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Cost and Benefit Analysis of Renewable Energy Opportunities for Cambodia

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Abstract

Today, as the global renewable energy use represents about one fourth of the total world energy inputs, the costs and benefits of renewable energy use in electricity generation are more frequently assessed worldwide. This industry has grown almost by 20% in annual average for 5 years, compared to nearly no growth for the fossil fuel related industry. In the meantime in Cambodia, the changes of consumers' electricity patterns and the growth of supply is but the blackout remains frequent in the dry season, and the tariff remains also high compared to neighboring countries. An explanation to this situation could be found in the lack of the renewable energy potential and its possible integration into the current power system. Definitely, diversification in electricity generation can in the long term reduce the costs and positively impacts the consumers' electricity prices. As fossil energy has limit, reducing rapidly the energy costs is becoming a major priority for our utilities. Constraints on new search of supply sources, increasing regulations, technologies, growing populations, and climate change all combined will require us to design a new future where higher demands will proportionally match higher energy inputs.

The purpose of this paper is to also understand the risks in implementing renewable energy technologies in Cambodia. This research outlines the cost and benefits, but also the financial risk of renewable energy with a focus on solar, wind, hydro, in Cambodia.

Methodology

The research methodology is basically based from data collection from various sources such as publications (books, electricity specialized websites search, articles, investment banks research, press articles in Phnom Post, Khmer Times, Cambodia Daily) and interviews. The interviews were mainly with the some representatives of the government (such as Ministry of Mines and Energy, Ministry of Environment, Ministry of Economy & Finance. Electricity Authority of Cambodia, Electricite du Cambodge), with the workshops and seminars organized in Phnom Penh by Amcham (Energy 2020), Eurocham (as member of the advocacy working group on Green Business, Government Private Sector Forum, CSR) and professional consultations with lawyers and tax advisers (DFDL, VDB Loi, Bun & Associates, E&Y), conferences and booth visits at Exhibition Center in Koh Pich such as the Cambodia Constructors Association (CCA) Summit, and a selection of private discussions with the local and international companies "EPC" (Engineering Procurement Construction).

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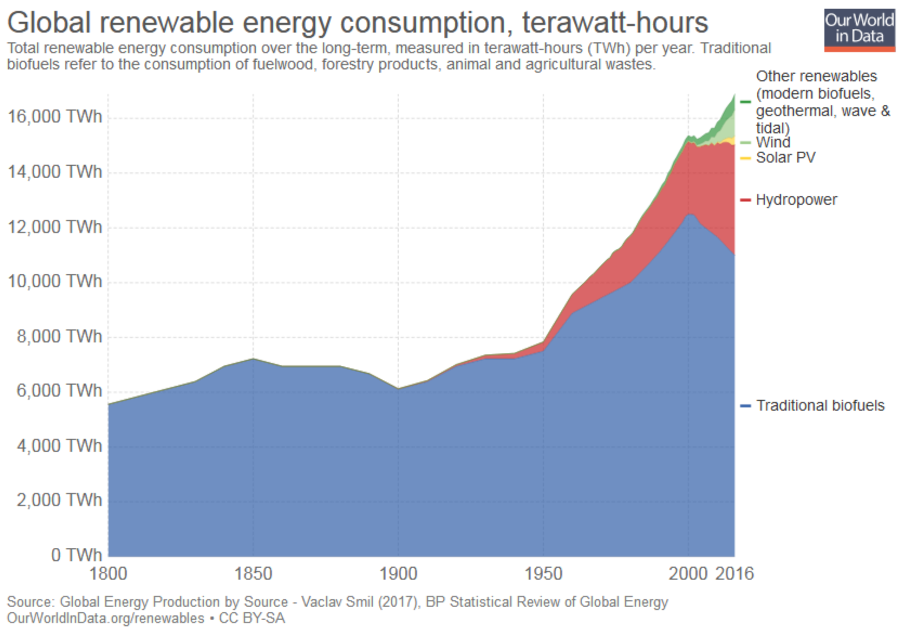
The Global Trends of Renewable Energy

The term "Renewable energy "is mostly associated with positive benefits for environmental, social and economic goals, but what does in represent in terms of numbers? The Renewables are expected to strongly grow by 20% annually in the next five years from 2017 to 2023. The industry will experience the fastest growth in the electricity sector (figure 1), and will soon contribute to almost 30% of the global power demand in 2023, compared to 26.5% in 2017 (figure 2) according to REN21. And within the next five years, the renewable energy is forecast to represent more than two-third of global electricity generation, especially with by solar (PV) wind, hydropower, and bioenergy/biomass.

Figure 1. Global Renewable Energy versus Conventional Energy from 1800 to today[1]



The Renewable power generating capacity is raising total capacity, and in Cambodia as well. Globally, renewable energy accounted for an estimated 70% of net additions to global power capacity in 2017, and for a total capacity around 2,195 GW – enough to supply an estimated 26.5% of global electricity (figure 2).

The reason of the success of Renewable energy is also explained by the climate change awareness, the will of having into a less carbon-intensive society and more sustainable economies. And these challenges could be met, by using reliable, renewable and efficient energy system. These technologies have also rapidly improved in recent years, accompanied by sharp cost reductions, especially for solar photovoltaic and also with a new general of powerful wind turbines (Figure 18).

[1] *Global renewable energy consumption over the long-run, https://ourworldindata.org/renewable-energy*

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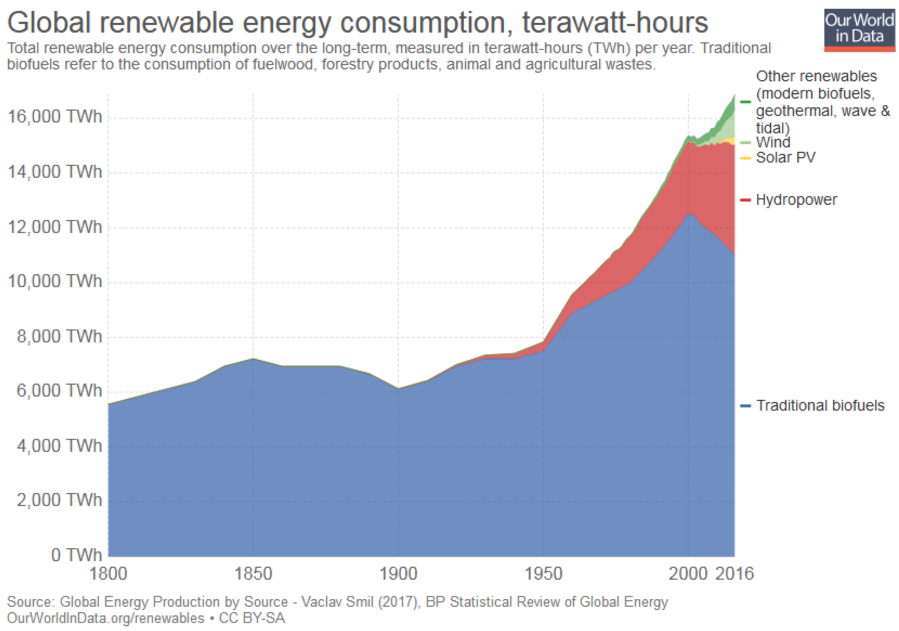

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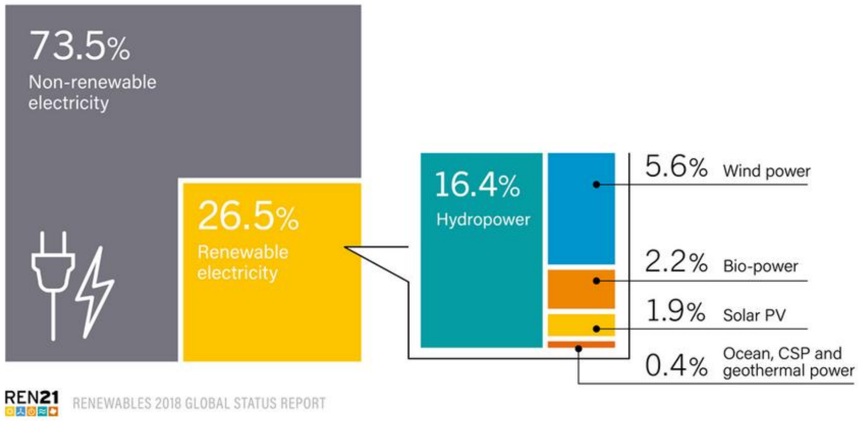
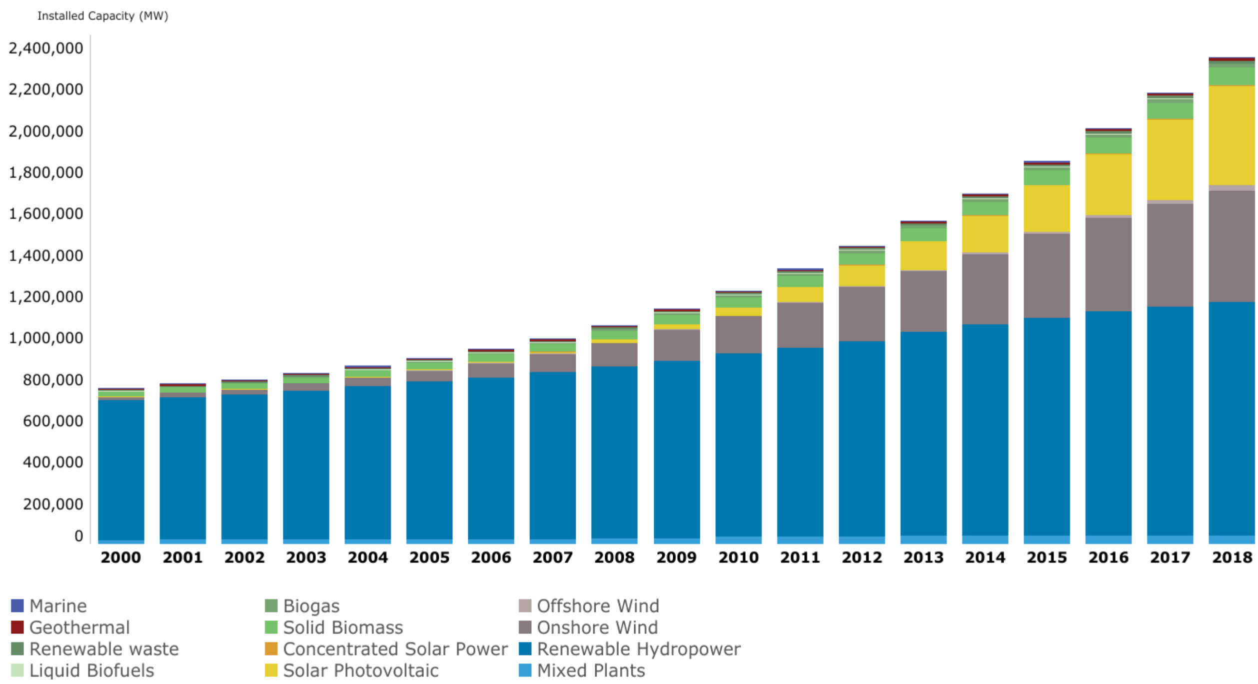
Figure2. An Estimated Renewable Share of Total Energy Consumption in 2017[2]



As illustrated in the figure 2, the Hydropower dominates globally, with its 16.4% share (about 20% currently in Cambodia), closely followed by superstar technologies known as Solar PV and Wind. The Bioenergy/Biomass and the other alternative energy like ocean, tidal remain "niche" market in the main energy forecasts. The biomass is also limited in Cambodia (rice husk, sugarcane,) because of the poor supply chain and heavy transportation costs.

Figure 3. Trends in Renewable Energy from 2010-2018[3]

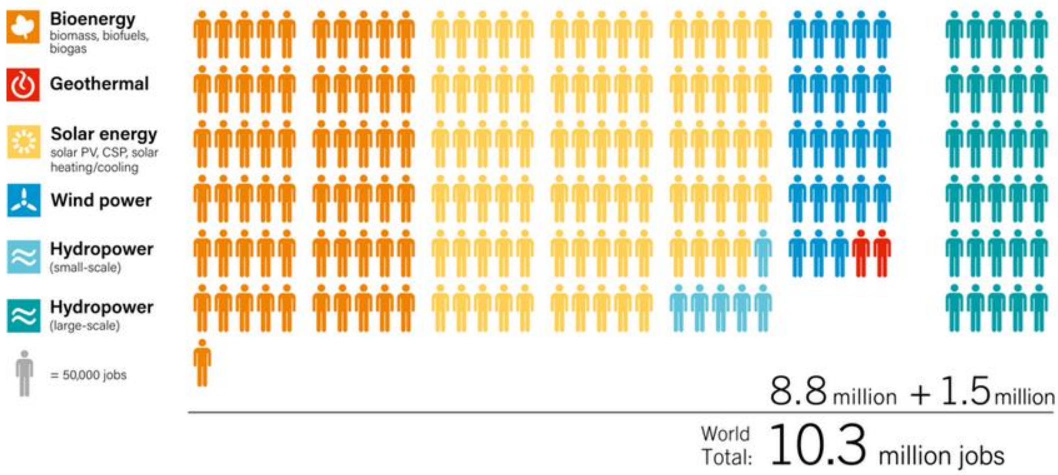


The renewable energy sector is expected to contribute to a lot of new jobs and skills, and according to IRENA, it currently represents, directly and indirectly, 10.3 million people in 2017. The large-scale hydropower represents 15% of direct jobs (figure 4). And the overall sector will continue to expand due to falling cost of technology, changes in labor productivity, corporate strategies and industry

[2] *Renewables 2019 Global Status Report, https://www.ren21.net/reports/global-status-report/*
[3] *Trends in Renewable Energy from 2010-2018, https://www.irena.org/*

restructurings. The ongoing public-private policies in some countries also get the renewable energy quickly integrated in the power development plan.

