Capacity & institutional strengthening for rural electrification and development - Decentralised Energy Option (CAP-REDEO)

Innovation Energie Développement (IED)

CAP-REDEO project

SUPPLY OPTIONS REPORT

FINAL REPORT

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Spatial Analysis Report

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ABBREVIATION/ACRONYM

Cambodia

CDEC	Local Cambodian engineering firm
DIME	Department of Industry, Mines and Energy (Province)
EAC	Electricity Authority of Cambodia
EDC	Electricité du Cambodge
HC	Health Centre
HP	Health Post
JICA	Japan International Cooperation Agency
MIME	Ministry of Industry, Mines and Energy
MoEYS	Ministry of Education, Youth and Sport
MoH	Ministry of Health
MoP	Ministry of Planning, National Institute of Statistic
MPWT	Ministry of Public Works and Transport
OD	Operational district (administration office)
PPP	Public Private Partnership
REF	Rural Electrification Fund
RH	Referral Hospital
UoA	University of Agriculture, Department of Geographical System

Lao PDR

DOE	Department of Energy/MEM
EDL	Electricité du Laos
MEM	Ministry of Energy and Mines
NUOL	National University of Laos
PDEM	Provincial Department of Energy and Mines
NGD	National Geographical Department, Office of Prime Minister
MoE	Ministry of Education
MoH	Ministry of Health
MIC	Ministry of Industry and Commerce

Commonly used

DP	Development Pole
IPD	Indicator for Potential Development
HDI	Human Development Index
HH	Household
GIS	Geographical Information System
GPS	Global Position System
NPV	Net Present Value

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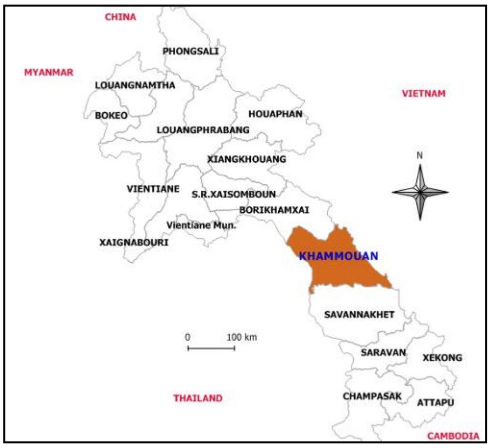
1 CAP-REDEO project

The rate of access to electricity in Cambodia and Laos remains low though contrasted today – respectively under 10% and approximately 50%, and it will still be a many years until the grid network will reach all the isolated population. Informed policy formulation and decisions for rural electrification sector require an adequate planning tool, that was developed in the framework of CAP-REDEO project (Intelligent Energy - Europe programme), implemented by Innovation Energie Développement (IED, France) in collaboration with IEG, EDC, MIME, EAC in Cambodia and SV, MEM, EDL in Lao PDR.

Currently used in other countries (Cameroon, Burkina Faso, Ethiopia...) the GEOSIM© rural electrification planning aid-decision tool was adapted to Cambodian and Lao contexts and designed for policy makers in charge of rural electrification planning[1]. It is based on Geographic Information Systems (GIS)[2] functionalities and, in the perspective of improving the impact of rural electrification on sustainable development and poverty alleviation, provides the required tangible elements for the formulation of rural electrification plans and programmes, taking into account national priorities and constraints.

Kampong Cham (Cambodia) and Khammuane (Lao PDR) were selected as pilot provinces to develop rural electrification plans, taking into account local energy potentials and, in a context where fuel prices are reaching exorbitant levels, giving priority to renewable energy sources as hydro and biomass.

Figure 1: Kampong Cham province – Cambodia



During mid-term workshop held in Vientiane on June 2nd 2008, during which the first results of the supply options component of the project were presented, some adjustments were required by Cambodian and Lao authorities on both hypothesis and data used to simulate the rural electrification plans and identify the related Network Options.

Figure 2: Khammuane province – Lao PDR

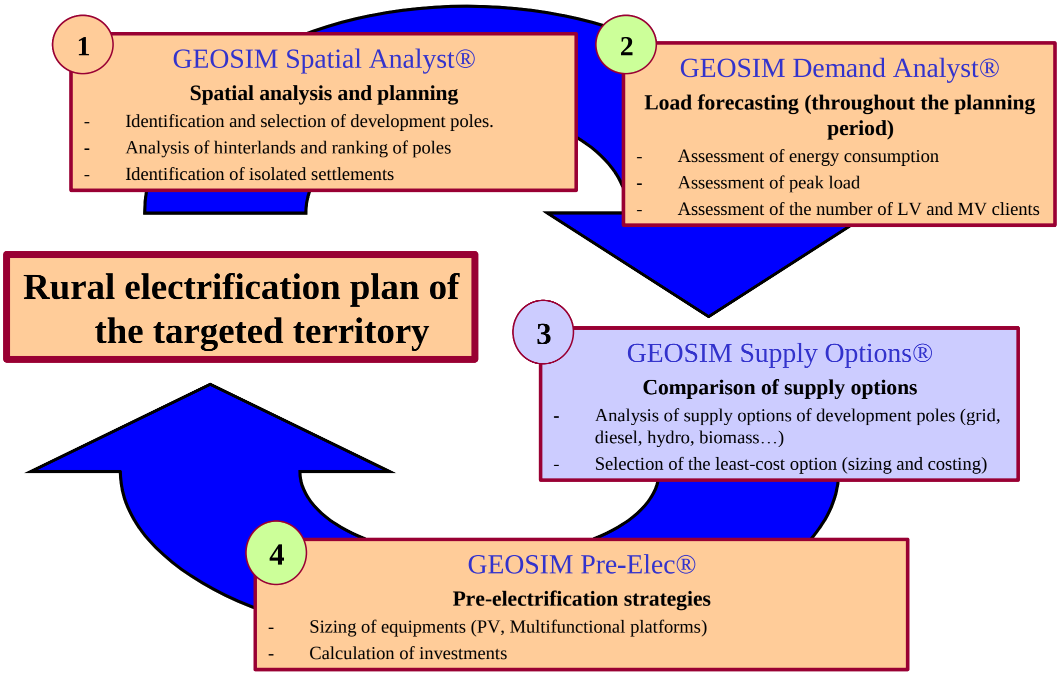
On the basis of these comments, new simulations were run to obtain results with higher relevance. These latter are presented in this report. This report also provides a short explanation of the method used, to allow replication to other provinces. For detailed information on the various algorithms used, please refer to the previous CAP-REDEO reports (Spatial Analysis, Load Forecast, Hydro & Biomass, Network Options) and GEOSIM user guides..

[1] Policy makers were trained on the planning tool through various training sessions during CAP-REDEO project and institutional partners were equipped with GEOSIM© software.

2 GIS (Geographic Information System): software system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth.

2 The GEOSIM Network Options© model

2.1 The 3rd step of the planning process



The overall planning process adopted in CAP-REDEO project was to successively answer the following questions:

- **Which villages should be electrified first to optimise the socio-economic development within the provinces?**

  GEOSIM Spatial Analyst® ➔ *identification of Development Poles at the Province level*

- **What is and what will be energy consumption in provinces villages?**

  GEOSIM Load Forecast® ➔ *assessment of consumption growth over the planning period*

- **Which technical options would be the most appropriate to supply the electric clusters built on the Development Poles?**

- ***GEOSIM Network Options®➔identification of Network Options to fulfil various scenarios objectives***

The Network Options® model is therefore the core module of the GEOSIM® package. It analyses the different technical options to supply electricity to the Development Poles identified by the Spatial Analyst® model, on the basis of the demand forecast assessed with the Demand Analyst®[3] model.

[3] Results on Spatial Analysis and Load Forecast were presented in March 2008

2.2 Approach main features

2.2.1 Overall process

Given the Development Poles previously identified by Spatial Analyst®, the objective of the Network Options® module is to:

1. Define those of these Development Poles which will be considered "off-grid", i.e. not likely to be connected to the utility grid in the near future
2. Find the lowest cost technical options to supply them, using conventional technico-economic calculations

At the end of the planning exercise, all targeted Development Poles will have been allocated a supply option, whether grid extension or decentralized option.

Before actually undertaking least-cost sizing of decentralised supply options, the Network Options® module first defines the areas not likely to be connected to the utility grid in the near future.

This planning of the national grid network is done by either entering directly the forecasted grid extensions as input data, or by simulating the extension of the national grid, taking into account several possible constraints (investment budgets, available energy on the grid, number of villages to be electrified per year…).

In CAP-REDEO project, the grid extension model was used only for Kampong Cham province, where MV grid is to date poorly developed. Regarding Khammuane province, the MV network is covering most of the province territory and no extension had to be simulated as the network development was known when the study started.

When simulating grid extension, a crucial issue is to specify an ending year for this simulation; this time limit will be considered as a threshold date beyond which all localities that will not have been connected to the grid will be candidates for off-grid electrification.

Grid extension can be simulated at different scales (country, province, district, specific zone…) and for different purposes:

- in the perspective of developing a private network in a specific zone, the planner has the possibility to specify the area within which the extension should be simulated, and to indicate whether (a) the localities that should be connected or (b) the investment limit for the project.
- In the same way, if a planner wishes to extend the utility network from existing grid in a restricted specific area, this can be done by demarcating the zone concerned.

The module then identifies the best decentralised options to supply electricity to previously identified Development Poles (cf. glossary) and the settlements included within the same electric cluster, using one of the following methods:

- Comparison of different supply options: selected projects are those with the lowest electricity levelized cost among projects using different technologies (diesel, small hydro and biomass[4]). At this level, for a given project, all technologies are therefore competing.
- Technologies are ranked by preference. For example, if hydropower is deemed more important than diesel and biomass, then settlements located near potential sites of hydropower will be supplied by this technology, even if diesel or biomass would have been cheaper.

[4] The model supports direct biomass combustion (in a boiler) with or without cogeneration, gasification and anaerobic digestion (biogas).

In any case, projects using each type of technology optimise the levelized cost of electricity, i.e. the cluster of settlements (see 2.2.2.2) supplied matches the production of the power source (hydro, biomass or diesel), so that adding or removing a settlement would result in an increase of the levelized cost of kWh. The cost calculation follows a detailed structure, taking into account many technical and non technical parameters which can be modified by the planner *(Lists of socio-economic parameters used for the study are provided in Appendix).*

2.2.2 Main steps : overview

2.2.2.1 Off-grid area identification - Grid extension simulation

Given the timescale of rural electrification planning (usually ranging from 10 to 20 years), it is recommended to anticipate future evolutions of the national grid network. Indeed, some non electrified areas located near existing lines might be connected in the next few years, and any decentralised option project in these areas would be of low interest.

Therefore, the Network Options® module offers different possibilities to simulate this grid extension, to make sure identified projects will remain “off-grid” long enough to make them relevant.

Ideally this is already planned by the Power Utility, and the user would only have to integrate it in the Geographic Information System (GIS) database. If this is not the case, GEOSIM® can simulate this extension with basic financial cost-benefit analysis.

A set of different criteria and parameters can be defined to run the simulation:

- Distance to the grid
- Investment budgets
- Available energy on the grid
- Maximum number of settlements to be electrified per year

According to these different constraints, the algorithm will strive to connect in priority settlements with the highest Net Present Value (NPV), typically those located near the grid and with significant demand. The formula is the following, with “Benefits” being the number of kWh sold multiplied by an average tariff of customers, and r the financial discount rate:

$$NPV = \sum_{i=1}^{horizon} \frac{Benefits\,(i) - Costs(i)}{(1+r)^i}$$

Equation 1 Net Present Value

2.2.2.2 Off-grid projects identification

The basic “unit” of the off-grid rural electrification planning is the “project”. These projects are defined by the following components:

- A settlement or a list of settlements
- A mini-grid connecting these settlements if there are more than one
- A technical supply option (diesel, hydro, biomass, hybrids…)

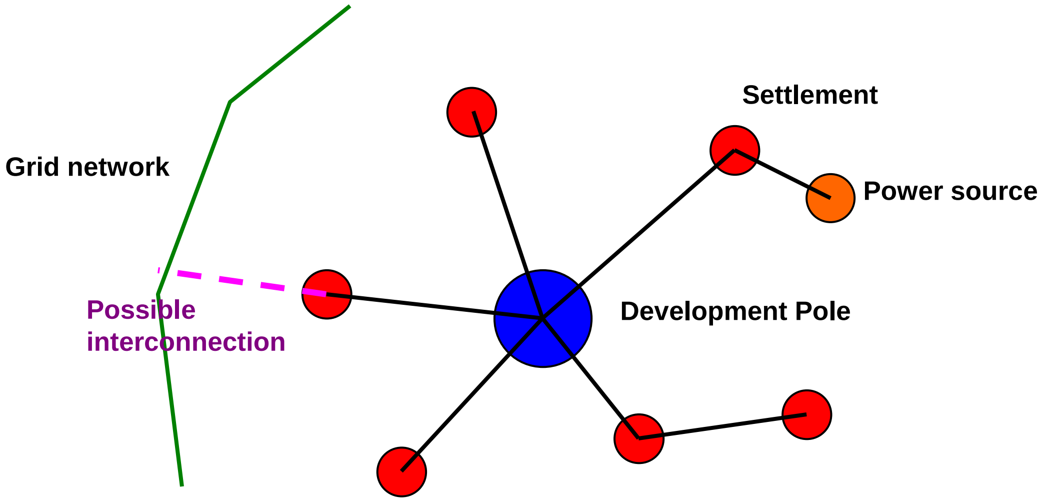


Figure 3: Project definition

They have the following characteristics:

- They often include one or more Development Poles which are not yet electrified
- They are small-scale, i.e. they will usually involve not more than about fifteen settlements and their total capacity will range from about ten kW to a few MW for the largest
- They are usually isolated from the grid but the planner may chose to also study interconnection with the forecasted grid
- In the case of the development of a private grid, a project will be a group of localities whose number will be set by the planner or will be depending on financial constraints.

