RENEWABLE ENERGY ASSESSMENT IN CAMBODIA









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Solar PV-ISPP Cambodia © ACE

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List of Abbreviations

ACE	ASEAN Centre for Energy
ADV	Advanced Effort Scenario
AGEP	ASEAN-German Energy Programme
AMS	ASEAN Member States
ASEAN	Association of Southeast Asian Nations
BAU	Business-as-Usual
CAGR	Compound Annual Growth Rate
CAM	Cambodia Targets Scenario
CO_2	Carbon Dioxide
CPI	Consumer Price Index
EE	Energy Efficiency
EE&C	Energy Efficiency & Conservation
ERIA	Economic Research Institute for ASEAN and East Asia
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GWh	Gigawatt-hour
GWP	Global Warming Potential
INS	Install Higher Solar Power Scenario
ktoe	Kilotonne of Oil Equivalent/Thousand Tonnes of Oil Equivalent
kWh	Kilowatt-hour
LEAP	Long-range Energy Alternatives Planning System
LPG	Liquefied Petroleum Gas
MME	Ministry of Mines and Energy
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatt
NIS	National Institute of Statistics
PDP	Power Development Plan
POP	Population
RE	Renewable Energy
SHS	Solar Household System
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USD	United States Dollar
WDI	World Development Indicators

Foreword

As one of the new emerging economies in ASEAN, Cambodia's energy demand has doubled from 3.5 to 6.3 Mtoe between 2005 and 2017. The annual electricity generation growth rate had been observed to increase by 17% in the same period. Despite rapid energy supply growth, Cambodia is still currently one of the ASEAN Member States which need more improvement in electricity access (including on- and off-grid). In 2016, the urban population has attained 100% access to electricity, in contrast to only one-third of rural population with access to grid. Consequently, the total percentage of electrification access for the whole population in Cambodia is around 51% in 2017. In addition, the country needs to increase the percentage of clean cooking accessibility, which is only 19% in 2017. Along this line, Cambodia aims to improve the current state of electricity access through the Rural Electrification Development Programme, by promoting grid expansion, cross border supply, and renewable energy, called Solar Home System programme (SHS). In addition, the country plans to increase the access to clean cooking by encouraging the use LPG or biogas in rural community.

To support the policy assessment, the ASEAN-German Energy Programme (AGEP), a jointly implemented programme by ASEAN Centre for Energy (ACE) and Deutsche Gesellschaft fur International Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), cooperated with the Ministry of Mines and Energy had developed the Cambodia Renewable Energy Assessment Outlook up to 2040 to address comprehensive medium- and long-term energy supply and demand projections with four specified scenarios; Business-as-Usual (BAU), Cambodia Target (CAM), Advance Effort (ADV), and Install Higher Solar (INS).

The study shows that Cambodia will face a major challenge of increasing energy demand, with TFEC reaching 12.2 MToe in 2040, almost three times the 2017 level. However, under CAM and ADV, Cambodia will save its energy intensity by 11.3% and 22% respectively, compared to BAU. In case of renewable energy, since this study considered SHS and biogas policies, the RE projection shows that the combination of biogas and solar will have 1.6% and 3% share in total residential energy consumption in 2040 under CAM and ADV, respectively. Cambodia might consider more ambitious RE actions and include other key sectors such as transportation, industrial and commercial, apart from residential sector. Moreover, this study includes concrete recommendations that can be further incorporated in the energy modelling using LEAP. These recommendations will facilitate policymakers to have a better vision in designing a proper energy framework, in order to enhance the country's energy security in a sustainable manner.

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Two country visits were conducted for the development of this study, attended by the Senior Officials on Energy (SOE) Leader, Alternate SOE Leader, and energy data experts of Cambodia. The first country visit was conducted on 29 March 2019 in Phnom Penh, Cambodia, to gather initial inputs on scenario for the modelling process, while the second was conducted on 22 April 2019 to verify the preliminary findings and analysis prepared by ACE with inputs from the Stockholm Environment Institute (SEI).

The completion of the study was made possible through the cooperation and support of the Ministry of Mines and Energy of Cambodia, in particular the New and Renewable Energy Department as the RE-SSN Focal Point in Cambodia, and the Energy Development Department that provided the data and information used in the study. AGEP would like to thank everyone involved, in particular those named below:

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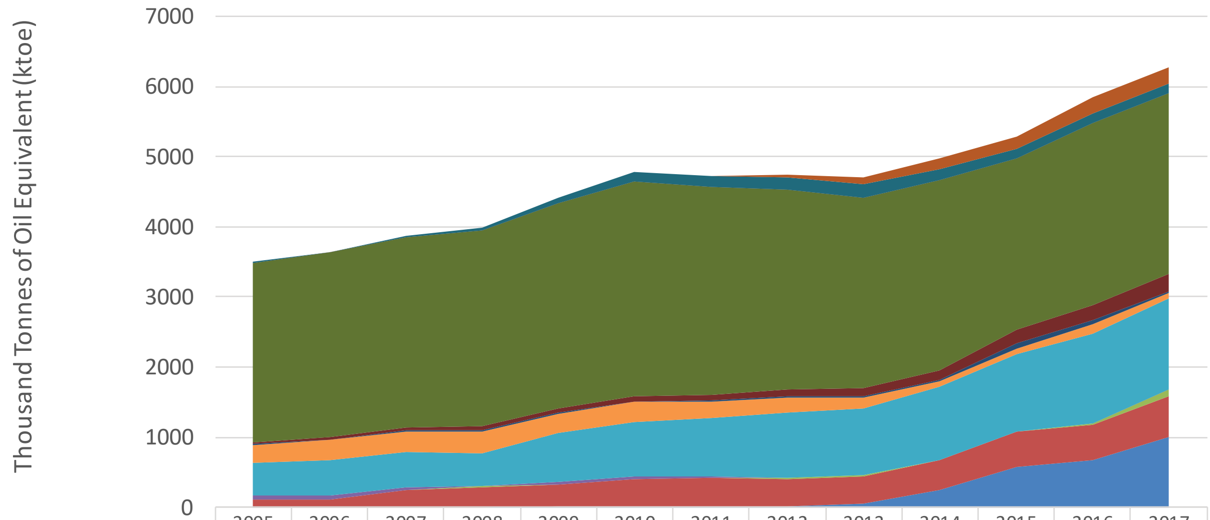
Chapter 1
Background

1.1 Energy Situation

As one of ASEAN's developing countries, The Kingdom of Cambodia's energy needs have been increasing over the years, almost doubling its TPES from about 3,503 ktoe in 2005 to 6,276 ktoe in 2017. Historically, Cambodia's energy supply has been reliant on biomass, primarily fuelwood consumption. In 2005, biomass accounted for the largest share in the TPES at 2,558 ktoe, or 73% of the total 3,503 ktoe.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hydro and Other (Solar)	4	4	4	4	5	4	5	45	88	160	174	229	240
Electricity	7	9	14	32	72	133	157	181	196	155	133	136	127
Biogas	-	-	-	-	-	-	-	-	-	-	-	3	3
Fuel Wood	2,558	2,622	2,700	2,795	2,921	3,061	2,957	2,842	2,711	2,710	2,446	2,591	2,574
LPG	35	38	55	61	67	77	85	100	117	132	191	229	264
Other Oil Products	12	13	12	16	14	16	21	20	21	15	76	50	16
Fuel Oil	259	280	294	310	270	277	229	214	166	89	71	139	78
Diesel Oil	461	498	508	470	698	785	840	926	946	1,036	1,106	1,277	1,286
Kerosene	54	58	34	-	40	32	12	6	4	-	-	-	-
Jet Kerosene	1	1	3	3	2	3	5	4	5	7	7	20	111
Gasoline	112	121	242	297	319	390	405	394	398	433	488	498	568
Coal-Bituminous	-	-	-	-	8	13	15	16	52	242	587	679	1,009

Figure 1. Cambodia's Total Primary Energy Supply, 2005- 2017. Source: MME, 2019

However, an energy transition has begun in Cambodia. Biomass consumption steadily increased until 2011, then steadily dropped until in 2017. Fuel wood/traditional biomass consumption reached 2,574 ktoe in 2017, close to what it was 2005, but accounted for a smaller share of about 41% of TPES. Fossil fuel consumption, especially oil, also accounted for a large share of Cambodia's TPES mix. Fossil fuels use increased from around 934 ktoe (26.7%) in 2005 to around 3,332 ktoe (55%) in 2017, driven by the increasing use of diesel oil and gasoline in the transportation sector. Coal use for power generation was 8 ktoe in 2009, and rose to 242 ktoe in 2014. By 2017 it amounted to 1,009 ktoe or 16% of the TPES.