Figure 4. Jobs Creation in Renewable Energy[4]



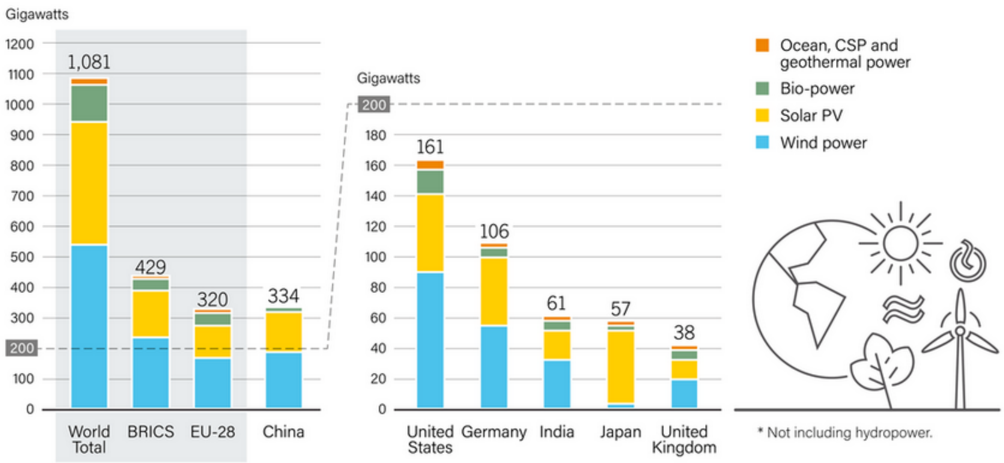
To sum up, the renewables will continue to experience exponential growth, influenced the success and popularity of solar photovoltaic (PV) and wind energy in recent years, but on the other side, hydropower generation will be challenged by growing concerns on financial and social impact, and risks of damaging the environment.

1. Renewable Energy Resources & Technologies

In our research, the renewable energy sources will mainly refer to hydropower, solar energy, and wind energy. In the broad definition the renewable also includes biomass energy, geothermal energy, and ocean energy, but these technologies are still marginal in Cambodia and prospects remains limited due to limited access and funding. Moreover and as illustrated in the figure 5, wind and solar capacity are the main drivers, and the exponential growth in term of new added capacity are observed all over all the continents. Its expansion seems to stay limited in the industrialized world, where it has nearly reached its economic capacity, but the potential in the developing world (Asia) considerable remains high.

[4] *Source: IRENA. https://www.irena.org/newsroom/pressreleases/2019/Jun/*

Figure 5. New Capacity in Renewable Energy[5]



Cambodia looks like to be the ideal place and location to expand the renewable energy technologies such as hydro, solar, biomass, and wind. However, some renewables, particularly non-hydro ones, have not yet being completely deployed in the country. As illustrated in the figure 6a (Cambodia) and figure 6b (OECD regions), Cambodia has a different power generation mix challenges as oil/coal represent currently 58% of the sources, whereas Hydro 40% and the rest being biomass for less than 2% (for comparison, renewable represent 5% in Asia, 8% in the Americas and 14% in Europe)

Figure 6b.Electricity Generation in OECD Regions[6]

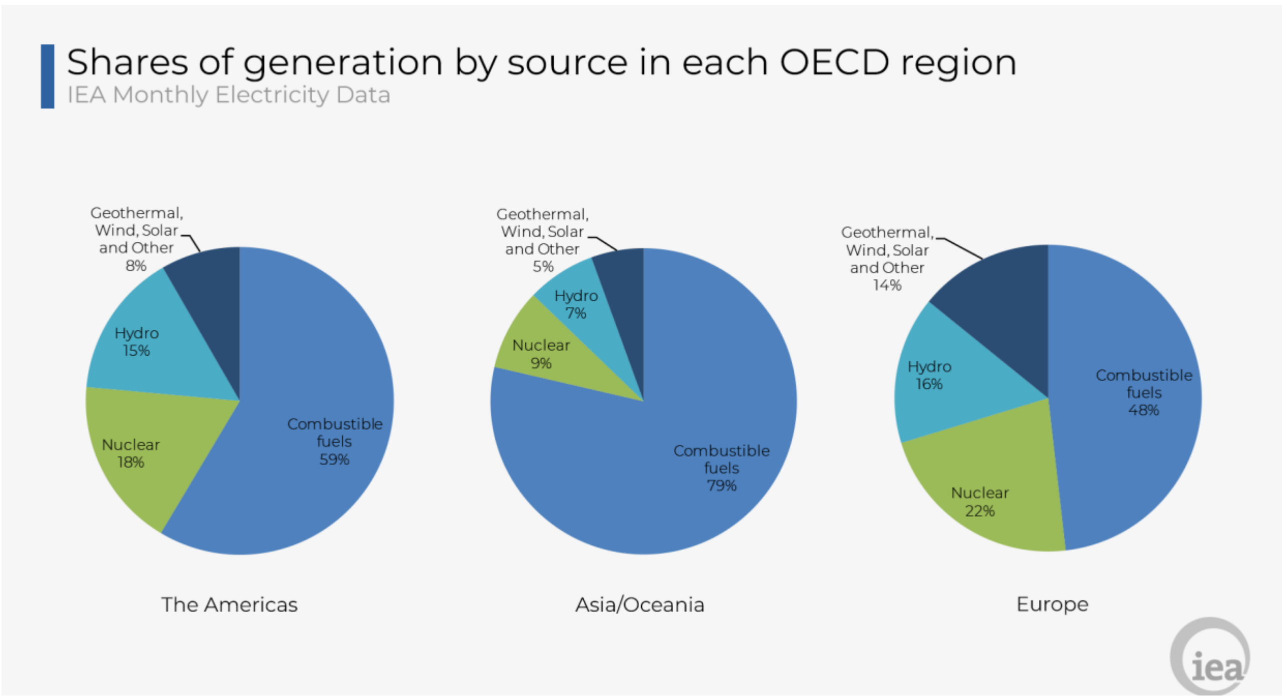
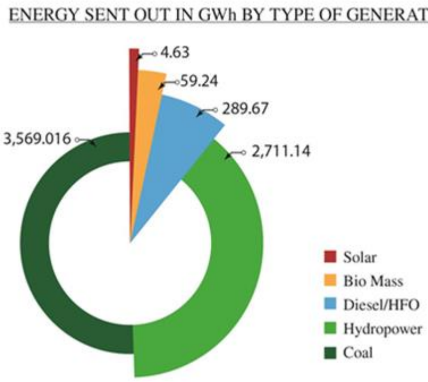


Figure 6a. Electricity Generation in Cambodia, EAC 2017[7]

[5] https://www.irena.org/publications/2018/Jul/Renewable-Energy-Statistics-2018
[6] International Energy Agency (IEA) 2018, https://www.iea.org/newsroom/news/2018/april/key-electricity-trends-2017.html
[7] Electricity Authority of Cambodia, Annual Report 2018 https://www.eac.gov.kh/

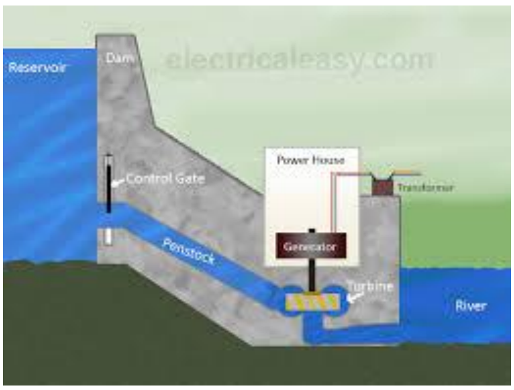


1.1 Hydro Technologies

The Hydroelectric power uses ***the kinetic energy***[8] of the flowing water. The water flow "turns" the turbines and the turbines generate electricity. In Cambodia we can find these two main types of hydropower: the dammed hydro and run of river.

- The Dammed hydro uses the potential energy of water at a height. This water is often contained in lakes and reservoirs, which drives turbines as this water is released so that it can fall to a lower level, transforming its potential energy into kinetic energy. Hydro dams can provide a continuous generation of electricity, even in times of low rainfall. Hydro dams can also be used as pumped storage, with a pump to drive water up to the reservoir during times of surplus or cheap electricity, before it is released during times of scarce or expensive electricity.
- Run of river hydro is more variable than dammed hydro, as it is reliant on the flow of the river, that may vary with rainfall levels

Figure 7. Hydro Renewable Energy (Dammed and Run of River)[9]



Koh Kong *Stung Treng*

[8] https://www.khanacademy.org/science/ap-physics-1/ap-work-and-energy/kinetic-energy-ap
[9] http://www.whyhydropower.com/HydroTour3d.html, https://www.electricaleasy.com/2015/09/hydroelectric-power-plant-layout.html

The Hydro power is considered a renewable source of electricity, as the water cycle is constantly renewed. But on the other side, the construction of large scale hydroelectric dams can however cause severe environmental damage and the water flows may contribute to water scarcity in some places.

1.2 Hydropower in Cambodia

In 2006, the Ministry of Mines and Energy (known now as the MME) and the Cambodian National Mekong Committee (CNMC) reviewed hydropower in the Kingdom and identified possible sites for hydro development in with the potential of 10,000 MW power generation, of which "*50% was on the mainstream Mekong river, 40% on its tributaries, and 10% in the southwest outside the Mekong Basin*"[10] as quoted by MME/CNMC. Therefore 63 possible sites have been identified for small and large hydropower projects throughout the country. As of today only around 1,330 MW has been tapped, which is only 13% of its potential, and the other projects are still under development (it roughly takes four years to build a dam) and some under feasibility studies. In the recent years, the production of electricity from hydro has increased significantly in Cambodia: hydropower electricity production in 2011 was just 51.5 GWh and increased by almost 50 times to 2,711 GWh in 2017.

The figure 8, illustrates the Power Deployment Plan (PDP) of the country from 2017 to 2030. Out of the 22 project, 11 are coal fired plant stations, 11 hydropower. Recent blackouts in May 2019, led the government to add temporary capacity of 400 MW comprised of additional 200 MW in HFO/Diesel and 200 MW in LNG capacity.

[10] *https://opendevelopmentcambodia.net/topics/hydropower-dams/*

Figure 8. Conventional Energy Expansion Plan of Power Sources[11]

No.	Project name	Type	Capacity (MW)	Year	Company
1	Coal Power Plant I-2	Coal	135	2017	CIIDG ERDOS HONGJUN Electric Power Co., Ltd.
2	Sesan II lower	Hydro	400	2018	Hydro Power Lower Se San 2 Co., Ltd.
3	Coal Power Plant	Coal	135	2019	Cambodia Energy Limited (CEL II)
4	Coal Power Plant II-2	Coal	200-250	2020	Cambodia International Investment Development Group (CIIDG)
5	Coal Power Plant II-3	Coal	200-250	2021	Cambodia International Investment Development Group (CIIDG)
6	Coal Power Plant IIII-1	Coal	350	2022	Royal Group Co., Ltd.
7	Stung Sala mum Thun	Hydro	70	2022	
8	Middle Stung Russey Chrum	Hydro	70	2022	China Huadian Lower Stung Russey Chrum Hydro-Electric Project (Cambodia) Co., Ltd.
9	Veal thmor kambot	Hydro	100	2022	
10	Prek Liang	Hydro	120	2022	Asia Ecoenergy Development Ltd.
11	Coal Power Plant IIII-2	Coal	350	2023	Royal Group Co., Ltd.
12	Stung Battambang II	Hydro	36	2023	Stung Battambang II Hydro Power Plant
13	Stung Pursat I	Hydro	40	2023	Stung Pursat I Hydro Power Plant
14	Sambor (Step 1)	Hydro	600	2025	Sambor Hydro Power Plant
15	Sambor (Step 2)	Hydro	600	2026	Sambor Hydro Power Plant
16	Coal Power Plant V	Coal	300	2026	
17	Sambor (Step 3)	Hydro	600	2027	Sambor Hydro Power Plant
18	Coal Power Plant VI	Coal	300	2027	
19	Coal Power Plant VII	Coal	300	2028	
20	Coal Power Plant VIII	Coal	300	2029	
21	Lower Sesan I	Hydro	96	2029	
22	Coal Power Plant VIIII	Coal	300	2030	

Total Capacity in 2030
- Coal/gas: 2,373 MW - Oil: 251 MW
- Hydro: 1,602 MW - Biomass: 185 MW - Solar/wind: 305 MW

Source: Electricite Du Cambodge (2016).