2.2.2.3 Least-cost sizing and economic analysis

Since rural electrification projects are not profit oriented, least-cost sizing of projects is based purely on an economic analysis, which means that the profitability of projects will not be assessed in any way[5]. Therefore, the only criteria will be the levelized cost of the kWh, symbolizing the cost of supplying electricity borne by the community as a whole. Its formula is:

$$\text{Levelized cost of kWh} = \frac{\sum_{i=1}^{horizon} \frac{Costs(i)}{(1+r)^i}}{\sum_{i=1}^{horizon} \frac{Energy\ placed\ (i)}{(1+r)^i}}$$

Equation 2 Levelized cost of kWh

With:

- **Costs(i)** the costs in year i of the planning period, including investments and operating and maintenance costs
- **Energy placed (i)** the quantity of kWh sold in year i
- **r** the economic discount rate

[5] Of course, this will have to be done later on during feasibility studies.

Both benefits and costs depend on the demand in electricity, since the supply option is sized according to it and benefits are the number of kWh sold. Therefore the list of settlements supplied by the project will have a direct consequence on cost of kWh. The algorithm will thus find the optimal configuration by <u>starting with a Development Pole and adding new nearby settlements to the project, until the NPV of kWh stops decreasing.</u>

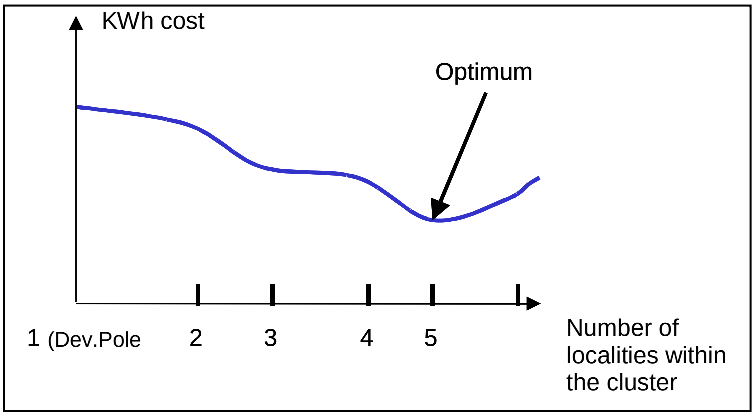


Figure 4: Construction of an electric cluster

Algorithms and cost structures specific to each supply option are presented in details in the GEOSIM Network Options® User Manual.

2.2.2.4 Power lines laying out

GEOSIM® takes into account some geographic favourable conditions as well as obstacles while laying out MV lines and networks. As shown in the example below, roads are generally considered as a favourable layer[6], meaning that whenever it will be possible, MV lines will be drawn along the roads. On the other hand, rivers will be avoided when possible (constraints layer), lakes will not be crossed at all (forbidden layer).

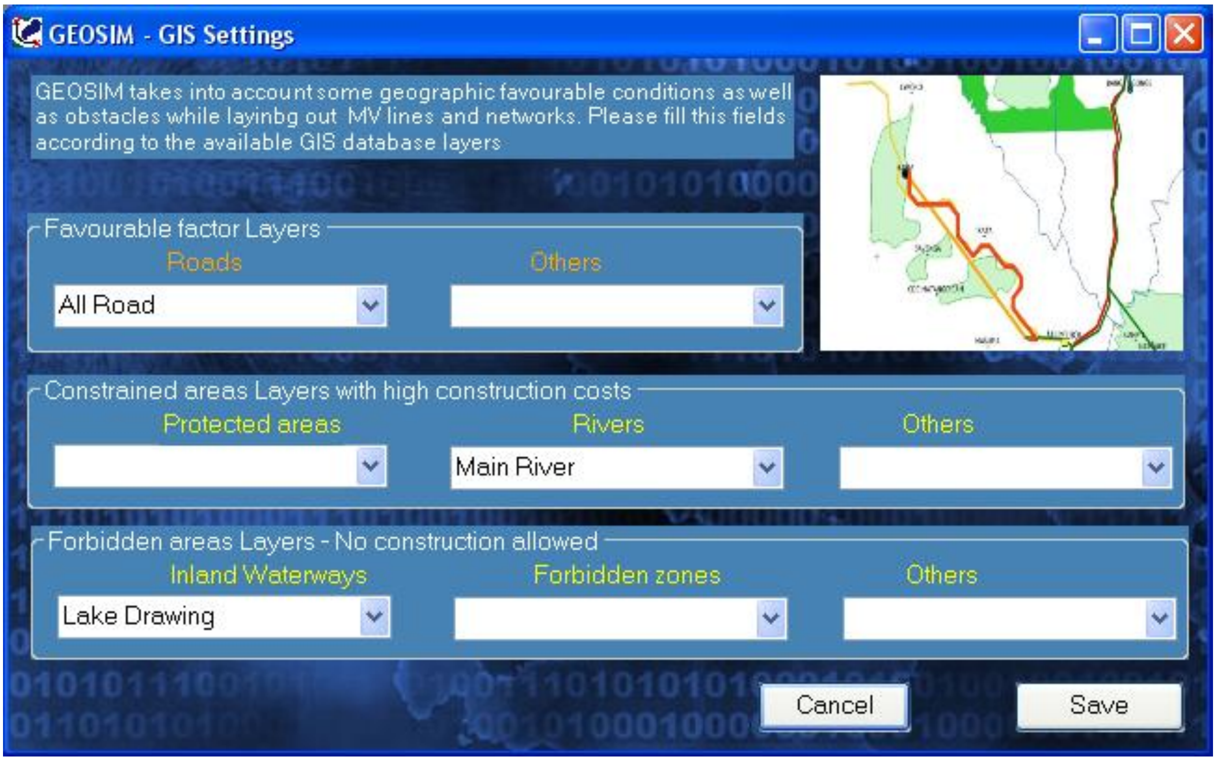


Figure 5: GIS layers setting for MV lines laying out

[6] Maps show drawings, images, surfaces and labels components stacked in layers

3 Electrification status

3.1 Kampong Cham province

3.1.1 General overview

Kampong Cham province is poorly covered by electricity network. No HV transmission line is reaching or crossing the Province and only few districts - Kampong Cham, Ponhea Kraek, Memot, Kampong Siem and Kang Meas - currently benefit from some EDC MV lines. Additional 22kV MV lines, managed by REEs, do exist but because of lack of data, they had to be simulated for the purpose of the study. These REEs are mostly located on Memot-Cheung Prey backbone and should be connected to EDC network within the foreseeable future.

Out of the 1758 localities of the province, only 333 are to date electrified, of which 295 served by REEs (89%). The electrified settlements rate[7] is 23%.

Table 1: Kampong Cham province key figures (2008)

Population	**1 750 284**
Number of settlements	**1 758**
non-electrified	*1425*
electrified	*333*
Electrified settlements rate	**23%**

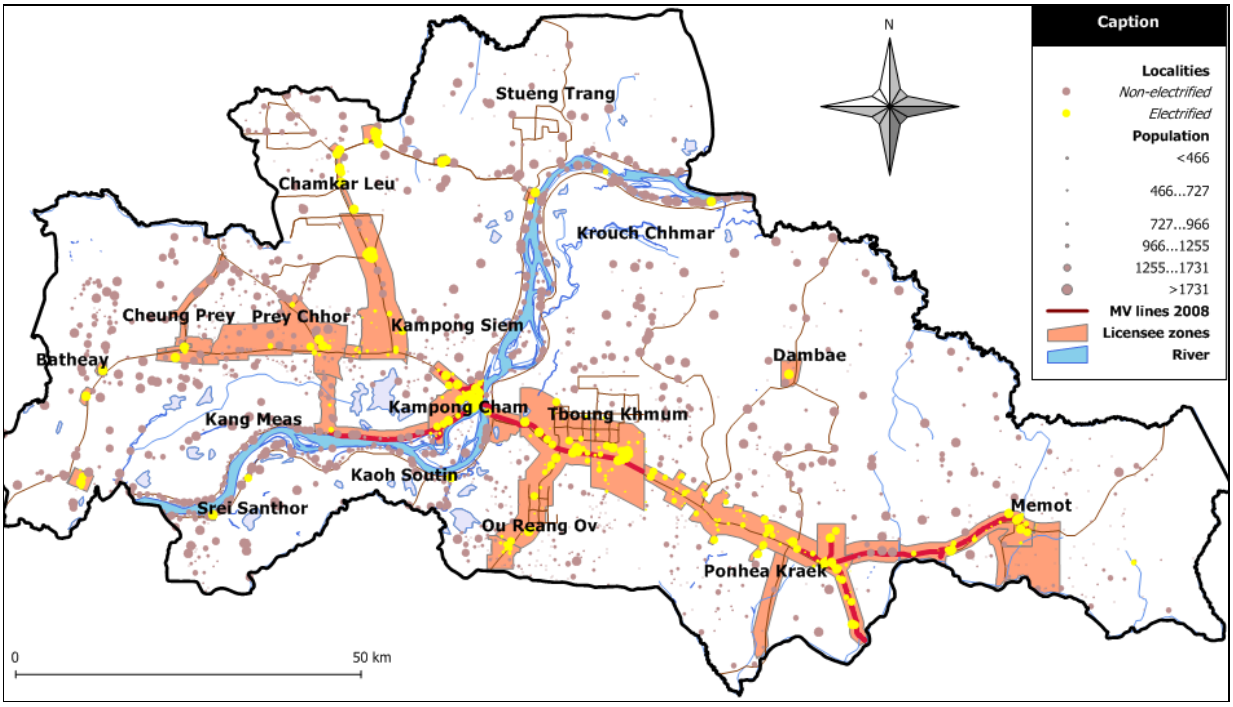


Figure 6: Kampong Cham province electrification status (2008)

[7] % of the province population leaving in electrified settlements

3.1.2 Development Poles electrification status

In agreement with MIME, EDC, REF and EAC, 90 Development Poles were identified. At this level, it is important to underscore that the Development Pole notion is only based on socio-economic parameters highlighting the quality of services offered to the population of the Pole itself and to the population located in its hinterland. Poles could be therefore electrified or not.

As we will see in the next chapter, various electrification scenarios were studied. For all those scenarios, it was crucial to take into account the electrification status of the Development Poles, in order to make strategic decision on how they should be considered at planning level.

In 2008, out of the 90 Development Poles identified, 50 are already electrified, which is logical.

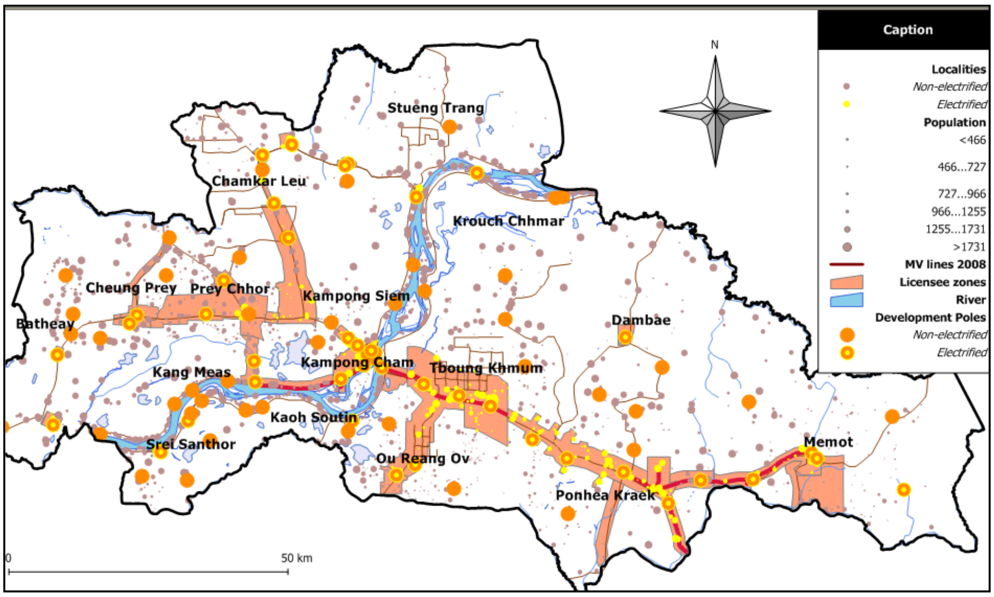


Figure 7: Kampong Cham Development Poles electrification status

3.2 Khammuane province

3.2.1 General overview

The grid network is, so far, well developed within the Khammuane province. Only some remote areas remain out of the scope of the national electrification plan, as illustrated on the map below. Currently, electricity is at a relatively low cost thanks to large Hydro power plants and reasonable grid extension.

Out of the 887 localities of the province, 600 are to date electrified, with an electrified settlements rate[8] of 81%.