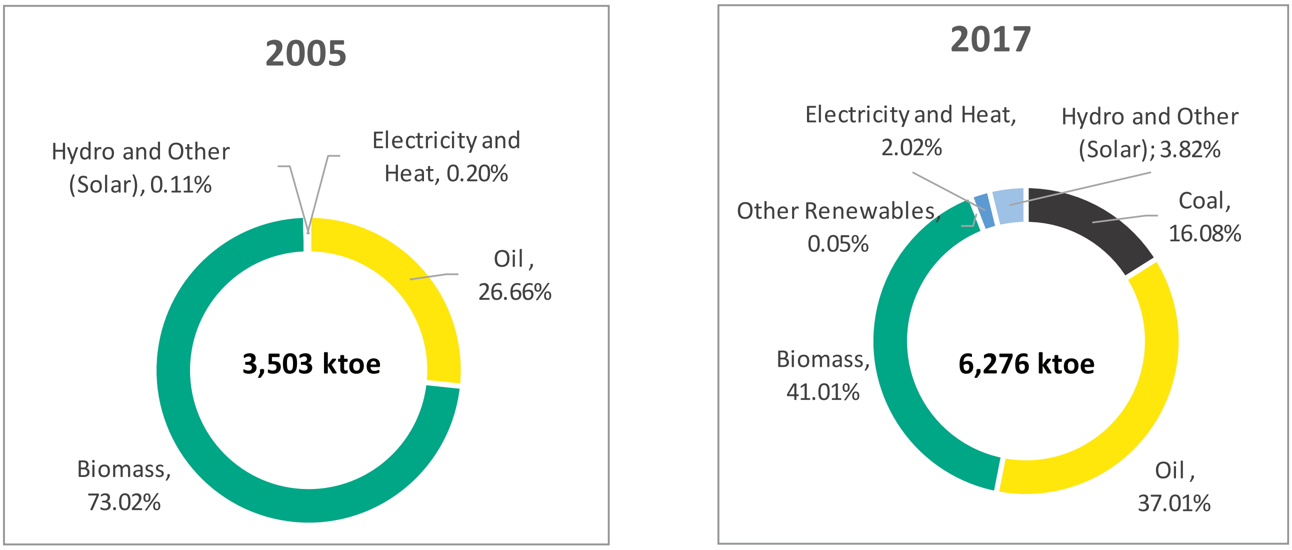
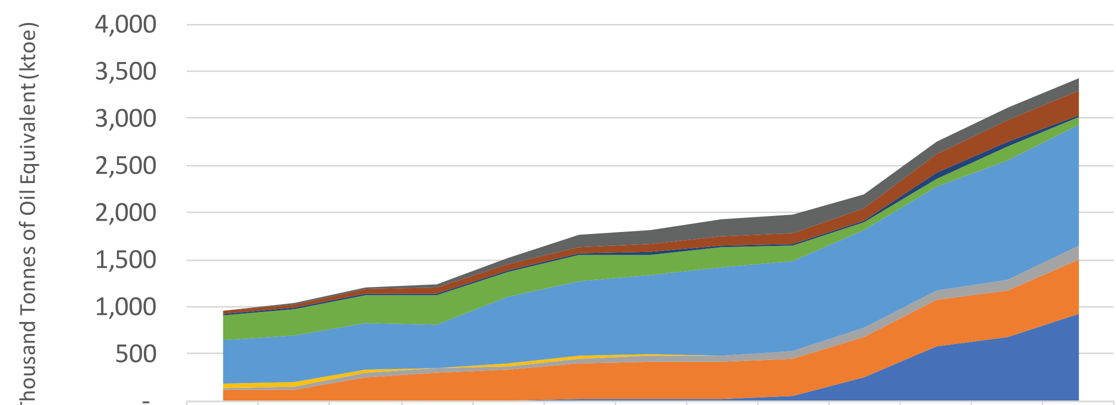


Figure 2. Shares in Cambodia's TPES, 2005 and 2017. Source: MME, 2019

Renewable energy, not including fuelwood, accounted for a small percentage in Cambodia compared with fossil fuels. Hydropower accounted for the largest share at around 240 ktoe in 2017 (3.82%) compared to 4 ktoe in 2005 (0.11%). Other renewable forms of energy, including solar and biogas still paled in comparison, at 3 ktoe in 2016 and 2017. Cambodia also directly imported electricity from neighbouring countries amounting to 127 ktoe (2%) in 2017.

1.2 Energy Imports

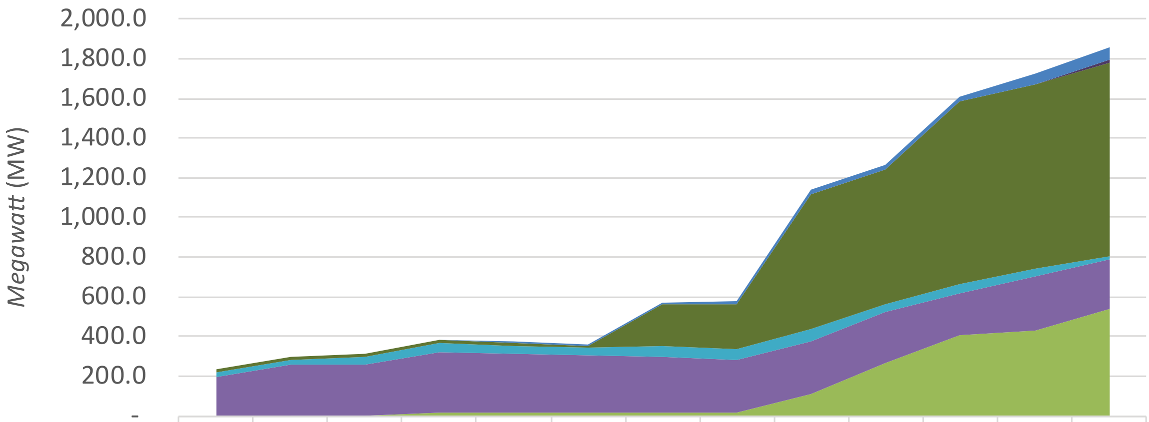
With exploration, production, and refining of oil still in the early stages, and lacking coal for power generation, Cambodia was dependent on imports to fulfil its energy supply needs. It can be seen from Figure 3 that from the 6,276 ktoe TPES in 2017, 3,423 ktoe or around 54% of Cambodia's energy supply was in the form of imported fuels. The major fuel imports were oil products: diesel, gasoline, and coal.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Electricity	7	9	14	32	72	133	157	181	196	155	133	136	127
LPG	35	38	55	61	67	77	85	100	117	132	191	229	264
Other Oil Products	12	13	12	16	14	16	21	20	21	15	76	50	16
Fuel Oil	259	280	294	310	270	277	229	214	166	89	71	139	78
Diesel Oil	461	498	508	470	698	785	840	926	946	1,036	1,106	1,277	1,286
Kerosene	54	58	34	-	40	32	12	6	4	-	-	-	-
Jet Kerosene	22	24	50	45	36	47	57	71	81	95	100	108	157
Gasoline	112	121	242	297	319	390	405	394	398	433	488	498	568
Coal	-	-	-	-	8	13	15	16	52	242	587	679	928

Figure 3. Cambodia's Fuel Imports, 2005- 2017. Source: MME, 2019

1.3 Installed Capacity



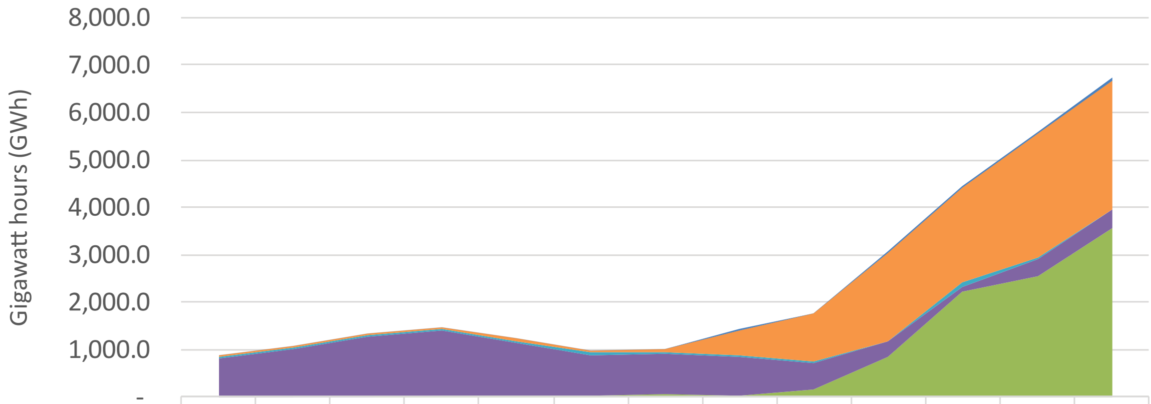
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biomass	0.1	4.5	4.6	5.1	5.8	5.8	6.5	22.5	22.5	22.6	16.6	51.3	64.8
Solar	-	-	-	-	-	-	-	-	-	-	-	-	10.0
Hydro	13.0	13.0	13.0	13.4	13.4	13.3	207.1	225.4	682.1	682.1	927.0	929.7	979.7
Diesel	20.0	20.0	35.0	43.0	38.0	39.0	57.0	54.0	59.0	34.0	40.0	40.0	13.0
Heavy Fuel Oil	199.0	262.0	262.0	310.0	302.0	289.0	285.0	267.0	266.0	257.0	218.0	274.0	251.0
Coal	-	-	-	13.0	13.0	13.0	13.0	13.0	113.0	268.0	403.0	429.2	538.0

Figure 4. Cambodia's Installed Power Generation Capacity by Fuel, 2005 to 2017. Source: MME, 2019

Since 2011, Cambodia has been working on reducing its reliance on expensive heavy fuel oil by increasing its power generation from hydropower and coal. In 2017, hydro accounted for the largest share of installed capacity at 53%, followed by coal at 29%. The use of renewables, notably biomass and solar has increased, though they yet account for relatively small shares. In 2017, heavy fuel oil accounted for an approximately 14% share.

1.4 Power Generation

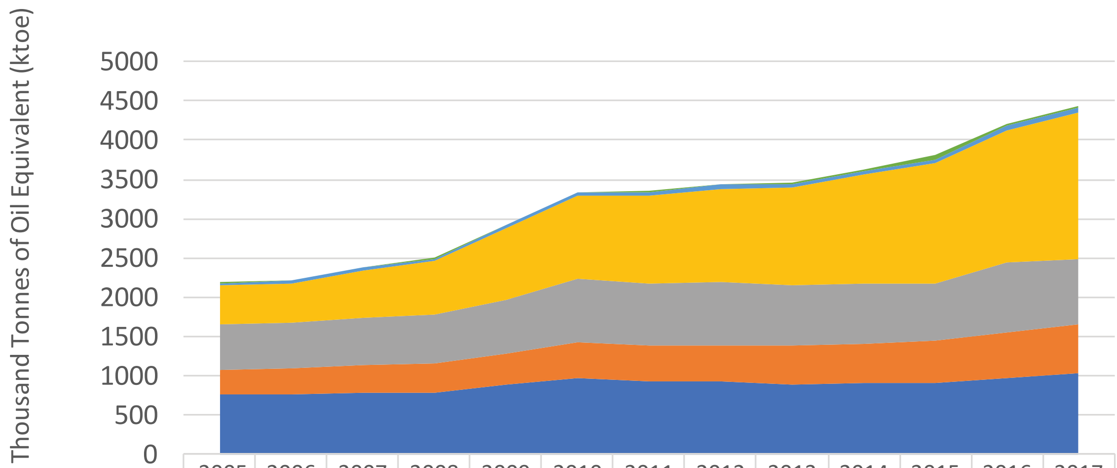
Cambodia's total power generation increased from 879.7 GWh in 2005 to 6,727.7 GWh in 2017. Although this increase was quite significant (around 650%), Cambodia still requires more power generation to meet its surging demand. Power shortages and blackouts are still commonplace. In 2017, hydropower accounted for 40% of the total power generation (2,711 of the total 6,727 GWh generated), coal accounted for 53% with 3,569 GWh, and the remainder came from oil (see Figure 5).



