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CEPIA User Guide (DRAFT VERSION v1.0)

Configured version for Cambodia MEF

16/12/2021

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Table of content

General Introduction to CEPIA

CEPIA description

- **CEPIA** is an excel based tool allowing for user friendly assessment of energy and climate scenarios through multiple economic and environmental indicators.
- The tool is entirely based on a library of possible levers and the assessment of their environmental impacts and costs. It allows users to forecast the effect of the levers on the different economic and energy sectors, permitting the evaluation of the different impacts and the definition of operational goals (e.g. switch to LPG stove for cooking, increased penetration of renewables, etc).
- The modelling in the tool uses a mixed bottom-up approach and optimisation of the power supply:
  - The energy consumption of the different sectors of the Cambodia economy are estimated based on a detailed representation of the consumers of the sector. For example, the energy consumption of the residential sector is based on the estimation of the consumption for households (cooking, electric appliances, air cooling) multiplied by the number of households.
  - Based on the estimation of the power demand, an optimisation of the power generation mix is realized
- The parameters used in the modelling can represent concrete actions or objectives of policy makers: an energy scenario will then be based on the definition of these structural parameters. In **CEPIA**, thanks to the bottom-up approach, the user can see the influence of one parameter (or lever) on the different indicators available.

CEPIA structure

The tool is divided into six groups of tabs :

Indicators

Dashboard
Power_Generation_Indicators
Indicators

The **dashboard displays key indicators for Cambodia energy sector**, including total energy consumption, greenhouse gases emissions and power generation mix. Indicators include more detailed indicators for all sectors (demand and supply side), while **Power_Generation_Indicators** only focuses on power generation mix.

Input data and scenarios parameters

Var. of context
Var. of actions

These tabs contain the input data of the model.

- **Variables of context** : general contextual assumptions which are not differentiated by scenario (population, international price of energy, etc.)
- **Variables of action** : variables that can be associated that reflect possible political decisions (development of renewable energy in the power sector, better usage of biomass, etc.). These variables are differentiated by scenario.

Power supply

PowerSupply_Param
PowerGeneration_AdvancedParam

These tabs include **additional hypotheses for power generation** mix optimization. While the first tabs includes data that a policy maker would like to modify, the second tab contains advanced data that should only be modified by advanced users.

User defined scenario

User defined scenario

Hypotheses used to define the "user defined scenarios", based on the **combination of ambitions** for the other preconfigured scenarios

Calculation tabs

Residential, Commercial and services, Transport, Industry, Agriculture, Biomass supply

These tabs detail the model used for each sector to calculate the associated energy consumption.
A dedicated tab is used to determine the biomass supply of Cambodia, based on the availability of the different resources (renewable and non-renewable)

Databook

Databook

This tab is used to list the sources of all the data used in the tool.
The ID of the different sources are then used in the variables of context and variable of actions tabs to point for each data the relevant source.

Step-by-step guide to use CEPIA

CEPIA software requirement and installation

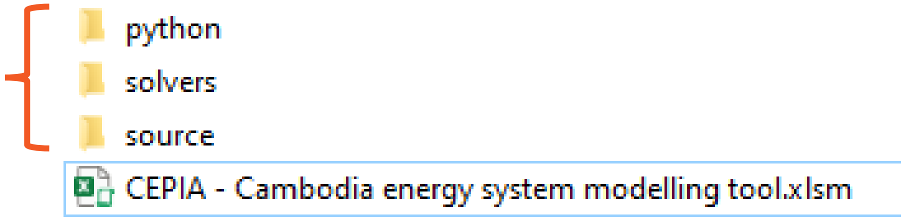
- System and equipment requirements
  - Windows OS 64 Bit Configuration
  - Microsoft Office Pack with Excel 2016 or later

- Installation
  - Unzip the CEPIA archive on the desired location, then double-click on the Excel worksheet to open CEPIA.

- CEPIA user interface and a large part of the calculation are done within a single Excel worksheet. However, the power supply optimization is done with a dedicated Python script that is automatically launched by the Excel worksheet with a VBA macro.
  - To work properly, the structure of the different folders present in the zip archive should not be modified by the user
  - The content of the different folders should not be modified either : only the Excel worksheet itself can be modified by the user

Specific scripts and dependencies for power supply optimisation : should not be modified by the user

The Excel worksheet is the only file that needs to be open to run CEPIA.



Definition of the user profiles

- CEPIA has been developed keeping in mind that different kind of users will use the tool. Some users only want to analyze the results from predefined scenarios, while others would want to update hypotheses for a given sector in order to create a new energy scenario.

- In order to create user documentation that answers the key interrogations of these different users, two categories of user are defined:

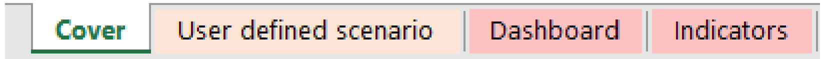
  - **Decision maker**
    - Focus on the analysis of the indicators for already configured energy scenarios
    - Possibility to create a "user defined scenario" based on the combination of different policy ambitions already defined in the preconfigured scenarios

  - **Policy analyst**
    - Advanced analysis of the different energy scenarios
    - Possibility to modify the underlying hypotheses of the different scenarios to create a new scenario.

Decision maker step-by-step user guide

Structure of the tool

- For the analysis of preexisting scenarios, the user only needs to use the first 4 tabs of the tool:



Cover
Brief description of CEPIA, and description of the different tabs available in the tool

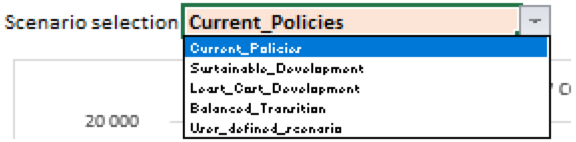
User defined scenario
Possibility to create a new user-defined scenario based on a simple combination of the policy ambitions of predefined scenarios

Dashboard
Key graphs and tables illustrating the key indicators of the Cambodia energy system (energy consumption, GHG emissions, power generation mix)

Indicators
Advanced sectoral indicators

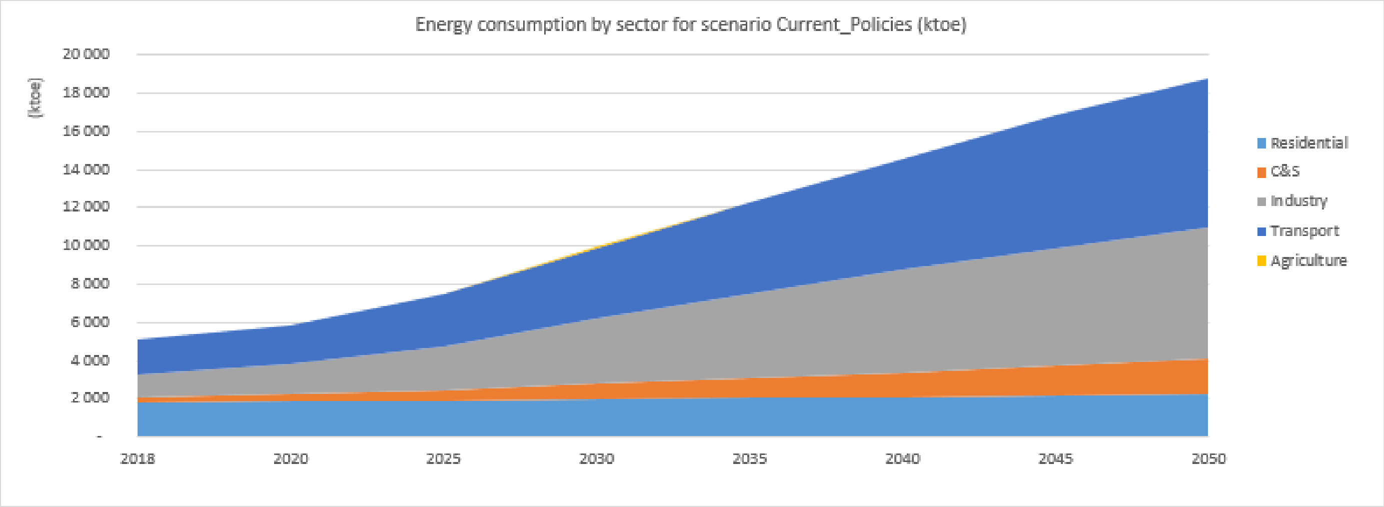
Dashboard

- The dashboard sheet includes key indicators for Cambodia’s energy sector:
  - Total final energy consumption, by sector and by energy
  - Total greenhouse gases emissions, by sector and by energy
  - Power installed capacities, and power generation by type
- For each indicator, a drop-down menu is available to display the data for the desired scenario



Total energy consumption by sector (ktoe)

Scenario selection Current_Policies



Scenario : Current_Policies

	2018	2020	2025	2030	2035	2040	2045	2050
Residential	1788	1857	1845	2 000	2 052	2 094	2 181	2 279
C&S	249	364	569	839	1068	1310	1553	1784
Industry	1193	1633	2 308	3 384	4 346	5 347	6 134	6 926
Transport	1867	1961	2 772	3 707	4 816	5 812	6 964	7 840
Agriculture	1	1	1	2	2	3	4	5

Decision maker

Indicators tab

- On top of the key indicators available in the dashboard menu, additional sectoral indicators are available in **Indicators** :
- These indicators are divided in 7 categories:

All sectors → Additional indicators covering the whole Cambodia energy consumption and GHG emissions

Residential sector
C&S sector
Transport sector
Industry sector
→ Sectoral detailed indicators

Biomass supply → Indicators about biomass supply

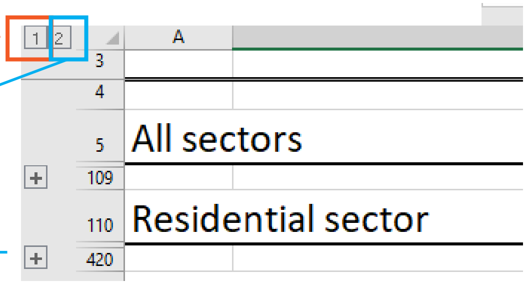
Power Sector → Additional indicators about power sector

- An Excel group have been created for each category to simplify the navigation:

Collapse all indicators inside the groups

Expand all indicators inside the groups

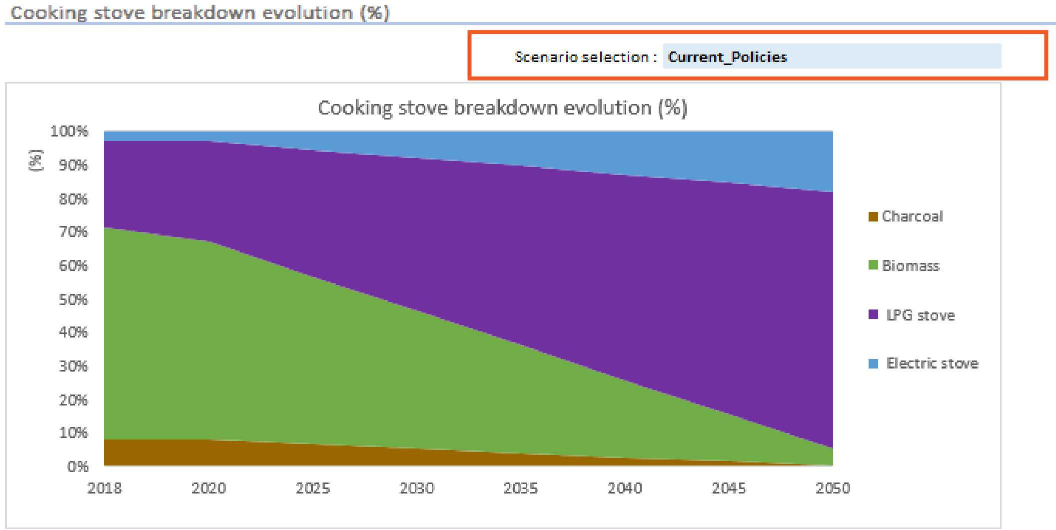
Expand all indicators inside the category defined above (here "Residential sector")



Decision maker

Indicators tab

- Similarly to the dashboard sheet, some indicators include a drop-drown menu to select the appropriate scenario to display, or other information such as the year of the scenario:



	2018	2020	2025	2030	2035	2040	2045	2050
Charcoal	8%	8%	7%	5%	4%	3%	1%	0%
Biomass	63%	59%	50%	41%	32%	23%	14%	5%
LPG stove	26%	30%	38%	46%	54%	61%	69%	77%
Electric stove	3%	3%	6%	8%	11%	13%	16%	18%

- At the top of the Indicator tab, a toolbar is available in order to update power supply indicators if changes have been made in the hypotheses of the scenarios:
  - This is an advanced menu only necessary for users that are changing the hypotheses of the scenario. Please ignore this if you do not plan to update the scenarios, and refer to the corresponding section in the “Policy analyst” section of this step-by-step user guide if you want to have more information about how to use this toolbar.

Decision maker

User defined scenario

- The "User defined scenario" is an additional scenario that can be defined by mixing the ambitions of the 4 pre-existing scenarios:
  - For each action (for example "evolution of cooking equipment"), the user can choose a level of ambition among the ones from the 4 pre-existing scenarios.
  - Then, the "user defined scenario" results are based on the combination of the ambitions defined by the user in this tab. Energy demand results are automatically updated, but a click on the "launch optimization" button is required to update the results of the power mix and update greenhouse gases indicators.