Population	**371 000**
Number of settlements	**887**
non-electrified	*287*
electrified	*600*
Electrified settlements rate	**81%**

[8] % of the province population leaving in electrified settlements

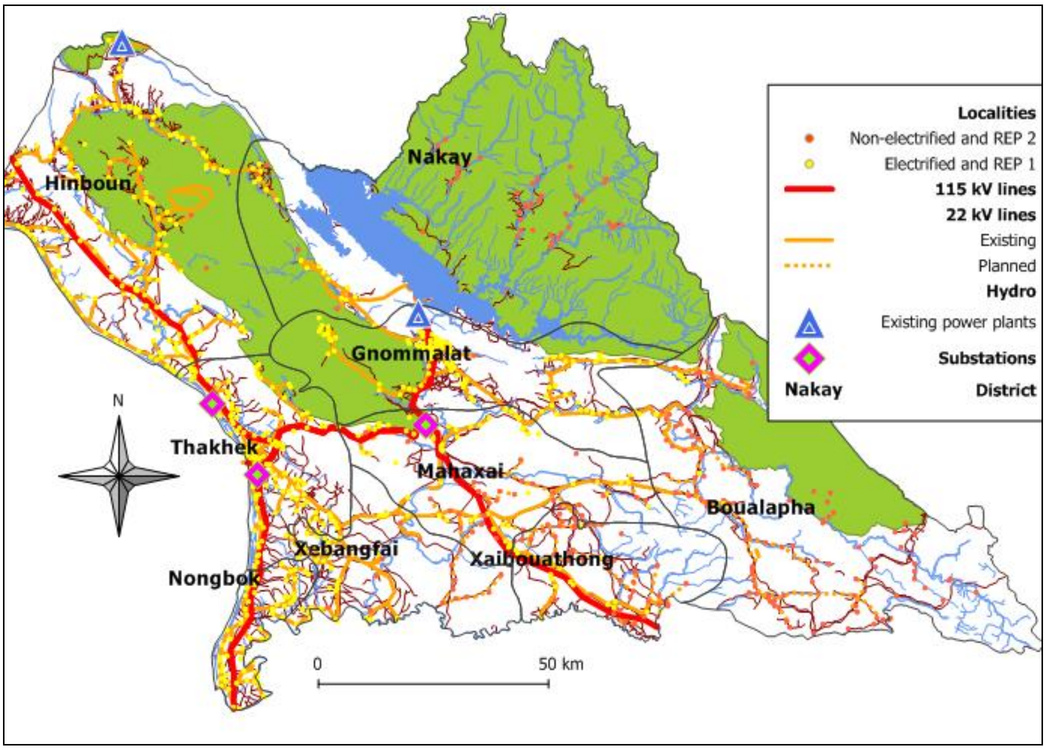


Figure 8: Khammuane province electrification status (2008)

. Two main programs have actually been programmed:

- *Rural Electrification Project (REP 1):* Two components: The first component extends electrification to about 42,000 rural households through connection to EDL grid. The second component provides electrification to about 10,000 households through off-grid technologies; REP 1 is nearly complete.
- REP 2: still subject to resource availability and earliest construction would be mid 2012.

Hence, it was agreed that (i) villages planned for REP 2 and those with no plan for electrification are considered as eligible for off-grid electrification and (ii) no simulation will be carried out then using the GEOSIM© grid extension module, as EDL has already decided on its development plan.

3.2.2 Development Poles electrification status

150 Development Poles have been identified, out of which 132 are or will be soon (through REP1) electrified:

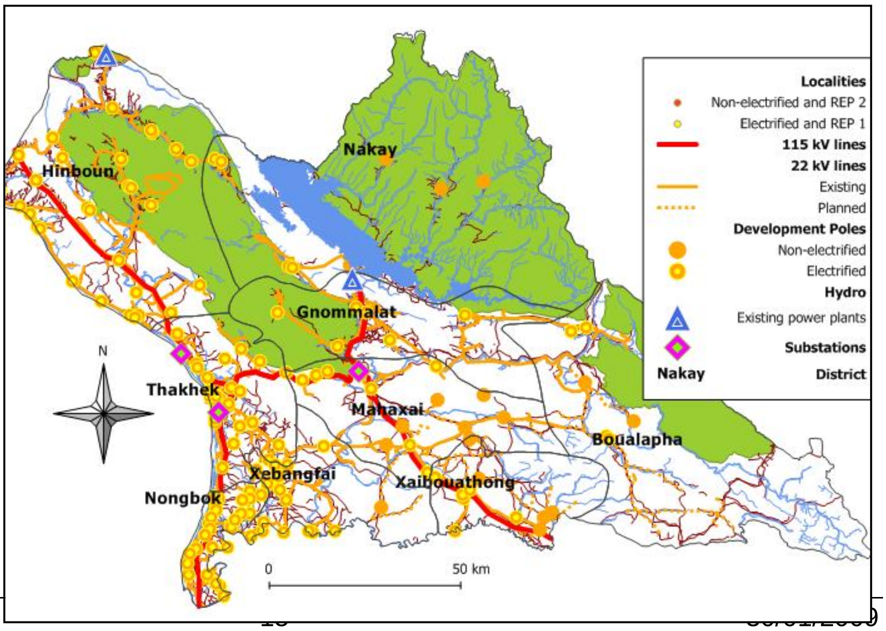


Figure 9: Khammuane Development Poles electrification status

4 Kampong Cham province rural electrification plan(s)

Based on interactive discussions and exchanges with MIME, EDC, REF and EAC, three different scenarios were considered for Kampong Cham province:

- ***Scenario 1*****: by 2020, all villages should be grid-connected**

  ➔ Expected outputs: total length of MV lines used, approximate cost for the total investment

- ***Scenario 2:*** **assessment of the cost for the extension of three additional 22 kV lines which could be undertaken by private operators by 2012, in addition to the lines for which investments have been secured: *Kampong Siem towards Chamkar Leu, Kampong Cham towards Stueng Treng (2 sides of river), from Ponhea Kraek-Skon back-bone towards Dambae*. All villages located less than 5 km from the extended grid should be connected**

  ➔ Expected outputs: total length of MV lines used, approximate cost for the total investment for the lines considered.

- ***Scenario 3:*** **by 2012, all villages located within a 5 km buffer around existing and planned 22 kV lines should be grid-connected; remaining villages will benefit from an off-grid option (biomass, hydro, diesel)**

  ➔ Expected outputs: projected grid network likely to exist in 2012 (projected MV lines and electrified settlements) + off-grid projects

All these scenarios were developed and presented using the GEOSIM® software, and presented more in detail in Appendix.

4.1 Scenario 1:100% village electrification by 2020 through grid extension

4.1.1 Working hypothesis

The objective is to assess the required investment to electrify the entire province of Kampong Cham by 2020, considering the MV grid as the only option to supply all the province localities.

<u>Scenario 1 hypothesis:</u>

- 100% village will have been electrified by 2020
- MV grid network to be the unique Network Options
- 98% household will be connected

This simulation was done using the GEOSIM© Grid Extension module, dedicated to assist planners when simulating grid extension.

4.1.2 Simulation phases

Although the objectives at the planning horizon were very ambitious, it is crucial to remain realistic when starting simulating the grid extension, as the current capacity on existing MV lines is quite low. This first scenario was therefore divided in three distinct phases in line with the Cambodian planning process, enabling to take progressively into account new MV lines that would be commissioned during the planning period; each phase was based on specific assumptions.

4.1.2.1 Phase 1: 2009-2010

- ***Step 1: What is the real electric power landscape in 2008?***

As mentioned above, additional 22kV lines do exist in the vicinity of EDC network, within the REEs zones and, although data on their location were not available, it would have been too approximate to build a grid extension only on the basis of known data. The same observation can be made for Ou Reang and Tbung Khmum districts.

First step therefore consisted in simulating unknown “potential existing MV lines” by connecting all electrified villages located within the licensee zones and close to the existing network. These potential lines are displayed in green on the map below.

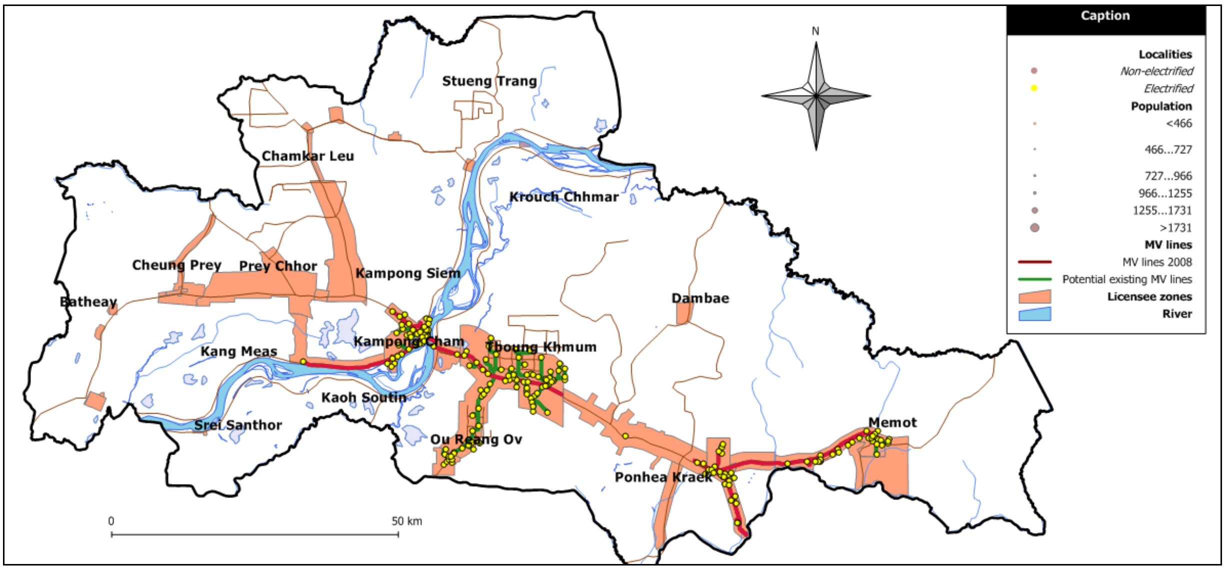


Figure 10: 22 KV lines (2008 + simulation of REEs network)

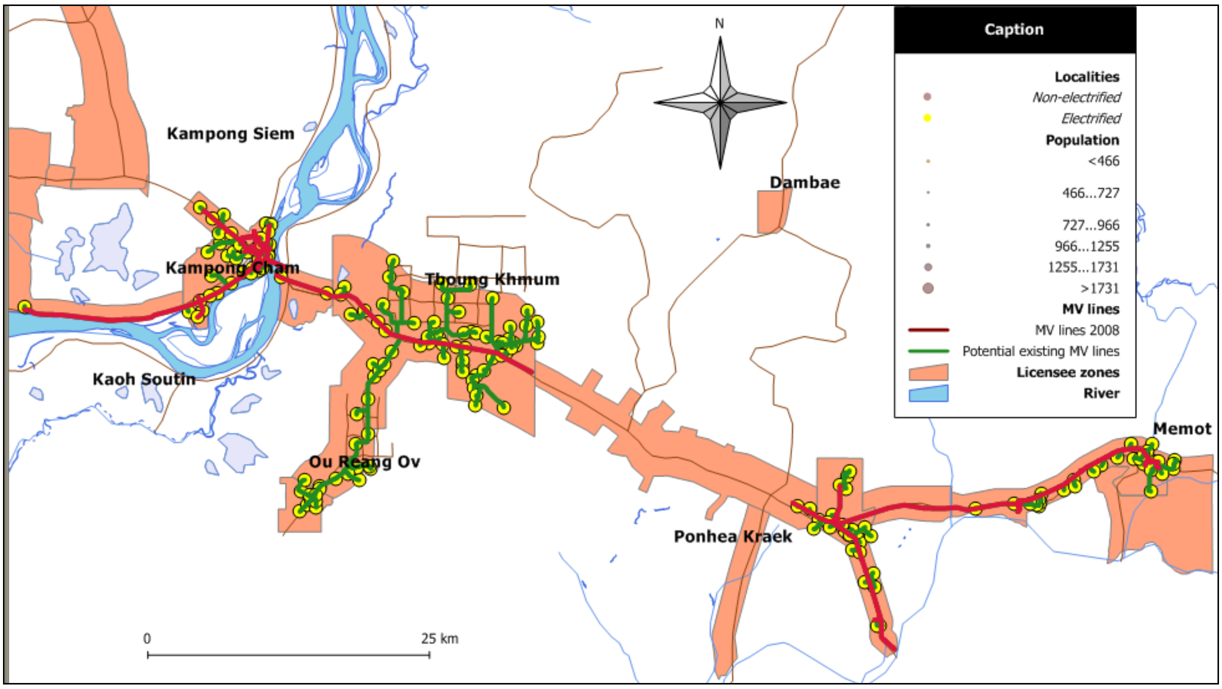


Figure 11: Zoom on potential existing MV lines

➢ ***Step 2: 2009-2010 grid extension***

This 1st phase was based on conservative parameters because of low power availability. Taking into account the low penetration of the grid, it was extended to electrify a few villages within reach, at a rate of 15 villages per year, all of them located within a 5 km buffer around the existing network.