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biomass	0.1	1.7	5.3	4.5	6.5	5.8	11.9	11.7	6.7	16.8	38.0	43.4	51.9
Solar	-	-	-	-	-	-	-	-	-	-	-	-	4.7
Hydro	43.5	50.6	49.7	46.3	47.4	31.7	51.5	517.4	1,015	1,851	1,988	2,619	2,711
Diesel	21.0	24.0	36.0	38.0	42.0	41.0	38.0	40.0	28.0	28.0	94.0	16.0	10.0
Heavy Fuel Oil	815.0	1,011	1,258	1,372	1,111	858.0	871.0	816.0	551.0	299.0	118.0	362.0	381.0
Coal	-	-	-	23.4	28.0	32.1	46.5	37.4	168.8	863.0	2,210	2,551	3,569

Figure 5. Cambodia's Power Generation by Fuel, 2005 to 2017. Source: MME, 2019

1.5 Total Final Energy Consumption (TFEC) Sector Share

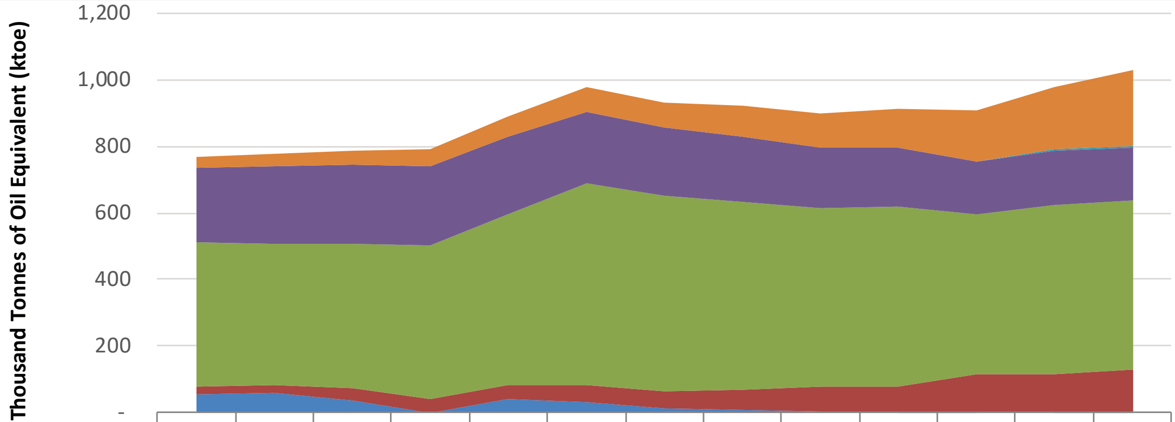


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Non-Energy Sector	12	13	12	16	14	16	19	18	20	16	49	27	14
Agricultural Sector	27	29	31	34	36	39	53	43	45	48	53	57	62
Transportation	486.0	507.0	617.0	675.0	910.0	1,056	1,111	1,199	1,240	1,377	1,520	1,684	1,855
Industrial	596	582	600	619	673	809	795	799	771	770	732	875	845
Commercial	302	320	346	376	404	446	456	467	486	498	543	583	617
Residential	767	776	785	790	890	980	931	922	900	915	909	978	1032

Figure 6. Cambodia's TFEC by Sector, 2005- 2016. Source: MME, 2019

Of Cambodia's TFEC, most of the energy demand in 2005 came from the residential sector, at 767 ktoe or around 35% of the 2,190 ktoe TFEC. However, over the years the transportation sector has grown significantly, overtaking the residential sector in accounting for the largest share in since 2010. In 2017, its 1,855 ktoe consumption equated to 42% (4,425 ktoe), compared to around 22% in 2005. The residential sector consumed 1,032 ktoe in 2017, or around 23% of the TFEC, second after the transportation sector.

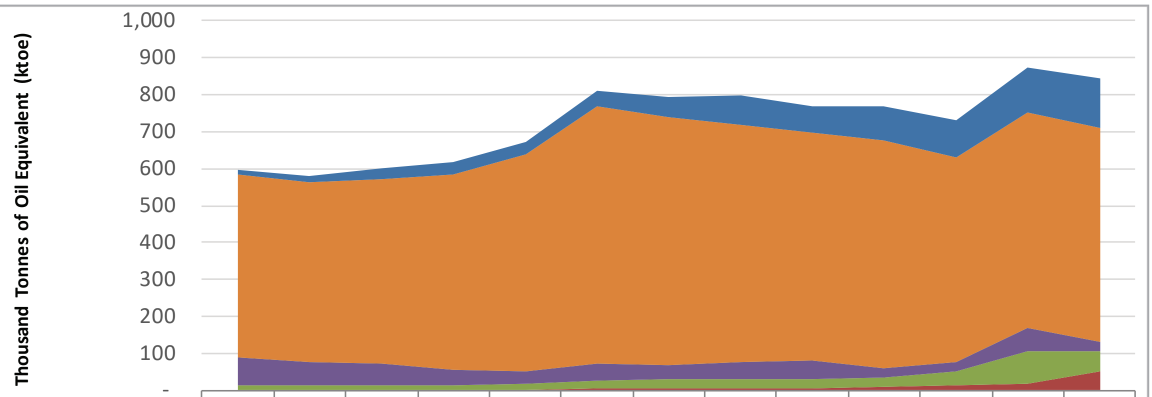
From 2005 to 2017, the residential, industrial, and commercial sectors all still relied primarily on traditional biomass, specifically fuelwood and charcoal consumption. With modernisation over the years, however, more electricity and LPG were used for cooking/heating especially in the residential and commercial sectors. The use of non-traditional renewable energy, such as biogas, was little expansion. In 2017 only 3 ktoe (0.3%) were consumed.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Electricity	32	34	40	50	59	75	74	94	104	119	155	187	232
Biogas	-	-	-	-	-	-	-	-	-	-	-	3	3
Charcoal	225	233	237	237	233	215	204	194	181	178	157	163	159
Fuel Wood	431	425	436	462	513	608	587	564	539	538	483	511	508
LPG	25	26	38	41	45	50	54	64	72	80	114	114	130
Kerosene	54	58	34	-	40	32	12	6	4	-	-	-	-

Figure 7. Fuel Use in Cambodia's Residential Sector, 2005- 2017. Source: MME, 2019

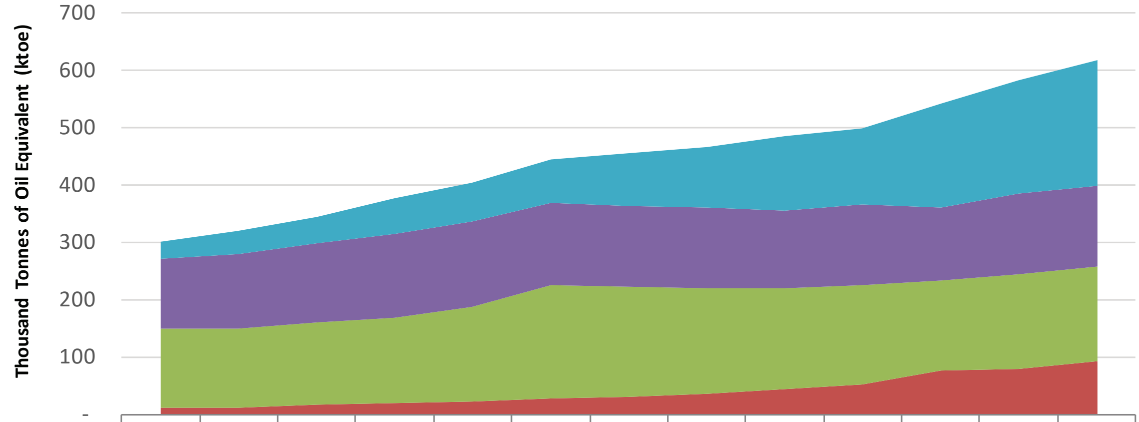
Cambodia's industrial sector was reliant on fuelwood, but the use of electricity, various oil products, and coal has increased from 2010.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Electricity	12	19	29	34	34	42	55	79	72	94	102	121	133
Fuel Wood	493	486	499	528	586	695	671	645	616	615	552	585	581
Other Oil Products	-	-	-	-	-	-	-	-	-	-	-	-	-
Fuel Oil	78	63	58	44	33	45	40	44	51	24	26	64	24
Diesel Oil	13	14	14	13	20	22	23	25	26	28	39	88	56
Coal - Bituminus	-	-	-	-	-	5	6	6	6	9	13	17	51

Figure 8. Fuel Use in Cambodia's Industrial Sector, 2005-2017. Source: MME, 2019

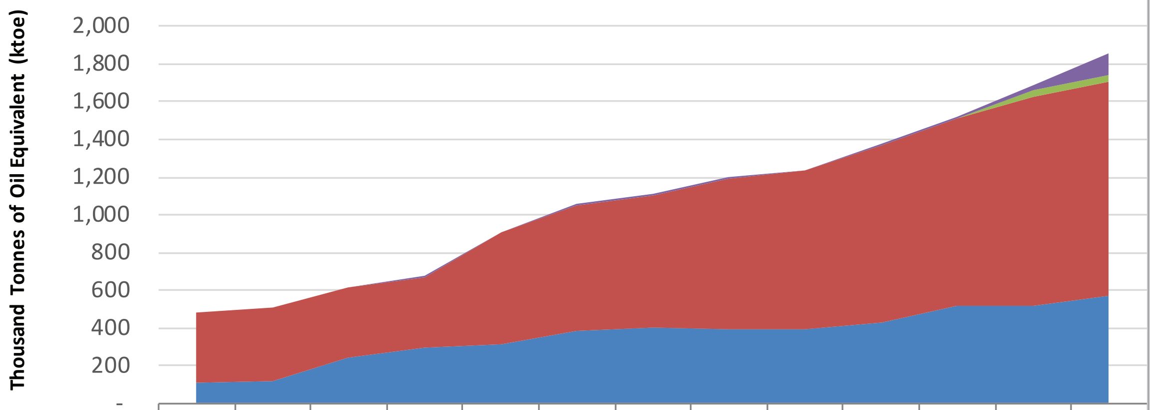
Compared to the other sectors of Cambodia's economy, the commercial sector used less of the traditional fuels. Figure 9 shows the significant use of electricity and LPG.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Electricity	30	39	47	60	66	77	92	107	129	132	181	198	218
Charcoal	121	131	139	146	149	144	142	139	137	139	128	139	140
Fuel Wood	140	138	142	150	167	198	191	184	175	175	157	167	165
LPG	11	12	18	20	22	27	31	37	45	52	77	79	94