			Energy consumption (ktoe)							
Sector	Action name	Level of ambition	2018	2020	2025	2030	2035	2040	2045	2050
Residential	Evolution of cooking equipments (Residential)	Current_Policies	1 788	1 857	1 845	2 000	2 052	2 094	2 181	2 279
	Evolution of Fan Cooling (Residential)	Current_Policies								
	Evolution of Air Cooling (Residential)	Current_Policies								
	Evolution of Lighting (Residential)	Current_Policies								
	Evolution of Refrigerator (Residential)	Current_Policies								
	Evolution of Other Usages (Residential)	Current_Policies								

Sustainable_Development

- Current_Policies
- Sustainable_Development
- Least_Cost_Development
- Balanced_Transition
- User_defined_scenario

Level of ambition	2018	2020	2025	2030	2035	2040	2045	2050
Sustainable_Development	1 788	1 857	1 824	1 948	1 973	1 979	2 040	2 112
Current_Policies								
Current_Policies								
Current_Policies								
Current_Policies								
Current_Policies								

1 Update the ambition of a given action

2 Analyse the influence of your decision in the energy consumption indicators, but also in the other Indicators in "Dashboard" and "Indicators" sheets.

- At the top of the sheet, a toolbar is available in order to update power supply indicators if changes have been made in the hypotheses of the scenarios:
  - Click on the "launch optimization" button to reoptimize the power mix if you want to analyze the impact on your modifications on the power mix but also on greenhouse gases emissions, since power emissions are impacted by the power supply optimization.

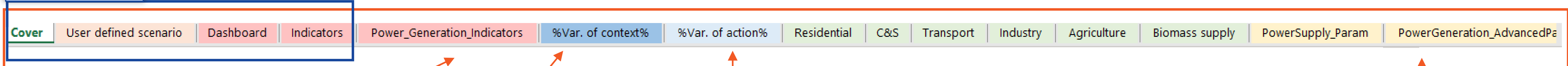
Policy analyst step-by-step user guide

Policy analyst

Structure of the tool

- In addition to the analysis of the results of the energy scenarios, policy analysts can also update the hypotheses of the different scenarios included in the tool in order to make some adaptations :

Decision maker



Policy analyst

Power_Generation _Indicators
Detailed indicators for power generation

Var. of context
Definition of the variable of context (general contextual assumptions which are not differentiated between scenarios)

Var. of action
Definition of the variable of context (assumptions which are differentiated between scenarios)

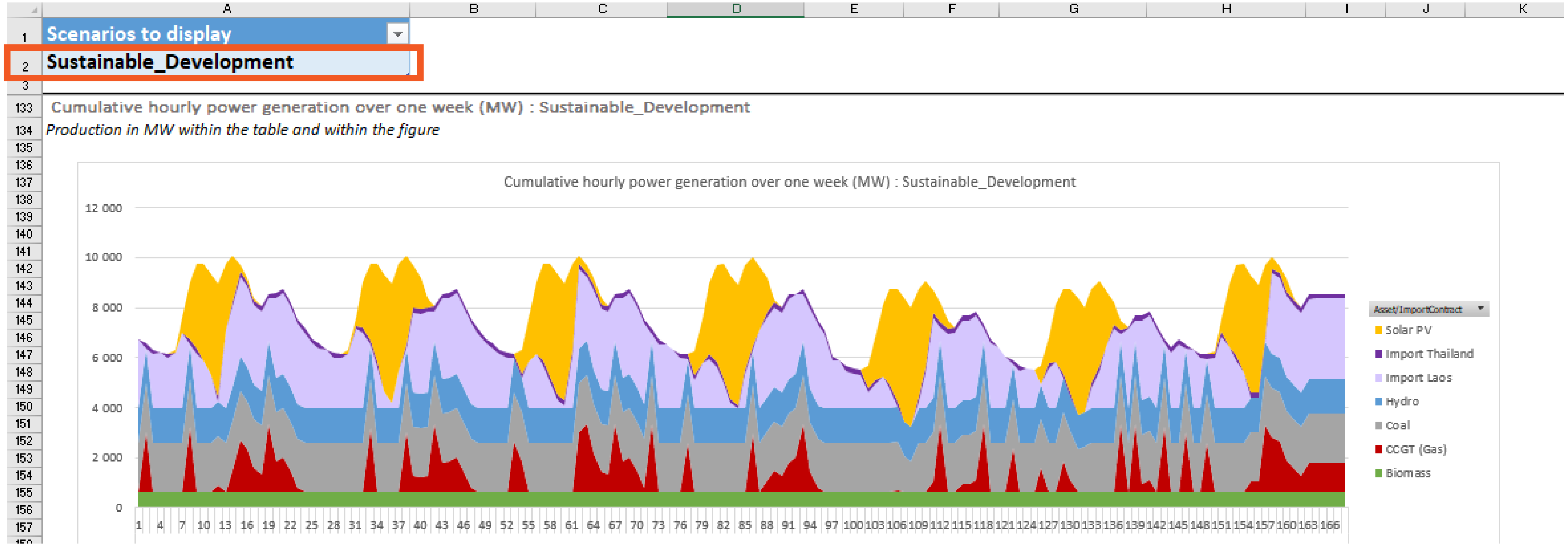
Calculation tabs
These tabs detail the model used for each sector to calculate the associated energy consumption.
A dedicated tab is used to determine the biomass supply of Cambodia, based on the availability of the different resources (renewable and non-renewable)

Power supply parameters
These tabs include additional hypotheses for power generation mix optimisation.

Policy analyst

Power_Generation_Indicators

- This sheet displays specific indicators regarding the power generation mix optimisation
  - Installed capacities
  - Power generation
  - Hourly cumulative power generation
  - Investment and operation costs
- All figures and graphs are based on the scenario selected by the user in cell A2 :



Policy analyst

Modifying context variables

- Variable of context are **general contextual assumptions** that are **not differentiated between scenarios** (population growth rate, international energy prices , efficiency level of end use appliances and equipment, etc.)
- They are used in the different calculation sheets to estimate the energy consumption, and other relevant indicators
- The user can easily update the existing context variables by modifying their value in the **%Var. of context%** tab
  - **Please modify only the values and not the variable name, since this is used as an ID in the calculation sheet.**

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	General contextual assumptions which are not differentiated by scenario												
2				Data common accross all scenarios								Sources	
3	Sector	Variable name	Unit	2018	2020	2025	2030	2035	2040	2045	2050	Source current situation	Source scenarios
4	General	Population	hab	16 249 795	16 718 971	17 806 000	18 781 000	19 686 000	20 527 000	21 261 000	21 861 000	1	
5		Population - urban	hab	3 800 502	4 051 341	4 720 000	5 453 000	6 260 000	7 139 000	8 061 000	8 996 000	1	
6		Population - rural	hab	12 449 293	12 667 630	13 086 000	13 328 000	13 426 000	13 388 000	13 200 000	12 865 000	1	
7		Average size of HouseHolds	hab	4,62	4,57	4,50	4,40	4,20	4,00	3,75	3,50	2	
8		Number of HouseHolds	households	3 517 271,65	3 658 418,16	3 956 888,89	4 268 409,09	4 687 142,86	5 131 750,00	5 669 600,00	6 246 000,00	2	
9		Households with access to electricity	households	2 538 031,24	2 829 288,50	3 508 501,94	4 054 988,64	4 452 785,71	4 875 162,50	5 527 860,00	6 246 000,00	3	
10		Population with access to electricity	hab	11 725 704,35	12 929 848,47	15 788 258,72	17 841 950,00	18 701 700,00	19 500 650,00	20 729 475,00	21 861 000,00	3	
11		Electrification of HouseHolds	%	72,16%	77,34%	88,67%	95,00%	95,00%	95,00%	97,50%	100,00%	0	
12		GDP - Total	million $	23 763	25 054	34 246	49 298	68 376	91 289	116 508	144 132	4	
13		GDP - Services	million $	9 440	9 876	13 140	18 364	24 786	32 297	40 669	49 669	4	
14		GDP - Industry	million $	7 418	8 163	11 861	17 352	23 718	30 523	37 333	43 907	4	
15		GDP - Manufacturing - Total	million $	3 950	4 286	6 116	8 934	12 350	16 220	20 351	24 597	4	
16		GDP - Manufacturing - Food, Beverages & Tobacco	million $	579	628	897	1 310	1 811	2 378	2 983	3 606	4	
17		GDP - Manufacturing - Textile,Wearing Apparel & Footwear	million $	2 589	2 809	4 008	5 856	8 095	10 631	13 339	16 122	4	
18		GDP - Manufacturing - Wood, Paper & Publishing	million $	119	130	185	270	374	491	616	744	4	
19		GDP - Manufacturing - Rubber Manufacturing	million $	140	151	216	316	436	573	719	869	4	
20		GDP - Manufacturing - Other Manufacturing	million $	523	567	810	1 183	1 635	2 147	2 694	3 256	4	
21		GDP - Electricity, Gas & Water	million $	127	128	159	211	277	362	472	614	4	
22		GDP - Mining	million $	412	472	711	1 014	1 295	1 513	1 655	1 746	4	
23		GDP - Construction	million $	2 929	3 275	4 876	7 194	9 796	12 428	14 855	16 950	4	
24		GDP - Agriculture	million $	5 396	5 304	6 463	8 861	12 215	16 606	22 016	28 359	4	
25		GDP - Taxes on Products less Subsidies	million $	1 509	1 711	2 782	4 722	7 657	11 862	16 491	22 197	4	
26		Useful energy for cooking (Residential)	MJ/day	3	3	3	3	3	3	3	3		
27		Efficiency Firewood/Charcoal - Tier 0 stove	%	10%	10%	10%	10%	10%	10%	10%	10%		

Policy analyst

Modifying action variables

- Variables of action are **assumptions that are differentiated between scenarios** (Share of biomass stove for cooking, share of efficient electric boilers in Industry, etc.)
- They are used in the different calculation sheets to calculate the energy consumption evolution but also the energy supply (biomass and power).
- The first year 2018-2020 have the same value for each scenario.
- The user can easily update the existing action variable by modifying their value in the **%Var. of action%** tab
  - Please modify only the values and not the variable name or Action category, since the name is used as an ID the calculation sheet.

Scenarios are indexed by column

Specific variables of the different scenarios

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
2					Current_Policies								Sustainable_Development				
5	Sector	Variable name	Action category	Unit	2018	2020	2025	2030	2035	2040	2045	2050	2018	2020	2025	2030	2035
6		Carbon Budget	Evolution of Carbon budget	tCO2													
7		Carbon Price	Evolution of Carbon price	$/tCO2	0	5	5	10	15	20	25	30	0	0	5	10	15
8		Transport grid losses	Evolution of Grid Losses	%	6,0%	6,00%	4,00%	3,00%	3,00%	3,00%	2,50%	2,00%	5,0%	4,00%	4,00%	3,00%	3,00%
9		Distribution grid losses	Evolution of Grid Losses	%	12,0%	12,00%	11,00%	8,00%	8,00%	7,00%	7,00%	6,00%	12,0%	11,00%	9,00%	8,00%	8,00%
10		CO2 Emissions - LPG	Evolution of energy	tCO2/ktoe	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648
11		CO2 Emissions - Oil	Evolution of energy	tCO2/ktoe	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976
12		CO2 Emissions - Heavy fuel oil	Evolution of energy	tCO2/ktoe	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251
13		CO2 Emissions - Coal	Evolution of energy	tCO2/ktoe	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043
14		CO2 Emissions - Charcoal	Evolution of energy	tCO2/ktoe	1047	1047	1047	1047	1047	1047	1047	1047	1047	1047	1047	1047	1047
15		CO2 Emissions - RDF	Evolution of energy	tCO2/ktoe	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921
16	General	CO2 Emissions - Natural Gas	Evolution of energy	tCO2/ktoe	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351
17		CO2 Emissions - Power	Evolution of energy	tCO2/ktoe	1801	4 497	8 153	4 278	5 723	6 693	7 116	7 317	1801	4 160	7 931	4 281	4 819
18		CO2 Emissions - Biomass	Evolution of energy	tCO2/ktoe	-	-	-	-	-	-	-	-	-	-	-	-	-
19		Cost - LPG	Evolution of energy	$/ktoe	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008
20		Cost - Oil	Evolution of energy	$/ktoe	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873
21		Cost - Coal	Evolution of energy	$/ktoe	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974
22		Cost - Charcoal	Evolution of energy	$/ktoe	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
23		Cost - Power	Evolution of energy	$/ktoe	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
24		Cost - Biomass	Evolution of energy	$/ktoe	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
25		Cost - RDF	Evolution of energy	$/ktoe	-	-	-	-	-	-	-	-	-	-	-	-	-
26		Cost - Natural Gas	Evolution of energy	$/ktoe	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008
27																	
28																	
29		Share of Charcoal - Tier 0 stove	Evolution of cooking equipments (Residential)	%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
30		Share of Charcoal - Tier 1 stove	Evolution of cooking equipments (Residential)	%	1,4%	1,4%	1,2%	1,0%	0,7%	0,5%	0,2%	0,0%	1,4%	1,4%	1,2%	0,5%	0,4%
31		Share of Charcoal - Tier 2 stove	Evolution of cooking equipments (Residential)	%	6,6%	6,6%	5,5%	4,4%	3,3%	2,2%	1,1%	0,0%	6,6%	6,6%	3,0%	2,4%	1,8%
32		Share of Charcoal - Tier 3 stove	Evolution of cooking equipments (Residential)	%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,5%	1,2%	0,9%

Policy analyst

Link between action variables and user defined scenario

- The "action category" column is used to link the action variables to the different "actions" defined in the "user defined scenario" sheet
  - In the calculation, the "user defined scenario" will use the variable of action of the scenario selected for the ambition defined in its action category

- Example :
  - The user wants to use the ambition of scenario "Current_policies" for the action "Evolution of cooking equipment (Residential)"
  - Then the values of "Current_Policies" scenarios will be used for all variables tagged with the action category "Evolution of cooking equipment (Residential)"