The figure 8 & 9 shows supply demand forecasts prepared by the ERIA (the Economic Research Institute for ASEAN) and based on the existing Power Development Plan (PDP) of the MME. But what about the Renewables?

At the first glance ERIA's recommendation looks aggressive with the growing use on new generation pattern that includes the maximal use of solar/wind and biomass power and mainly hydro potential, in order to match the growing demand, but it may likely reflect a new energy landscape of Cambodia in the coming years.

[11] *Cambodia Basic Energy Plan, http://www.eria.org/publications/cambodia-basic-energy-plan/. Ministry of Mines and Energy of Cambodia, The Economic Research Institute for ASEAN and East Asia*

Figure 9. Conventional Energy Expansion Plan of Power Sources[12]

No.	Type	Capacity (MW)	Year	Total in 2030 (MW)
1	Coal/gas	-1,317	2021–2030: /10 years	1,056
2	Hydro	+3,526	2021–2030: /10 years	5,127
3	Biomass	+301	2031–2030: /10 years	486
4	Solar/wind	+368	2031–2030: /10 years	673

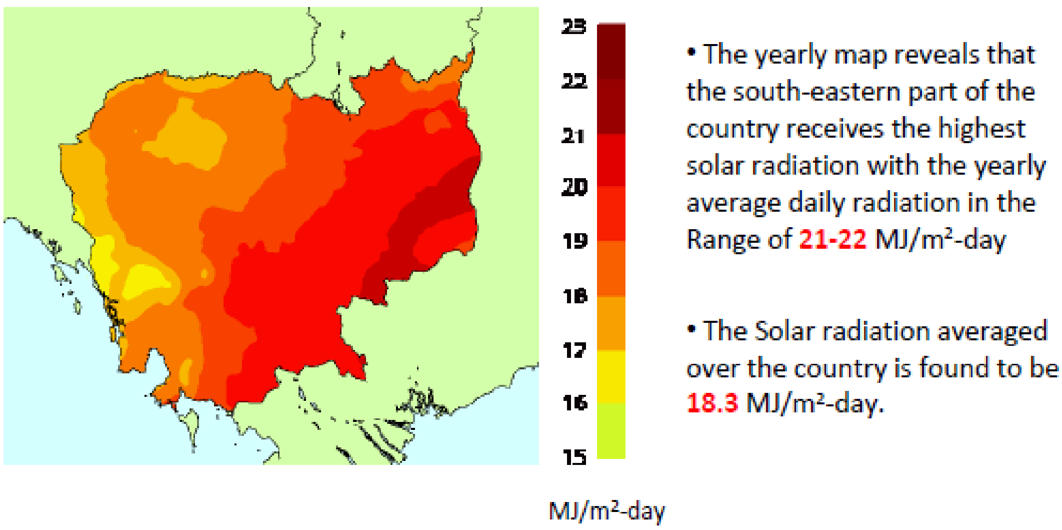
Source: Author (outcome of the dialogue with the Ministry of Mines and Energy).

In this aggressive outlook of ERIA forecast, a clear reduction of coal/gas/oil to 14% will be very positive, whereas I both solar/winds increase to 13%, biomass limited at 6% and the hydropower to 67%. The forecast seems to overrate excessively the hydro in Cambodia, which can be a competitive advantage for the Kingdom, but also may have catastrophic consequences in case of climate change and lack of seasonal water during the wet monsoon.

1.3 Solar Technologies

The Solar energy has immense potential in Cambodia. The map in the figure 10 (below) shows the geographical distribution of the global radiation in Cambodia. And the regions which are very close to Tonle Sap Lake and the South West look like the ideal location for the solar deployment.

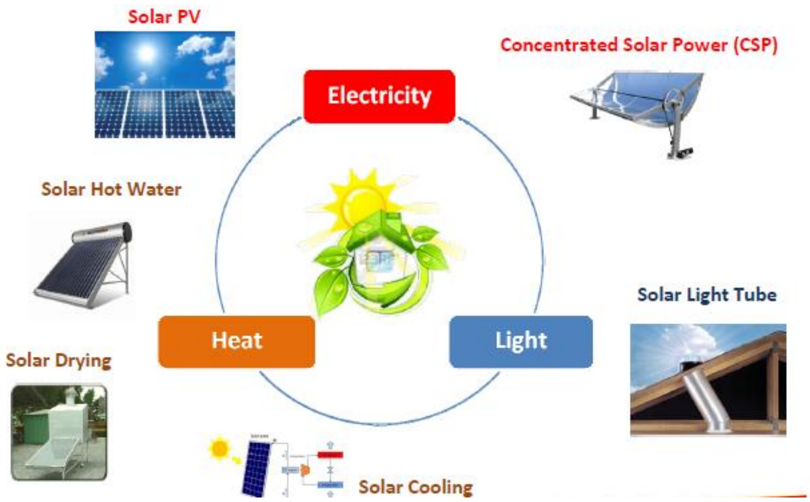
Figure 10. Daily global radiation in Cambodia[13]



[12] http://www.eria.org/publications/cambodia-basic-energy-plan/
[13] Estimation of solar radiation over Cambodia from long-term satellite data, https://www.sciencedirect.com/science/article/pii/S096014811000457X

The amount of solar radiation in Cambodia is much higher than annual global average. The large-scale deployment of solar energy will also depend on a region's geographic access, ground conditions, and land availability. The Solar energy is versatile and can be used to generate electricity, heat, cold, steam, light, ventilation, or hydrogen. The figure 11 shows the different technologies deployed by the solar industry, Solar PV remains the most popular technologies used.

Figure 11. Solar technologies



Photovoltaics (PV)

The technique is to produce electricity from the direct conversion of solar light (photon) to electricity using photovoltaic (PV) systems. Solar PV converts basically sunlight into electricity. Their key features are:

- A solar PV module, a solar cell encapsulated (semi-conductor material such as silicon).
- The photon energy, which is absorbed by atoms or molecules in the semiconductor freeing electrons which are then driven to an external electrical circuit
- The DC power is then sent to devices called inverters that convert for use in the electricity grid (solar and wind produce continuous power, that's why we need inverters)
- Solar PV is dependent on sunlight and will therefore the capacity factor will depend on the amount of sunlight/daylight in a given locality. Solar PV typically has a capacity factor between 15%-25%.

Solar Thermal Electricity

On the other hand, the solar thermal systems use high temperature and heat to produce and generate electricity. The Solar Thermal Electricity (STE) technologies for instance are parabolic systems, solar power towers surrounded by a large array of two-axis tracking mirrors reflecting direct solar radiation onto a receiver on top of the tower. Besides, we can also find large water heating systems, widespread used for swimming pools, hotels, hospitals, and homes.

In both technologies, it appears that several factors will determine the extent and use to specific technologies. These factors include the availability of efficient and low cost technologies, effective energy storage technologies, and high- efficiency end-use technologies.

1.4 First 10 MW Solar in Cambodia

According to the 2016 Mekong Strategic Partners[14], the average solar radiation (see also figure 10) in Cambodia is *"around 5 kWh/day, with an average sunshine duration of 6–9 hours per day, or around 1,400–1,800 kWh/m2"*. The report also projected the potential for solar PV in Cambodia about a minimum of 700 MW, which can be installed on 1,400 hectares of land. Solar PV projects are projected to increase faster than other renewables. However, as land is a sensitive issue in Cambodia, the development of rooftop solar PV is potentially to be grow faster for residential buildings and also existing dam reservoirs instead of land.

The first pilot utility scale-project was a 10 MW pilot solar project in Bavet, in Svay Rieng Province (a special Economic Zone close to Vietnam). On a 21 ha land and with the total USD 12.5 Mn investment, it has been in operation since October 2017. This first Cambodian utility-scale PV power plant and first competitively tendered renewable energy project was won by Singapore based construction company, SUNSEAP[15]. Sunseap Asset Cambodia Co. Ltd (owned subsidiary by Sunseap Group), has signed with a 20-year PPA (0.091 US$/kWh) with EDC under a public-private partnership (PPP) arrangement and produce for ¼ of Bavet City's energy.

Most of the solar and wind are project finance based (70%/30%). The Debt Funding of the Bavet Solar Project, amounts of USD 9.55 Mn (70% of the financing), which are financed by Asian Development Bank, Canadian Climate Fund for the Private Sector (CFPS), Clean Energy Financing Partnership Facility Loan, and also from Commercial Banks loans (BRED).

The government currently plans to add more solar projects in Cambodia about 200 MW solar power (versus 100 MW planned before the pilot)in the master plan, in areas identified in Kampong Speu, Takeo and Kampong Chhnang provinces. The latter one involves in 2018, the ADB financing in collaboration of EDC, to develop a 60 MW solar park infrastructure, through feasibility studies, and organization of a competitive tender process in order to attract and select the viable private sector IPP (Independent Power producer) and PPA.

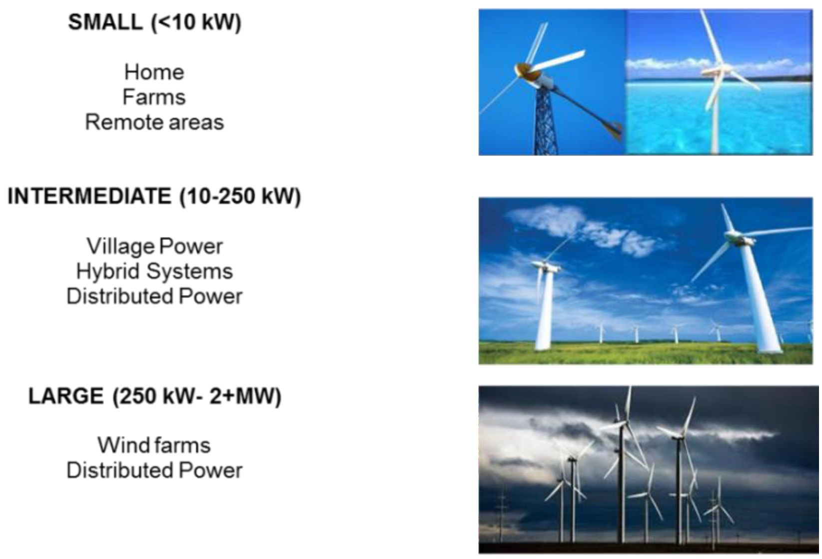
1.5 Wind Technologies

The Wind turbines convert kinetic energy in the wind to electrical energy. The Turbines come in varying sizes and designs, with increasingly large turbines (which are more cost-effective) being made available by manufacturers such as Vestas, Siemens-Gamesa or General Electric (figures 12). Recently the new generation of turbines can generate more than 4 MW in 2019 (compared to 2-3 MW there years ago).

[14] *Switching On: Cambodia's Path to Sustainable Energy Security, http://www.mekongstrategic.com/switching-on--cambodia-s-path-to-sustainable-energy-security.html*

[15] *https://www.khmertimeskh.com/79197/solar-power-set-shine-bavet/, https://www.sunseap.com/cambodias-solar-development-moves-forward-with-10-mw-project/*

Figure 12. Wind Turbines Technologies



The Key features are:

- Blades of the turbine harness the kinetic energy in the wind to turn the turbine.
- The movement of the turbine rotates an axel that connects to a gearbox.
- A gearbox increases the relatively slow speed of the turbines

The gearbox connects to a generator, and like any other power plants, the rotating magnets around coils of wire generate current. However, this current is first converted to alternating current of the right frequency by using an inverter, before sending to the grid. (Figure 13)

Generally, the wind speeds vary depending on different factors such as climate, geography and local topography. Winds speeds tend to be higher and more consistent at higher altitudes. Therefore, the higher the elevation, the better outcome, In general, compared to the solar, wind has the greater capacity factor. But as with solar PV, wind the wind is weather-dependent as its output will vary at will at any time, mostly stronger in the morning and evening.