Figure 9. Fuel Use in Cambodia's Commercial Sector, 2005- 2017. Source: MME, 2019

The transportation sector was Cambodia's fastest growing sector in terms of energy consumption. From the 586 ktoe consumed in 2005, there was a quadrupling to 1,855 ktoe in 2017. Road transport dominated the share, mostly with the consumption of gasoline and diesel oil. From 2016, an alternative fuel, LPG, was used for road transport.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jet Kerosene	1	1	3	3	2	3	4	4	5	6	6	20	111
LPG	-	-	-	-	-	-	-	-	-	-	-	35	40
Diesel Oil	373	385	372	375	589	663	702	801	837	938	999	1,107	1,134
Gasoline	112	121	242	297	319	390	405	394	398	433	515	522	570

Figure 10. TFEC by Fuel in the Transportation Sector, 2005-2017. Source: MME, 2019

1.6 Energy Challenges and National Targets

Outlining the prevalence of traditional biomass in Cambodia's TPES and TFEC brings an initial picture of the major challenges facing the country, namely the urgent need to increase electrification and clean cooking access.

Access to Electricity

Cambodia is among the ASEAN Member States that needs to raise its electrification rate to meet the needs of its citizens. From 2016, the urban population had attained 100% access to electricity. However, around 77% of the population lives in rural areas, and only about one-third (36.46%) had access to electricity as of 2017. For the country as a whole that year, 51% of the population had access to electricity.

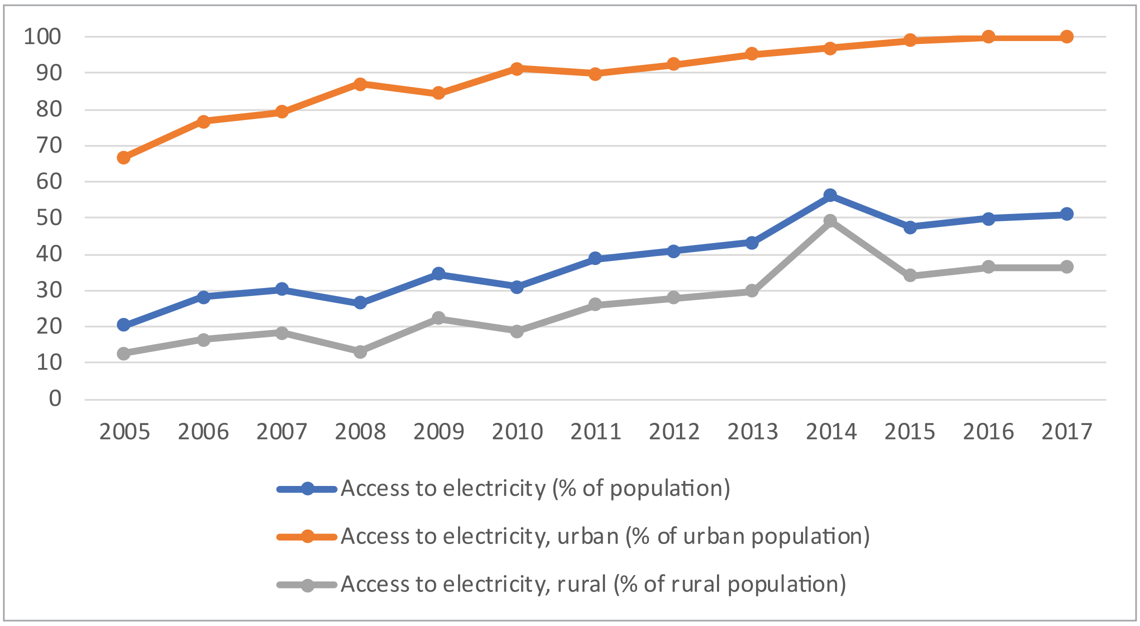


Figure 11. Cambodia's Urban and Rural Access to Electricity, 2005-2017. Source: EAC, 2018.

Grid access is one of the challenges facing Cambodia. In 2017, the percentage of households with access to grid-quality electricity stood at around 68.64%, while the percentage of electrified villages was 81.55%. In 2005, the percentages were 11.78% and 7.82%, respectively. These figures reflect the considerable effort that went into raising the electrification rates in the mid-2000s.

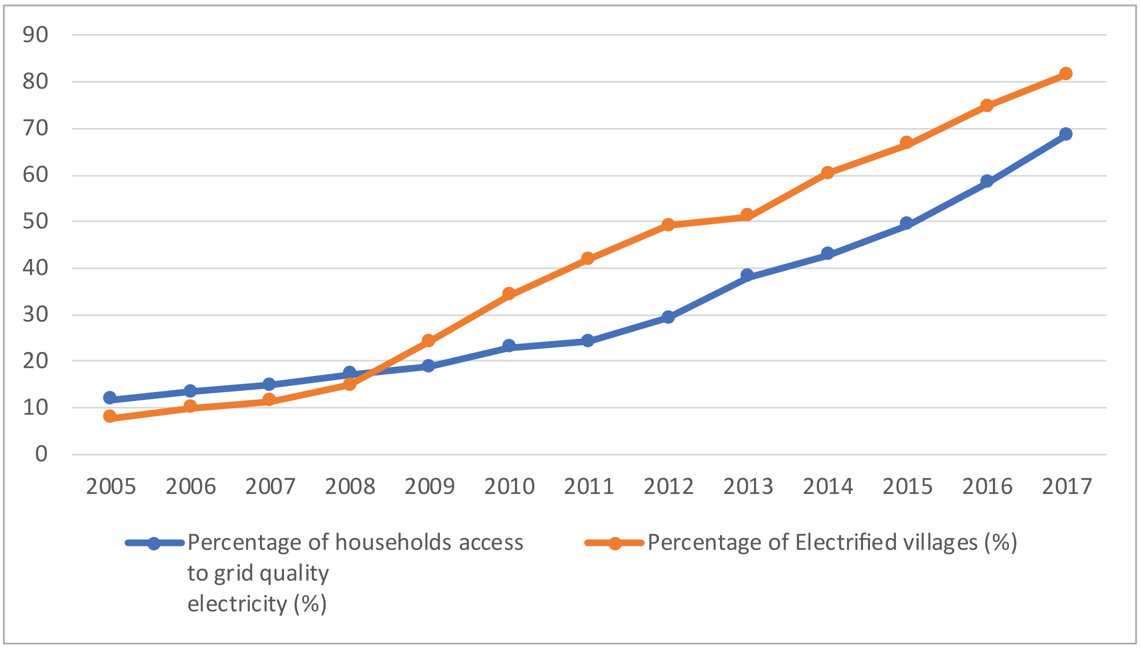


Figure 12. Percentage of Electrified Households with Access to Grid Quality Electricity, and of Electrified Villages, 2005-2017. Source: EAC, 2019.

The Rural Electrification Development Programme to increase the electrification rate for households in rural areas. Its purpose was to promote grid expansion, cross border supply, mini grids, and renewable energy. The national target set were: 1) all villages to have access to electricity of any type by 2020; and 2) at least 95% of all households to have access to grid quality electricity by 2030 (ERIA, 2019).

Clean cooking accessibility

According to the World Bank (2019), only 18.69% of Cambodia's population had access to clean fuels for cooking in 2017. Therefore, it is a national energy priority for the government to increase the access to LPG or biogas.

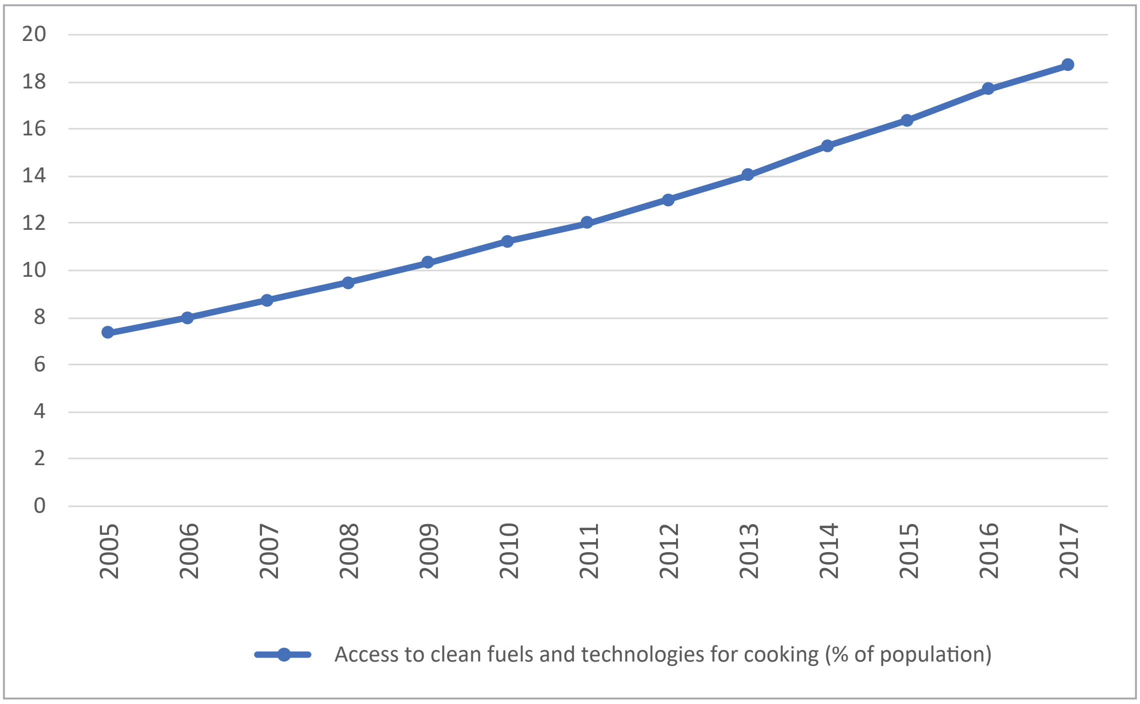


Figure 13. Clean Cooking Fuel Accessibility, 2005- 2017. Source: World Bank (2019).