"Var. of action" tab

Sector	Variable name	Action category	Unit	Current_Policies 2018	2020	2025	2030	2035
	Share of Charcoal - Tier 1 stove	Evolution of cooking equipments (Residential)	%	1,4%	1,4%	1,2%	1,0%	0,7%
	Share of Charcoal - Tier 2 stove	Evolution of cooking equipments (Residential)	%	6,6%	6,6%	5,5%	4,4%	3,3%
	Share of Charcoal - Tier 3 stove	Evolution of cooking equipments (Residential)	%	0,0%	0,0%	0,0%	0,0%	0,0%
	Share of Charcoal - Tier 4 stove	Evolution of cooking equipments (Residential)	%	0,0%	0,0%	0,0%	0,0%	0,0%
	Share of Biomass - Tier 0 stove	Evolution of cooking equipments (Residential)	%	0,0%	0,0%	0,0%	0,0%	0,0%
	Share of Biomass - Tier 1 stove	Evolution of cooking equipments (Residential)	%	11,3%	10,6%	5,0%	4,2%	3,4%
	Share of Biomass - Tier 2 stove	Evolution of cooking equipments (Residential)	%	51,7%	48,4%	30,0%	24,2%	18,4%

"User defined scenario" tab

Action name	Level of ambition	Energy consumption (ktoe) 2018	2020	2025	2030	2035
Evolution of cooking equipments (Residential)	Current_Policies	1 788	1 857	1 845	2 000	2 052
Evolution of Fan Cooling (Residential)	Current_Policies					
Evolution of Air Cooling (Residential)	Current_Policies					
Evolution of Lighting (Residential)	Current_Policies					
Evolution of Refrigerator (Residential)	Current_Policies					
Evolution of Other Usages (Residential)	Current_Policies					

Policy analyst

Calculation sheets

- The estimation of the energy consumption of the different sectors is calculated in dedicated sheets, based on the hypotheses defined in %Var. of context% and %Var. of action% tabs. Each sector modelling is done in one sheet:
  - Residential, C&S (Commercial and Services), Transport, Agriculture and Industry
- Other sheets are dedicated to the calculation of the energy supply :
  - Biomass Supply : used to estimate the biomass potential
  - Power generation : PowerSupply_Param and PowerGeneration_AdvancedParam (in Yellow)
- Computation are done within these sheets however all values are taken from the sheets **%Var. of context% and %Var. of action%.**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		Residential														
2				User_defined_scenario								Current_Policies				
5		Variables	Unit	2018	2020	2025	2030	2035	2040	2045	2050	2018	2020	2025	2030	
21																
22	-	**Cooking**														
23	Var. of context	Useful energy for cooking (Residential)	MJ/day	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	
24	Var. of action	Share of Charcoal - Tier 0 stove	%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	
25	Var. of action	Share of Charcoal - Tier 1 stove	%	1,4%	1,4%	1,2%	0,5%	0,4%	0,3%	0,1%	0,0%	1,4%	1,4%	1,2%	1,0%	
26	Var. of action	Share of Charcoal - Tier 2 stove	%	6,6%	6,6%	3,0%	2,4%	1,8%	1,2%	0,6%	0,0%	6,6%	6,6%	5,5%	4,4%	
27	Var. of action	Share of Charcoal - Tier 3 stove	%	0,0%	0,0%	1,5%	1,2%	0,9%	0,6%	0,3%	0,0%	0,0%	0,0%	0,0%	0,0%	
28	Var. of action	Share of Charcoal - Tier 4 stove	%	0,0%	0,0%	1,0%	1,2%	0,9%	0,6%	0,3%	0,0%	0,0%	0,0%	0,0%	0,0%	
29	Var. of action	Share of Biomass - Tier 0 stove	%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	
30	Var. of action	Share of Biomass - Tier 1 stove	%	11,3%	10,6%	5,0%	4,0%	3,0%	2,0%	1,0%	0,0%	11,3%	10,6%	5,0%	4,2%	
31	Var. of action	Share of Biomass - Tier 2 stove	%	51,7%	48,4%	30,0%	24,0%	18,0%	12,0%	6,0%	0,0%	51,7%	48,4%	30,0%	24,2%	
32	Var. of action	Share of Biomass - Tier 3 stove	%	0,0%	0,0%	12,0%	9,8%	7,6%	5,4%	3,2%	1,0%	0,0%	0,0%	12,0%	10,2%	
33	Var. of action	Share of Biomass - Tier 4 stove	%	0,0%	0,0%	3,0%	3,2%	3,4%	3,6%	3,8%	4,0%	0,0%	0,0%	3,0%	2,4%	
34	Var. of action	Share of LPG stove (Residential)	%	26,0%	30,0%	29,2%	28,3%	27,5%	26,7%	25,8%	25,0%	26,0%	30,0%	37,8%	45,7%	
35	Var. of action	Share of Electric stove (Residential)	%	3,0%	3,0%	14,2%	25,3%	36,5%	47,7%	58,8%	70,0%	3,0%	3,0%	5,5%	8,0%	
36	Var. of context	Efficiency Firewood/Charcoal - Tier 0 stove	%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	
37	Var. of context	Efficiency Firewood/Charcoal - Tier 1 stove	%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	
38	Var. of context	Efficiency Firewood/Charcoal - Tier 2 stove	%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	
39	Var. of context	Efficiency Firewood/Charcoal - Tier 3 stove	%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	
40	Var. of context	Efficiency Firewood/Charcoal - Tier 4 stove	%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	
41	Var. of context	Efficiency of LPG stove (Residential)	%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	
42	Var. of context	Efficiency of Electric stove (Residential)	%	60%	63%	65%	70%	75%	80%	80%	80%	60%	63%	65%	70%	
43																
44	Calculation	Final energy consumption of Tier 0 - Charcoal	ktoe	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
45	Calculation	Final energy consumption of Tier 1 - Charcoal	ktoe	40,80	41,98	37,26	16,37	12,87	8,95	4,63	0,00	40,80	41,98	37,26	31,44	
46	Calculation	Final energy consumption of Tier 2 - Charcoal	ktoe	111,52	114,74	55,88	47,15	37,07	25,77	13,35	0,00	111,52	114,74	101,83	85,93	
47	Calculation	Final energy consumption of Tier 3 - Charcoal	ktoe	0,00	0,00	19,96	16,84	13,24	9,20	4,77	0,00	0,00	0,00	0,00	0,00	
48	Calculation	Final energy consumption of Tier 4 - Charcoal	ktoe	0,23	0,23	10,35	13,10	10,30	7,16	3,71	0,00	0,23	0,23	0,25	0,26	
49	Calculation	Final energy consumption of Tier 0 - Biomass	ktoe	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
50	Calculation	Final energy consumption of Tier 1 - Biomass	ktoe	321,29	309,58	155,23	130,98	102,97	71,58	37,07	0,00	321,29	309,58	155,23	137,53	
51	Calculation	Final energy consumption of Tier 2 - Biomass	ktoe	878,20	846,19	558,83	471,54	370,70	257,69	133,45	0,00	878,20	846,19	558,83	475,47	
52	Calculation	Final energy consumption of Tier 3 - Biomass	ktoe	0,00	0,00	159,67	137,53	111,80	82,83	50,84	16,34	0,00	0,00	159,67	143,15	
53	Calculation	Final energy consumption of Tier 4 - Biomass	ktoe	0,23	0,23	31,05	34,93	38,90	42,95	46,96	50,82	0,23	0,23	31,05	26,25	
54	Calculation	Average efficiency of Charcoal stove	ktoe	2%	2%	2%	2%	1%	1%	0%	0%	2%	2%	2%	1%	

... Indicators | Power_Generation_Indicators | %Var. of context% | %Var. of action% | **Residential** | C&S | Transport | Industry | Agriculture | Biomass supply | PowerSupply_Param | PowerGenerat ...

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Sectorial sheet : Example for residential sector

- Within sectorial sheets you will find the formula that lead to the result presented in the indicator.
  - When a row is labelled as Calculation within the **$A** column then a computation is done within each cell of its row.
  - When a column is indicated as Var. of action within the **$A** column then it means that the row values has been retrieved from the sheet **%Var. of action%, the value wear the same name as the value located in column $B.**
  - When a column is indicated as Var. of context within the **$B** column then it means that the row values has been retrieved from the sheet **%Var. of context%, the value wear the same name as the value located in column $B.**
- Every row is automatically updated when modification are done within the %Var. of context% or %Var. of action%.
- However the name of the variable in the sectoral sheet must match the name used in %Var. of action% or %Var. of action%, otherwise CEPIA will not be able to retrieve the appropriate value.

D97 =SOMMEPROD(D84:D85*D86:D87*D83)*D10*Wh_to_MWh

	A	B	C	D	E	F	G	H	I
1		Residential							
2				User_defined_scenario					
5		Variables	Unit	2018	2020	2025	2030	2035	2040
72	Var. of action	Share of LED (Residential)	%	1,0%	2,0%	6,0%	5,0%	10,0%	25,0%
73		**Refrigerating (Residential)**							
74	Var. of action	Average number of hours per year for Refrigerating (R	h/HH	8760,0	8760,0	8760,0	8760,0	8760,0	8760,0
75	Var. of context	Avg consumption of Inefficient Refrigerator (Residenti	Wh	90,0	90,0	90,0	90,0	90,0	90,0
76	Var. of context	Avg consumption of Efficient Refrigerator (Residential	Wh	50,0	50,0	50,0	50,0	50,0	50,0
77	Var. of action	Share of Inefficient Refrigerator (Residential)	%	37,0%	42,0%	52,0%	65,0%	63,0%	55,0%
78	Var. of action	Share of Efficient Refrigerator (Residential)	%	2,0%	3,0%	13,0%	22,0%	30,0%	45,0%
79		**Cooling (Residential)**							
80	Var. of action	Average number of hours per year for FAN (Residentia	h/HH	6250,0	6400,0	6550,0	6164,0	5778,0	5392,0
81	Var. of action	Share of FAN (Residential)	%	58,0%	70,0%	81,4%	99,0%	100,0%	100,0%
82	Var. of context	Avg consumption of FAN (Residential)	Wh	58,0	56,1	51,4	46,8	42,1	37,4
83	Var. of action	Average number of hours per year for Cooling (Reside	h/HH	1100,0	1100,0	1158,4	1219,8	1284,5	1352,7
84	Var. of action	Share of AC (Residential)	%	22,0%	25,8%	26,5%	32,0%	35,0%	35,0%
85	Var. of action	Share of Efficient AC (Residential)	%	1,5%	3,0%	10,8%	18,0%	25,0%	35,0%
86	Var. of context	Avg consumption of AC (Residential)	Wh	950,00	950,00	950,00	950,00	950,00	950,00
87	Var. of context	Avg consumption of Efficient AC (Residential)	Wh	650,00	650,00	650,00	650,00	650,00	650,00
88		**Other Usages (Residential)**							
89	Var. of action	Average number of hours per Other Usages (Resident	h/HH	1350,0	1450,0	1629,4	1831,1	2057,7	2312,3
90	Var. of context	Avg consumption of Inefficient Other Usages (Resider	Wh	210,0	210,0	220,5	231,5	243,1	255,2
91	Var. of context	Avg consumption of Average Other Usages (Resident	Wh	140,0	140,0	147,0	154,3	162,1	170,2
92	Var. of context	Avg consumption of Efficient Other Usages (Residenti	Wh	126,0	126,0	132,3	138,9	145,8	153,1
93	Var. of action	Share of Inefficient Other Usages (Residential)	%	30,5%	35,0%	37,0%	35,0%	32,0%	27,0%
94	Var. of action	Share of Average Other Usages (Residential)	%	28,0%	35,0%	35,0%	35,0%	35,5%	37,0%
95	Var. of action	Share of Efficient Other Usages (Residential)	%	10,0%	15,0%	17,0%	20,0%	25,0%	31,0%
96									
97	Calculation	Electric consumption for AC (Residential)	MWh	610 714	823 493	1 309 317	2 082 399	2 831 255	3 692 911
98	Calculation	Electric consumption for Fan (Residential)	MWh	533 621	711 396	962 482	1 156 829	1 082 192	982 472
99	Calculation	Electric consumption for Lighting (Residential)	MWh	376 212	456 053	642 266	878 615	883 655	858 882

Power supply

- The power supply module is used to determine for each scenario the optimal power generation mix to satisfy the power demand estimated in the demand module, based on different techno-economic constraints set by the user.
  - The result includes the optimal production mix, meaning the installed capacity per type of power production unit per year, the investment needed per year and the power dispatch.
- The model minimizes the total power system cost while respecting user defined and power system constraints.
  - The Power Generation module optimize the capacity from 2020 until 2050.
    - We divide this horizon in 5 years timestep.
    - A representative year corresponding to the first year of the period is used to represent each 5-year period
  - Power flows within Cambodia are not modelled, the grid is represented as a single point of demand and production. Import from neighboring countries are however explicitly represented.
  - Each generation unit is not modelled explicitly, but are rather gathered by generation type (Solar, wind, hydro, gas, coal, biomass, oil).
- In order to have a fine representation of the supply-demand equilibrium, the optimization is done using two typical weeks:
  - One in the dry season
  - One in the wet season
- Every time a modification is done in the bottom-up model **the optimization must be relaunched** in order to get a power system in adequacy with the demand.