Figure 13. How does a wind energy works[16]

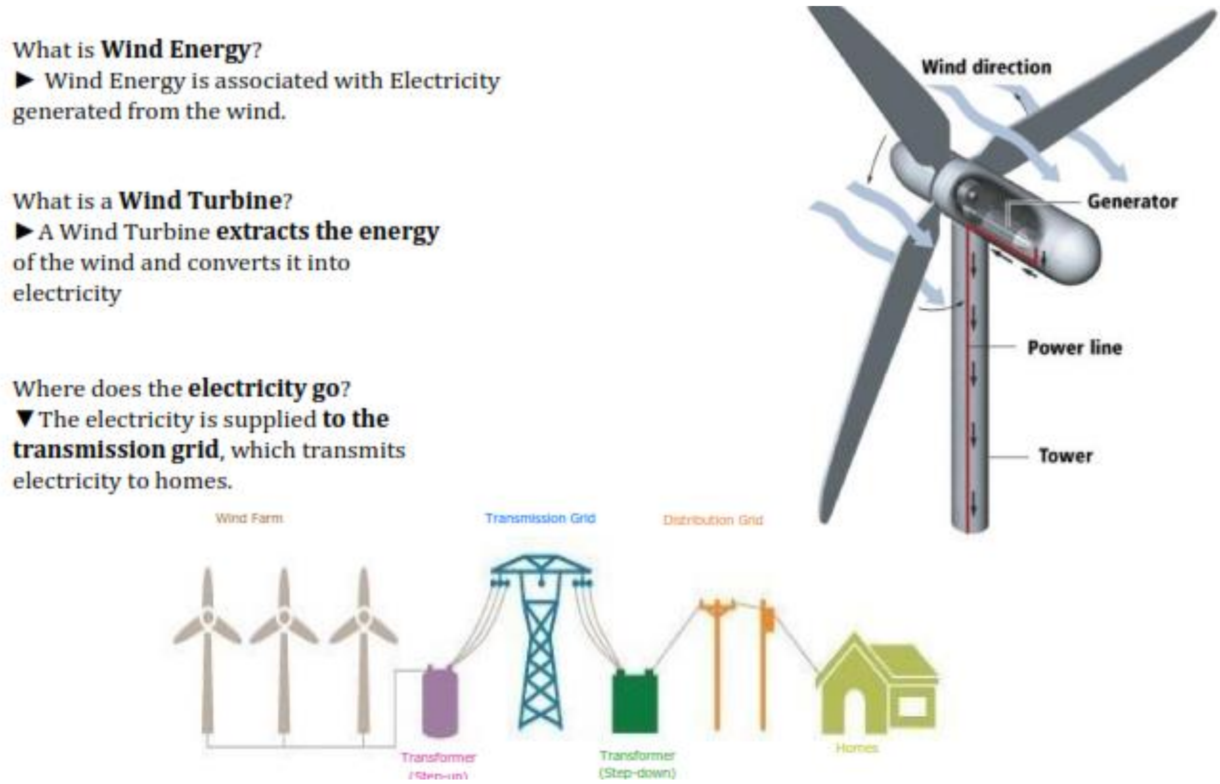
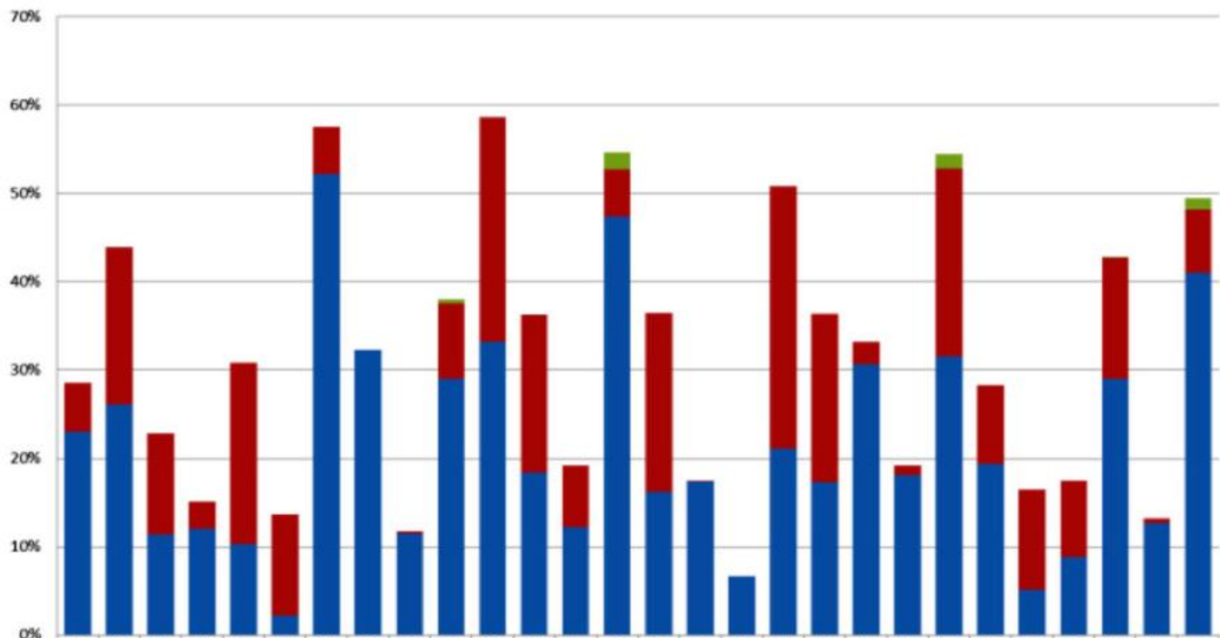


Figure 14. Significant growth of wind vs. solar in Europe[17]



	AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	UK
%Other	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	1%
%Solar	6%	18%	11%	3%	21%	11%	5%	0%	0%	9%	25%	18%	7%	5%	20%	0%	0%	30%	19%	3%	1%	21%	9%	11%	9%	14%	1%	7%
%Wind	23%	26%	11%	12%	10%	2%	52%	32%	11%	29%	33%	18%	12%	47%	16%	17%	7%	21%	17%	31%	18%	32%	19%	5%	9%	29%	13%	41%

[16] The Blue Circle Pte. http://www.thebluecircle.sg/
[17] IRENA, https://www.irena.org/publications/2018/Feb/Renewable-energy-prospects-for-the-EU

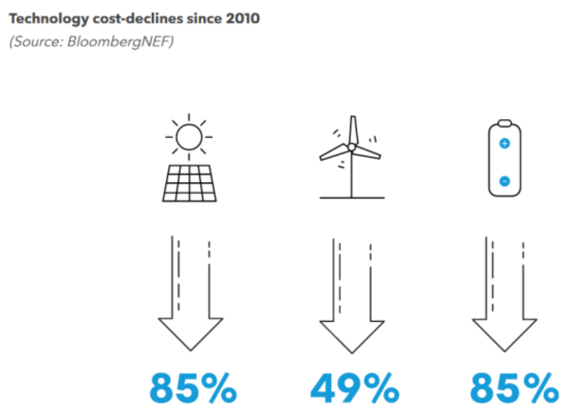
Cambodia's wind potential is located mostly "*in the southern part of the great lake Tonle Sap, the mountainous districts in the southwest and the coastal regions, such as Sihanoukville*[18]*, Kampot, Kep, and Koh Kong, which have an annual average wind speed of 5 m/s*", quoted by the MME in Bangkok presentation in 2016[19].

2. Economic Cost and Benefits of Renewable Energy

2.1 Cost Reduction Trend

The Renewable Energy industry has and will continue to experience decline in costs due to international competition and pressure on margins. In the past few decades , the cost reductions, has been also accelerate through the support of government policies (subsidies , feed in tariff, ..) and the combination of both have made these green technologies more competitive compared to fossil fuel technologies. And the drastic decline (in relative and absolute terms) of cost is illustrated by respectively figures 15 and 16 (solar) and 17 & q8 (wind). The decline of solar (-85%) and wind (-49%), can be explained but factors such as technology improvements, reduced installations and development costs and economies of scales with increasing large scale production projects.

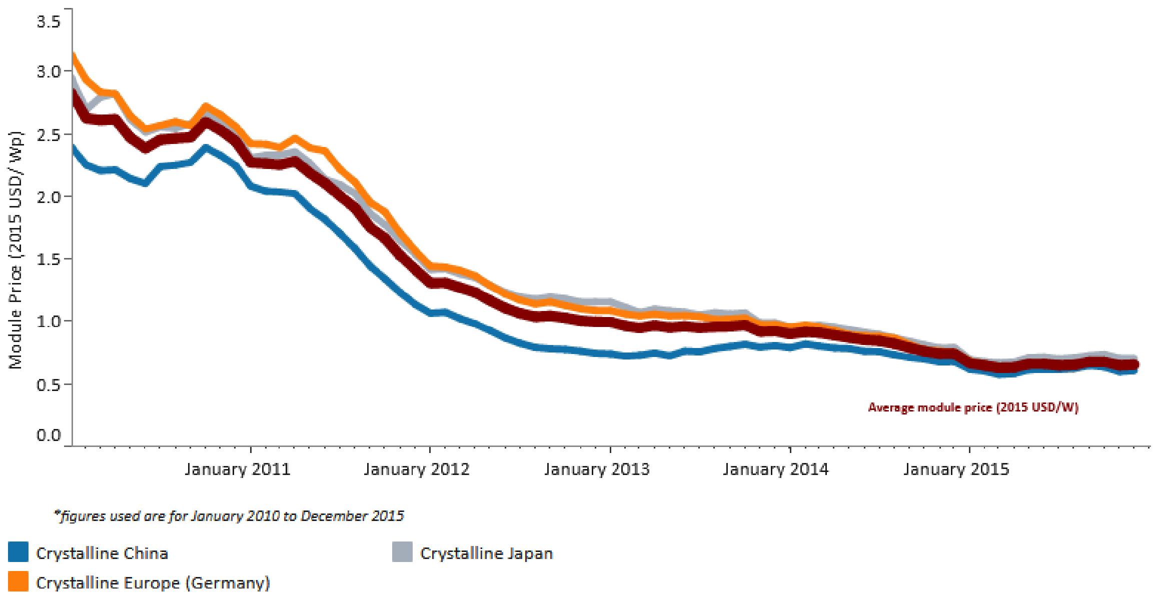
Figure 15. Cost declines of solar vs. wind vs. storage 2010-2019[20]



The predicted cost will continue to fall because also of the improvement of designs, progress in materials and manufacturing and supply chain management. On the other Solar rooftops represent an alternative as they will use exiting unused spaces (rooftop, parking, ..) instead of land, which sensitive to price increase and speculation. In final, to scale up solar PV and wind power costs, the project development will require huge investment (i.e. a minimum of 100 MW) and also a strong collaboration international development banks which can provide financing, such as from the Asian Development Bank (ADB) or IFC.

[18] https://www.phnompenhpost.com/post-focus/blue-circle-add-wind-power-cambodias-energy-production
https://www.khmertimeskh.com/50585976/cambodia-has-wind-energy-potential-study/
[19] https://www.irena.org/-/media/Files/IRENA/Agency/Events/2016/Dec/12/
[20] BloombergNEF https://about.bnef.com/

Figure 16. Solar module price[21]



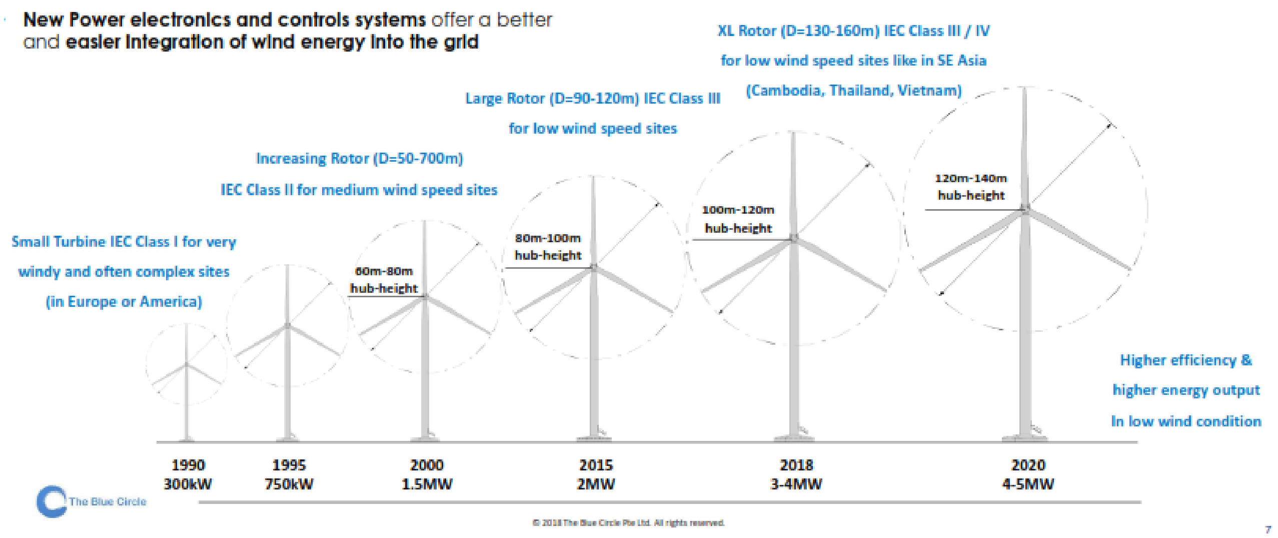
The Wind power in coastal (onshore) and offshore are both promising energy source. Emerging storage possibilities (like Compressed Air Energy Storage) and new strategies for operating grids will definitely offer promising perspectives for the renewable. Because of their intermittent technologies (variability of electricity generation), the storage solutions can be a natural extension, and complimentary to it.

Figure 17. Wind costs per MWh[22]

[21] *Solar Energy Data, https://www.irena.org/solar*
[22] *Wind Energy Data , https://www.irena.org/wind*

Technology of wind turbine has improved a lot over the last 30 years enabling the development of new potential sites. New Power components such as electronics and controls systems offer a better and easier integration of wind energy into the grid. For instance the last generation of General Electric Wind turbines can produce 4-5 Mwh (figure 18) instead 0f 2-3 MW, three years ago.