Chapter 2
Scenarios and Data

2.1 Scenarios

The following four scenarios were specified in the study referred to as "Cambodia National Energy Target, Focal Point Discussion with Ministry of Mines and Energy", and the studies such as UNDP and USAID.

1. ***Business-as-Usual Scenario (BAU)*** projects the future development of Cambodia's energy system assuming no significant changes to past practices, and that the government will put little effort into reaching its most recently issued RE targets.

2. ***Cambodia Targets Scenario (CAM)*** projects the future development of Cambodia's energy system in which the energy efficiency (EE) and renewable energy (RE) targets set at the national level are successfully implemented.

3. ***Advanced Effort Scenario (ADV)*** projects that Cambodia commits to more ambitious targets.

4. ***Installed Solar Power Scenario (INS)*** projects that Solar energy technologies are deployed in Cambodia to reach their maximum potential.

Scenarios	LEAP Implementation Recommendations	**Source of information**
BAU	• Specify growth rate or future values for population = 1.3%, GDP = 5.5% (ERIA, 2019), annual vehicle growth rate = 4% (assumption)	POP growth is based on historical GDP projections. See Cambodia Outlook (ERIA, 2019)
	• Projects sectoral energy demand using a regression function, and a specified growth rate where the regression is not capable.	Based on historical data
CAM	• Increases the target of households connected to the national grid from 70% to 95% by 2030	USAID, National Energy Target, ERIA
	• Increases the total share of the population with access to clean fuels and technologies for cooking. This means increasing LPG and community-scale biogas, and displacing traditional biomass or kerosene. The exact targets are still under discussion. In this study, the targets for LPG and biogas were discussed during the Focal Point Discussion. The initial target was to increase only a small portion of biogas in non-grid areas, i.e. an increase in biogas from 0.29% of total household energy consumption in 2017 to 1% in 2030 and 1.5% in 2040. The share of LPG was assumed to increase from 10% in 2017 to 50% in 2040.	Consult with Ministry of Mines and Energy

CAM	• Continue the Solar Home System (SHS) Programme. From 2018, the SHS will continue being installed in non-grid households at the rate of 5,900 units per year. The size of the SHS is 50 Watt-peak (Wp) with 6 operational hours per day. Based on this information, 41 and 60 MWh can be generated from SHS systems in 2030 and 2040, respectively.	Consult Cambodia Ministry of Mines and Energy
	• Reduce electric transmission and distribution losses from 13% in 2016 to 8% in 2030.	Basic Energy Plan
	• Set the power generation mix in 2030 to coal (50%), oil (5.3%), hydro (34%), biomass (5.5%), and solar (4.7%) by dispatching generation technologies using a fixed percentage share, ensuring that enough capacity exists.	Cambodia PDP
	• Reduce the energy intensity of industrial energy consumption by 15% in 2030.	National Energy Target
	• Determine additional energy savings beyond the industrial sector to meet a 10% savings target by 2030 across all end-uses (transportation, commercial, and agricultural sectors). Modify the energy efficiency targets accordingly.	National Energy Target
ADV	• Double the biogas and SHS targets over the CAM scenario	
	• Reduce the energy intensity of industrial energy consumption by 30% in 2030	
	• Devote more efforts towards energy savings beyond the industrial sector to meet a 20% savings target by 2030 across all end-uses (transportation, commercial, and agricultural sectors).	
	• Set the power generation mix in 2030 to solar (10%) and biomass (10%). Reduce coal to 44% and oil to 2%. Keep hydro constant at 34% by dispatching generation technologies using a fixed percentage share.	
	• Double the installed solar power target stated in the PDP	
INS	• This scenario was inherited from the CAM scenario.	
	• Double the SHS target from the CAM scenario	
	• A feasibility study estimated that Cambodia has the potential to generate electricity by installing 700 MW of solar power by 2030.	UNDP, 2019

2.2 Additional Assumption Inputs for the Model

These additional assumptions were required for conducting the modelling work as specified below

Disaggregated Household Group
• Based on the national targets and policy implementation, the residential sector was disaggregated into two residential groups: "grid connected households" and "non-grid connected households".
Energy Shares
• Energy shares for grid-connected households **2017** 100% electrified households using electricity and charcoal, 30% of electrified household using LPG for cooking, and 70% using fuelwood. **2040** 100% of electrified household using LPG for cooking, with only 10% of electrified household using fuelwood.
• Energy shares for non-grid connected households **2017** 100% non-electrified households using wood, 10% using LPG and 40% using charcoal for cooking. Only 1% using biogas for cooking and 1% using solar power for lighting. **2040** 90%, 80% and 60% of non-electrified households using wood in 2020, 2030, and 2040, while those using LPG in non-electrified households will increase to 20%, 30% and 50% in 2020, 2030, and 2040, respectively. The share using biogas and solar power will increase to 5%.
• The energy intensity represents the efficiency with which households use energy (energy consumption (ktoe) divided by the number of households). This study assumed it remained constant until 2040, meaning that although Cambodia will transition towards higher shares of electrified households and clean cooking in 2040, unfortunately there is no significant improvement in households' energy efficiency.
Residential Energy Consumption
• Residential energy consumption data is available at only the national scale. Thus, there is no energy consumption data, which is disaggregated into deeper tiers. This study disaggregated national household data into two residential groups based on Cambodia's policy targets which are "grid connected households" and "non-grid connected households". • Therefore, assumptions were required to decompose one household dataset into two groups as follows: • Fuelwood and Charcoal: acknowledged to be the main fuel for households in remote areas (non-grid connected households) for cooking. Therefore, in order to aggregate the final energy consumption of fuelwood, charcoal and LPG, these assumptions were needed: – 20% of the residential LPG consumption was assumed to be consumed by the non-grid household group. – 80% of the fuelwood and charcoal consumption was assumed to be consumed by the non-grid household group. • Biogas: allocate 100% of the biogas consumption to non-grid connected households • Electricity: allocate 100% of the electricity consumption to the grid connected households • The installed SHS units for rural electrification projects are referred from Cambodia SHS programme (MME, 2019). The capacity of SHSs was 50 Wp, operating 6 hr/day. From 2018, 5,900 new units are to be installed annually until 2040.

2.3 Data

To conduct the LEAP model, the data was compiled from various sources. The energy, power data, and SHS data relating to rural Cambodia were obtained from the Ministry of Mines and Energy. The gross domestic product (GDP) and consumer price index (CPI) were obtained from the National Institute of Statistics of Cambodia (NIS, 2019). The GDP growth rate (5.5 %) came from ERIA's Cambodia Basic Energy Plan (2019). The GDP deflator, exchange rate, population, pump diesel price, gasoline price, percentage of population with access to clean fuels and technologies for cooking, and electricity prices were obtained from World Bank (2019). Transmission line losses were found in ADB (2013). The number of road vehicles was calculated from the total number of registered road motor vehicles listed in (ASEC, 2018) and Ministry of Public Works and Transport of Cambodia (2018). The percentage of households with access to grid quality electricity was obtained from the Electricity Authority of Cambodia (2018). The average crude oil import costs were from the IEA (2018).

Chapter 3
Regression and Results

3.1 Energy Demand Projection

Industry	Projection Functions/ Growth Rate
Electricity	function (f) (relative price of industrial electricity, industrial GDP, previous year value)
Diesel	f (manufacturing GDP, relative pump diesel price, previous year's value)
Fuel Oil	f (industrial oil consumption, relative pump diesel price, industrial GDP, previous year's value of industrial oil consumption)
Fuelwood	f (manufacturing GDP, previous year's value)
Coal	compound growth rate = 5%

Transportation	Projection Functions/ Growth Rate
Road-Gasoline	f (relative price of gasoline price, total number of road vehicles, previous year's value)
Road-Diesel	f (industrial GDP)
Road-LPG	Specified growth rate 10%
Rail-Diesel	f (population)
Water-Diesel	f (population)
Air-Jet Kerosene	f (relative price of imported oil, national GDP, previous year's value)

Commercial	Projection Functions/ Growth Rate
Electricity	f (commercial GDP, relative price of commercial electricity)
LPG	f (commercial GDP, charcoal consumption in the commercial sector)
Fuel wood and charcoal	f (commercial GDP, total consumption of charcoal and fuel wood in the commercial sector)

Agriculture	Projection Functions/ Growth Rate
Diesel	f (agriculture GDP, relative pump diesel price)

Residential	Projection Functions / Growth Rate
Grid-connected households Fuel wood Electricity LPG Charcoal	• f (household growth rate, percentage of household access to the grid) • Energy intensity remains constant until 2040
Non-grid connected households Fuel wood LPG Charcoal Solar Biogas	