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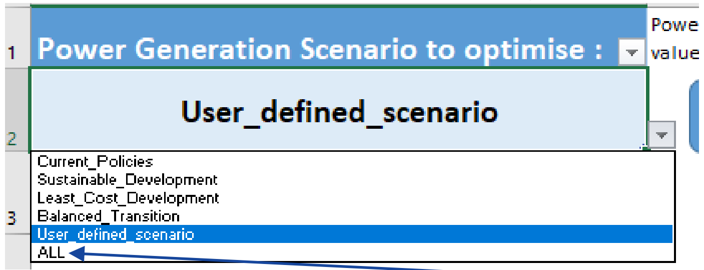
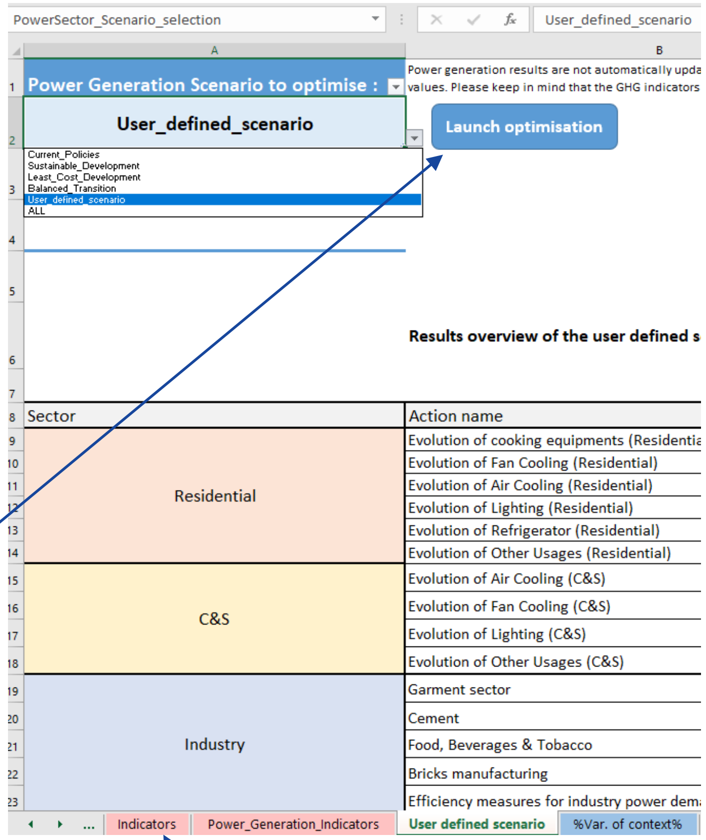
How to run the optimisation of the power mix

- The power module has to **be relaunched every time a modification is done**.
- The power module generate multiple outputs such as :
  - Carbon intensity of power
    - ↳ Hence all indicators linked to GHG emissions are updated.
  - Installed power capacities
- To launch the power supply optimization :
  - The user must select a scenario within the drop-down list :



    - ↳ A user can also decide to optimise all scenario by selecting **ALL**.
  - And then the user must click on the button :

  - This button is located on the top left within the following sheets :
    - ↳ User Defined Scenario
    - ↳ Indicators



Sheets where the optimisation can be launched.

Power generation : Data scope

- The power generation module uses data from multiple sources including %Var. of action% and %Var. of context% **but not only**.
  - Some inputs are only present in the specific Power Generation Sheets :
    - Power supply_Param
    - PowerGeneration_AdvancedParam

	%Var. of context%	%Var. of action%	PowerSupply_Param	PowerGeneration _AdvancedParam
Fuels		Cost & CO2eq emission when burnt for fossil fuel		
Production technologies	CAPEX, OPEX, Production Cost, Installed capacity	Minimum capacity and Maximum capacity	Availability timeseries, techno-economic characteristics	
Import		Capacity, cost, CO2eq emission and maximum yearly imported volume.	Availability timeseries	
Demand		Grid losses	Load curve	
Time periods				Share of year represented
CO2 parameters		Budget & Price		
Other				Simulation parameters

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Techno-economic characteristics of power generation technologies

- Investment are allowed in the first optimization year (2020)
- Efficiency described the volume of fuel needed for the production of one unit of power.
  - 25% is equivalent to say that we need 4 MWh of Oil to generate 1 MWh of power.
- Renewable technologies do not consume fuel
- Their lifetime must be a multiple of 5 years.
  - The RemainingLifeTime have to be smaller or equal to the lifetime.
- MaximumYearlyInvestmentInMW defines the maximum capacity that can be added each year.
  - **As we represent the horizon by period of 5 years the model can actually invest 5 times more.**

- The second table corresponds to the actual installed capacity
  - The install capacity has to be specified for each technology modelled.
  - Be aware that the installed capacity is not greater than the maximum capacity or smaller than the minimum capacity for the year 2020.
- The RemainingLifeTime must be less or equal to the lifetime of the equivalent technology specified on the left.

Yearly values are per representative year and not for the intermediary period of 5 years

Technology	Type	LifeTime	Efficiency	Fuel	LoadEfficiency	PmaxToStorageVolume	MaximumYearlyInvestmentInMW	YieldRate
Oil	Thermal	25	25,71%	Oil			10000	0,00%
Coal	Thermal	30	36,00%	Coal			10000	0,00%
CCGT (Gas)	Thermal	25	50,00%	Natural Gas			10000	0,00%
OCGT(Gas)	Thermal	25	36,00%	Natural Gas			10000	0,00%
Hydro	Renewable	40	100,00%				10000	0,00%
Biomass	Thermal	20	35,00%	Biomass			10000	0,00%
Solar PV	Renewable	20	100,00%				10000	5,00%
Wind Onshore	Renewable	20	100,00%				10000	5,00%
Battery Storage	Storage	30	100,00%		90,00%	4	10000	0,00%
Wind Offshore	Renewable	20	100,00%				10000	5,00%
Other	Other	20	100,00%				10000	0,00%

Technology	InstalledCapacities	RemainingLifetime
Oil	643,95	25
Coal	675	30
CCGT (Gas)	0	25
OCGT(Gas)	0	25
Hydro	1329,7	35
Biomass	30,57	20
Solar PV	236,8	20
Wind Onshore	0	20
Battery Storage	0	10
Wind Offshore	0	20
Other	0	20

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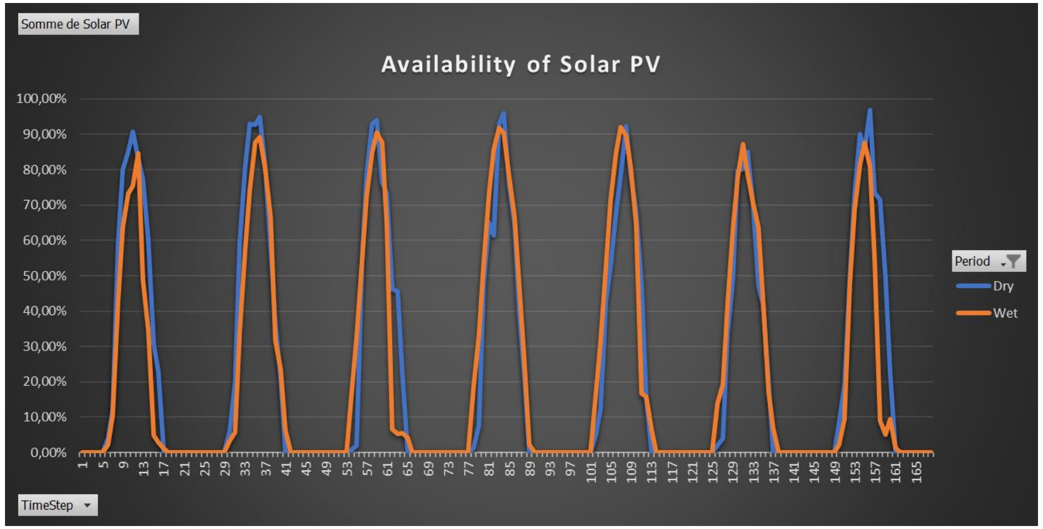
Power generation : Capacity constraints

- Maximum and minimum capacity of a technology are defined per year and scenario
  - To fix the capacity of a technology set the minimum equals to the maximum
- Import contract can be constrained to a maximum volume (in MWh) per year.

Yearly values are per representative year and not for the intermediary period of 5 years

- For each technology, the power generation is bounded by its installed capacity at the given year multiplied by its hourly availability:
  - The availability represent the % of the capacity available at each hour
  - The availability is a TimeSeries (hourly values) defined for each typical year (one for the wet and another one for the dry season)
  - The timeseries are defined in the PowerSupply_Param sheet
    - ↳ A timeseries is associated to a technology based on its column name



The availability of a solar panel.
Sheet : **PowerGeneration_TimeSeries**

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Power Generation : Demand & carbon parameter

- There are two parameters associated to the CO2 emissions (defined in var of action and context tabs:
  - The cost of carbon in $/tCO2eq
    - Per MWh of fuel consumed
    - **This parameter assigns a cost for each emission of CO2eq, hence some technology such as Coal have to consider this additional cost when producing.**
  - The carbon budget in tCO2eq/year
    - The maximum amount of emission that the power system can emit per year.
    - This parameter allow the user to specify a maximum amount of emission that the system will respect at all cost.
    - When specifying 0 then the system will not use any Thermal Central using fossil fuel.

Yearly values are per representative year and not for intermediary years, for example a carbon budget for 2020 is a carbon budget for one year of the period 2020-2025. In fact during the period 2020-2025 the power system can emit up to 5 times the carbon budget indicated for 2020 since there are 5 years in the period.

- The demand is defined as:
  - YearlyDemand :
    - A total volume per year in GWh
  - LoadCurve :
    - A shape of demand, this allows to model the different consumption during the hour of the day.
  - ShareOfDemand :
    - A share of demand per period, for example we can specify that 70% of the annual demand is during the dry period.
  - ShareOfTime :
    - A share of time specifies what is the temporal representation of the period.
    - For example if set 70% for the dry period in 2020, then we state that the dry period represent around 8 month of year, hence all the hourly cost computed for this period will have a bigger impact than the one of the wet period (who must have a share of ShareOfTime equal to 30%)
  - DistributionLosses and TransportLosses:
    - Total losses are the sum of distribution and transport losses.
- The instant demand of an hourly simulation for a given period increases as the ShareOfDemand increases and the ShareOfTime decrease.

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Power generation : Simulation parameters

- These parameters define the simulation and the exported data.
  - SimulationDuration is the number of hourly timesteps simulated per year and period
  - SimulationPerYear is equal to the number of periods
  - DiscountRate is used to compute discounted cost
  - OptimisationHorizon :
    - NumberOfYearsSimulated is the number of optimized year
    - YearIncrement is number year separating each year
    - StartYear is the starting year
  - AccountForCO2Import
    - True - Account for emission from import (within the carbon cost and the carbon budget)
    - False– Do not account

The simulation parameters

Parameter	Value
SimulationDuration	168
SimulationPerYear	2
DiscountRate	0,05
NumberOfYearSimulated	7
YearIncrement	5
AccountForCO2Import	False
StartYear	2020

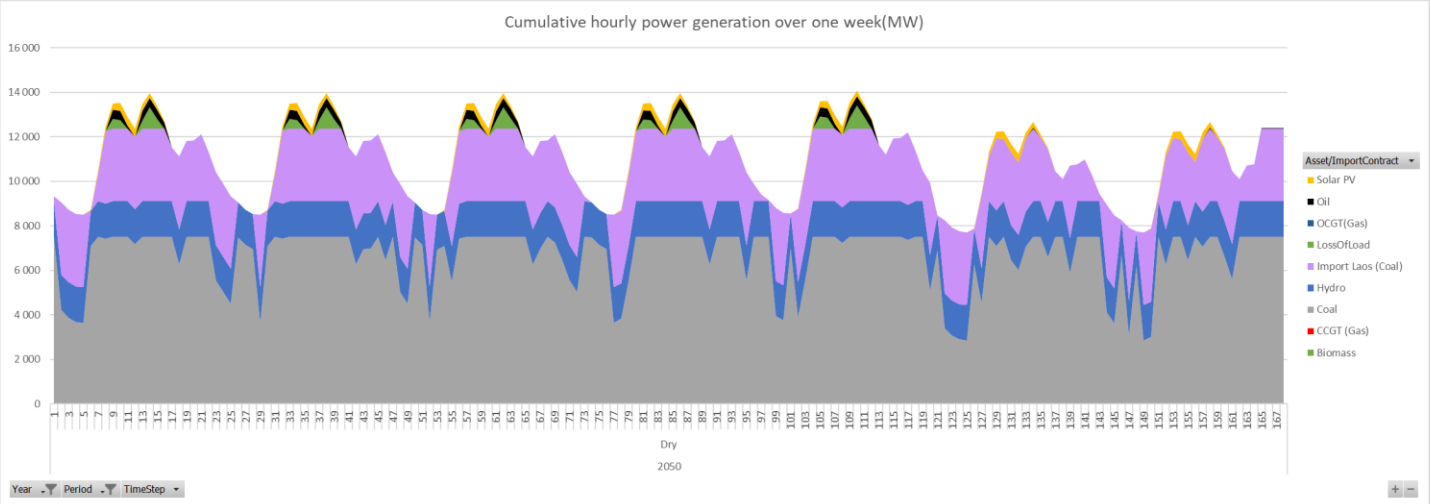
Sheet : **PowerGeneration_AdvancedParam**

- The power simulation to be exported
  - Here only the dry period of 2020 and 2025 year will be exported and available within the indicators

The power dispatch simulation to be exported

Year	Period	ExportPowerDispatch
2020	Dry	True
2025	Dry	True
2020	Wet	False
2025	Wet	False

Sheet : **PowerGeneration_AdvancedParam**



A power dispatch exported (2050, Dry) – Available in the sheet Power Generation Indicators

Power generation : Costs & GHG emissions

- There are six main categories of costs considered in the power generation optimization module:
  - Fuel costs:
    - Per $/MWh of fuel consumed
    - The cost associated to the consumption of fuel such as Oil, Coal or Natural Gas as the operator of the power plant must purchase these fuel on the global market.
  - Investment costs:
    - Per $/MW newly installed
    - Capital expenditure, when a new capacity is installed then an investment has to be done. Also called CAPEX.
  - Operational cost of capacities
    - Per $/MW installed per year.
    - The operative cost of a power plant necessary to maintain the plant in working conditions (Maintenances etc..). These costs depend on the current installed capacity.
  - Production cost (different than fuel cost)
    - Per $/MWh produced
    - These cost represent additional cost for each unit of power produced, such as the mechanical wear from using a turbine but not the fuel costs.
  - Import cost
    - Per $/MWh imported
    - This price should be equal to the average cost of the neighboring country.
  - Carbon cost
    - Per $/tCO2Eq emitted.
    - This price is explained within (See slide *Power Generation : Demand & Carbon parameter)*

- There are two sources of greenhouse gases (GHG) emissions considered in the module :
  - GHG emissions from the fuel burnt in Cambodia power plants
    - Per tCO2eq/MWh of fuel consumed
    - These represent the emission cause by the carbon-emissive combustion of fuel.
  - GHG emission from import
    - Per tCO2eq/MWh of import
    - This emission should be equal to the average carbon intensity of the neighbor country.
    - This emission can be accounted within the carbon budget or cost or excluded. (See slide *Power generation : Simulation parameters*)

All these data are available in the “var. of context” and “var. of action tabs”

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Example 1 : Creating a scenario

- The user wants to design a scenario :
  - With a net zero objective in 2050.
  - Gas price increase of 10% every 5 years.