Figure 18. New wind technologies [23]



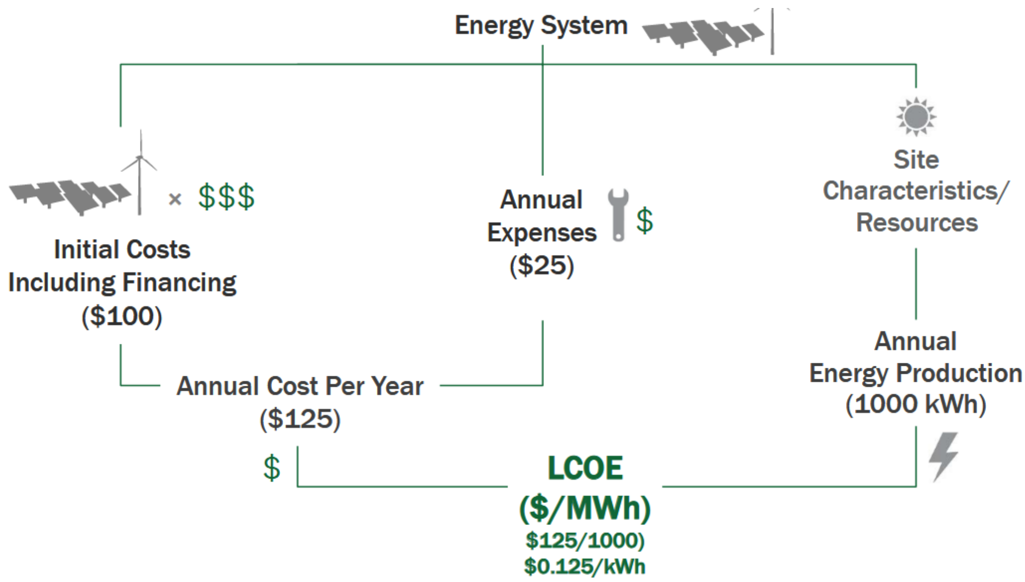
For sure, the cost reductions of new technologies, and capacity development, will make the development and diffusion of renewable energy technologies fast and possible. In some countries, subsidies can be used to accelerate the process and make the investments more attractive. In the near future, the technologies could be also more cost-effective, and be additionally reduced by 25%-35% in industrialized countries (new composite materials, R&D, new energy efficiencies…). In developing countries, the reduction is expected to be even more than 40%. Clearly, there will significant opportunities for continuing to deploy renewable energy in the long run.

2.2 LCOE

One way to compare "cost "and "cost" is the use of the **LCOE**, the **Levelized Cost Of Energy**. It basically measures lifetime costs divided by energy production, illustrated by the figure 19 (the LCOE is USD 0.125/kWh) and figure 20 (formula):

[23] *The Blue Circle Pte, http://www.thebluecircle.sg/*

Figure 19 . Example of LCOE calculation[24]



The LCOE takes into account ***"the present value of the total cost of building and operating a power plant over an assumed lifetime".*** The measures can be applied in the hydro, wind and solar, and allows the comparison of different technologies whereas the easeful economic life and maintenance are different, also the same for capital cost, risk, return, and capacity utilization.

Figure 20. LCOE Formula

$$\frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

It = Investment expenditures in year t (including financing)

Mt = Operations and maintenance expenditures in year t

Ft = Fuel expenditures in year t

Et = Electricity generation in year t

r = Discount rate

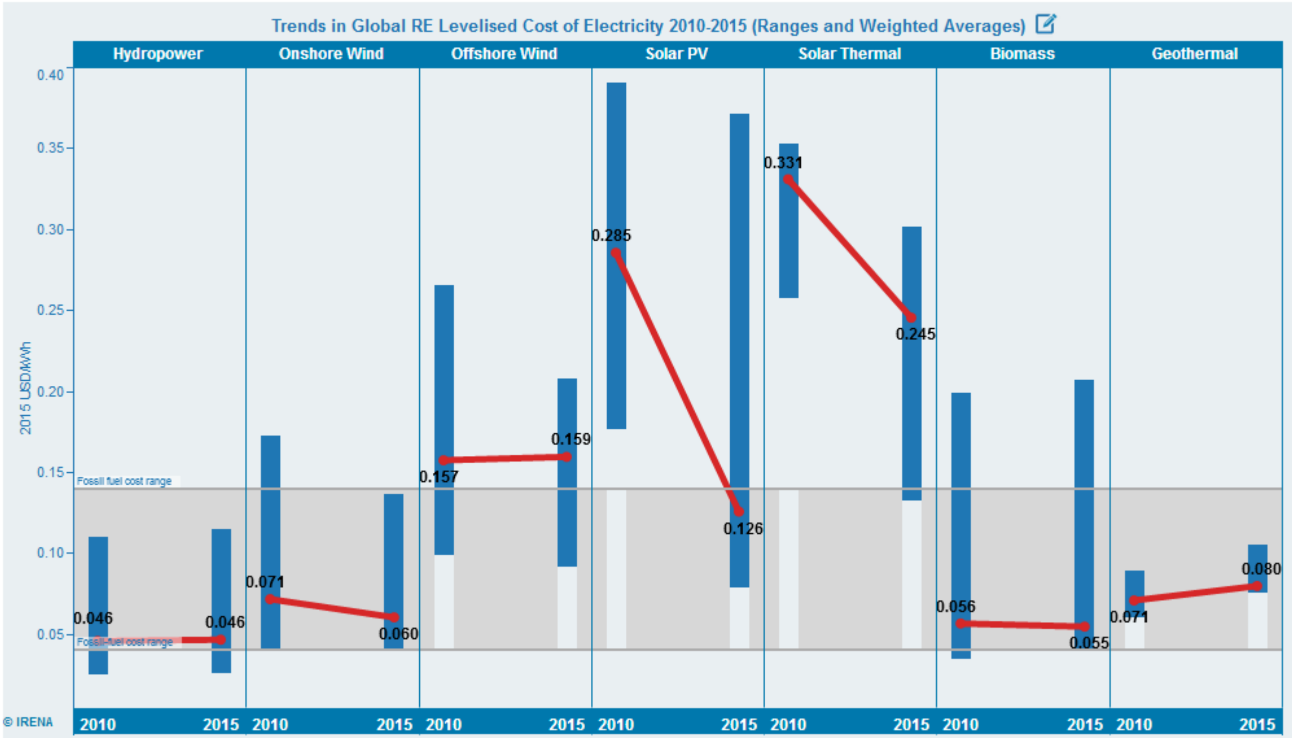
n = Life of the system

**In case of renewable such as solar, wind and hydro, Ft=0, thanks to Mother Nature.*

[24] *https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf*

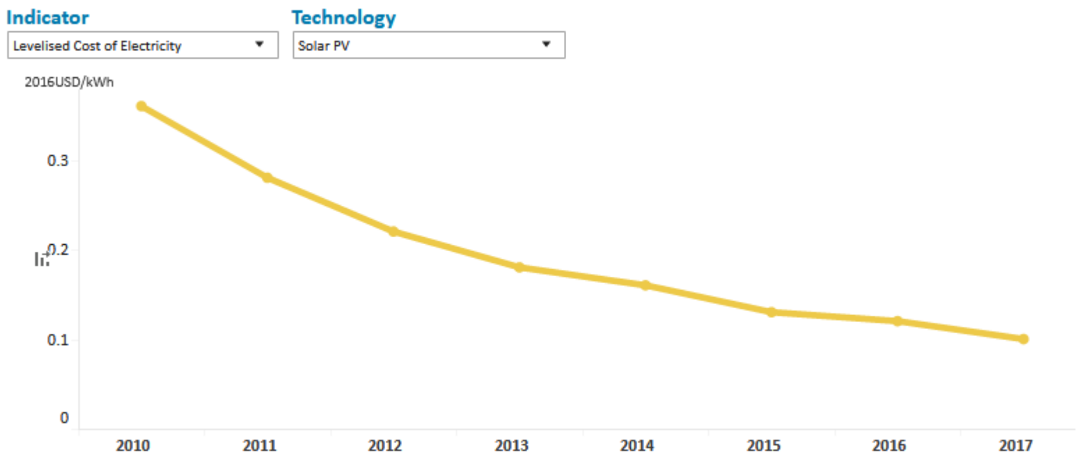
The cost is definitely one of the key factors influencing the choice of the electricity generation means. However, factors such as capital, maintenance costs, operating expenses, and financing costs often vary significantly across conventional and new technologies. In addition, there are also some regional differences in terms of construction services (we usually call them "EPC" or Engineering, Procurement, Construction), in the electricity infrastructure (grid, transmission lines, capacity, frequency, …), and the road access and location do matter. The figures 21a and 21b clearly shows the competitive advantage of the wind and the solar, which may be an explanation to the past massive and successful deployment worldwide. Added with the recent report of Lazard bank [25] (figure 22) the matrix provides also a wider and precise comparative view of the renewable energy versus the conventional ones.

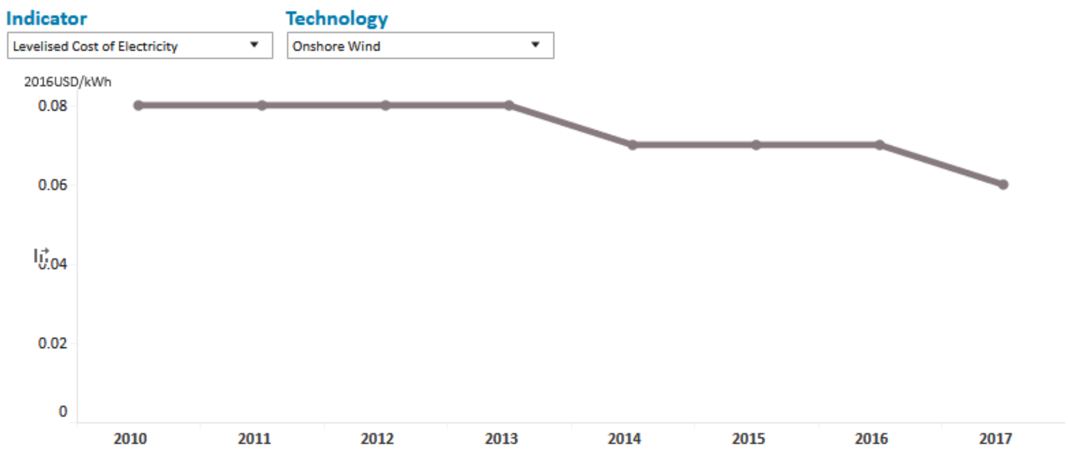
Figures21a. Global LCOE 2010-2015[26]

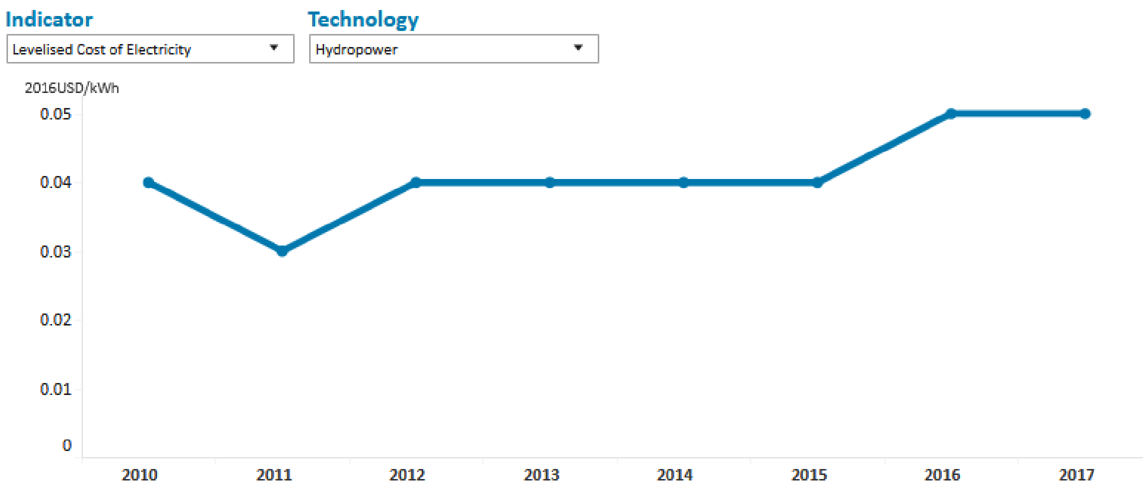


[25] *Lazard's Levelized Cost of Energy ("LCOE") version 12.0, "an analysis on Comparative LCOE analysis for various generation technologies on a $/MWh basis, including sensitivities, as relevant, for U.S. federal tax subsidies, fuel prices and costs of capital"*
[26] *IRENA, https://www.irena.org/costs*

Figures21b. Wind, Solar, Hydro LCOE 2010-2017[27]