3.2 Results

3.2.1 Final energy demand projection

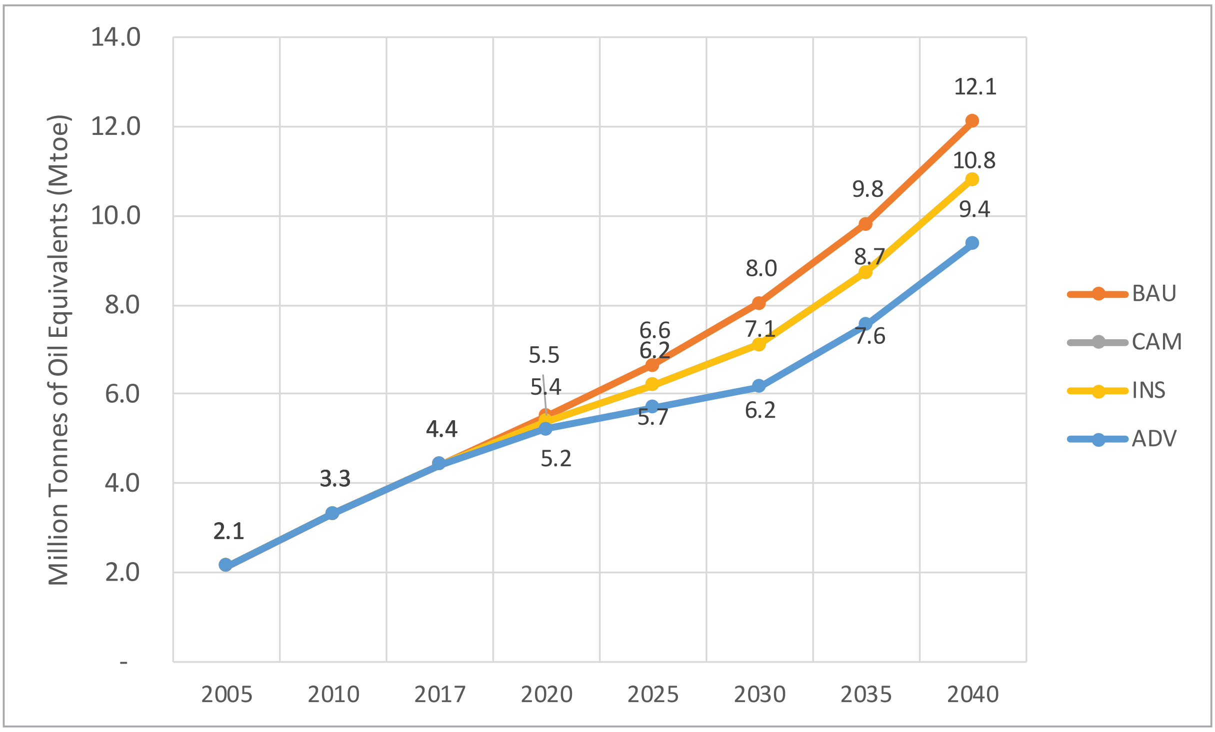
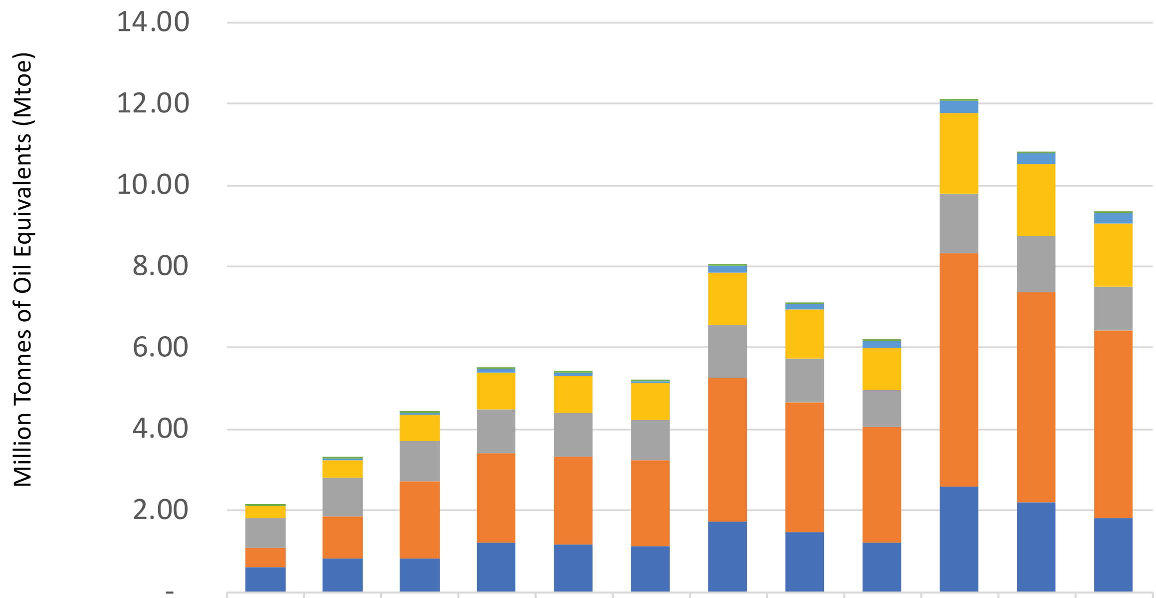


Figure 14. Cambodia's TFEC Projections to 2040 by Scenario

A comparison of the final energy demand among the four scenarios shows that the CAM Scenario decreases the country's energy consumption between 2005 and 2040 from 12.1 Mtoe to 10.8 Mtoe, equivalent to 11% savings. Since the INS scenario is based on the CAM Scenario, but only doubles solar consumption in non-grid households by installing SHS. This is a very small portion of consumption, increasing from 0.005 ktoe in the CAM Scenario to 0.01 ktoe in the INS Scenario. Thus, total energy demand from the INS equals that in the CAM Scenario. In addition, under the ADV Scenario, Cambodia could achieve energy savings of around 22% in 2040, compared to those in the BAU Scenario.



	2005	2010	2017	2020 BAU	2020 CAM & INS	2020 ADV	2030 BAU	2030 CAM & INS	2030 ADV	2040 BAU	2040 CAM & INS	2040 ADV
Non Energy Use	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Agriculture and others	0.03	0.04	0.06	0.08	0.07	0.07	0.17	0.15	0.13	0.32	0.29	0.26
Commercial	0.30	0.45	0.62	0.92	0.90	0.88	1.30	1.17	1.04	1.96	1.76	1.56
Household	0.71	0.95	1.03	1.08	1.09	1.03	1.27	1.10	0.93	1.47	1.37	1.11
Transport	0.49	1.06	1.86	2.20	2.15	2.10	3.53	3.18	2.83	5.75	5.18	4.60
Industry	0.60	0.81	0.85	1.21	1.16	1.12	1.74	1.48	1.22	2.58	2.20	1.81

Figure 15. Cambodia's TFEC Projections to 2040 by Sector from Each Scenario

Branches	CAGR 2017 - 2040		
	BAU	CAM and INS	ADV
Industry	4.8%	4.1%	3.2%
Transport	4.8%	4.4%	3.9%
Household	1.5%	1.2%	0.3%
Commercial	4.9%	4.5%	4.0%
Agriculture and Others	7.1%	6.7%	6.1%
Non-energy Use	0.0%	0.0%	0.0%
Total	4.3%	3.8%	3.2%

Table 1. Compound Annual Growth Rate of TFEC for Each Scenario

The final energy demand projection in Figure 15 illustrates that the transportation sector is the largest energy consumer in all of the projection years, followed by the industrial, commercial and residential sectors, respectively. However, industrial energy demand will overtake household demand in 2020. The fastest annual energy consumption growth rate will be in the agricultural sector followed by the commercial, transportation and industrial sectors which will have moderate annual energy demand growth of around 4%. Annual household energy demand is projected to increase to around 1% to 2%.

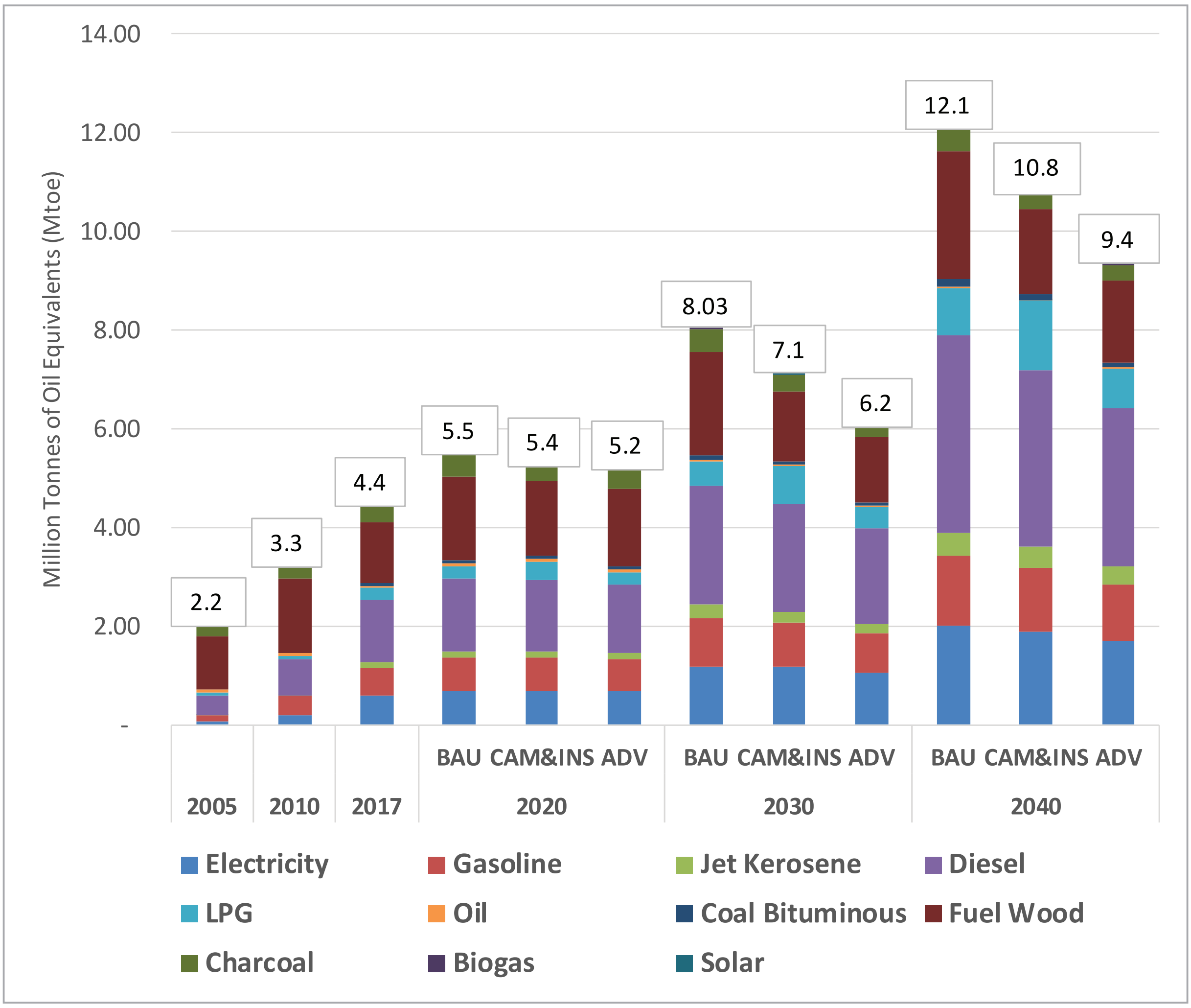


Figure 16. Cambodia's TFEC Projections by Fuel and Scenario

Energy demand projection by fuel in Figure 16 illustrates that energy savings will be obtained for the CAM and INS Scenarios and from the ADV Scenario in terms of fuel wood, diesel, gasoline and electricity demand reduction compared to the BAU scenario. In contrast, there will be higher consumption of LPG, biogas, and solar power.