"Var. of action" tab

A	B	C	D	E	F	G	H	I	J	K	L
Specific variables of the different scenarios											
				Current_Policies							
Sector	**Variable name**	**Action category**	**Unit**	2018	2020	2025	2030	2035	2040	2045	2050
General	Carbon Budget	Evolution of Carbon budget	tCO2								0
	Carbon Price	Evolution of Carbon price	$/tCO2	0	5	5	10	15	20	25	30
	Transport grid losses	Evolution of Grid Losses	%	6,0%	6,00%	4,00%	3,00%	3,00%	3,00%	2,50%	2,00%
	Distribution grid losses	Evolution of Grid Losses	%	12,0%	12,00%	11,00%	8,00%	8,00%	7,00%	7,00%	6,00%
	CO2 Emissions - LPG	Evolution of energy	tCO2/ktoe	2 648	2 648	2 648	2 648	2 648	2 648	2 648	2 648
	CO2 Emissions - Oil	Evolution of energy	tCO2/ktoe	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976
	CO2 Emissions - Heavy fuel oil	Evolution of energy	tCO2/ktoe	3 251	3 251	3 251	3 251	3 251	3 251	3 251	3 251
	CO2 Emissions - Coal	Evolution of energy	tCO2/ktoe	4 043	4 043	4 043	4 043	4 043	4 043	4 043	4 043
	CO2 Emissions - Charcoal	Evolution of energy	tCO2/ktoe	1047	1047	1047	1047	1047	1047	1047	1047
	CO2 Emissions - RDF	Evolution of energy	tCO2/ktoe	3 921	3 921	3 921	3 921	3 921	3 921	3 921	3 921
	CO2 Emissions - Natural Gas	Evolution of energy	tCO2/ktoe	2 351	2 351	2 351	2 351	2 351	2 351	2 351	2 351
	CO2 Emissions - Power	Evolution of energy	tCO2/ktoe	1801	4 497	8 153	4 278	5 723	6 693	7 116	7 317
	CO2 Emissions - Biomass	Evolution of energy	tCO2/ktoe	-	-	-	-	-	-	-	-
	Cost - LPG	Evolution of energy	$/ktoe	505 008	505 008	505 008	505 008	505 008	505 008	505 008	505 008
	Cost - Oil	Evolution of energy	$/ktoe	742 873	742 873	742 873	742 873	742 873	742 873	742 873	742 873
	Cost - Coal	Evolution of energy	$/ktoe	177 974	177 974	177 974	177 974	177 974	177 974	177 974	177 974
	Cost - Charcoal	Evolution of energy	$/ktoe	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
	Cost - Power	Evolution of energy	$/ktoe	1000	1000	1000	1000	1000	1000	1000	1000
	Cost - Biomass	Evolution of energy	$/ktoe	1000	1000	1000	1000	1000	1000	1000	1000
	Cost - RDF	Evolution of energy	$/ktoe	-	-	-	-	-	-	-	-
	Cost - Natural Gas	Evolution of energy	$/ktoe	505 008	555 509	611 059	672 165	739 382	813 320	894 652	984 117

Policy analyst

Example 2 : Creating a scenario

- The user wants to design a scenario :
  - With different renewable potential :
    - 1500 MW for Onshore Wind
    - 5100 MW for solar
  - Laos imports limited to 5 TWh per year
    - *Be aware that the unit is in MWh*

“Var. of action” tab

Sector	Variable name	Action category	Unit	2018	2020	2025	2030	2035	2040	2045	2050
	Maximum capacity for Oil	Evolution of technology capacities	MW	10000,00	575,00	490,00	490,00	490,00	490,00	490,00	490,00
	Maximum capacity for Wind Offshore	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Maximum capacity for Wind Onshore	Evolution of technology capacities	MW	0,00	1500,00	1500,00	1500,00	1500,00	1500,00	1500,00	1500,00
	Maximum capacity for Coal	Evolution of technology capacities	MW	[illegible]	675,00	2305,00	2305,00	3484,48	5440,98	7102,75	8803,96
	Maximum capacity for Hydro	Evolution of technology capacities	MW	10000,00	1189,06	1154,34	1463,04	2300,29	3016,22	3774,69	4508,58
	Maximum capacity for CCGT (Gas)	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Maximum capacity for OCGT(Gas)	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Maximum capacity for Solar PV	[illegible]	[illegible]	[illegible]	5100,00	5100,00	5100,00	5100,00	5100,00	5100,00	5100,00
	Maximum capacity for Battery Storage	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Maximum capacity for Other	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Maximum capacity for Biomass	Evolution of technology capacities	MW	10000,00	0,00	6,60	15,01	23,43	30,44	38,00	45,29
	Minimum capacity for Oil	Evolution of technology capacities	MW	0,00	575,00	490,00	490,00	490,00	490,00	490,00	490,00
	Minimum capacity for Wind Offshore	[illegible]	[illegible]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Minimum capacity for Wind Onshore	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Minimum capacity for Coal	Evolution of technology capacities	MW	0,00	675,00	2305,00	2305,00	3484,48	5440,98	7102,75	8803,96
	Minimum capacity for Hydro	Evolution of technology capacities	MW	0,00	1189,06	1154,34	1463,04	2300,29	3016,22	3774,69	4508,58
	Minimum capacity for CCGT (Gas)	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Minimum capacity for OCGT(Gas)	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Minimum capacity for Solar PV	Evolution of technology capacities	MW	0,00	0,00	411,57	467,59	486,63	474,26	473,64	470,38
	Minimum capacity for Battery Storage	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Minimum capacity for Other	Evolution of technology capacities	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Power generation	Minimum capacity for Biomass	Evolution of technology capacities	MW	0,00	0,00	6,60	15,01	23,43	30,44	38,00	45,29
	Capacity for Import Thailand	Evolution of interconnexion	MW	188,62	188,62	188,62	188,62	188,62	188,62	188,62	188,62
	Capacity for Import Vietnam	Evolution of interconnexion	MW	[illegible]34,57	634,57	634,57	634,57	634,57	634,57	634,57	634,57
	Capacity for Import Laos (Coal)	Evolution of interconnexion	MW	[illegible]50,00	250,00	611,81	2971,81	3271,81	3271,81	3271,81	3271,81
	Capacity for Import Laos (Hydro)	Evolution of interconnexion	MW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Ref import capacity			0,00	925,00	1435,00	3795,00	4095,00	4095,00	4095,00	4095,00
	Maximum import volume for Import Thailand	Evolution of interconnexion	MWh	8[illegible]7,32	897224,1069	519144,4321	0	0	0	0	0
	Maximum import volume for Import Vietnam	Evolution of interconnexion	MWh	144[illegible]96,90	1444530,81	519144,43	0,00	0,00	0,00	0,00	0,00
	Maximum import volume for Import Laos (Coal)	Evolution of interconnexion	MWh	5000000,00	5000000,00	5000000,00	5000000,00	5000000,00	5000000,00	5000000,00	5000000,00
	Maximum import volume for Import Laos (Hydro)	Evolution of interconnexion	MWh	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Modelling methodology for sectoral modules

Modelling methodology for sectoral modules

The energy sector modelling in CEPIA can be divided in three different steps:

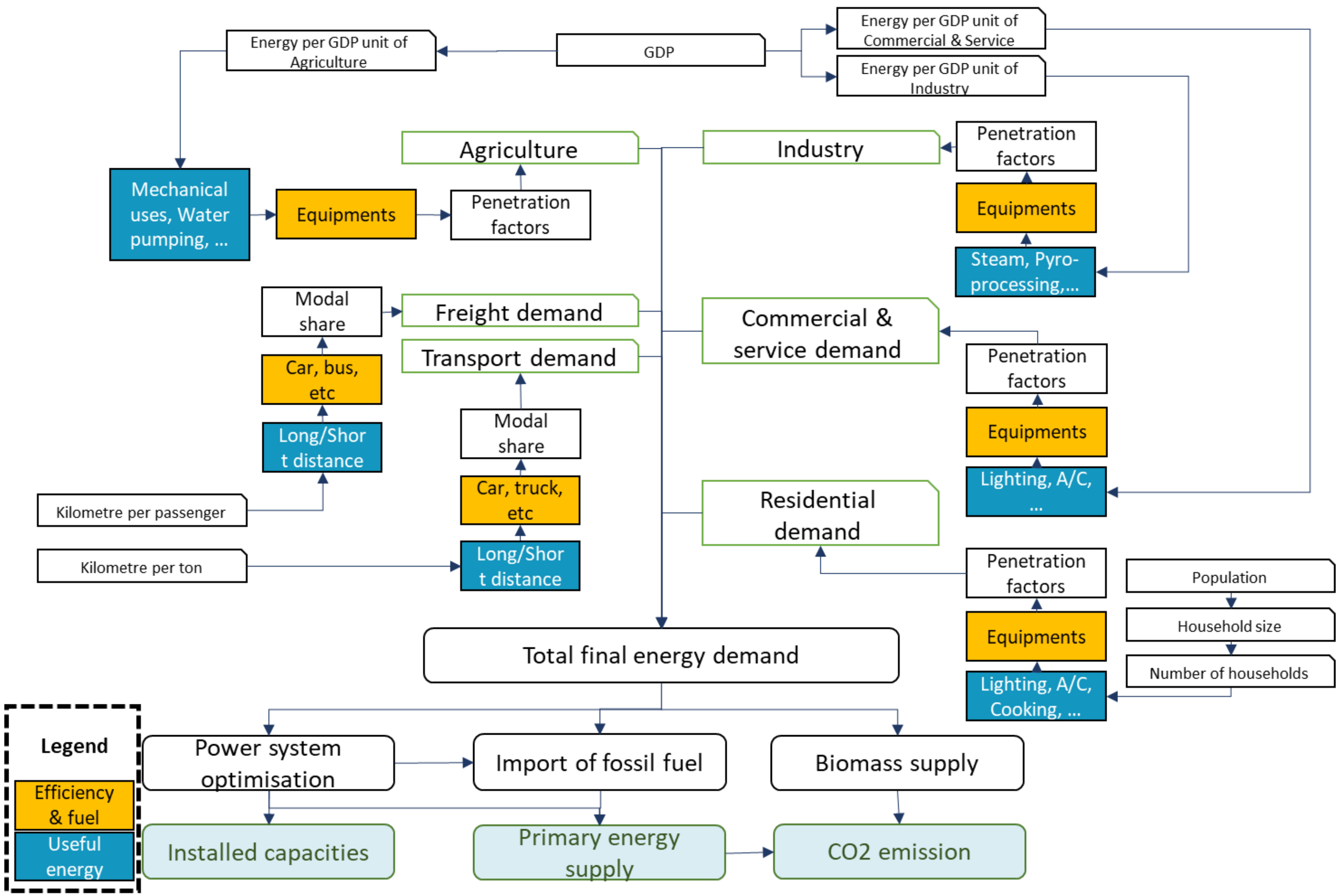
- Estimation of the energy consumption of the different sectors
  - A bottom-up approach is used to determine the final energy demand of the different sectors of the Cambodia economy. The main output of this calculation is final energy demand by energy carrier (electricity, biomass, Natural gas, petroleum products), by sector and subsector.
  - Sector breakdown: Residential, Commercial and Services (C&S), Transport, Industry and Agriculture

- The second step of the model is to determine how this final energy demand is met. For natural gas and petroleum products, only imports from other countries are considered, at a given price. However, power and biomass supply are explicitly represented in the model:
  - Biomass supply is used to determine the origin of biomass consumed in the different sectors, in order to estimate the share that is sustainable.
  - According to the power demand determined in the bottom-up approach, the power generation mix is optimized based on different techno-economic data. Both investments in new capacities and the operation of these units is optimized in order to minimize power system costs.

- Last, greenhouse gases emissions are estimated based on the energy consumed and emissions factors from IPPC AR4 report.

