energy policies can promote the use of clean energy generation technology. In 2007, Indonesia enacted the Energy Law which strengthened the utilisation of sustainable energy technologies and stated that the government had to provide incentives for renewable energy developers for a certain period of time. Furthermore, in 2010 the Electricity Law was passed which stated that the use of clean energy generation technologies was a high priority and introduced measures that encouraged private investment in the sector. However, the most notable measure that promoted the use of solar PV technologies for the Solar Home Systems was the Ministerial Decree on Solar PV issued in 2013, which allows any solar electricity producer to sell the power generated to the national grid if the PV panels contained at least 40% of local components. This measure, not only encouraged people to adopt the technology but also boosted its domestic solar PV industry. The solar power capacity installed in Indonesia was only 14 MW in 2011, but thanks to these regulations it increased to 60 MW in 2018, being the solar home systems the most developed sector.

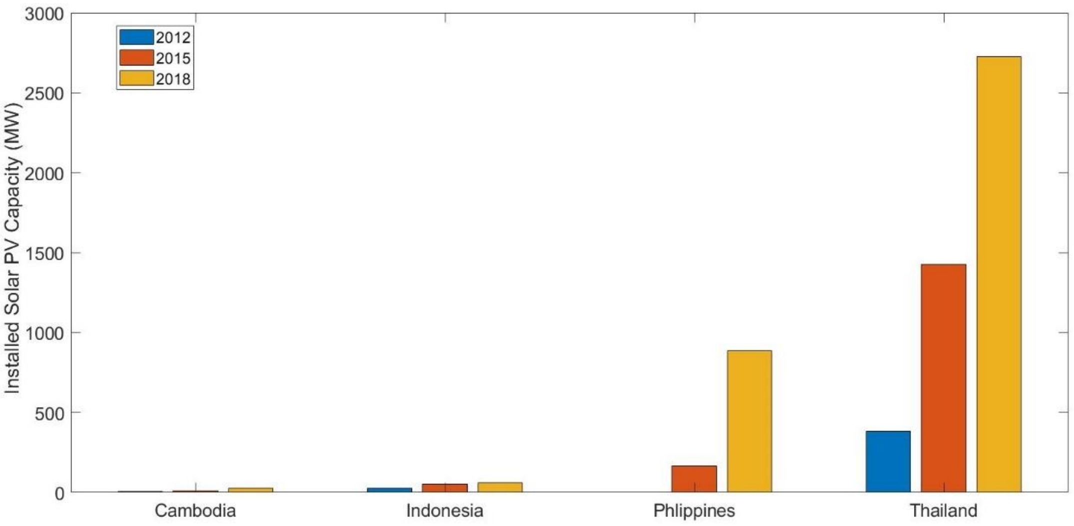

Figure 10: Evolution of the installed Solar PV Capacity. Source: irena.org

The Philippines, as Cambodia, has a very high potential of for solar energy technology usage both on-grid and off-grid. The Philippines Department of Energy issued the National Renewable Program (2011-2030) so as to encourage the use, development and commercial exploitation of renewable energy sources. The incentives included in this program are: income tax exemption for 7 years, 0% value added tax rate on the sale of power generated, duty free of machinery, equipment and materials importation as well as tax exemption from carbon credits. In 2012, the Energy Regulatory Commission (ERC) implemented a FiT scheme to attract private investors and to increase the energy production from renewable energy resources. The FiT scheme will let power producers to have an advanced contract with the power utilities, facilitate the obtention of bank loans for solar panel installation, earn profit, reduce the cost of panel module and installation from market competition. [26]

These examples show that the implementation of effective polices that promote the use of renewable energy technologies have proven to have a very positive impact so as to make these technologies profitable. The main conclusions extracted from these examples are: Cambodia needs to establish FiT regulations so as to make increase the profitability of the use of solar home systems; it also needs to issue policies that help the local PV industry so as to develop its technology and make it appealing for Cambodian consumers to buy their own technology and the implementation of tax exemptions is fundamental to encourage that consumers adopt the solar PV panels for its own use as it helps makes the investment profitable.

10. Conclusion

In the present Bachelor's Thesis, the study of the economic viability of the use of solar PV panels for the Community Service Centre of Prek Hou is done, so as to make it more sustainable and energetically independent. The motivation of this project is to accomplish the objective of the UN's "2030 Agenda for Sustainable Development" which, among other goals, proposes affordable and clean energy and sustainable cities and communities.

A study of the current Cambodian electricity sector has been made as a means to have an overview of the electricity generation sources that are available. Thus, the most viable technology for the school is the use of solar PV panels as the Cambodian yearly average solar irradiation is 1,443 kWh/m^2. In addition, this technology can be easily installed and provides a lot of versatility for this kind of small projects.

The analysis of the Cambodian renewable energy situation has proven to lack some of the basic regulations. Although there are existing policies that encourage the use of sustainable technologies in the country, the support for solar home system projects is only available for rural areas with no access to electricity. There are no regulations for on-gird rooftop solar systems where the excess of electricity is sold to the national grid by feed-in-tariffs or net metering. Hence, in order to make the centre more sustainable, an off-grid solar energy system has been designed in order to make it energy self-sufficient and environmentally friendly.

The energy system has been designed based on the electricity consumption calculated using a bottom up approach, obtaining an average daily consumption of 11.87 kWh/day. The optimal design for the energy system consists in a 5.5 kWp solar PV system with 20 batteries for the energy storage.

The economic analysis of the designed system has been done calculating the LCOE, which is 0.185 $/kWh. Hence, the price of the electricity produced by the off-grid renewable energy system is higher than if it were purchased from the national grid, as the last costs 0.17 $/kWh. Furthermore, the Learning Effects calculation has also been considered in the economic analysis. With this method, the price of the solar PV panels has been estimated based on the expected cumulative output capacity of the technology. For 2025, based on the production database, the price of the technology is expected to decrease 18.89%, making it a more suitable time to make the investment as there would be a cost reduction.

In conclusion, the use of solar PV panels in order to make the Community Service Centre of Prek Hou energetically independent has proven not to be profitable. The cost of the electricity produced by the energy system is 1.5 cents/kWh higher than the electricity bought from the national grid. Therefore, a solution to this problem could be making the investment in 5 years' time as the costs of the technology used are expected to decrease, which would make the investment more profitable. Furthermore, as seen from the study of the renewable energy policies of some ASEAN countries, if Cambodia adopted similar approaches, a high development of the Cambodian solar market would take place. Thus, the consumers would be encouraged to invest in this kind of renewable energy technology as there would be economical benefits such as tax exemptions or they could sell the electricity produced to the grid.

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