3.2.1 Primary Energy Supply projection

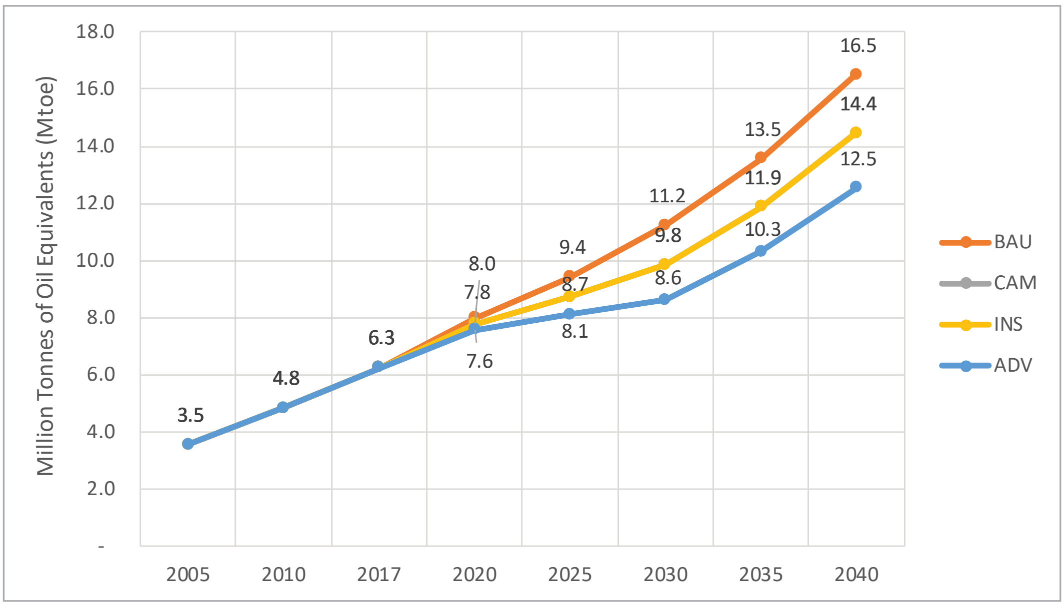


Figure 17. TPES in Each Scenario, 2020 to 2040 with the Average Annual Growth Rate (%)

Units: Million Tonnes of Oil Equivalent

Primary Supply						Average Annual Growth Rate (%)
Scenario	2020	2025	2030	2035	2040	2005-40
BAU	7.99	9.42	11.23	13.55	16.49	4.49%
CAM	7.77	8.73	9.84	11.86	14.44	4.09%
INS	7.77	8.73	9.84	11.86	14.44	4.09%
ADV	7.58	8.10	8.62	10.32	12.53	3.67%

Table 2. TPES in Each Scenario from 2020 to 2040, with the Average Annual Growth Rate (%)

Similar to final energy demand, primary energy supply savings occur in the CAM, INS and ADV Scenarios relative to the BAU scenario. In 2040, the energy supply in the CAM and INS Scenarios was 13% lower than in the BAU scenario, and in the ADV Scenario it was 24.2% lower than in the BAU Scenario.

As for the renewable energy portion, hydropower accounted for the largest share at approximately 85 to 90% of the renewable energy supply in all four scenarios from 2020 to 2040. Of the total RE supply, biogas supply was around 4% in the CAM and INS Scenarios, and 6% in the ADV Scenario. In 2040, solar supplies around 1.3%, 2%, and 9% of total RE supply in the CAM, ADV and INS Scenarios.

Fuels (Units: Thousand Tonnes of Oil Equivalent)	2020				2030				2040			
	BAU	CAM	INS	ADV	BAU	CAM	INS	ADV	BAU	CAM	INS	ADV
Biogas	3.0	4.5	4.5	5.9	3.1	11.0	11.0	18.6	3.10	20.6	20.6	33.2
Solar	0.5	1.1	7.5	1.7	0.9	7.4	49.8	11.8	1.52	7.4	52.7	11.8
Hydro	267.5	255.6	255.6	254.0	484.2	389.0	389.0	371.3	543.00	535.5	535.5	530.5
Total	271.0	261.2	267.6	261.6	488.2	407.4	449.8	401.7	547.6	563.4	608.8	575.4

Table 3. Renewable Energy in then TPES by Scenario, 2020 to 2040

3.2.2 Emission projection

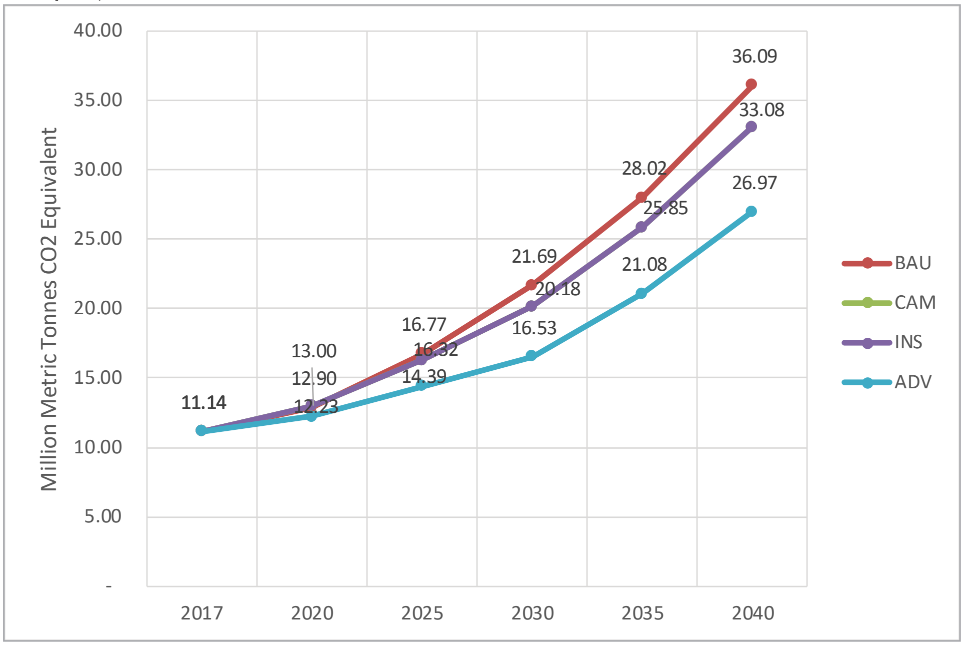


Figure 18. GHG Projections from Each Scenarios

Units: Million Metric Tonnes CO_2 Equivalent

							Annual-. Average Growth Rate (%)
Scenarios	2017	2020	2025	2030	2035	2040	2005-40
BAU	11.14	12.90	16.77	21.69	28.02	36.09	5.24%
CAM	11.14	13.00	16.32	20.18	25.85	33.08	4.85%
INS	11.14	13.00	16.32	20.18	25.85	33.08	4.85%
ADV	11.14	12.23	14.39	16.53	21.08	26.97	3.92%
Total	44.56	51.13	63.79	78.57	100.81	129.23	4.74%