Modelling methodology for sectoral modules

Overview of CEPIA model



Energy demand modelling

Modelling demand with useful energy and by end-use

- The energy demand of Cambodia will be modelled using a bottom-up approach, starting from the useful energy consumption of the end-uses of the different sectors (example: energy necessary to heat aliments for cooking) to the final energy consumed to satisfy this end-use (for example, the biomass use in a stove).
- A bottom-up approach allows to distinguish the origin of each final energy demand, to include behavioral aspect or increase in energy efficiency, by doing so we can represent the main variables that drive change in final energy demand such as cooling needs, increasing electrification of usages or a modal shift from a conventional ICE car to an electric car.
- As a policy tool CEPIA is also meant to offer the possibility to represent energy efficiency policy, such policy is hard to be truthfully represented without a bottom-up approach.
- Each sector and subsector are associated with a set of end-uses that are associated with a demand for useful energy per period. Representing the demand as evolving through time allows reckoning with the demand changing because of economic growth or other factors.
- Every end-use can be met by a variety of end-use equipment or appliances, with different characteristics and efficiencies. These are run using different energy sources (electricity, biomass, coal, etc). Total energy consumption is the sum of energy required to run the different appliances/equipment required in order to meet the end-uses of the different sectors.

Residential modelling : Approach

- Energy demand of the residential sector consists of end-uses from household demand; main end-uses are isolated while others end-uses are aggregated:
  - Cooking
  - Cooling (A/C)
  - Refrigerators
  - Lighting
  - Other aggregated end-uses for power (Phone charging, television etc.)

- Global evolution of energy needed per inhabitant is a function of population and household size; some end uses are expressed at the household level (eg refrigeration) while others depend on the household size, and as such derive from an individual need (eg phone charging).

Residential modelling : Approach

- The approach is based on the number of inhabitants or on the number of households.
  - Consumptions are defined per household for all end-uses except cooking which is per inhabitant.
- Cooking specificity :
  - The amount of useful necessary for cooking is given by person, and represent the amount of heat necessary to cook an typical meal in Cambodia.
  - Cooking is also the only end-use where multiple energy source can be used (Charcoal, Biomass, Gas & Power)
  - **The sum of the penetration share of cooking equipment must always be equal to 100%**.
- For cooking :

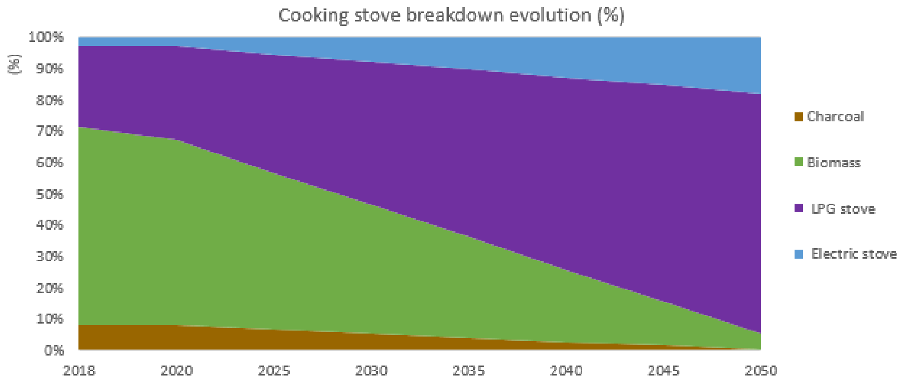
$$Equipment_e^{\text{cooking}} = \frac{UsefulEnergy_{cooking} \cdot penetration_e}{efficiency_e}$$

$$Demand_{energy}^{cooking} = \sum_{e \in Equipments_{energy}^{cooking}} \frac{UsefulEnergy_{cooking} \cdot penetration_e}{efficiency_e} \cdot population$$

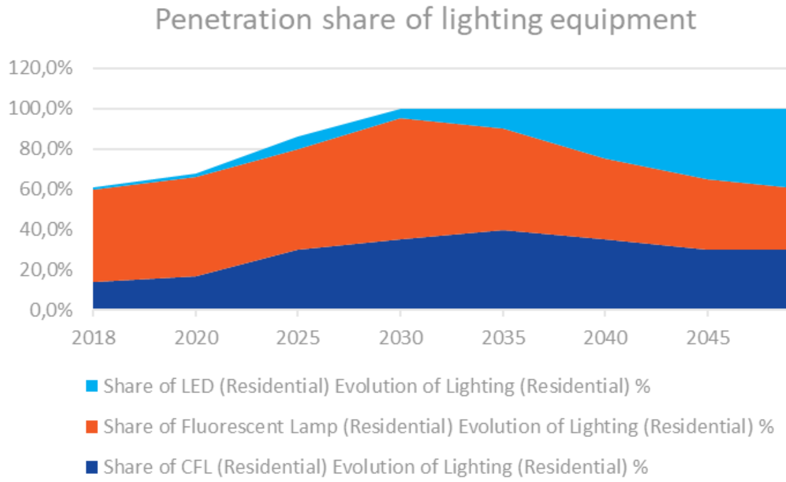
- For all other end-uses (Cooling, Lighting, Refrigerating, Fan and end-use) :
  - Only power consumption is modelled.
  - **The sum of the penetration share of equipment for a given end-use can be smaller than 100%.**
    - **To model unequipped household, whereas everyone cooks not everyone has a refrigerator.**

$$Equipment_{power}^{\text{end-use}} = DailyUseInHour_{end-use} \cdot penetration_e \cdot powerConsumption_e$$

$$Demand_{power}^{end-use} = \sum_{e \in Equipments_{power}^{end-use}} Equipment_e^{\text{end-use}} \cdot \frac{population}{averageHouseholdSize}$$



Residential : Cooking stove breakdown evolution.



Residential : Cumulative penetration share for lighting equipment.

Residential modelling : Usages except cooking

- Within the residential sector we use four main component to model the demand of a given usage :
  - The average energy consumption of equipment
  - The penetration of the equipment within an household
  - The average hour of use per usage per day per household.

$$\text{Consumption per household for the equipment} = \text{Penetration share of the equipment} \times \text{Average hour of use per usage per day per household} \times \text{Power consumption of the equipment}$$

$$\text{Annual power demand of the equipment} = \frac{\text{Population}}{\text{Average inhabitants per household}} \times \text{Household electrification rate} \times \text{Consumption per household for the equipment} \times 365$$

$$\text{Residential Annual power demand} = \text{Annual power demand of the equipment 1} + \text{Annual power demand of the equipment 2} + \ldots$$

Variable of context

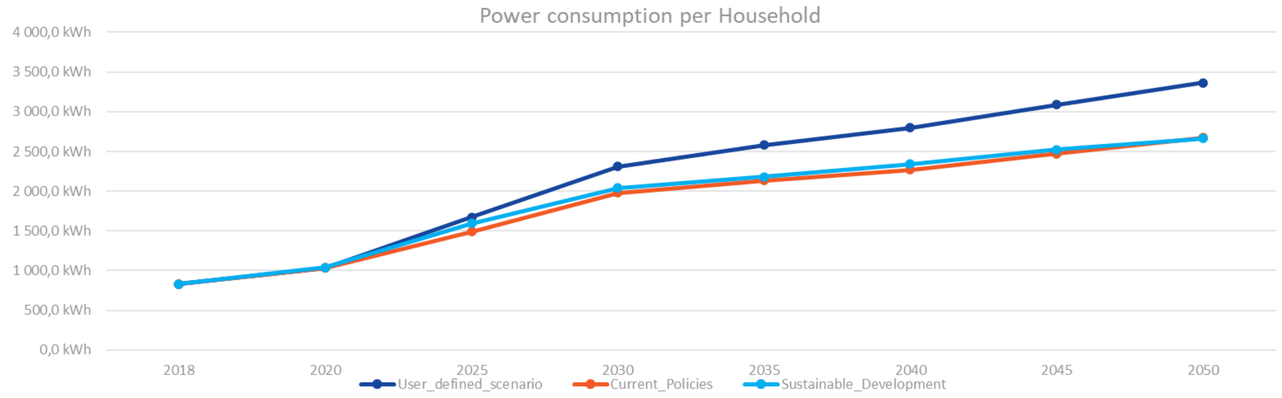
Variable of action

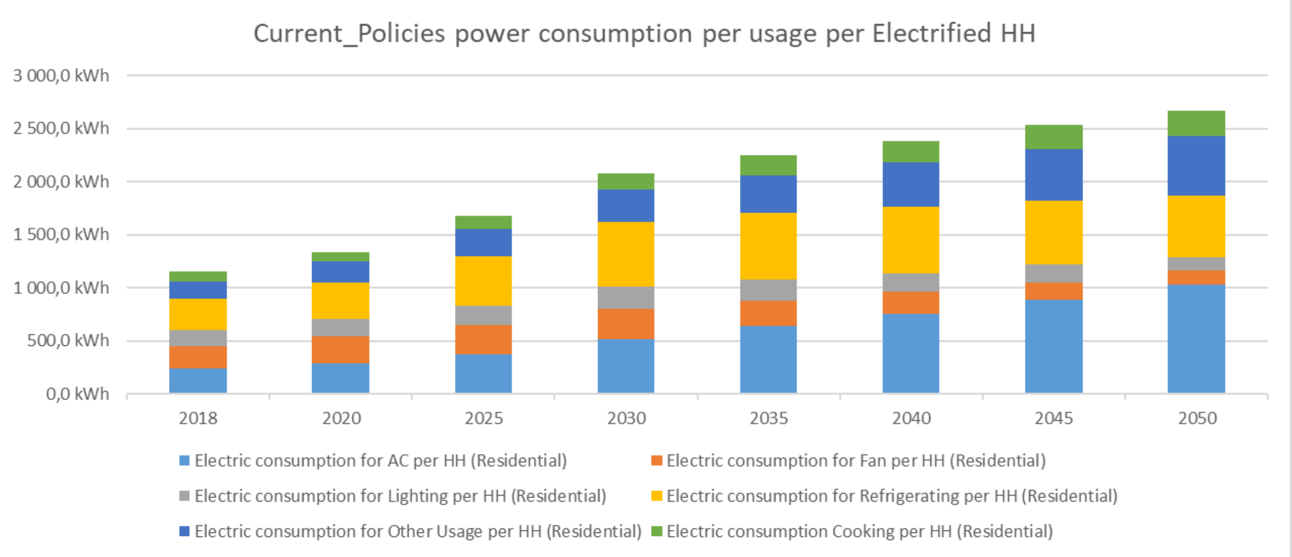
Residential modelling

- The different scenarized component used allows to model a variety of concepts
  - For example :
    - Average hours per day per usage :
      - Increased usage of appliances as household incomes grow or conditions change (eg increase in cooling degree days for AC or Fan usage)
      - Owning of multiple equipment
      - For example the average number of hours of lighting might increase because one might own more and more lamps
    - Penetration rate of the equipment:
      - The share of the population using at least one of a certain type of equipment
      - The sum of the penetration rate of all the equipment associated to **an end-use does not has to be equal to 100%,** not everyone may own a refrigerator for example. 100% minus the sum of the penetration rates is equal to the share of the population that is unequipped with a given equipment or appliance.

Residential hypothesis

- Penetration of end-use :
  - For calibrating the penetration factor for a given set of end use equipment,
    - The Cambodia - Multi-Tier Framework (MTF) survey .
    - “Analysis of Energy and Emission Savings for Residential and Commercial Buildings Sectors for Cambodia”. ” (CCDE Cambodia Consulting Development Engineering Co)
    - “Energy Efficiency : The key pilar of Cambodia Future” (UNDP)
  - For calibrating the average power consumption per equipment and average hour of usage for a given set of end use:
    - The “Analysis of Energy and Emission Savings for Residential and Commercial Buildings Sectors for Cambodia” (CCDE Cambodia Consulting Development Engineering Co for UNDP) was used.





Commercial and services modelling : Approach

- The commercial & service sector (C&S) includes :
  - Commercial businesses at any scale
  - Hospital, school, administration and any other public institutions

- For the commercial & services sector, we use GDP to estimate the consumption as we use population for the residential sector. GDP energy intensity is a common indicator used to project energy demand at a macro scale.

- The following end-uses are considered for the commercial & services sector:
  - Cooling (A/C)
  - Lighting
  - Other end-uses

Commercial and services modelling : Approach

- To avoid double counting of energy between residential and commercial & services sectors, the "average electricity consumption per GDP" is calibrated based on the current sales explicitly labelled for this sector.
  - This means that small businesses using their house as a place to operate is counted in the "residential" demand

Annual power demand = GDP × Average electricity consumption per GDP

Hours of usage per GDP unit for the different end-uses

Penetration of the different equipments

Variable of context — General contextual assumptions which are not differentiated by scenario (population, international price of energy, etc.

Variable of action — Variables that can be associated to possible political decisions (development of renewable energy in the power sector, better usage of biomass, etc.). These variables are differentiated by scenario.

C&S modelling : Usages except cooking

- Within the C&S sector we use three main component to model the demand of a given usage :
  - The average energy consumption of equipment
  - The penetration of the equipment within C&S sector
  - The average hour of use per point of GDP.