2009-2010 extensions are displayed in blue on the map below:

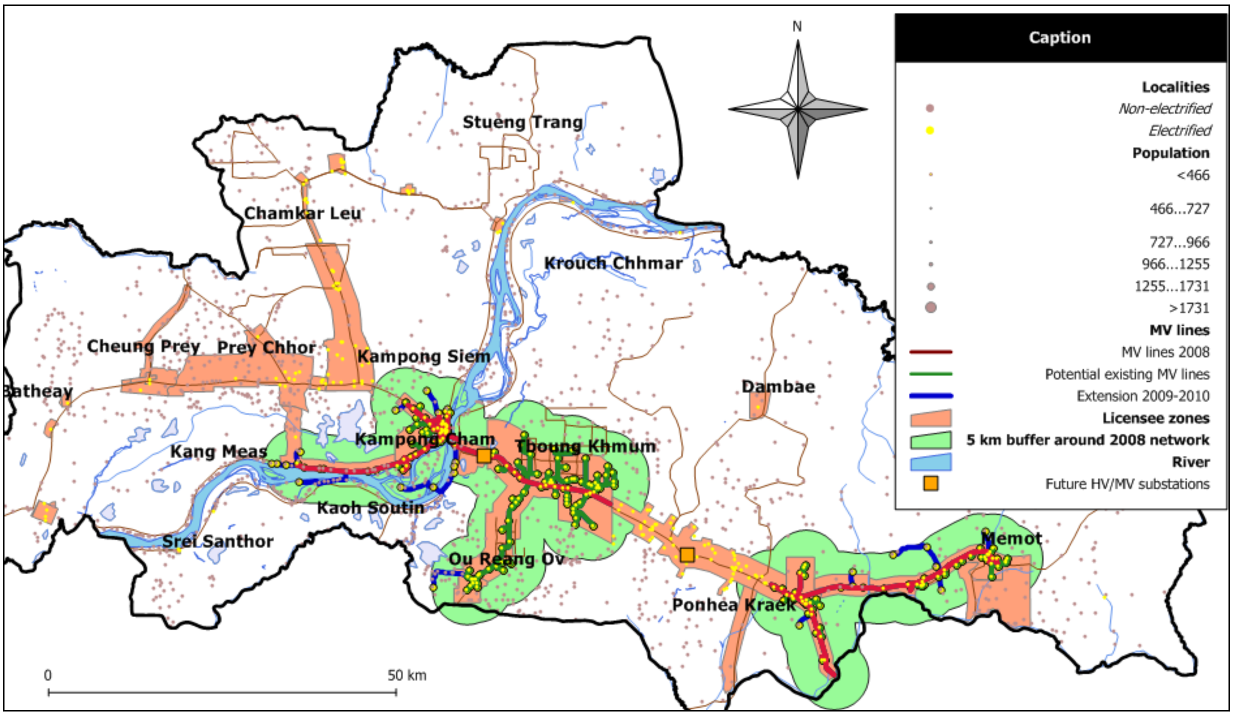


Figure 12: 2009-2010 extension

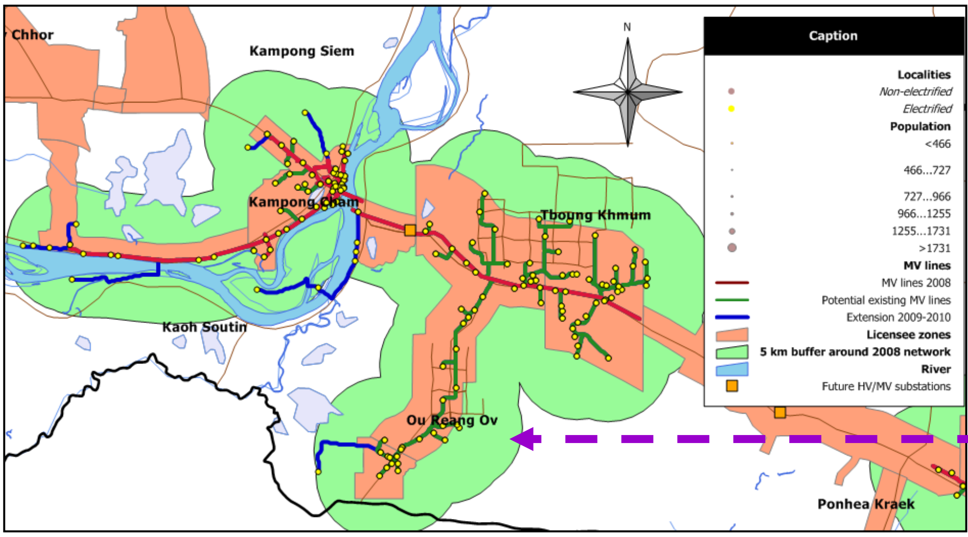


Figure 13: 2009-2010 extension (zoom on K.Cham, Ou Reang Ov, T.Khmum and Kaoh Soutin districts)

List of localities connected by 2010 is provided in Appendix.

- ***Phase 2: 2011-2015***

According to Cambodian authorities, by 2011 the 22 kV lines between (i) Ponhea Kraek to Skun via Kampong Cham should be commissioned and therefore that villages can be connected up from them. This new line was therefore added to the network obtained after phase 1 extension before launching phase 2 simulation.

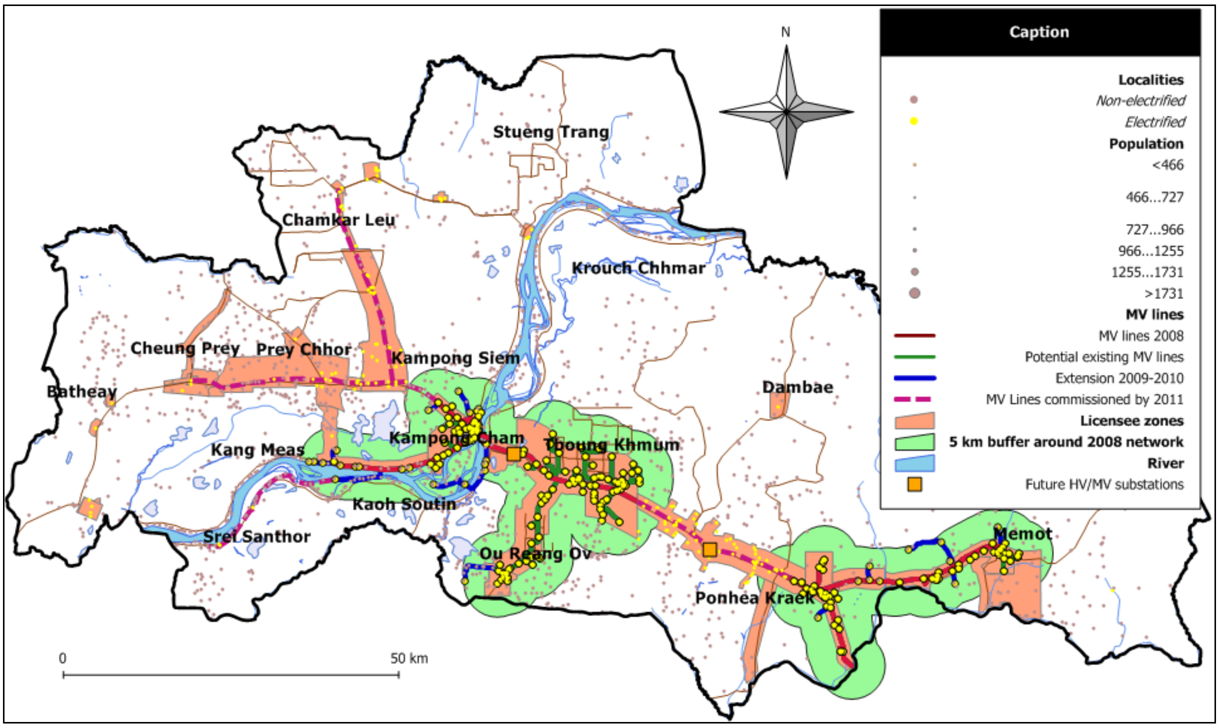


Figure 14: MV lines planned to be commissioned by 2011 (pink lines)

In parallel, the 115 kV line that will be coming from Vietnam will provide increased capacity to the Province and therefore the opportunity (i) to connect localities at a highest rate and (ii) to extend the network more in depth. 154 villages per year were considered for electrification.

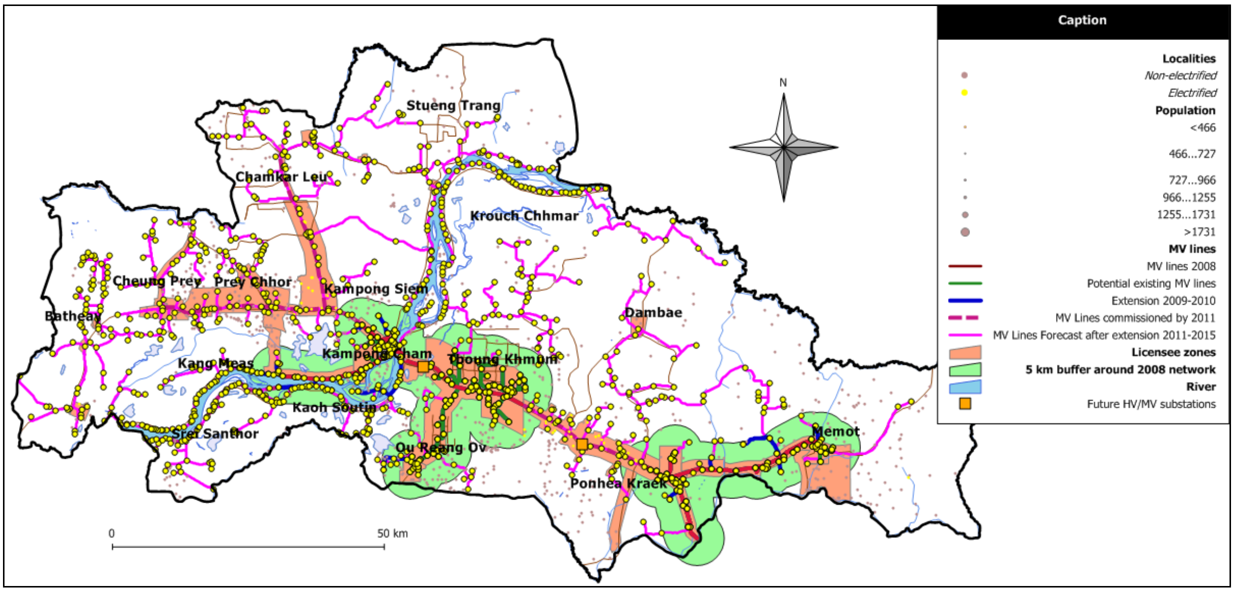


Figure 15: 2013-2016 extension

List of localities connected by 2015 is provided in Appendix.

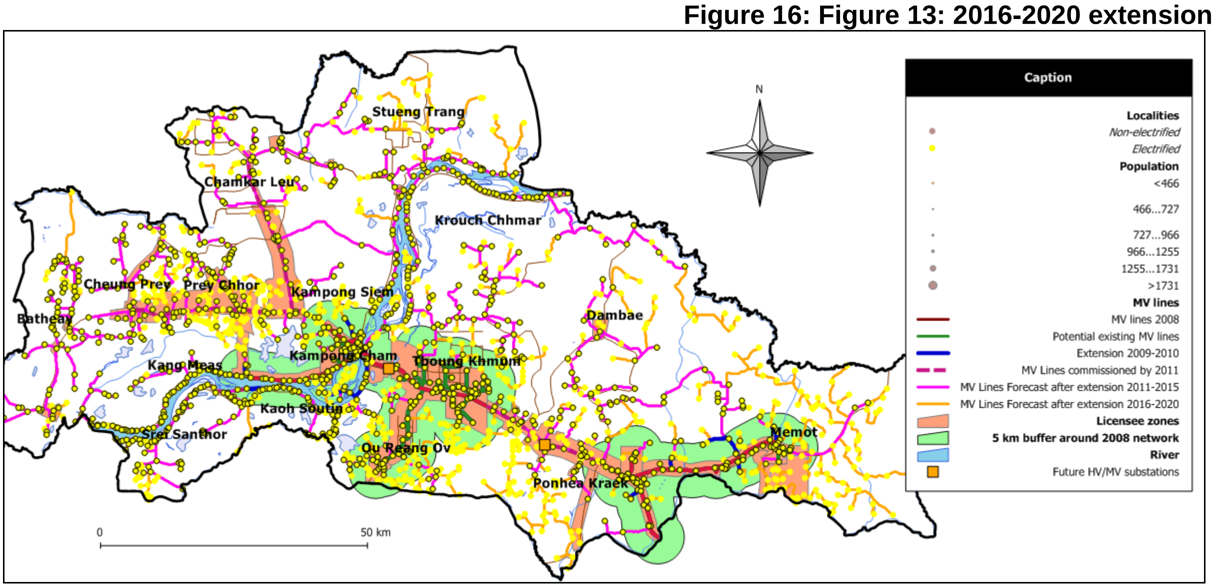
- ***Phase 3: 2016-2020***

Assumption was made that the following MV lines would be commissioned by 2016:

- Skun (Cheung Prey) – Phnom Penh (South West)
- Kampong Cham – Kratie (North East)
- Kampong Cham to the North along the river to Stueng Trang
- Kampong Cham to the South along the river to Srei Santhor

This assumption is fully in line with results got in phase 2 of the extension, as the labove mentioned lines were identified by GEOSIM© as structuring lines for Kampong Cham province. In order to reach 100% village electrified by 2020, a number of 154 villages to be electrified each year was considered.

Figure 16: Figure 13: 2016-2020 extension



List of localities connected by 2020 is provided in Appendix.

4.1.3 Scenario 1 synthesis

If the whole Kampong Cham province was to be electrified considering the grid as the only supply option, around 2 500 km of additional MV lines would be required by 2020, for a total investment of 134 MUS$ (transmission + distribution).