Table 4. Emissions Projection by Scenario, 2020-2040

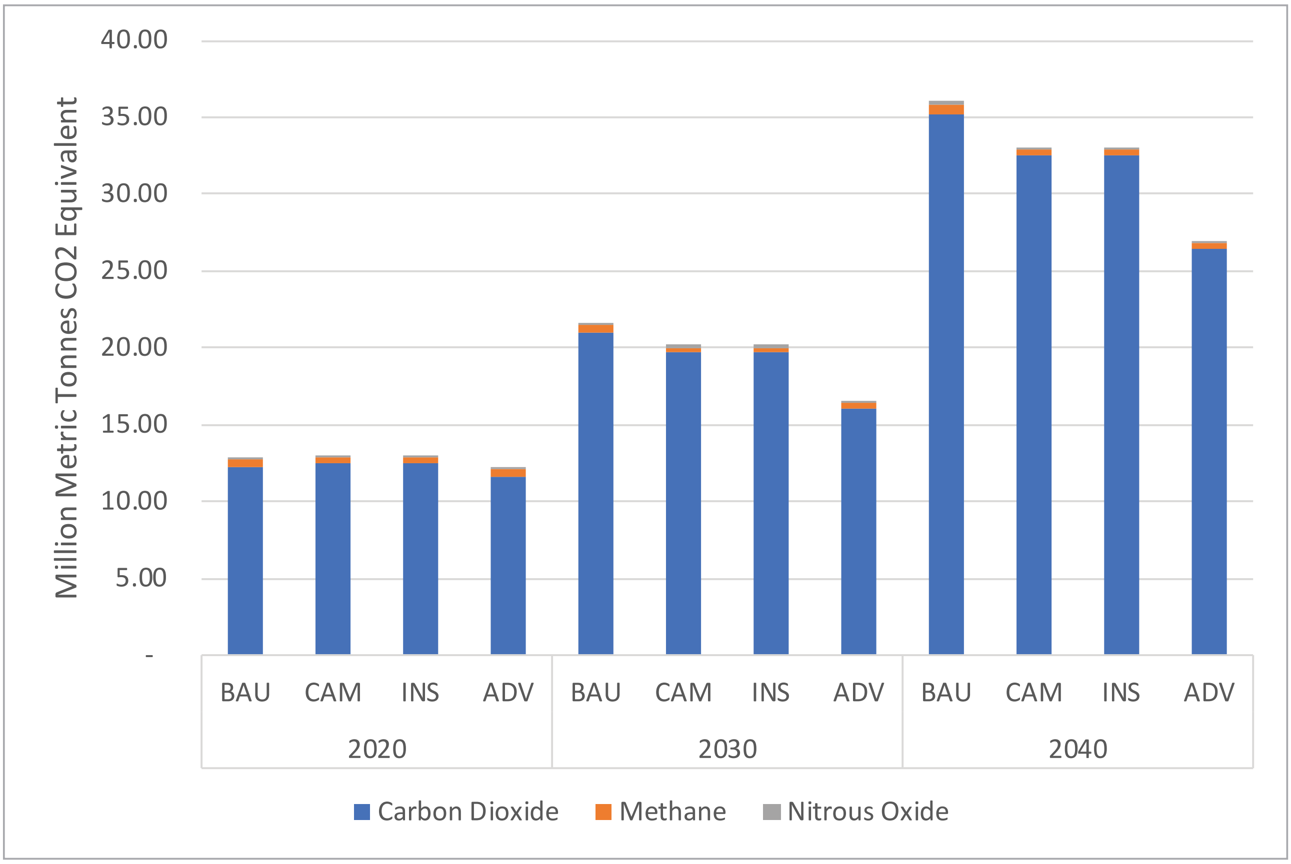


Figure 19. GHG Projections from Each Scenario by Emission Type

Figure 18 illustrates the greenhouse gas emissions (GHG) in each of the four scenarios. GHG emission reductions can be observed in the CAM and NIS Scenarios, amounting to approximately 3 million metric tonnes of CO_2 equivalent lower than in the BAU Scenario. Up to 9.12 million metric tonnes CO_2 equivalent can be mitigated under the ADV Scenario, equivalent to a 25% reduction. Figure 19 shows that 92% of the GHG emissions were carbon dioxide, followed by methane and nitrous oxide.

Chapter 4
Recommendations

4.1 RE Policy recommendations

I. Develop RE-target policies in various sectors

Cambodia is one of the AMS in which there are large numbers of people lacking access to electricity. In addition, the share of the population with access to clean cooking fuel is currently less than 20%. In order to alleviate these energy access challenges, the government has implemented two renewable energy programmes: the Solar Home Systems (SHS) and biogas for Communities in rural areas. However, based on the projections from the model, Cambodia will also face major challenges from the increases in energy demand, with the TFEC reaching 12.2 Mtoe in 2040, almost three times the 2017 level.

As the SHS and biogas policies focus only on the residential sector, which accounted for 23% of the TFEC in 2017 and had the lowest energy growth rate among the sectors, the projection result showed that these two policies will impact Cambodia's future energy consumption mix very little. Consequently, Cambodia will still rely heavily on fossil fuels, especially petroleum products in the future. This will put Cambodia at risk of import dependency and render it crippled by high priced energy.

Hence, policymakers should consider not only implementing RE programmes in the residential sector, but also in the transportation, industrial and commercial sectors which have higher shares of energy demand and also faster energy consumption growth rates. Having RE policies in place for these key sectors could decrease Cambodia's fossil fuel demand in the future and sustain the country's energy security through decreased imports of fossil fuels.

Attention should also be given to cleaner power generation, as Cambodia has the potential to generate electricity from RE sources such as solar and wind. A feasibility study could be conducted to increase the installed capacity of solar and wind in the future power mix.

4.2 Model's Development

To conclude, we present a set of concrete tasks that could further the modelling performed for this report using LEAP.

I. Use the model to explore additional scenarios

In addition to the four scenarios summarised in this report, the model establishes a foundation for further exploration of energy scenarios for Cambodia. Some additional scenarios that were considered but not modelled, due to insufficient data, included:

a. Electrification of on-road vehicles, including light-duty cars and trucks;
b. Transport mode switching, favouring higher-occupancy forms of transport;
c. Blending of biodiesel or bioethanol into the national diesel and gasoline supplies, and;
d. Direct use of solar energy for hot water in commercial and residential buildings.

II. Emissions for imported power

Greenhouse gas (GHG) emissions in each scenario are calculated by applying multiplicative emission factors for each unit of fuel consumed. Only combustion-based emission factors are included, expressed as the mass of each major GHG per quantity of energy consumed. Further, these emission factors are *direct*, which means that they are applied to the fuel consumed at the point of

its combustion – in contrast to *indirect* emission factors that embody emissions arising from earlier stages in a fuel's lifecycle. In the power sector, emission factors are associated with each feedstock fuel for each generation technology, so that the emissions arising as a result of Cambodia's electricity consumption depend each year[1] on the electricity mix. But to get a more realistic picture of future emissions arising from Cambodia's electricity consumption – especially in the face of large amounts of imported electricity that back-fill for any capacity deficits – indirect emissions from imported electricity may need to be explicitly included. These emissions can still be included in a LEAP model using a multiplicative emission factor, where the emission factor is the weighted average of emissions from each electric grid of origin.

III. Include exogenous import or export forecasts

The model reproduces all historically observed trade in fuels that are produced in Cambodia: electricity, and also fuelwood and charcoal (of which there is no appreciable trade with neighbours). Electricity imports steadily grew since 2005, before experiencing a drop-off beginning in 2013. The most recent available imports data is from 2017. This is carried forward for future years in the analysis. This is a simple and transparent modelling assumption in the face of unknown electricity imports in the future. But a more accurate picture of future energy and capacity needs could be attained by gathering any known plans for power imports to (or exports from) Cambodia. These plans may be reflected in memoranda of understanding with neighbouring countries, power purchase agreements with foreign utilities, or any other suitable plans for electricity wheeling. Including these plans effectively modifies the electricity demand forecast, which could have the effect of warding off or delaying the need to build new capacity.

IV. Constraints on the technical potential of renewable energy sources

Generally, resource constraints - whether they are imposed by import pipeline or transmission line capacities or naturally through the annual availability of renewable energy - should be included in a LEAP model by limiting production capacity. In the case of renewable resources such as hydro, solar, wind or other alternative energy, this is because it is necessary to ensure that no more capacity is built than can be supplied with renewable inputs. If resource availability constraints are cast as maximum capacities (for example, a limit on the total installable megawatts of hydro), care should be taken to ensure whether these capacities represent maximum installable generation capacities (i.e. outputs) or pure power available from the resource (i.e. inputs). If instead the resource constraints are given as maximum energy production values (for example, a limit on the number of available megawatt-hours of hydroelectricity), these values must be converted to an equivalent capacity by using an estimated capacity factor.

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1 Or, for each time slice within a year that is represented in the model. LEAP permits time slices containing an arbitrary number of hours to be used to divide the year into separate dispatching periods.

Appendix A

Compiled regression results for energy demand projection in the LEAP model

A.1 Industry Sector

- **Electricity = f()**

  INEL = -49.0692*CONS + 15.2019*RELIN + 0.010001*INGDP + 0.080465*INEL(-1)

  INEL Electricity consumption in Industry (ktoe)

  MNUGDP GDP Manufacturing (Billion Riel)

  ELIN Relative electricity price – Industrial (USD/kWh)

- **Diesel = f ()**

  INDG = 42.4686*CONS + .0029723*MNUGDP -0.81651*RDPDSL + 0.28413*INDG(-1) - 48.1754*DUM16

  INDG Diesel Consumption (ktoe)

  RDPDSL Relative Pump Diesel price (USD/L)

  DUM16 Dummy variable for year 2016

- **Fuel Oil = f ()**

  INPP = Diesel + Oil consumption in ktoe

  INPP = 146.3931 CONS + 11.6463 RDPDSL - 0.0010087 INGDP + 0.29348 INPP(-1) -96.7627 DUM16

  INGDP GDP industrial sector (Billion Riel)

- **Fuel Wood = f ()**

  INTT = 243.3259 CONS + 0.012767MNUGDP + 0.54050 INTT(-1)

  INTT Total Industry energy consumption (ktoe)

A.2 Transportation Sector

ROAD

Total number of road vehicles -> convert motorcycles to cars: assumption: 4 motorcycles to 1 car

- **Gasoline = f ()**

RDGS = 37.4149 CONS – 25.8950 RMPGSL + 0.12747RDVEH + 0.67281RDGS(-1)

RMPGSL	relative price of gasoline
REVED	total number of road vehicles in thousands unit

- **Diesel = f ()**

RDDG = 190.1633*CONS + 0.051501*INGDP

INGDP	GDP of industrial sector (Billion Riel)

AIR

- **Jet Kerosene = f ()**

TTJET = -110.4671*CONS -0.7666E-5*RPOILJ + 0.0061963*TTGDP - 0.40079*TTJET(-1)

TTJET	total energy consumption by air transport both domestic and international
RPOILJ	relative imported oil price (CIF Japan) (USD)
TTGDP	Total GDP (Billion Riel)

RAIL

- **Diesel = f ()**

RAILDG = -146.5685 CONS + 0.010762 POP

INLAND WATER WAY

- **Diesel = f ()**

IWDG = -176.4229 CONS + 0.013917 POP

A.3 Commercial

- **Electricity = f ()**

CMEL = -126.1775*CONS + 0.028004*COMGDP + 12.3602*RELCM

COMGDP GDP of Commercial sector (Billion Riel)

ELCM Relative electricity price in commercial sector (USD/kWh)

- **LPG = f ()**

CMLP = -5.3087 CONS + 0.012478 COMGDP -0.41499 CMCH

CMCH Charcoal consumption in commercial sector (ktoe)

- **Fuelwood and Charcoal = f ()**

TTCMFW = 110.8662*CONS -.0016712*COMGDP + .69327*TTCMFW(-1)

TTCMFW Total consumption of charcoal and fuel wood by commercial sector (ktoe)

CMLP Commercial – LPG (ktoe)

A.4 Agricultural sector

- **Diesel = f()**

AGGDG = -44.9890*CONS + 0.011714*AGGDP -7.3086*RDPDSL -6.6912*DUM11

AGGDP GDP of agricultural sector (Billion Riel)

RDPDSL Relative pump diesel price (USD/L)

DUM11 Dummy variable for year 2011

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