Consumption per GDP for the equipment = Penetration share of the equipment × Average hour of use per usage per GDP × Power consumption of the equipment

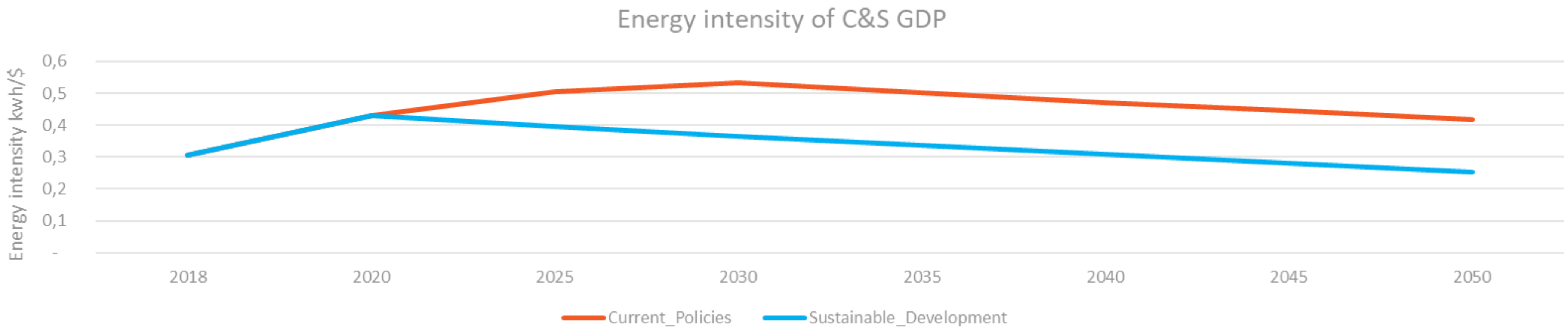
C&S Annual power demand = **Annual power demand of the equipment 1** + **Annual power demand of the equipment 2** +…

Variable of context

Variable of action

C&S modelling

- We assume that the C&S sector only consumes power, since the energy consumption for cooking is included in the Residential sector.
- The current energy intensity of the C&S sector was targeted for 2018 and 2020.
- The share of power consumption per usage was set to follow the trend of residential with a bit of “advance” when coming to energy efficiency as the business put more effort into optimizing energy consumption as it impacts their bottom line.
  - Lowering the energy intensity of the C&S sector



Industry modelling : approach

- Reflecting the relative importance of the different sub-sectors in GDP, eg cement and Brick manufacturing (200,000 workers employed in the sector, 30% of the GDP growth), garment (35% of the GDP, 70% of manufacturing exports and more than a thousand factories) the following breakdown is used for energy demand from industry:
  - Garment (Textile, Wearing Apparel & Footwear)
  - Food processing (Food, Beverages & Tobacco)
  - Brick manufacturing
  - Cement
  - Remainder of power demand for other industries

- Demand for industry is determined by GDP per subsector ***ss***:

$$Demand_{ss}^{y} = GDP_{ss}^{y} \cdot AverageConsumptionPerGDP_{ss}^{y}$$

The averageConsumptionPerGDP represents the typicial energy necessary for a given process (for example steam generation for food processing industries).

For brick manufacturing and cement production, the total production of brick and cement is used instead of the GDP for the quantification of the total energy needs

Industry modelling : details for the different subsectors

- Garment sector and Food, Beverages & Tobacco sector:
  - Most of the energy consumption of these sectors come from the boilers used to produce steam
  - Based on the lack of information regarding the other processes, only this end-use is represented explicitly
  - The energy consumption is then based on a typical need of steam per GDP point for each sector (calibrated for the current situation with boiler inventory), and then the share of boilers for each scenario and year :
    - Biomass, electric, coal, fuel oil

- Brick manufacturing
  - The energy consumption is based on the total production of brick and the share of the different processes used for each scenario and year:
    - Traditional kiln (boat, elephant)
    - Improved traditional kiln (modified boat)
    - Continuous kiln (Rotary/Hoffman)
    - Advanced kiln (tunnel or VSBK)
  - The energy consumption is then calculated based on the typical consumption of fuel per brick produced of the different processes involved.

Industry modelling : details for the different subsectors

Cement production

- Thermal energy
  - The energy consumption is based on the total production of cement and the average thermal intensity of clinker production.
  - The energy consumption by fueled is then derived from a share between the fuels used by year and by scenario:
    - Biomass, coal or Refuse derived fuel (RDF)
- Electricity
  - The electricity consumption is based on the total production of cement and an electricity intensity factor that can vary between the different scenarios and years

Power remainder

- In order to capture the electricity consumption of the different processes that are not explicitly represented, the model includes a “power remainder”
- For the current situation, this remainder is calibrated by subtracting the estimation of the electricity consumption of the already modeled industry sectors to the “known” Industry power demand given by EDC/EAC statistics.
- Based on this power remainder, an average electricity consumption per GDP point for Industry is derived, but for the scenarios the user can provide an higher value to take into account the fact the industry that will develop in the Cambodian economy in the future will be more power-intensive in the future than today

Transport: modelling approach

- The energy consumption of the transport sector represents the different fuel used by internal combustion engines of motorcycle and cars, and for other type of transport (train, boats, buses, trucks etc).

- In the modelling, the transport sector is divided in two subsectors:
  - Passenger transport : the sector itself is divided in two categories :
    - Daily mobility (breakdown between urban and rural areas)
    - Inter-regional trips
  - Freight transport

Passenger transport : modelling approach

- For passenger transport, the modelling follows a three-step process:
  - Determination of the total number of trips for Cambodia, with an average distance travelled
  - Determination of the modal share for these trips (percentage of travelers using a particular type of transportation)
  - Estimation of the energy consumption for the different types of transport (motorcycle, car, bus, train, etc.) based on average energy consumption of the different types of transport and their motorization (internal combustion engine versus electric vehicles for example)
- The **characteristics of the total number of trips** (average distance per trip, number of trips per person per day, average distance per trip) are **variables of context**.
- On the other hand, **modal share for these trips, and energy efficiency** of the different types of transport are **variables of action**, since public policy can have an impact on the development of public transport, and can set targets of efficiency for new cars/motorcycle sales.

Freight transport : modelling approach

- The determination of the energy consumption for freight transport follows a similar approach as the one for passenger transport.
  - Determination of the million ton/km transporter in Cambodia each year
  - Determination of the modal share for these trips (percentage of travelers using a particular type of transportation):
    - Small/heavy/very heavy good vehicles
    - Train
    - Inland waterways
  - Estimation of the energy consumption for the different types of transport based on average energy consumption of the different types of transport, and the type of motorization (conventional versus electric).

Biomass supply : Introduction

- Biomass can come from different sources:
  - Direct harvesting in forest: wood directly used as firewood, or transformed into charcoal, or pellets/briquettes from sawdust.
  - Tree plantation residues: firewood from the replacement of trees in cashew or rubber plantations generally used as firewood for the industry as not suitable for good quality charcoal.
  - Residues from land conversion to agriculture (Land cover change): trees harvested from land cleared for crops or livestock production, major source of commercial firewood and charcoal used both by households and industry.
  - Agricultural residues: Rice husk, sugarcane bagasse, palm kernel almost entirely used by the industry or for on-site applications.
- Resources of sustainable wood as well as agricultural residues are not unlimited. If wood demand exceeds the renewable potential that can be produced each year, this will lead to over-harvesting of forests. The quantification of the sustainable biomass potential is then crucial to estimate the amount of biomass that can be used without threatening the Cambodia forests.

- In CEPIA, each of this different potential is quantified, in order to estimate what is the potential of renewable and non-renewable biomass.

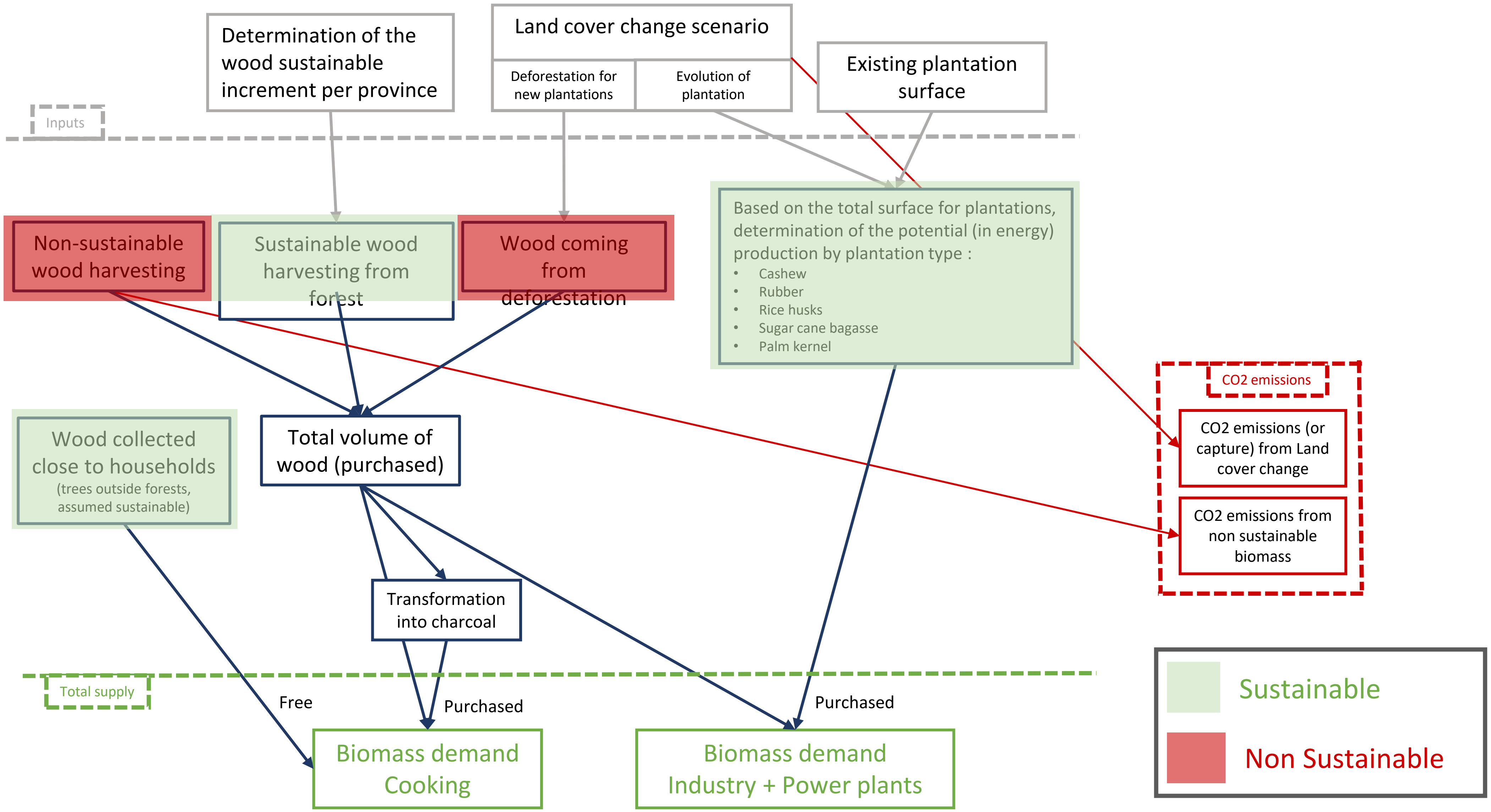
Biomass supply : Tree plantation and agriculture residues

- The methodology to assess the energy potentials will be similar for tree plantation and agriculture residues. For each agriculture/tree type, we will follow the same process:

  - Assessment of the cultivated surface:
    - The cultivated surface will be based on current data from the MAFF. The evolution of the cultivated surface will be derived from Land Cover Change scenario of the Cambodia NDC and consultation with MAFF experts. The cultivated surface, and then the energy potential will be different for each year between today and 2050, depending on the cultivated surface.
  - Determination of the residues production in tones:
    - For each type of plantation/tree, a ratio will be used based on literature review to assess the potential of residues that can be produced per year for a given area of plantation. For tree residues, the area used to determine the potential is not the one of the current year, but the surface of trees planted 27 years earlier (average tree lifetime) in the case of rubber/cashew or 7 years in the case of acacia/eucalyptus. For example, the potential tree residues production from cashew trees in 2050 will be based on the surface of trees planted in 2023.
  - Determination of the energy potential in ton of oil equivalent
    - The energy potential from these residues will then be calculated based on their calorific content, that is not the same for the different types of residues.

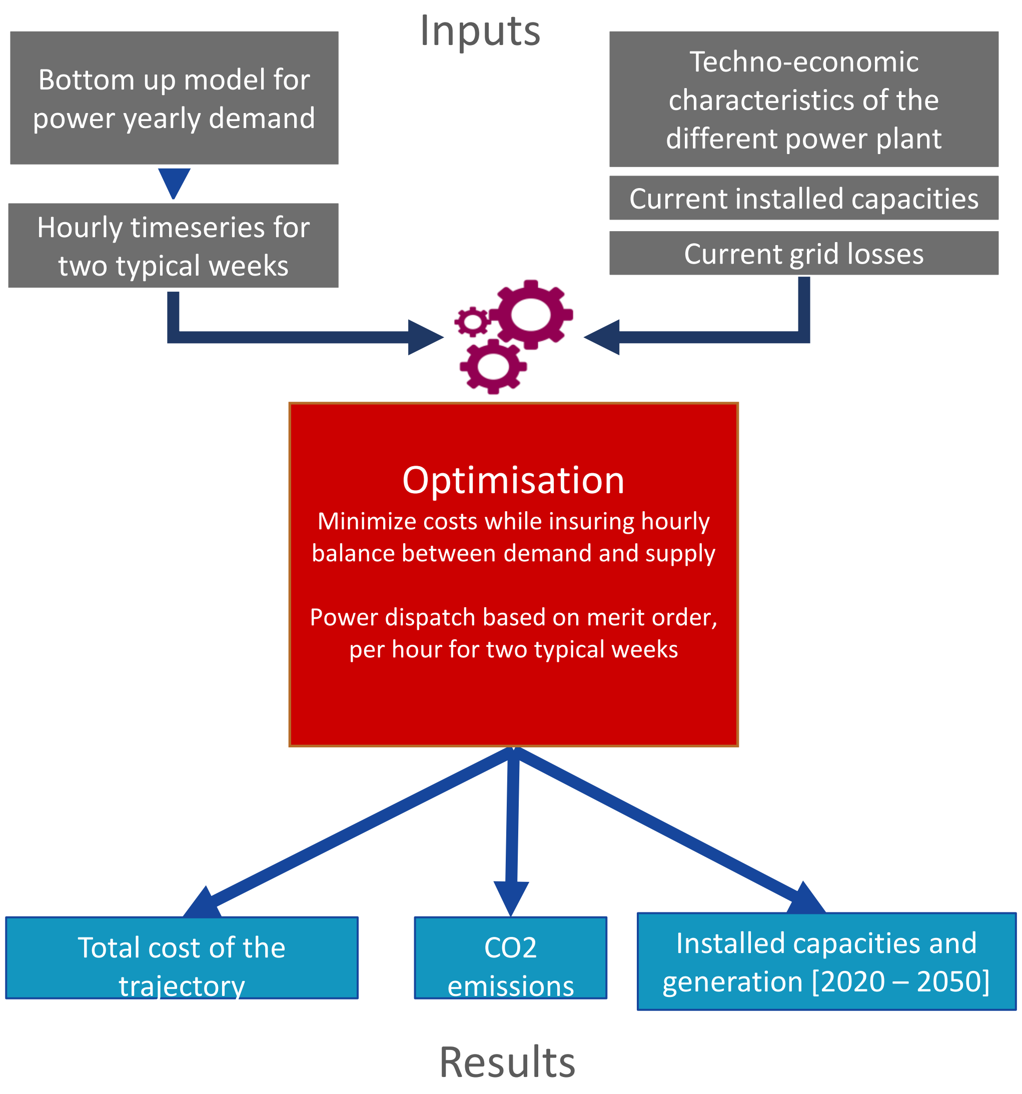
Overview of the methodology to asse the energy potential of tree plantation/agriculture residues