Table 2: Scenario 1 key figures

Phase	Localities connected	Population 2009	Power demand 2009 GWh	Peak MW	kWh /cap	MV line length (km)	km/ village	Cost / village (US$)	Cost per HH[9]
2008*	189	226 488	17,2	4,9	75,8	137	0,7	38 319,1	182
2009-2010	30	57 597	4,4	1,2	76,0	64,5	2,2	123 788,2	368
2011-2015	770	1 113 074	83,1	23,7	74,7	1317	1,7	96 989,6	382
2016-2020	770	448 024	36,0	10,3	80,3	1071	1,4	62 509,5	612
TOTAL	**1 758**	**1 845 183**	**141**	**40**	**76,2**	**2 589**	**1,5**	**76 046,9**	**413**

Table 3: Scenario 1 investments

Phase	Invest. for transmission (MUS$)	Invest. for distribution[10] (MUS$)	Total invest. (MUS$)
2008*	3,3	4,0	**7,2**
2009-2010	1,5	2,2	**3,7**
2011-2015	31,6	43,0	**74,6**
2016-2020	25,7	22,4	**48,1**
TOTAL	**62,1**	**71,5**	**133,7**

**Densification phase around existing MV lines (including simulated ones)*

Although an equal number of localities was targeted for phases 2 and 3, related total investments are not comparable. Investments for the transmission part are roughly in the same order of magnitude, respectively 31,6 and 25,7 MUS$, which is not the case for the distribution part. Indeed, Phase 2 is 20 MUS$ more costly than Phase 3 due to a targeted population much more higher (1 113 074 and 448 024 in 2009), Phase 3 extensions reaching more isolated areas. But the most relevant indicator when planning investments is the cost per household, which is obviously very high in Phase 3, 60% higher than in phase 2 (382 US$ in phase 2, 612 US$ in Phase 3).

Situation in 2020 is displayed on next page.

[9] Considering 5,7 people per household
[10] Assumption: 150 households per km of LV line

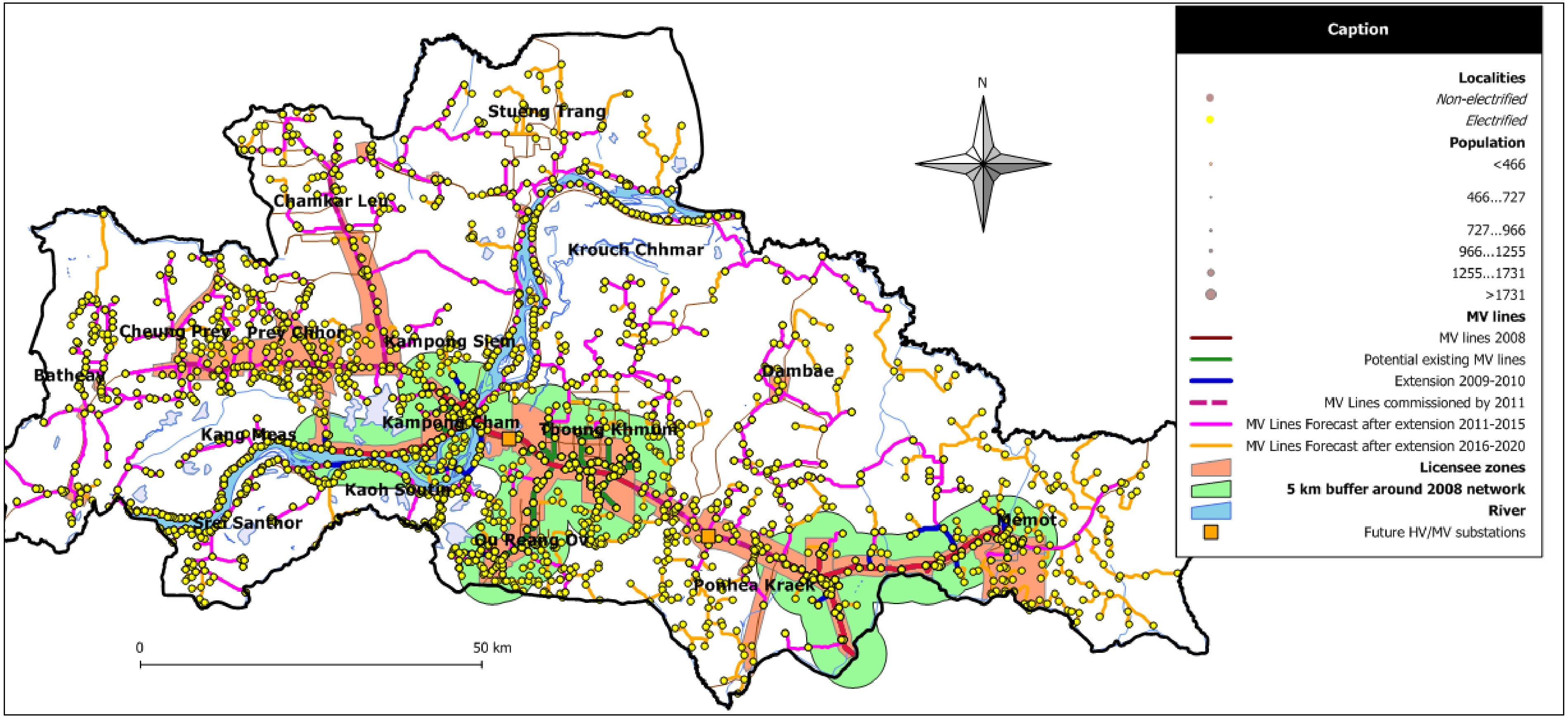


Figure 17: 100% village grid-connexion by 2020 in Kampong Cham province

4.2 Scenario 2: private grid extension projects

4.2.1 Working hypothesis

The 2nd simulation consisted in assessing the cost for the extension of three additional 22 kV lines by 2012, in addition to the lines already planned at this horizon (see Scenario 3 grid extension 5.1.3), and the connexion of all villages located less than 5 km from the extended grid.

The lines targeted were:

- **Kampong Siem towards Chamkar Leu**
- **Kampong Cham towards Stueng Treng (2 sides of river)**
- **From Ponhea Kraek-Skon back-bone towards Dambae**

Three specific buffers were defined to demarcate the areas within which villages should be connected to the grid.

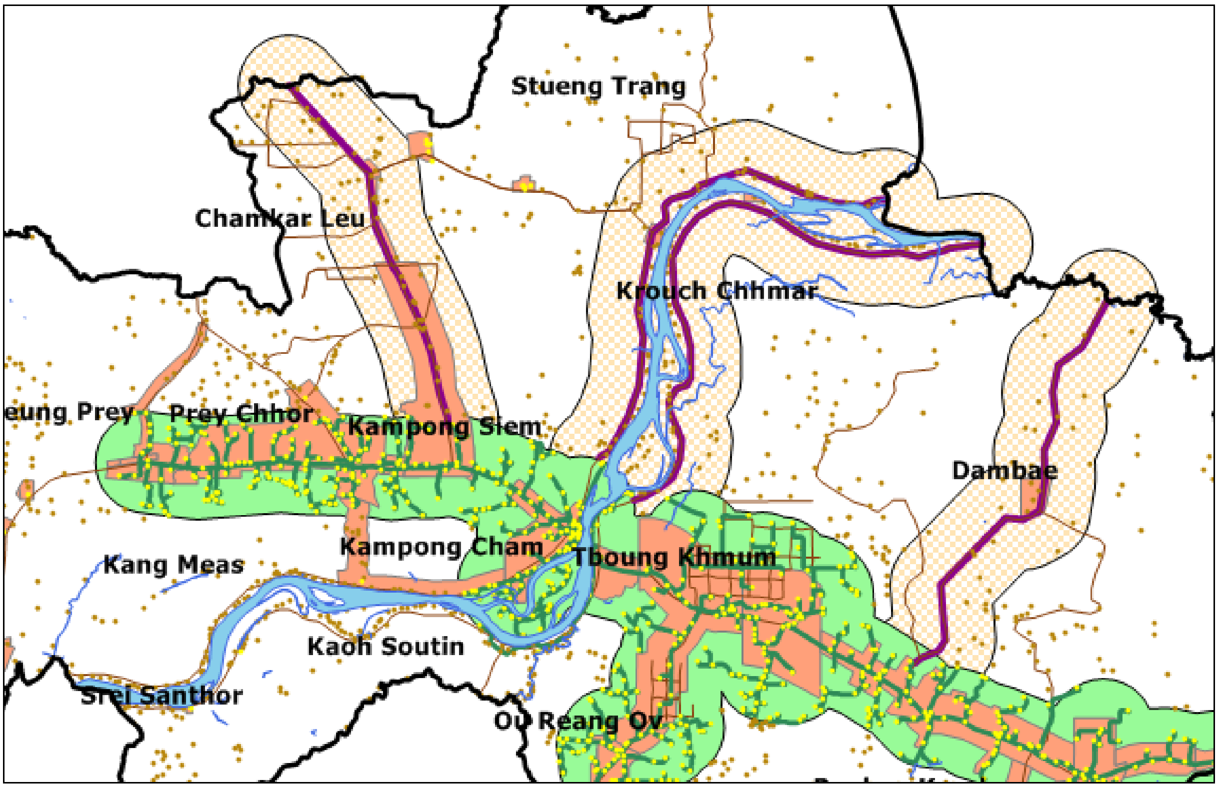


Figure 18: Scenario 2: 5 km buffers around targeted lines

The number of villages to be electrified was then adapted to fulfil the requirements:

	Number of localities targeted
Kampong Siem towards Chamkar Leu	62
Kampong Cham towards Stueng Treng	142
Back-bone towards Dambae	37

Table 4: Scenario 2 planning process

4.2.2 Scenario 2 results

The map below displays grid extensions from the three targeted lines.

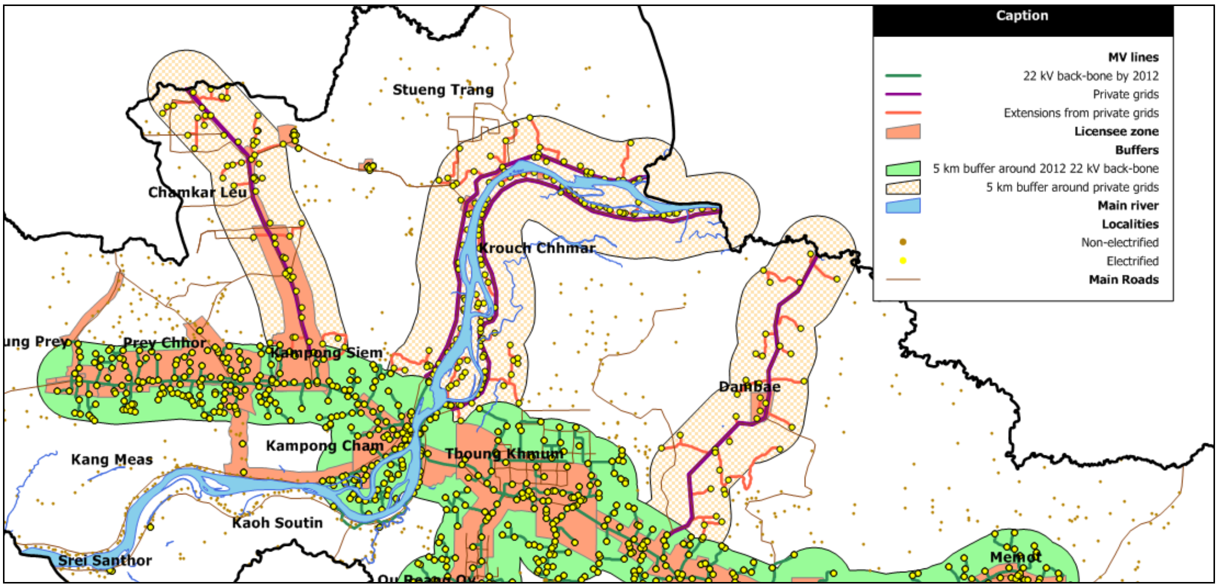


Figure 19: 22 KV lines – private grid extension projects

Key figures and investments

Table 5: Scenario 2 key figures

Grid extension *Towards...*	Localities connected	MV lines length (km)	Population 2009	Power demand 2009 GWh	Km / village	Cost / HH[11]	Cost / MWH
Chamkar Leu	62	84	83 028	6,3	1,3	362,7	845,3
Stueng Trang	142	165	185 335	13,9	1,2	348,9	815,4
Dambae	37	86	38 841	3,0	2,3	541,6	1 238,9
TOTAL	**241**	**335**	**307 204**	**23,1**	**1,4**	**377,0**	**878,0**

Table 6: Scenario 2 investments

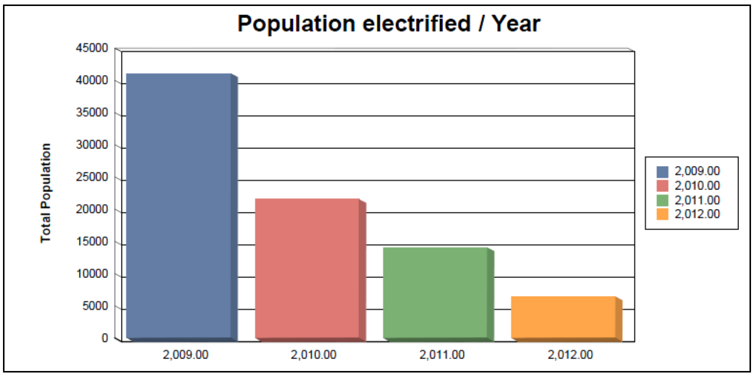
Grid extension *Towards...*	Investment for transmission (MUS$)	Investment for distribution (MUS$)	Total investment (MUS$)
Chamkar Leu	2,0	3,3	**5,3**
Stueng Trang	4,0	7,4	**11,3**
Dambae	2,1	1,6	**3,7**
TOTAL	**8,0**	**12,3**	**20,3**

[11] Considering 5,7 people per household

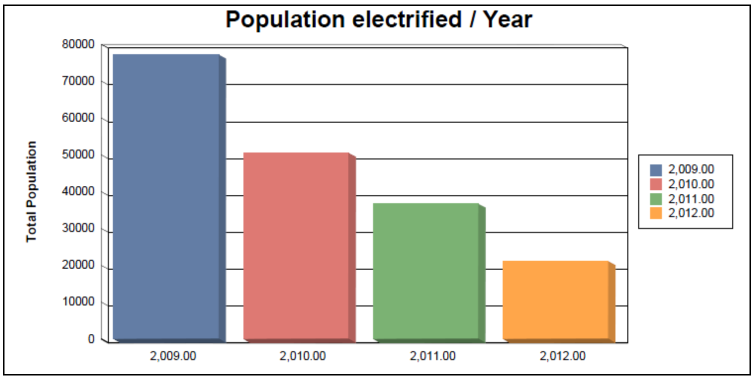
Cost per household is the roughly the same for Chamkar Leu and Stueng Trang extensions, because of very similar ratios (km of transmission MV lines per village, avarage population per village). Regarding Dambae extension, this cost is around 50% higher due to the fact that localities targeted are less populated and more distant from one to another.