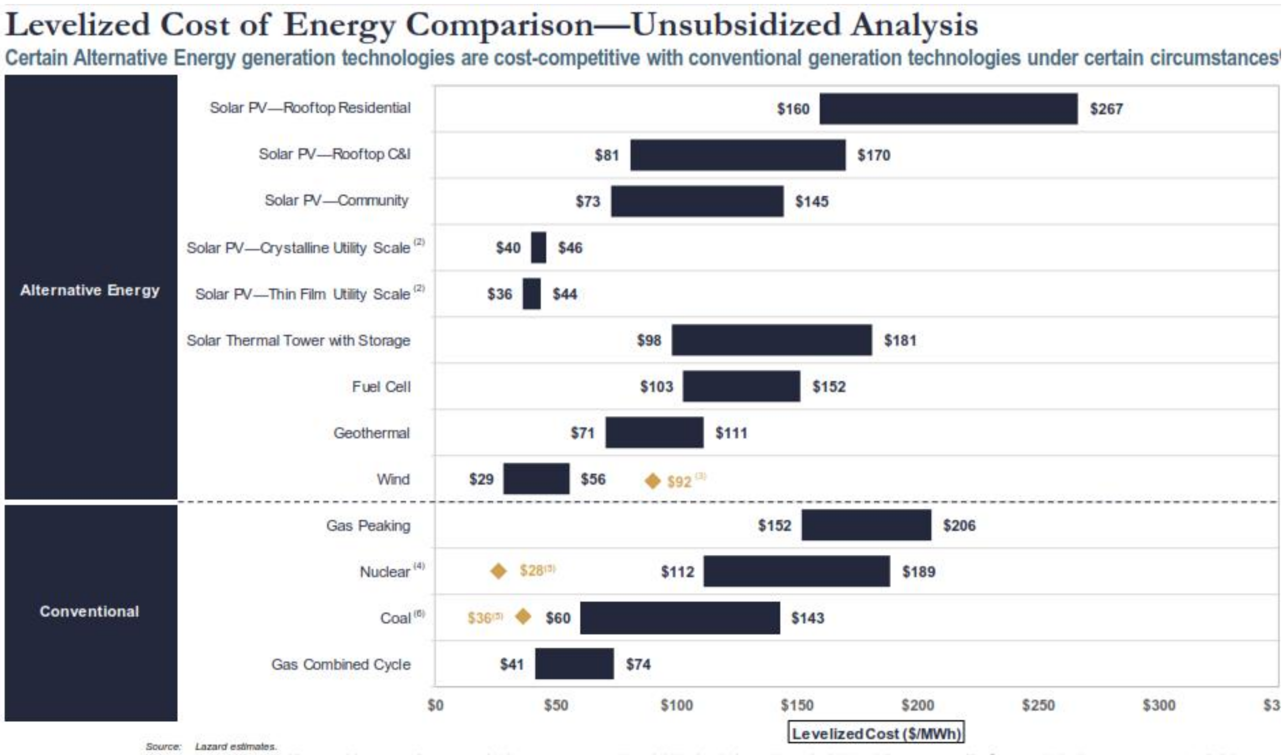






[27] *IRENA, https://www.irena.org/costs*

Figures22. Global LCOE Comparison[28]



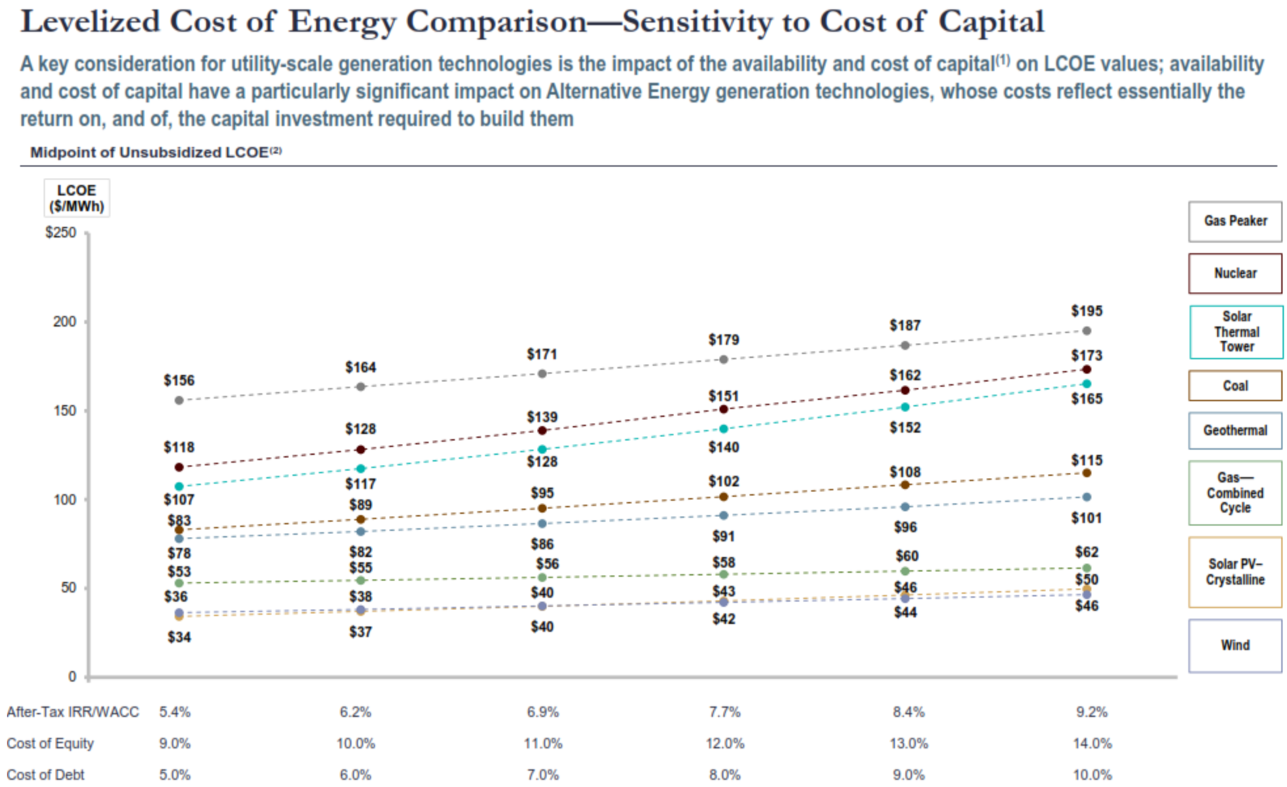
The Levelized cost of energy (LCOE), is one common mertic for cost comparisons across projects and technologies. It considers a plant's expected lifetime and operation cycle and assumed financial costs, but does not include contractual terms on price, duration, or price inflators. Compared with the other prices such as Power Purchase Agreement (PPA), which involve project- or corporate-specific finance terms, it does not reflect different contract terms with the power purchaser (EDC in that case), and rather reflects the value of cost of the energy. In another word, the differences rely on margin from the devlopper and its cost of capital (NPV, IRR, WACC)

Another complementary cost concept is the **levelized avoided cost of energy (LACE)**. The LACE attempts to measure the value to the electric system that certain technologies provide. LACE reflects the cost that would be incurred to provide the same supply to the system if new capacity using a specific technology were not added and used. For example, if a hypothetical new natural gas plant were not constructed, other technologies may need to be added or the utilization rate (and fuel use) of existing plants may need to be increased to meet the energy and capacity services that the hypothetical new plant would have provided. A technology is generally considered to be economically competitive when its LACE exceeds its LCOE.

Another advance LCEO analysis done by the prestigious investment Bank Lazard (figure 23), shows the sharp competitive advantage of solar PV and wind, if we use the LCOE versus the cost of capital (WACC) [29], Lazard assumes a Gearing Debt Ratio of 1.5x (60% debt, 40% Equity).

[28] Lazard's Levelized Cost of Energy ("LCOE") version 12.0, an analysis on Comparative LCOE analysis for various generation technologies
[29] https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf

Figures 23. Cost of Capital and LCOE Comparison[30]



2.3 Capacity Factor

As the wind and solar sources are intermittent, not running regularly and are not fully predictable, we need to also measure and take into account in our financial modeling the **Capacity Factor (CF)** also called Load Factor. This is another way to help comparison and the generic formula is:

Figure 24. General Formula of Capacity Factor

$$\text{CF} = \frac{\text{Actual energy delivered}}{\text{Rated power} \times 8760}$$

$$\text{Annual energy (kWh/yr)} = P_R \text{ (kW)} \times 8760 \text{ (h/yr)} \times \text{CF}$$

The net capacity factor is the "***ratio of actual output (energy delivered over a period of time), divided by its potential output (amount of energy the plant would have produced if at full capacit***y)". The higher Capacity factor, the better it is. The CF vary also depending on the technologies used, the design of the plant and the location (especially solar and wind). The **Availability Factor (AF)** (figure 25) is different from CF, "***it indicates the amount of time that the power plant is able to produce electricity over a certain period, divided by the amount of the***

[30] *Lazard's Levelized Cost of Energy ("LCOE") version 12.0, an analysis on Comparative LCOE analysis*

time in the period". For example Hydro typically has a CF about 60% and AF close to 80%- 90%. The solar PV has a CF around 15%-25% but an AF close to 100% because of low maintenance period, they are running most of the year, whereas hydro are shut down when level of water is low.

Example of a Baseload Power Plant[31]: A base load power plant such as nuclear power plant, with a capacity of 1,000 MW might produce 648,000 MWh in a month (observed or expected). But the number of megawatt-hours that it would have been produced, if the plant been operating at full capacity would be 1,000 MW × 30 days × 24 hours/day, 720,000 MWh. The CF is then determined by dividing the actual output 648,000 MWh with the maximum possible output 720,000 MWh, and the number is 0.9 or 90%. (in line with figure 25)

$$\frac{648,000\ \mathrm{MW{\cdot}h}}{(30\ \mathrm{days}) \times (24\ \mathrm{hours/day}) \times (1000\ \mathrm{MW})} = 0.9 \approx 90\%$$

Example of a Wind Farm: An old wind farm of 10 wind turbines of 2 MW for a total capacity of 20 MW generated 43,416 MWh of electricity in one year. The capacity factor for this wind farm is 25%. Nowadays new technologies can reach 35% CF.

$$\frac{43,416\ \mathrm{MW{\cdot}h}}{(366\ \mathrm{days}) \times (24\ \mathrm{hours/day}) \times (20\ \mathrm{MW})} = 0.2471 \approx 25\%$$

Example of Hydro Dam: A Hydro Dam as 26 main generator and each units of 700 MW and two auxiliary generator units of 50 MW, for a total installed capacity of 18,300 MW (=26*700+2*50). The total annual output generated was 79.47 TWh, in that case the capacity factor of just fewer than 50%, and far below international benchmark (60%-66%):

$$\frac{79,470,000\ \mathrm{MW{\cdot}h}}{(365\ \mathrm{days}) \times (24\ \mathrm{hours/day}) \times (18,300\ \mathrm{MW})} = 0.4957 \approx 50\%$$

When it comes to renewable energy sources such as solar, wind and hydro, the plant may be capable of producing electricity, but its *"fuel"* (wind, sun or water) may not be available. A hydro plant's production may also be affected by requirements such as to keep the water level from getting too high or low and or to provide water downstream. However, solar, wind and hydro plants do have high availability factor, so they are almost always available, and able to produce electricity. The figure 25 also gives an idea about the difference between technologies in terms of CF and AF. Some comments to help the comparison:

- The Hydroelectric plants have water available during the wet season (in Cambodia, the wet monsoon start in May and finish in October), but also during the dry season (dry monsoon from November to April) thanks to the water savings by using of the others renewable energy (energy mix); they are lower in terms of water but still useful for load. And a typical hydroelectric plant's operators can be brought to full power in just a few minutes (versus 8 hours for coal fired plant).

[31] *University of Denver, http://www.ucdenver.edu/*

- The wind power plants outputs are variable, due to the natural variability and change of direction of the wind. The typical capacity factor is mostly determined by the location of wind (mountain, hill, sea) and the quality of the transmission line capacity may also affect the capacity factor. In Cambodia, hills in the North east areas (moderate elevation) and coastal regions should be the perfect location.
- The solar power plant is as variable as wind plant, as sunlight is concentrated from morning to late afternoon. And because of the seasonal changes, and maybe climate change, and sometimes unexpected cloud or rainy storms, the CF may vary. Cambodia is close to the Equator and has a constant radiation. In the late afternoon or early evening the CF is then close to zero.
- The geothermal has a higher CF and AF factor than the previous sources, as they are available 24 hours a day, 7 days a week. Some sites have been discovered in the region of Kompong Speu [32] which benefits of naturals hot spring sources, and are identified as potential geothermal power sources.