Biomass supply : summary of the model



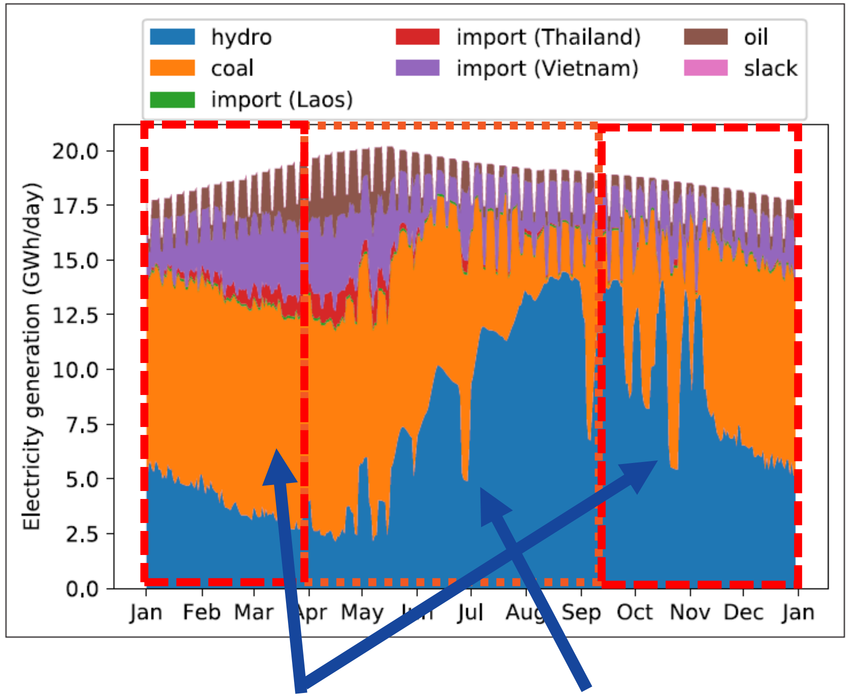
Power supply : modelling approach

- The objective of the power supply module is to determine the optimal generation mix in order to meet power demand as computed by the energy demand module.
- This optimal generation mix is determined with an Optimal Economic Dispatch (OED) module wherein the objective is to minimize the total cost of generation while guaranteeing supply-demand balance, for each period and optimized on a yearly basis in our case.



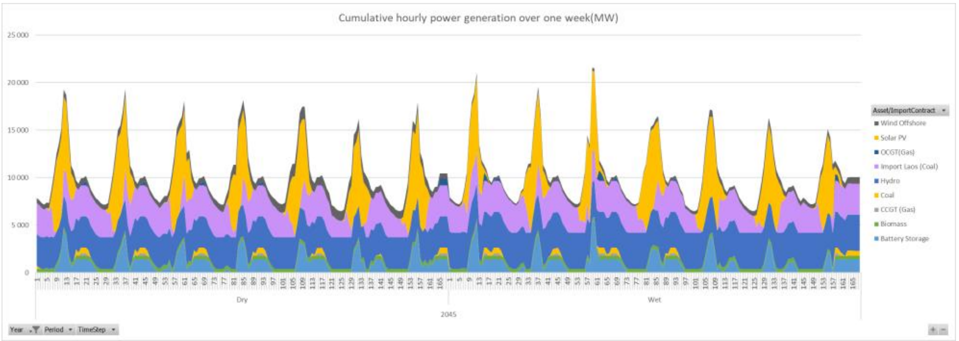
Power Generation : modelling approach

- The objective of the power supply module is to determine the optimal generation mix in order to meet power demand as computed by the energy demand module.
- For every representative years (every 5 years) from 2020 up to 2050 we model two typical weeks :
  - One in the dry season
    - Impact on both consumption and hydro production
    - Impact on solar production and storage dimensioning
  - One in the wet season
    - Impact on both consumption and hydro production
- Equilibrium between demand and supply :
  - Hourly demand balance
  - 168 timesteps per week
  - Loss of load and curtailment are possible, with an associated cost(typically $15000/MWh for Loss of load)
- Power grid:
  - Grid losses evolution from 2020 to 2050
- Neighbors & Interconnection :
  - Existing and planned capacity in MW until 2050
  - Interconnection capacity are not optimized and are part of a scenario (var. of action).
  - Modelled as an import contract with a maximum hourly capacity in MW:
  - Price & C02 associated per MWh
  - Example : 25$/MWh and 800gCO2/MWh



DRY SEASON

WET SEASON

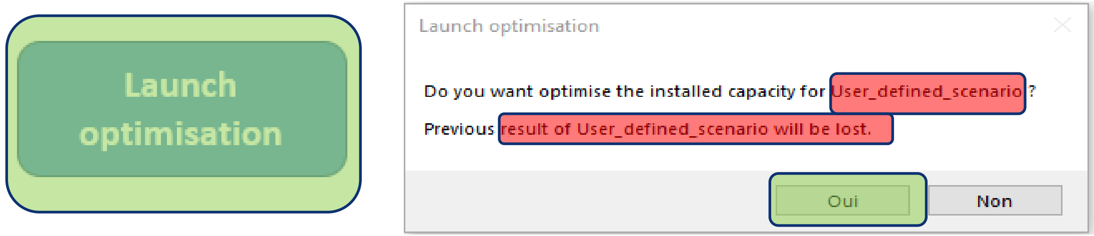


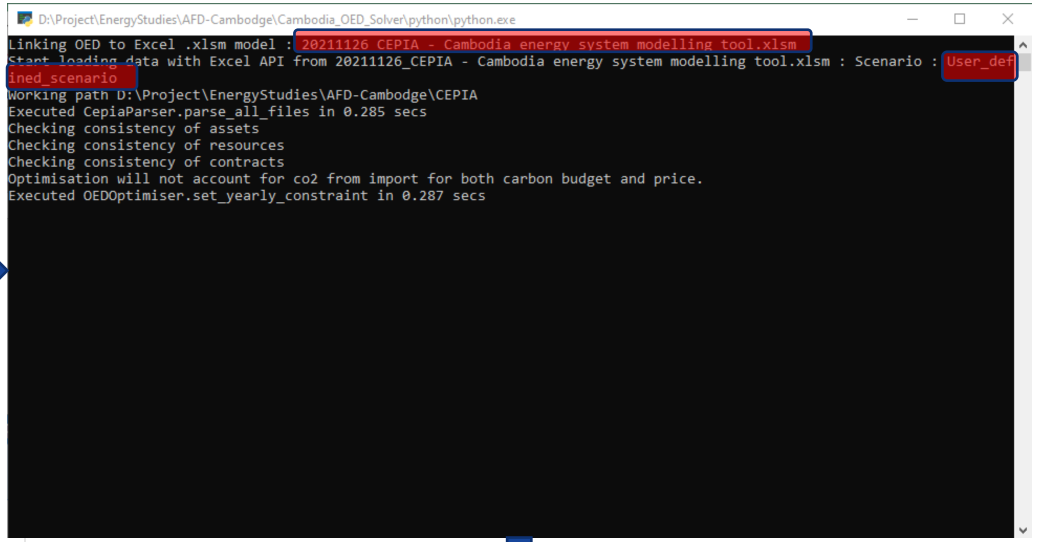
Power Generation : Main equations

- Objective :
  - $\min(Z) = \sum_{x \in X} ResourceCost_x + OPEXCost_x + productionCost_x + ImportCost_x + slackCost_x + CAPEXCost_x + CO2Cost_x$
- Under the equilibrium constraint :
  - $\forall x \in X, \forall y \in B, \forall p \in P, \forall t \in T^p$;
    - ↳ $balance_x^y(p,t) = -\sum_{y \in B} charging_x^y(p,t) + \sum_{y \in Y} prod_x^y(p,t) + import_x^c(p,t) = \ demand^y(p,t) + well_x(p,t) - lossOfLoad_x(p,t)$
- $\forall x \in X, \forall y \in Y, \forall p \in P, \forall t \in T^p$;
  - $prod_x^y(p,t) = conso_x^y(p,t) \cdot EFF\_O^y$
  - $maxProduction_x^y(p,t) = prod_x^y(p,t) \leq \text{capacityStock}_x^y \cdot availabilityFactors^y(p,t)$
- α_x^p: The coefficient to retrieve annual values for year *x* from period *p* for costs.
  - <u>Each period has the same duration</u> $|p|$
  - Exp: we have two periods of one week (168h), each of them representing part of a year (8760h). Then, the two α_x^p , with a balanced $r_x^p = 0.5$, are equals to:
    - ↳ $\alpha_x^p = \frac{8760}{|p|} \cdot r_x^p = 26.07$

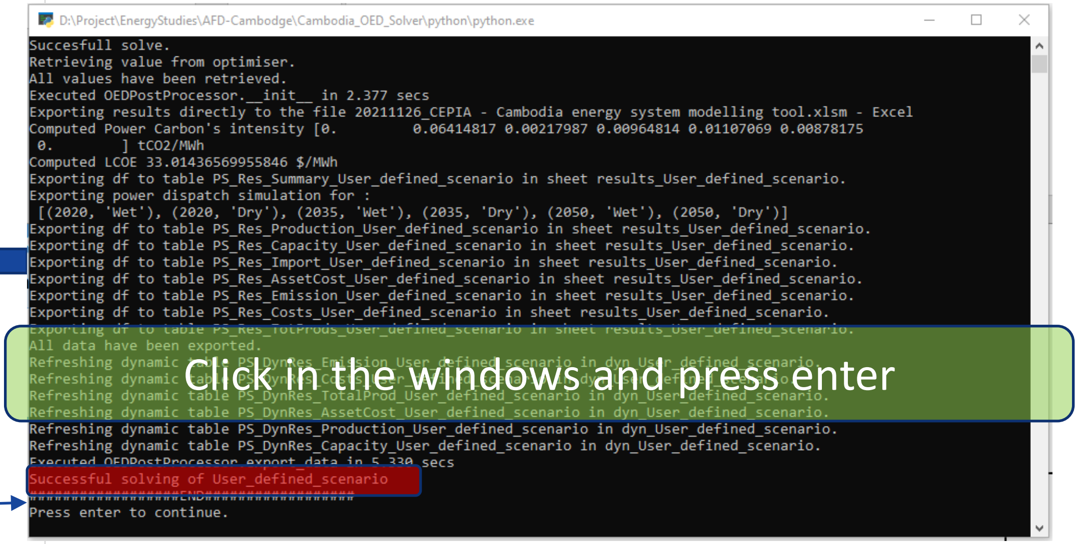
Annexes

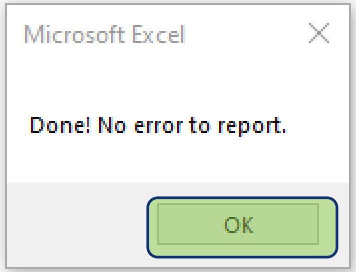
Power generation : Computation steps





- A VBA macro calls a Python script
- The python script reads directly from the excel sheet.
- The python script optimises a **given scenario**
- The python script writes directly the result within the Excel





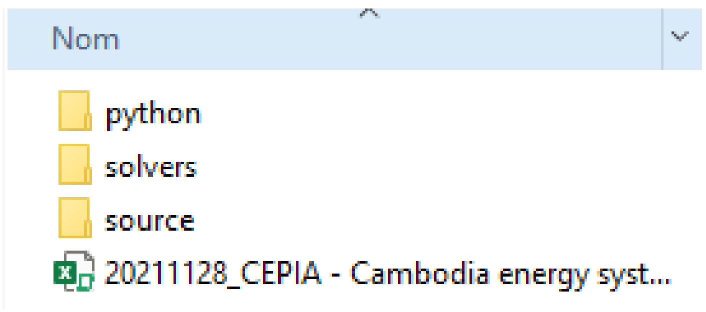
Where to click

Information highlight

Everything went smoothly.

Power generation : dependencies

- In order to use the optimisation the .xlsm file must be located within a folder containing the following folders :
  - Python library
    - Python 3.8.5 + libraries
  - Optimisation solver:
    - CBC
  - Python source code:
    - CEPIA power system optimiser



Power generation : handling errors

- Two kind of errors can arise :
  - Inconsistency or missing data :
    - Highlighted by the input check.
  - Impossibility of running the application:
    - The python windows does not appear.
    - The excel must be located in a folder along with the python, source and solvers folder
  - Infeasibility of the problem
    - Forced PMAX, minimum PMAX or maximumYearlyInvestment inconsistent.