The diagrams below give an indication on the population that would be covered each year of the planning period. It clearly highlights the fact that the more the network is extending, the more the population targeted is decreasing. As the grid extension algorithm strives to connect in priority villages with the highest Net Present Value, villages with highest demand, and therefore the most populated ones, will be first connected. Therefore, in 2012, less populated villages will be reached.

Extension towards Chamkar Leu



Extension towards Stueng Trang



Extension towards Dambae

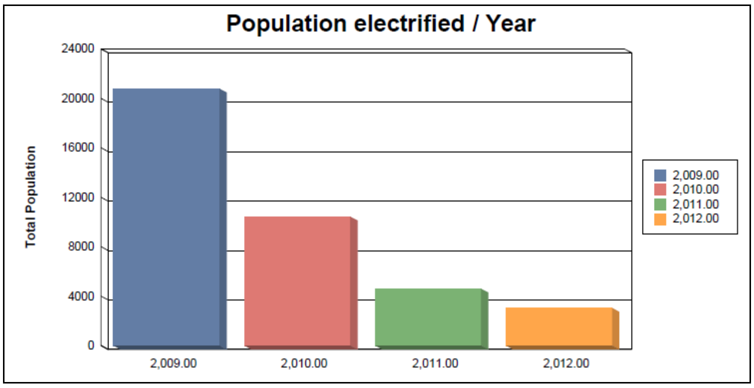


Figure 20: Population covered by 2012

4.2.3 Scenario 2 brief economic analysis

What are the potential financial schemes the scenario 2 could rely on? Different possibilities can be considered:

- If no subsidy could be foreseen → what should be the customer tariff to make the projects viable?
- private investment with a tariff fixed by the regulatory board → what would be the necessary initial subsidy to get an acceptable Internal Rate of Return (IRR)?

❑ ***Project not subsidized***

We make the following assumptions:

REEs purchase price from EDC	**0.15 US$**
Demand increase per year	**6%**
Load factor	**42%**

Table 7: Scenario 2 economic analysis hypothesis

Without any subsidy, and depending on the end-users tariff, we get the following IRR (calculated over the next 11 years, until 2020):

	Customer tariff (US$)		
	0.25	**0.30**	**0.35**
Dambae	1%	9%	15%
Chamkar Leu	8%	17%	25%
Stueng Treng (2 sides of river)	9%	18%	26%

Table 8: IRR without subsidies

For all projects to be viable, considering a discount rate of 10%, customer tariff must be in the range of 0.30-0.35 (IRR will be therefore greater than the discount rate and thus the NPV positive).

At this level it is important to underscore the importance of the demand analysis and therefore of the field surveys. In this kind of exercise, it is crucial to take into account all energy needs of the territory concerned, especially the sites requiring high demand levels that will significantly impact financial figures. If we consider for example in our calculations an additional demand of 1 MW in the vicinity of each line (required for example by a large industry), the respective IRR would evolve as follows:

Additional demand: 1MW	**Customer tariff (US$)**		
	0.25	**0.30**	**0.35**
Dambae	20%	33%	44%
Chamkar Leu	21%	33%	44%
Stueng Treng (2 sides of river)	15%	26%	36%

Table 9: IRR without subsidies - with additional specific demand 1 MW

Considering this additional specific demand, a 0.25$ tariff would make all the three projects viable, while proposing an affordable tariff to customers (and therefore increasing the number of candidates for connexion).

In the perspective to make a relevant economic analysis, demand analysis must therefore not be underestimated. Consumption sites like rubber plantations are for example industries that should be considered. Their required capacity is generally about few MW, with very high consumptions, and their consideration could significantly modify both (i) supply options identification and (ii) economic analysis results. This appear to be even more relevant for Kampong Cham province, where most of Cambodia rubber plantations are located.

- ***End-users fixed tariff***

As explained above, and if we do not take into account any specific demand, an end-user tariff of 0.25US$ would not make the projects viable, IRR being in the three cases lower than the discount rate. What would be therefore the needed subsidy to make them attractive?

	Subsidy (% of the initial investment)			
	0%	**10%**	**20%**	**40%**
Dambae	1%	3%	5%	11%
Chamkar Leu	8%	10%	13%	20%
Stueng Treng (2 sides of river)	9%	11%	14%	21%

Table 10: IRR with subsidies

As we could expect, Dambae project (involving less populated and distant localities) would require a high level of investment to make it viable (40% of the initial investment). For Chamkar Leu and Stueng Trang, an investment of around 10% of the initial investment would be enough.

5 Scenario 3: Grid extensions and off-grid options

5.1.1 Working hypothesis

The objective was to make an electrification plan within which all villages located within a 5 km buffer around existing and planned 22 kV lines should be grid-connected by 2012. Beyond grid extension, special attention was therefore given to the grid densification, to exclude situations where a locality would be located close to an MV line without being connected. Still with the ambition to optimise socio-economic development of the Province, an off-grid option (biomass, hydro, diesel) was to be identified for all the Development Poles that would not be located within the buffer and therefore not connected to the grid by 2012.

Scenario 3 hypothesis:

- Grid area: 5km buffer around existing and planned 22 kV lines
- All villages of the buffer connected by 2012
- All remaining Development Poles will benefit from an off-grid option

5.1.2 Scenario 3 approach

The approach adopted for scenario 3 addresses the energy access issue under the development angle, with the objective to optimise the socio-economic impact of rural electrification. This was done by carrying out a spatial analysis (through GEOSIM© Spatial Analyst module), to identify localities that should benefit first from a rural electrification programme in order that the maximum number of people could benefit from it.

Complementarily and prior to classical rural electrification planning approaches, this first step aims to optimise the mandatory public subsidy by giving higher priority to projects which will benefit to the largest number of people (inside and outside electrified settlements) and with the best social and economic impact, characterised by the (ii) the improvement of access to social services (health, education, drinking water, etc.) benefiting from electrification and (ii) the creation of local economic opportunities (business, employment, etc.).

The definition of an off-grid area within which decentralized supply options should be identified requires from the planner to be aware of existing and planned lines by a given horizon. Two questions therefore underlie this scenario and were successively addressed:

➔ Which villages (including Development Poles) are likely to be connected to the grid planned by 2012?

➔ What are therefore the off-grid area and the villages that will be concerned by an off-grid option?

The scenario 2 approach is based on the following observations:

- ➢ All Development Poles (not connected to the grid) are candidate for an off-grid supply option
- ➢ Priority is given to biomass (from rice husks and off-cuts residues) and hydro technologies over diesel option
- ➢ Possible diesel back up for renewable energy based options
- ➢ For all options, optimisation of the kWh levelized cost by continuing connecting settlements till this cost increases.

5.1.3 Grid extension

➢ Lines commissioned by 2012

This 3rd simulation appears to be more realistic as only grid extensions for which investments have been secured by 2012 were taken into account in addition to the existing network, constituting a 22 kV grid backbone going from Vietnam (Tan Bien) to Kampong Cham and ending in Kampong Siem.

In other words, localities that would benefit of a grid connexion from those additional lines will not be considered when addressing the off-grid supply options identification. 2012 is therefore a threshold date, beyond which any Development Pole that would not have been connected to the grid would be candidate for an off-grid option.

These additional lines are:

- Viet-Nam – Ponhea Kraek – Memot
- Ponhea Kraek - Kampong Cham
- Kampong Cham – Kampong Siem
- Towards Sieng Seng (Chamkar Leu)
- 22 kV in Tboung Khum region*
- 22 kV in Ou rang Ov region*

** Densification around existing lines carried out in Scenario 1 was retained to connect already electrified localities located in the vicinity of these lines.*

The map below displays the MV network as foreseen in 2012.

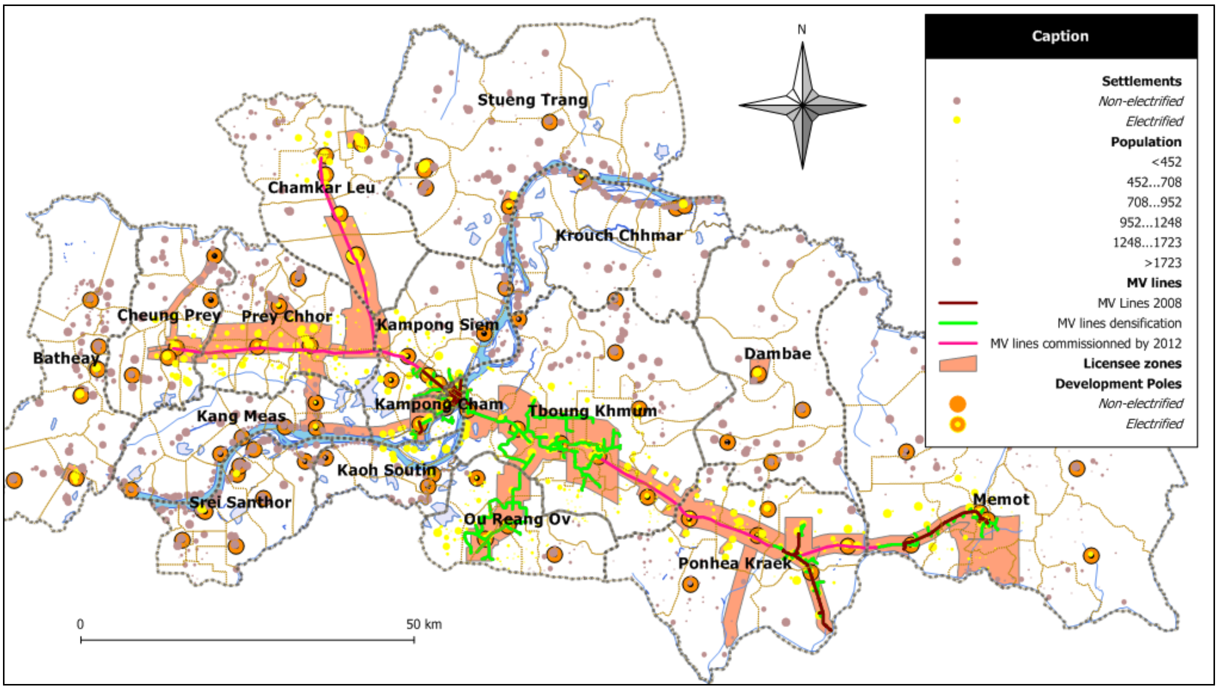


Figure 21: Lines commissioned by 2012

- **Grid-area specification**

A 5 km-buffer was created around the above mentioned backbone, covering roughly most of REE licensee zones which are supposed to be inter-connected with 22 kV lines within the next few years.

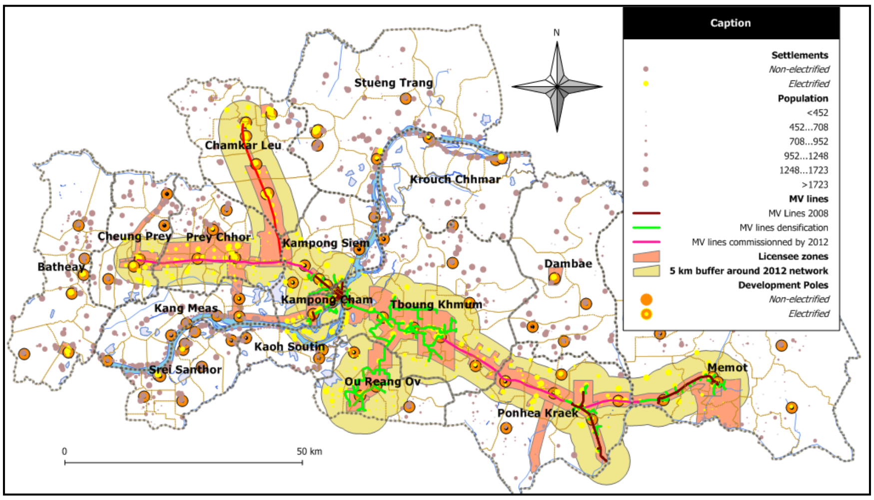


Figure 22: 5km buffer around MV lines

- **Grid extension**

708 localities are located within the buffer, out of which 520 are not electrified to date; an equal number of 130 villages to be connected each year from 2009 to 2012[12] was therefore considered. List of connected localities is provided in Appendix.