Figure 25 . A Quick Glimpse at Renewables Comparables[33]

Generation Type	Typical Capacity Factor	Maturity	Start-up time (hours)	Typical LCOE ($/MWh)	Capital Cost ($/kW)	Typical Ramp Rate (% Full load / Minute)	Typical Life-Cycle Emissions (g CO2e / kWh)	Availability Factor
Coal	53 - 85%	Mature	1.5 - 3	72 - 105	3900 - 3950	6	933 - 1048	> 80%
Gas CCGT	56 - 87%	Mature	01-Feb	30 - 36	1050	8	411 - 487	> 80%
Gas OCGT	8 - 30%	Mature	0.1 - 0.2	69 - 122	900	20	543 - 692	> 80 %
Oil	~ 8%	Mature	3	Not Available	~ 400	7	530 - 900	> 80%
Diesel	66%	Mature	< 0.01	200 - 280	500 - 800	25	800 - 1056	89 - 91%
Nuclear	92%	Mature	24	63	6070 - 6200	2	07 - 25	80-90%
Biomass	56%	Deployment	3	107 - 109	3940 - 4100	8	18 - 59	
Solar PV	15 - 27%	Mature		35 - 81	1770 - 1780		37 - 50	97-99%
Solar CSP	44 - 60%	Deployment	2.5	95 - 167	7840	6	16 - 37	
On-shore Wind	11 - 48%	Mature		22 - 169	1520 - 1750		8 - 20	95 - 99%
Off-shore wind	31 - 51%	Mature		95 - 268	3780 - 8200		10 - 15	95 - 99%
Hydro	60 - 66%	Mature	< 0.1	35 - 70	3960 - 7410	15	4 - 15	80 - 90%
Tidal	~ 25%	Demonstration		230 - 250	3300 - 3600		06 - 11	95 - 98%
Geothermal	80-90%	Mature	1.5	76 - 237	5100 - 13670	15	17 - 57	92 - 99%

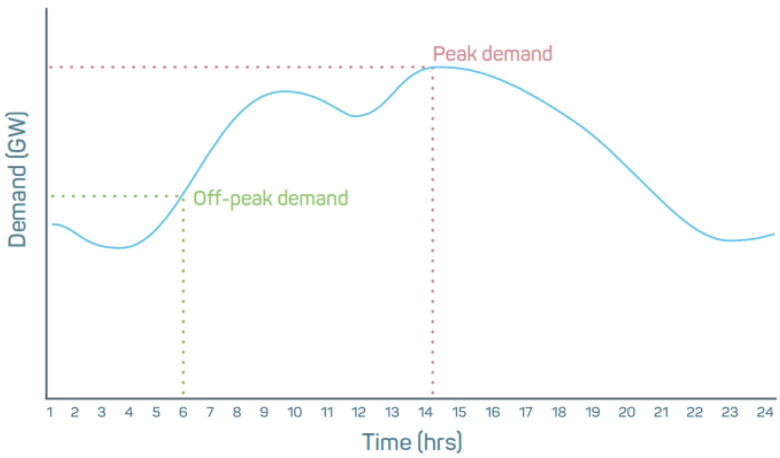
[32] *Cambodia-Geothermal-Potential.pdf. IEA2017*
[33] *https://www.imperial.ac.uk/*

2.4 Merit Stack Order

The Merit Stack Order (MSO) is by definition: "*the order in which generation plants are scheduled to supply electricity to meet demand*". The order will prioritize which generation plants would need to be scheduled first so that supply electricity meets demand. For instance in figure 26, we can see that demand is growing regularly in the morning and decline in the evening (except for some city like Bangkok, where the demand pattern remains strong until the evening). And the second objective is to get the cheapest-running plants in order to provide the power supply. In practice, the renewable energy electricity come first, and then the next-most-expensive plants do so such as oil/coal (figure 28). In this way, the total cost of electricity supplied will be minimized as well as the wholesale price, while meeting the demand pattern at any given time. In short, the marginal cost does matter.

Figure 26. Electricity demand varies throughout the day,

with peak and off-peak periods of demand[34]



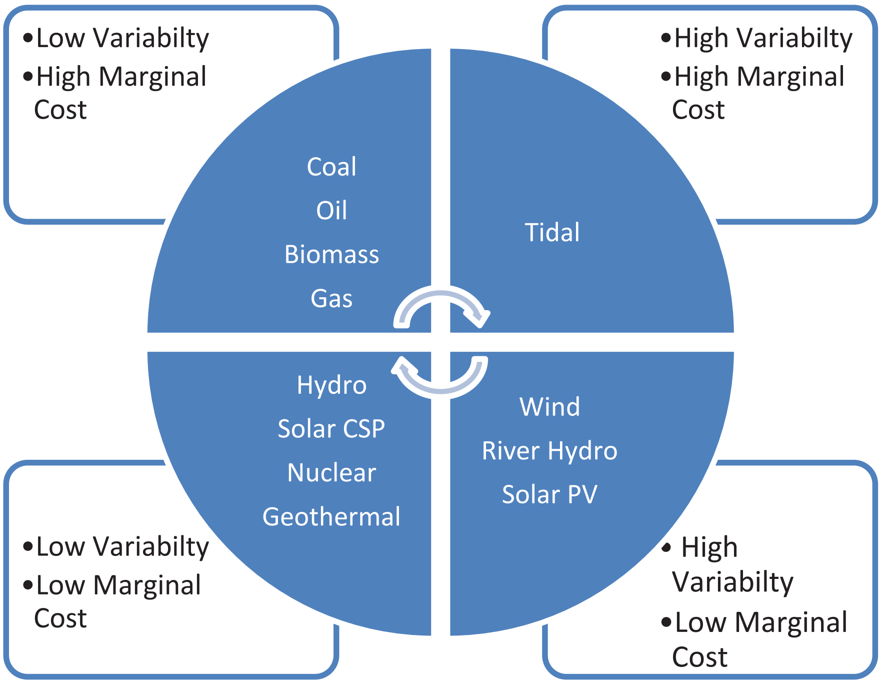
Depending on the cities, there will be times of lower demand (off-peak) and times of higher demand (peak).

The Figure 26 shows an example of the changing demand over one day within an electricity system.

In the energy industry, the schedule order (MSO) will give priority the lowest marginal costs power plants. Therefore, the power plants that produce electricity at very low prices (i.e. wind, solar, hydro) will the first to be first to be deployed and to supply power (the whole bottom of matrix figure 27). And then the power plants with higher marginal costs are subsequently added to the system until demand is met. These marginal costs are incurred by a power plant and refer to the cost of producing a single MWh. The aim is the optimization the price of the electricity supply.

[34] *https://www.imperial.ac.uk/*

Figure 27- Low Marginal Costs Energy First[35]

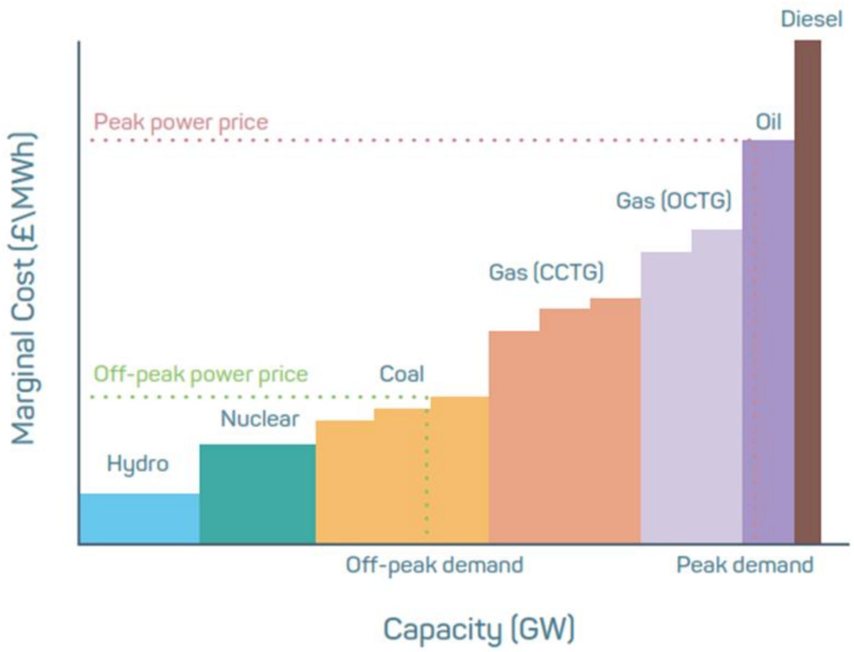


In general, wind and solar have no fuel costs (wind, sun), meaning that power generated from these sources comes first in the MSO. However water for hydro is normally a very low cost, but when the availability of water is low, the cost may be relatively high (low marginal cost, but some variability depending on the dry and wet season). In case, hydro comes after the wind and solar in the schedule. On the other hand, fossil fuel (oil, gas, cola) power plants are sensitive to commodities prices variation and are in general higher than nuclear ones (i.e. uranium). In the MSO, it means nuclear comes before them. Within the fossil fuel plant, the merit order will place first coal, followed by Gas and then Oil and at last the Diesel (figure 28).

The Figure 28 shows a MSO for a typical electricity system without renewables such as wind and solar, but hydro. It shows how the off-peak and peak demands in are met by a combination of power plants sequences

[35] *https://www.imperial.ac.uk/*

Figure 28. The merit stack order shows the ranking of different generation plants vs costs.



The power generation capacity available to meet demand is ranked by m marginal cost in ascending order. In this example, nuclear, hydro and coal generation plants at the bottom of the MSO are required throughout the day (hydro, nuclear, coal) and we say they are supplying base load power. In the figure 29 and 30, the merit order show how useful it is for the functioning of the electricity market. If we run the power plants with low marginal costs in the first order and complement by oil/gas/coal, we can therefore reduce the wholesale price of electricity and offer a lower tariff to the public. We call it the Merit Order Curve (MOC).

Figure 29- Electricity Prices and the Merit-Order Curve

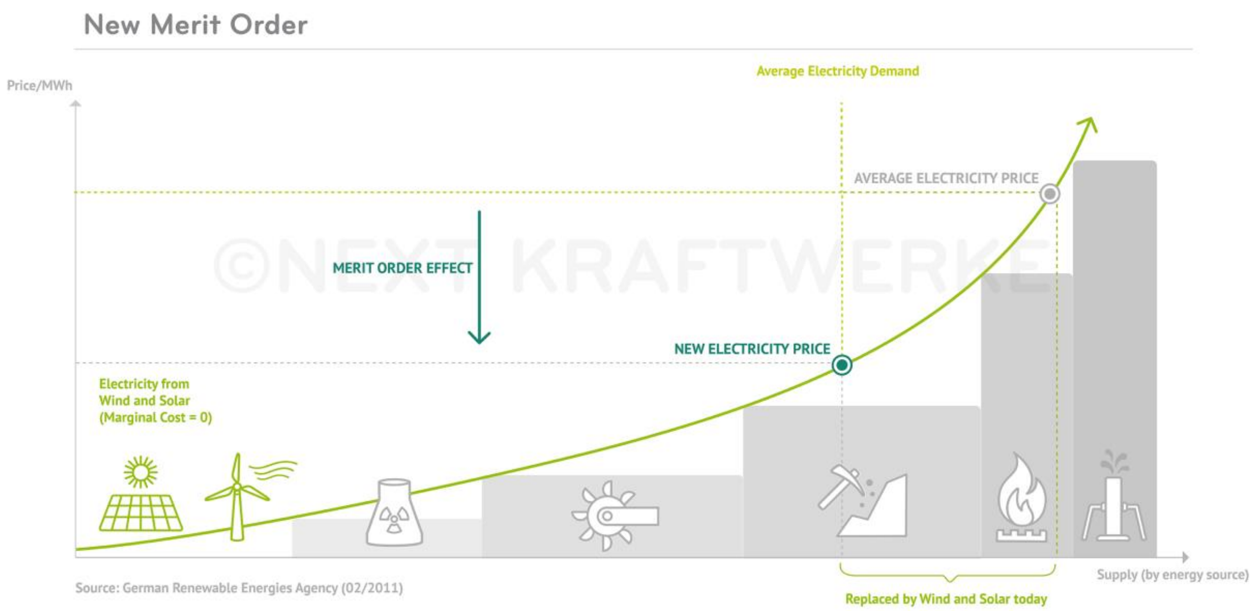
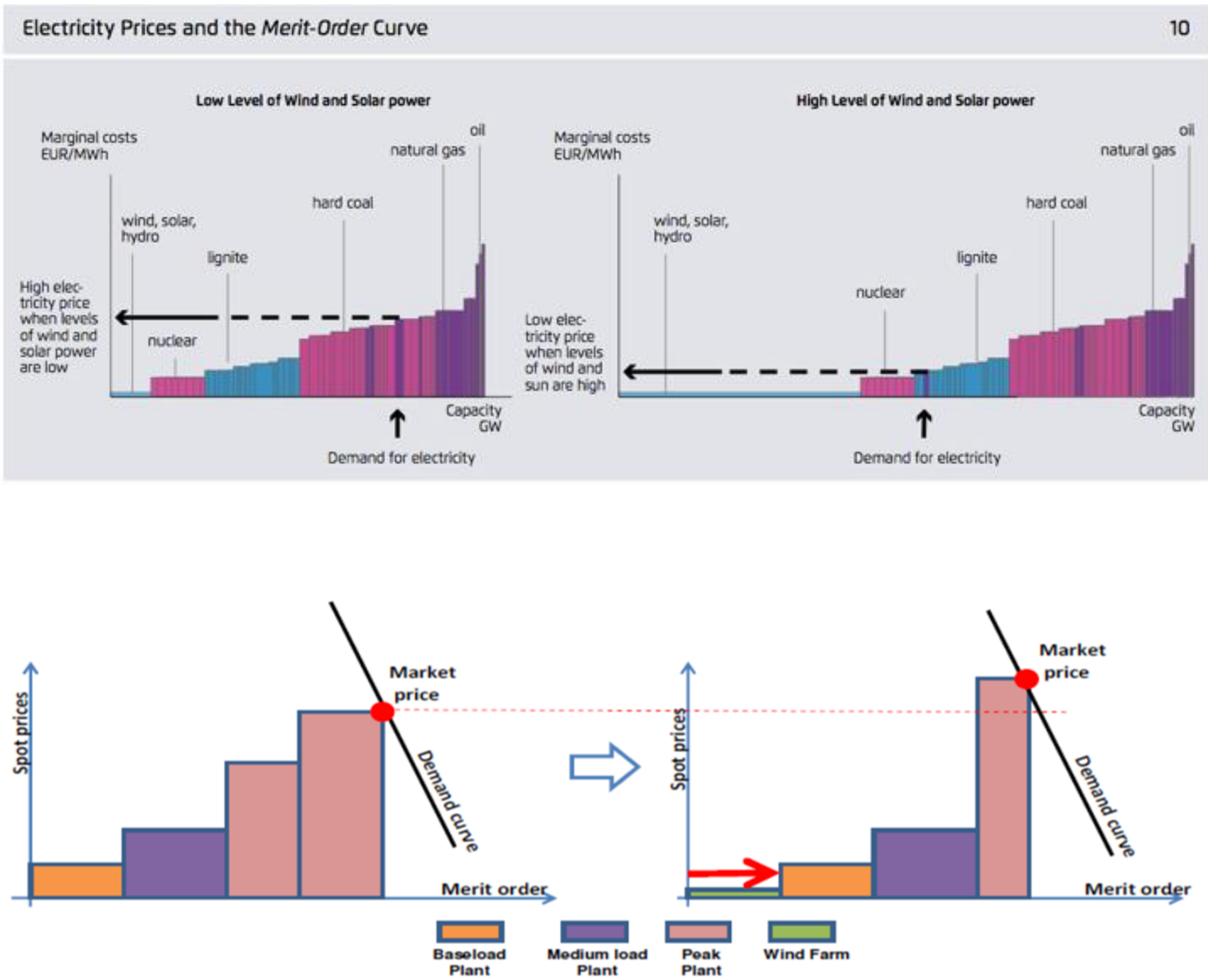