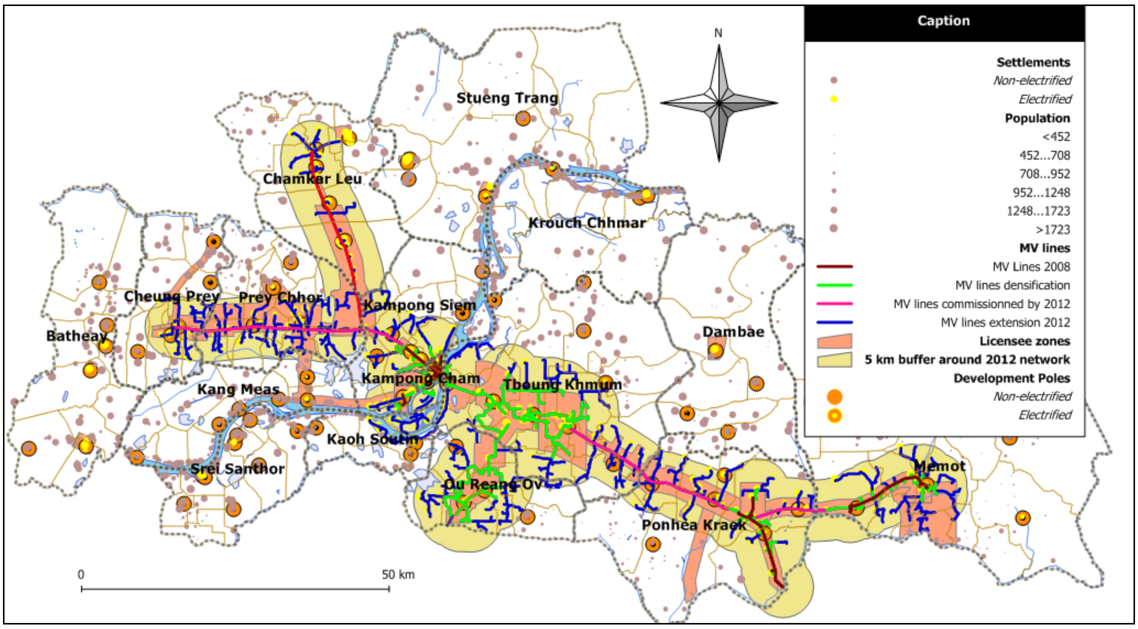


Figure 23: Grid extension by 2012

Over the four-year period, around 670 km of MV lines (displayed in blue on the previous map) would be needed to connect all the buffer villages, for a total investment of 36,7 MUS$.

[12] 2012 included

Table 11: Scenario 3_2012 grid extension key figures

2009 population	MV line length (km)	Investment for transmission (MUS$)	Investment for distribution (MUS$)	Total investment (MUS$)
465 885	668	15,9	20,8	36,7

It is important to keep in mind that, at this level, as in any grid-extension simulation carried out for the purpose of the project, the Development Pole notion does not appear yet and will be considered only in the off-grid approach. This highlights the innovative aspect of the methodology used as, depending on the planning process step, two different approaches were adopted:

- an "economic approach" when simulating grid extension, in line with utilities approach;
- a "development oriented approach" when identifying off-grid options, in order to boost socio-economic development of Poles.

5.1.4 Off-grid supply options

Off-grid area has now been specified; all development poles that were not concerned by grid extension, therefore located outside the 5 km buffer, were candidates for a decentralized supply option.

5.1.4.1 Renewable energy potentials

In Kampong Cham province, renewable technologies that were considered were small hydro and biomass, both of them being given priority over diesel option. The two tables below provides detailed information on selected sites[13].

5.1.4.1.1 Biomass potentials

For these projects, there are no identification and actual feasibility studies available, so some potentials were derived from available information on rice production.

Significant potential have been identified from rice husks and off-cuts in Kampong Cham province, as shown on map below.

Residue collection points were positioned within a 15 km radius from residue production sites.

Purchase price of residue was taken equal to 7$/tonne (according to the survey conducted in rice mills and saw mills, this is the threshold price under which the sell of residues would not profitable compare to other uses). A sensitivity analysis was nevertheless done with 10$.

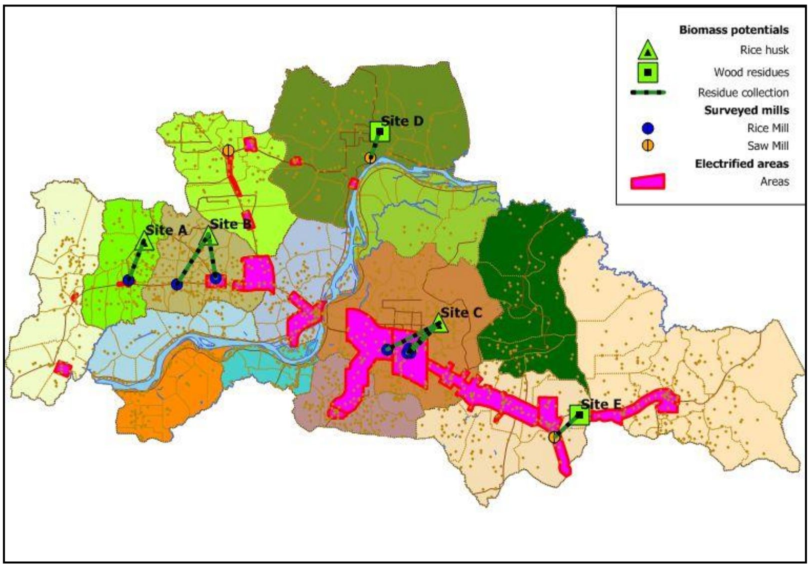


Figure 24: Biomass potentials

[13] Cf. CAP REDEO Hydro & Biomass report

Site	A	B	C	D	E
District	Cheung Prey	Prey Chhor	Tboung Khmum	Stueng Trang	Stueng Trang
Long. (dec)	105.1085	105.2414	105.7165	105.5942	106.0040
Lat. (dec)	12.1385	12.1506	11.9710	12.3585	11.7845
Type of residue	Rice husks	Rice husks	Rice husks	Offcuts	Offcuts
Estimated residues available (T per year)	2000	1400	1300	120	630
Collected from	1 rice mill in Skon	2 rice mills in Doun Dei and Tang Kouk villages	3 rice mills in Tboung Khmum district	1 saw mill in Boeng Ket Leu	2 saw mills in Trapeang Phlong Pir
Energy output from biomass only (MWh / year)	1000	650	550	80	420
Total energy output (MWh per year)	**1400**	**950**	**850**	**120**	**630**
Power (kW)	**330**	**220**	**194**	**27**	**144**

Table 12: Selected biomass potentials in Kampong Cham province

5.1.4.1.2 Hydro potentials

On the basis of site visits and map study, two potential hydro sites, located in Stueng Trang and Dambae districts, have been investigated.

Kampong Cham province stretches on a flat territory. Although low estimated capacities (4 kW and 20 kW), the objective was to assess the possibility for some neighbour localities to benefit from potential power plant.

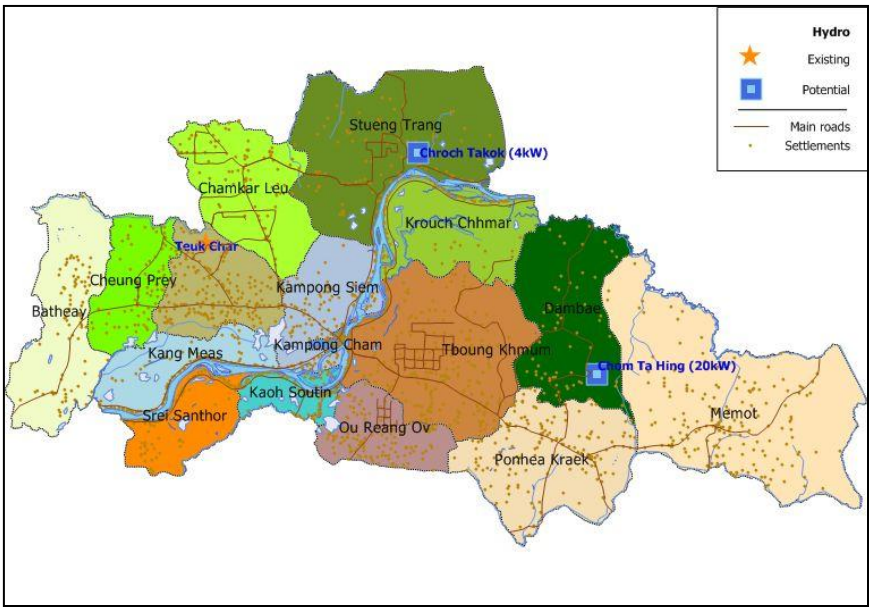


Figure 25: Hydro potentials

Site	A	B
Site name	Chroch Takok	Chom Ta Hing
District	Stueng Trang	Dambae
Long. (dec)	105.6131	105.9526
Lat. (dec)	12.3357	11.9203
River name	Châmbâk Méas	Stoeng Thom
Head (m)	40	10 to 20m
Flow (m3/s)	0,02	0,02 (dry) – 0,2 (av.)
Power (kW)	4	20
Availability (%)	100%	50%
Village(s)	Sre Sankai (1km)	Srâmâr (<1km)
Households	36	300
Comments	2 other nearby villages	2 other nearby villages

Table 13: Selected hydro potentials in Kampong Cham province

5.1.4.2 Projects identification

To identify projects (1 locality or groups of localities) that could benefit from hydro and biomass potentials, the model looks for the closest Development Pole within a defined radius, specified by the planner. If no Development Pole is located within this radius, then the closest settlement is taken. Projects are then optimised as explained in the “Off-grid projects identification Chapter”2.2.2.2

Diesel gensets will be the default option for all the Development Poles that will not have been allocated any option so far (grid or renewable energy based).

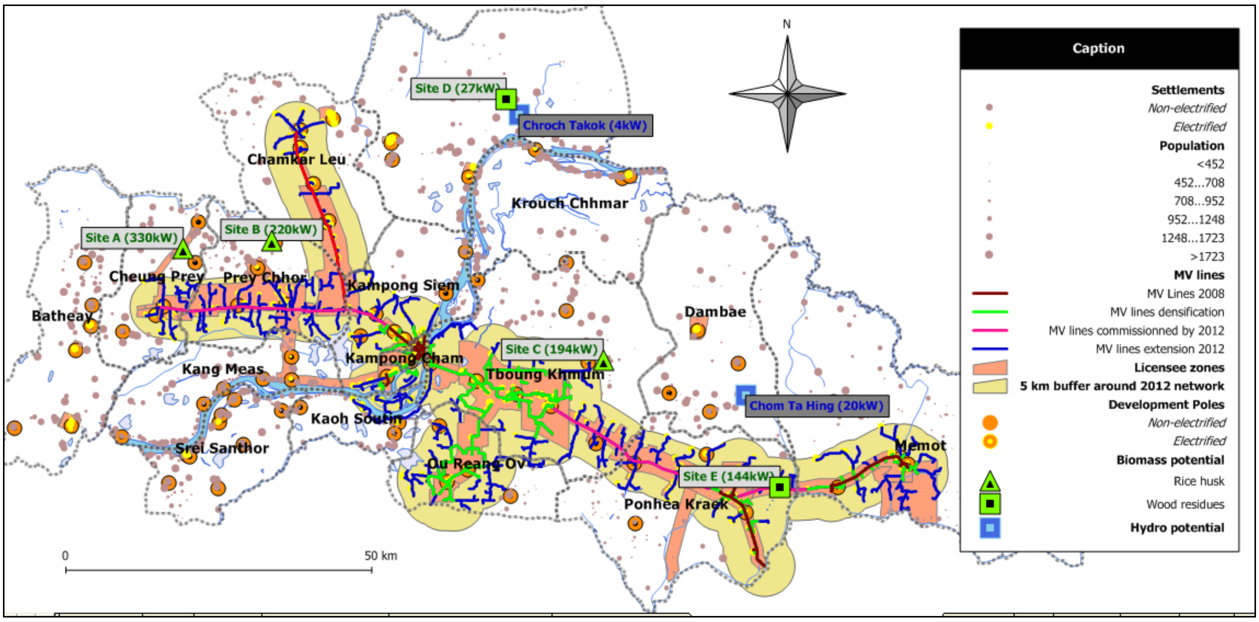


Figure 26: Development Poles & renewable energy sites location

5.1.4.3 Main working hypothesis

- Running hours: 24 h (for both hydro and biomass options)
- Equipments investment cost: Biomass: 1 350 $/KW Hydro: 3 000 $/KW
- Distance limit between potential biomass site and cluster: 10 km (4 km for site D because of low capacity)
- Distance limit between potential hydro site and cluster: 2 km for 4kW site, 4 km for 20 kW site
- Possibility for diesel back-up
- To take into account seasonality factors, capacity of biomass units is at twice the average load, to take into account seasonality effect: there are only one or two crops a year; as a first approach as well, 1/3 of back up fuel is assumed.

All parameters are listed in Appendix

5.1.5 Biomass projects

5.1.5.1 Isolated mode

Table 14: Biomass projects in isolated mode with possible diesel back-up

Site	A	B	C	D	E
District	Cheung Prey	Prey Chhor	Tboung Khmum	Stueng Trang	Stueng Trang
Type of residue	Rice husks	Rice husks	Rice husks	Offcuts	Offcuts
Installed capacity at the site	330 kW	220 kW	194 kW	27 kW	144 kW
Cluster settlements number	6	4	4	1	1
2009 Population covered	7 131	4 443	3 543	2 667	2 827
Energy from biomass (average on planning period)	59%	61%	63%	15%	61%
Total invest. (Years 1 & 2)	1 260 268	776 188	625 980	384 788	558 712
Total investment[14] over the planning period[15] US$ (excluding maintenance)	2 237 057	1 408 785	1 173 117	766 550	1 012 497
Fuel (dual fuel + back-up) cost over the planning period US$	2 135 974	1 238 237	932 395	1 754 442	771 652
% of total investment	***95%***	***88%***	***79%***	***229%***	***76%***
Levelized cost (US$/kWh) (residue cost: 7$/T)	0,35	0,34	0,34	0,44	0,37
Levelized cost (US$/kWh) (residue cost: 10$/T)	*0,35*	*0,35*	*0,35*	*0,44*	*0,37*

[14] Investments include Biomass generator, Back-up genset, MV & LV lines, Power house, Meters, Transformers

[15] Planning-period: 2009-2020

Investments for fuel (dual fuel + back-up) appear to be very high but if the sites were to be run without back-up, the demand of the connected localities would not be satisfied any more from year 4 in the best case.