Figure 30.Impact of Merit Order Effect on Electricity Price[36]



2.5 Merits and Limits of the Merit Order

Because or thanks to this economic principle, we have observed and will continue to witness this global shift to renewable power production, whose production costs are clearly declining all around the world. The Merit Order may have economically influenced this shift, a shift from conventional power plants to new technologies. But the exponential growth of solar and wind are also explained by subsidies and feed-in of renewable energies (such as solar rooftop in Thailand, wind energy in Vietnam, or biomass). Solar PV and wind power plants, with their low marginal costs and public subsidies will definitely grow and take more market share, and the operational risks will be gradually transferred to conventional power plants. In the MSO, we also assume that power plant operators are always being able to cover the cost of the next MWh they produced, but what about the countries where the renewables run at 40%-60% of the capacity like in Germany and in UK, would traditional power plant be able to produce and make profit? Because power plants with higher marginal costs, they will be scheduled as the last resort in some countries.

[36] *Impact of renewable energies on electricity prices and energy market structures "Presentation for the expert workshop with Dr. Uwe LeprichInstitut for Future Energy Systems (IZES)Berlin, April 3, 2014*

The Merit Order is not a fixed "law", fixed by decree or government, which is responsible to coordinate the use or no-use of power plants. The merit order is designed firstly to optimize economically the pricing on the electricity market. The model is also a static model that works well in the short-run, especially for the electricity price formation. The model does not take into account the long term effect of deciding the use or non-use on specific power plant, and may lead the electricity producer into a situation of insolvency/ bankruptcy, in case of absence of specific mechanism system which will balance costs and benefits among the producers. A more complex model is needed and maybe Big Data or AI technologies can support the development. Power plants developments are complex and the long term model has to integrate factors such as national operator(s) master plan and decisions for deployment, the forecast of possible expansion and addition of new capacity, as well as the construction costs and the consolidated cost of fixed/operational costs if decisions were made.

Some critics says that the merit order model overstate the merit of renewables such as wind and solar versus the traditional ones. Also some debates that model does not fully reflect the reality as the electricity technologies differ from one to another, in key characteristics such as marginal operating cost and because of the variability of output. And the model does not take into account the worst case scenarios what about the potential costs associated to insolvency or bankruptcy ? For example, what would be the cost dismantling a nuclear power plants, or a hydro power plant?

Conclusion: Outlook for Cambodia

The renewables energy technologies advantages and disadvantages are respectively summarized in the figure 31.

Figure 31. Advantages and Disadvantages

Renewable Energy Type	Advantages	Disadvantages
Biomass	Carbon neutral Large variety of feedstock Low capital investment	Pollution when operated incorrectly Good management required Controversial NIMBY (not in my backyard) High capital investment Potential air permitting issues
Geothermal	No fuel costs Predictable High load factor	Limited locations
Micro hydroelectric (low-impact hydroelectric)	No fuel costs Low operating costs Energy storage High load factor Installation in a pipeline or outfall	Power output is dependent on elevation changes
Solar photovoltaic / Solar thermal	Declining costs No fuel costs Low maintenance costs Quick installation	High capital investment Intermittent power generation Power output depends on solar irradiance Low efficiency
Wind	Low costs No fuel costs Offshore advantage	Low persistent noise Aesthetic impact Intermittent nature Sufficient wind not available in many areas
Tidal	Predictable No fuel costs Low maintenance costs High energy density High load factor	High capital investment Siting limited to tidal areas Effect on marine life Immature technology Difficulty in transmission Weather effects Not a mature technology

The Renewable Energy Technologies do “normally” not cause emissions during operation, but some of them do cause CO2 emissions during manufacturing process (PV cells production, mainframe and engines for wind) and possibly some construction costs before the commissioning (cement batch plant for the Hydro, strong foundations for wind turbines). The other controversial questions is also about the comparison of the cost for producing the solar/hydro/wind equipment, and especially the amount of energy required and needed to manufacture them, to transport them, and to complete a project, versus the carbon savings during the lifetime of the project. In that case, hydro will be in the heart of the debate, because not only of its capital intensive character but also on the real detrimental effect and potential accidents in Cambodia[37]. In the Solar level, some significant complaint of heat has

[37] https://theaseanpost.com/article/cambodias-hydropower-dilemma; *“Recently, hydropower projects in the region have come under heavy scrutiny after Lao’s dam collapse which killed over 30 people. Many are beginning to question the safety standards of dams constructed in the region”*

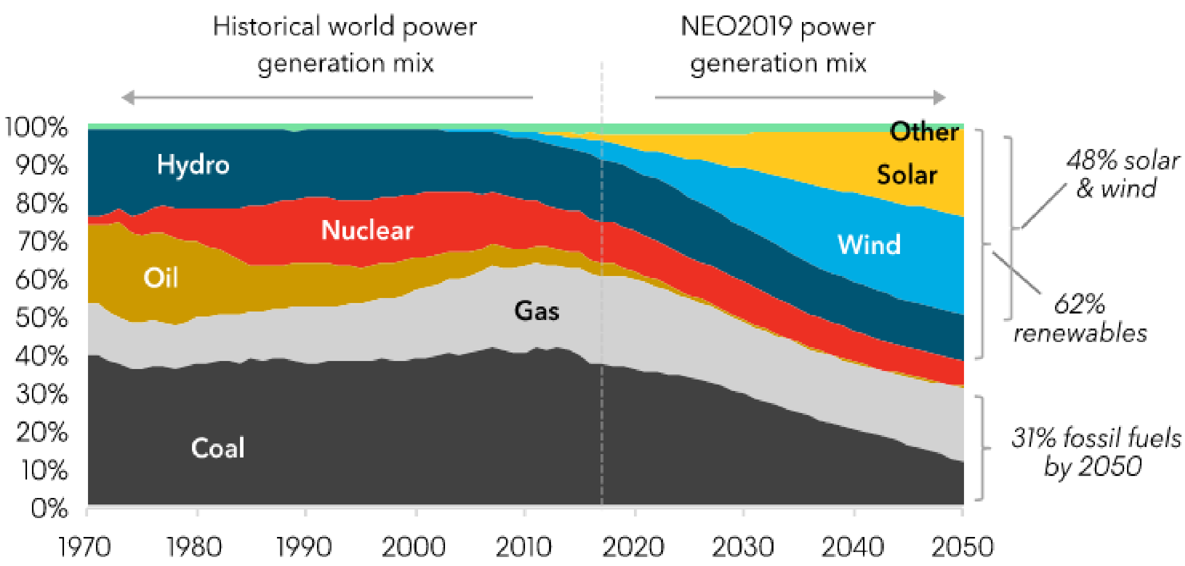
emerged has been in Bavet neighbors[38], not validated by third scientific parties.

In a different angle, if we look at the financial numbers, such as payback period, the numbers will not infinitely continue to improve. Previously grid-connected PV systems payback period was estimated in between 8 and 9 years, and now is expected to range 6-8 y years. But the availability of some elements of the PV modules (in the thin-film, like indium and tellurium) is also a subject of concern (risk of shortage), and the other concern is the acceptance of new rare materials in PV modules, such as cadmium but can very toxic for the public due to its radiation.

The limits of some technologies may also a reason why Cambodia takes so much time to deploy it. The average production cost of electricity from hydropower is currently less than US$0.07/kWh in Cambodia, which is more expensive than Laotian counterpart but less than the average national electricity tariff of US$0.20/kWh. From the technical and financial point of view, there is need for the government to work rapidly on newer regulation, on and master plan, since hydropower can be the only source in renewable energy and referencing to the merit stack order, and hydropower projects are always subject to environmental issues. According to a study done by the Mekong River Commission, dam construction has negative impacts on the "*riparian ecosystem, sustainability, and food security associated with fish production in Cambodia"*. In order to maximize the use of hydropower and minimize its negative impacts, the government needs to have strategies on how to mitigate the moral hazard, such as issuing strict regulations that guarantee that hydropower project developments will comply with international high-quality environmental impact assessment (EIA), especially the IFC and ABC standard.

The next challenges are clearly now: wind and solar, which will be the cheapest across more than two-thirds of the world. And by 2030, most of the countries will reduce coal and gas projects almost everywhere.

Figure 32 – Global Power Mix (Bloomberg NEF)[39]



[38] *https://capitalcambodia.com/solar-energy-users-feel-the-heat/*
[39] *https://about.bnef.com/new-energy-outlook/*

Cambodia will thus need to think about how to increase and stably integrate of solar PV and wind power into the national grid. At the present, the use of solar PV and wind power generation in Cambodia is insignificant, small compared to other countries, both in the ASEAN region and internationally. The development of solar PV generation is expected to emerge first and due high potential in the short term (high competition with Chinese supplier and funding, ADB support, and light civil engineering needed). But wind power will gradually increase, in the same pace as Solar, because they are both complementary in their of supply pattern (day and night, wet monsoon and dry monsoon) and will strengthen the security of the energy supply of the country, and help to tackle climate change (Paris Climate Change Agreement). The projection is realistic as costs of wind and solar will continue to fall because of more efficient designs and advances in materials (composite materials in the wind turbines, lighter and stronger) and manufacturing (efficient supply chain management). In some niche sector, solar rooftops will also increase because of the price of land. For instance, the Comin Khmer company (RMA group) has already installed few MW in country mostly off-grid. Moreover in any case, to scale up solar PV and wind power projects which both require huge investments (more than USD150 m for an 80 MW project in Cambodia). Therefore, a smooth cooperation and collaboration with international financing are essential (reducing the cost of debt), such as from the Asian Development Bank and IFC.

Electricity demand in Cambodia has grown at an average of nearly 20% per year since 2010, and will keep growing at that pace according to the MME. And the current blackout situation in the dry season is will not be completely solved by 2022. The current demand is mostly covered supplied by large-scale hydropower plants and coal-fired / HFO / Diesel power plants, which are not long term sustainable. Cambodia has to tap on its potential for non-hydro renewable energy deployment, such as wind, and solar. Hydro renewable energy is not yet optimally utilized due to the high barriers to entry such as higher upfront costs and no clear target or position for renewable energy status in the energy power plan mix. The lack of public-private policy and regulations to support the promotion of renewable energy utilization can be a hindrance for the quick deployment of renewable energy. In the near future, the government should definitely increase the use of renewable energy, which is locally available and should instead reduce the use of coal and diesel power plants.

Based on different forecast, the most possible energy mix in the year 2030 comprises hydro at 50%-60% and non-hydro renewable energy at 15%-20% (biomass, solar PV, and wind) of the projected total electricity installed capacity of 6,632 MW including the renewable in the PDP.

Renewable energy targets are currently not clearly defined in terms of numbers to reach, or to be achieved a specific amount of MW production or even in terms of demand coverage. The recommendation of ADB would be to limit the proportion in the first stage the renewable energy top 10% of the total growing capacity, in order to minimize risk of and grid connection instability, which are not complete ready to integrate high volume of renewable energy.

In the midterm run, Cambodia needs to set an ambitious target plan to meet by 2030: a reduced and contained energy Coal/gas (35%), oil (0%), hydro (about 55%), RE (biomass, solar, and wind, around or more than 10%). If so, the country will also be able to meet at least two goals, which is (a) meet the national demand constant growth with a lower electricity tariff and (b) to reduce imports, and in that case, can definitely pretend to be an emerging electricity exporter country (positive to GDP) to growing and voracious neighboring consumer countries such as Vietnam and Thailand. The Improvement of the utilization of diverse energy sources, and mastering the renewable energy mix (new jobs, new skills) will be our competitive advantage.

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