5.1.5.2 Grid integrated mode

An other option would be to consider the connexion of these sites to the grid for net-metering, enabling both (i) to purchase missing energy from the grid or (ii) to inject excess energy produced by the biomass power plants into the grid. Substituting diesel back-up and eventually part of the dual fuel with the grid would be a relevant option to benefit from a more reliable and possibly cheapest energy in case of shortage.

Moreover, this approach would enable to exploit the local renewable energy potentials while offering possibility for the operator to get extra income if an attractive Power Purchase Agreement could be agreed by both parties.

Three scenarios have been considered, depending on the power purchase price from utility - 0,15 US$/kWh, 0,25 US$/kWh and 0,35 US$/kWh - summarized in the table next page.

Considering a residue cost of 7$/T, main conclusions are:

➔ In grid integrated mode, levelized costs are significantly more attractive than the ones got in isolated mode (except for site D, located too far from the grid, with a power purchase price of 0,35 US$/kWh); this is because all the energy produced is placed (excess from the villages' needs is placed on the grid)

➔ With a power purchase price from utility at 0,15 US$/kWh or 0,25 US$/kWh, purchasing part of the needed power from the grid appears to be more interesting than producing it from dual fuel. For all sites, more than 68% of the energy would be drawn from the grid;

➔ With a power purchase price from utility at 0,35 US, levelized costs are still more attractive than in isolated mode (investments and demand remain the same), but the quantity of energy drawn from the grid would be very low, only when the peak load of the clusters will be higher than the plant capacity; at this level, the cost of dual fuel is more attractive. Moreover, in this configuration, operation and maintenance costs would be multiplied by 4 or 5 compare to isolated mode, reaching over the planning period between 3,8 and 9 MUS$

➔ Over the planning period, all sites except site D could sell excess power to the grid (ranging from 9,2 to 20 GWh).

Site	A			B			C			D			E		
Power purchase price from utility (US$/kWh)[16]	**0,15**	**0,25**	**0,35**	**0,15**	**0,25**	**0,35**	**0,15**	**0,25**	**0,35**	**0,15**	**0,25**	**0,35**		**0,25**	**0,35**
Energy from grid*	70%	70%	8%	69%	69%	7%	68%	68%	5%	83%	83%	51%	69%	69%	6%
Energy from biomass*	30%	30%	30%	31%	31%	31%	32%	32%	32%	17%	17%	17%	31%	31%	31%
Energy from dual fuel*	0%	0%	62%	0%	0%	62%	0%	0%	63%	0%	0%	32%	0%	0%	63%
Injectable energy over the planning period (GWh)	20			13,9			12,5			0			9,2		
Total invest. (Years 1 & 2)	1 326 020			960 788			693 652			1 094 450			568 712		
Total investment over the planning period (US$) (excluding maintenance)	**1 863 834**			**1 310 979**			**1 002 060**			**1 167 785**			**801 756**		
Cost of power purchased from the grid (US$)	421 794	702 990	984 186	232 797	387 995	543 193	154 395	257 325	360 255	409 629	682 714	955 800	141 912	236 520	331 128
% of total investment	*23%*	*38%*	*53%*	*18%*	*30%*	*41%*	*15%*	*26%*	*36%*	*35%*	*58%*	*82%*	*18%*	*30%*	*41%*
Dual Fuel cost US$	0	0	**7 392 227**	0	0	**4 908 599**	0	0	**4 337 955**	0	0	**598 733**	0	0	**3 214 918**
% of total investment	*0%*	*0%*	*397%*	*0%*	*0%*	*374%*	*0%*	*0%*	*433%*	*0%*	*0%*	*51%*	*0%*	*0%*	*401%*
Levelized cost (US$/kWh)	**0,09**	**0,14**	**0,21**	**0,09**	**0,14**	**0,21**	**0,09**	**0,13**	**0,19**	**0,33**	**0,42**	**0,66**	**0,09**	**0,13**	**0,20**

Table 15: Biomass projects in grid-integrated mode

*average on the planning period

[16] Considering a constant price over the planning period

5.1.6 Hydro projects

5.1.6.1 Isolated mode

The table below provides a synthesis of the results obtained in isolated mode with possibility of diesel back-up in case of shortage.

Table 16: Hydro projects in isolated mode with possible diesel back-up

Site	**A**	**B**
Site name	Chroch Takok	Chom Ta Hing
District	Stueng Trang	Dambae
River name	Châmbâk Méas	Stoeng Thom
Power (kW)	4	20
Village(s)	Sre Sankai (1km)	Srâmâr (<1km)
Hydro projects key figures	**A**	**B**
Cluster settlements number	1	1
2009 Population covered	174	1 735
Energy from hydro (average on planning period)	68%	47%
Investment (Years 1 & 2)	111 760	275 698
Total investment[17] over the planning period US$ (excluding maintenance)	**142 561**	**405 765**
Fuel cost over the planning period US$ *% of total investment*	**54 307** ***38,1%***	**681 971** ***168,1%***
Levelized cost (US$/kWh)	**0,49**	**0,31**

In isolated mode, global investment (including maintenance) for site A would be 211 554 US$. Regarding the targeted population, this investment appear to be extremely high (1 216 US$/capita). This project is not conceivable.

Site B could appear to be a bit more attractive in terms of levelized cost of kWh (0,31 US$/kWh), but only 47% of the total energy consumed would be produced by the hydro power plant. The remaining part would be ensured by the diesel back-up, entailing a fuel cost over the planning period of 0,7 MUS$, meaning 168% of the technical investment. Moreover, given the fluctuant aspect of fuel price, and its incidence on the local environment, this configuration should not be retained.

For both sites, a configuration without back-up is not conceivable, peak demand of connected settlements being much more higher, even in first year of operation, than the rated capacity of the sites.

[17] Investments include SHP generator, Back-up genset, MV & LV lines, Power house, Meters, Transformers

Map displays

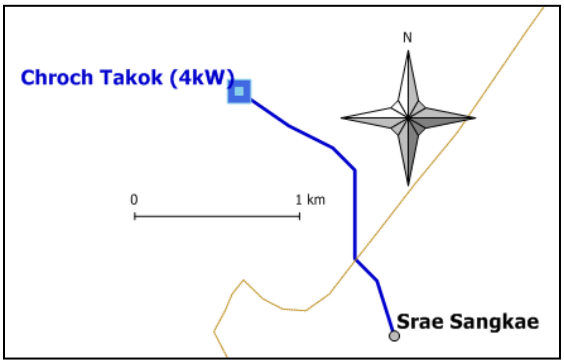


Figure 27: Hydro project from 4 kW site

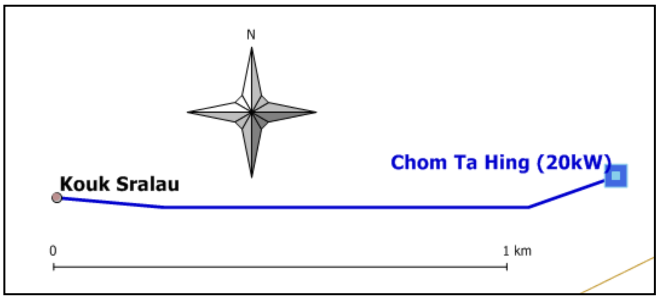


Figure 28: Hydro project from 20 kW site

5.1.6.2 Grid integrated mode

Table 17: Hydro projects in grid-integrated mode

Site	**A**			**B**		
Power purchase price from utility (US$/kWh)	**0,15**	**0,25**	**0,35**	**0,15**	**0,25**	**0,35**
Energy from grid	30%	30%	30%	50%	50%	50%
Energy from hydro	70%	70%	70%	50%	50%	50%
Injectable energy over the planning period (GWh)	0			0		
Total invest. (Years 1 & 2)	1 053 414			657 366		
Total investment over the planning period (US$) (excluding maintenance)	**1 055 414**			**677 766**		
Cost of power purchased from the grid (US$)	20 690	34 483	48 276	259 815	433 025	606 235
% of total investment	*2%*	*3%*	*5%*	*38%*	*64%*	*89%*
Levelized cost (US$/kWh)	**2,07**	**2,12**	**2,16**	**0,31**	**0,39**	**0,46**

Site A is located quite far from the grid planned for 2012. A connexion would entail very high investments (1,1 MUS$ over the planning period, out of which 94% would be spent for MV lines only) and a levelized cost of kWh absolutely unbearable by populations (above 2 US$/kWh), whatever would be the power purchase price from Utility. Site A can be definitely ruled out.

Conversely, it could be a relevant option for site B, particularly with a power purchase price at 0,15 US$/kWh. The levelized cost would be then the same than in isolated mode, for a global investment (investment + maintenance) 13% lower. Moreover, in this configuration, 50% of the energy consumed would be issued from hydropower plant, therefore a bit more than in isolated mode (47%).

5.1.7 Diesel projects

Out of the 90 Development Poles initially identified, 30 did not benefit from a grid-connection or a renewable energy based option. Electric clusters were therefore built on these remaining Poles to optimise their supply by diesel gensets.

As for renewable energy based projects, diesel projects built on Development Poles are optimised by connecting other localities to the identified project, until the kWh levelized cost stops decreasing. 29 projects were therefore identified (a project might contain several Poles).
220 additional localities could benefit from identified projects, with a levelized cost ranging from 0,45 to 0,51US$/kWh. Total population impacted would be 314 044 (2009 figure) for a total investment of 26,8 MUS$.

Diesel projects results are presented in Appendix.

5.1.8 Scenario 2 synthesis

The Table below synthesises the scenario 3 results.

	Targeted villages	2009 Population	Village average size	Investment (MUS$)*
Network	520	465 885	896	36,7
Hydro**	1	1 735	1 735	0,7
Biomass	16	20 611	1 288	3,6
Diesel	250**	314 044	1 256	26,8
Total	**787**	**802 275**	**1 019**	**67,8**

* 2009-2012 investment for network; years 1 & 2 investment for hydro and biomass

** Considering only Site B (grid-connected mode)

***Out of which 30 Development Poles

55% of the currently non-electrified settlements would be targeted (787 out of 1 425), increasing the electrified settlements rate[18] from 23% to 68%.

	Population (2009 figures)	Electrified settlements rate
Total population	1 750 284	
Population covered as 2009	395 703	23%
Population targeted	802 275	46%
Total population covered	**1 197 978**	**68%**

[18] % of the province population leaving in electrified settlements

6 Khammuane province rural electrification plan

6.1 Rural electrification strategy

The approach adopted for Khammuane province clearly highlights authorities' willingness to promote renewable energy based options to supply electricity to remote localities or to those not covered by REP1. Emphasis was therefore put on local resources as biomass and hydro, diesel technology being therefore excluded from potential options; a decision consolidated by the constant increase of oil barrel[19].

The methodology presented so far was based on the identification of localities that would be given priority in case rural electrification programs would be conducted in the province. Although the notion of socio-economic impact optimisation still underlies the approach, this latter is slightly different here. Indeed, in Khammuane province case, special focus is made on renewable energy technologies. Therefore, the objective is not any more to specify a supply option for all the Development Poles, as Diesel technology is not considered, but to exploit potential sites that were identified to supply first Development Poles that are located in the vicinity of the sites, and then to optimise the project created by adding other localities. If no Development Pole was to be found close to the sites, the nearest village would be first connected.

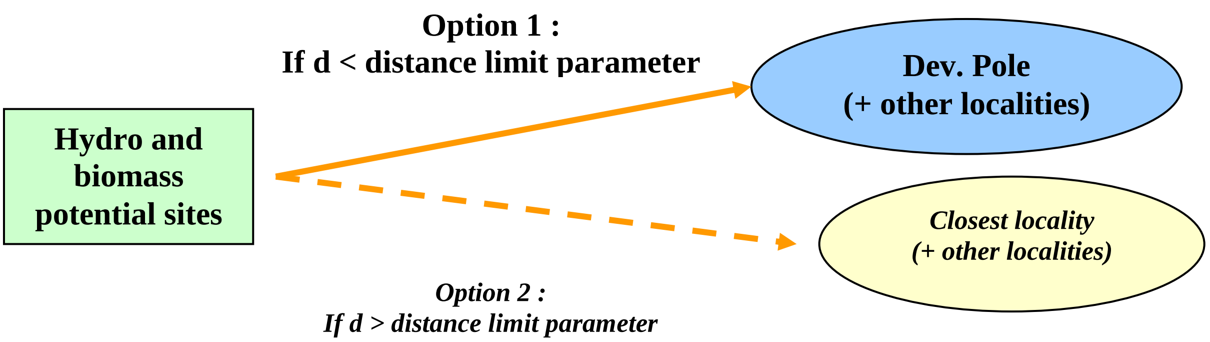


Figure 29: Exploitation of hydro and biomass sites

6.2 Biomass and hydro potentials

5 hydro and 4 biomass projects were identified[20]:

Hydro Site	A	B	C	D	E
District	Nakai	Gnommalath	Boualapha	Boualapha	Boualapha
River name	Môn	On	Xe Bangfai	Xe-Noy	Kok
Access	+/- OK	no road	+/- OK	OK	OK
Gross head (m)	40	40	40	80	100
Catchment area (km²)	80	204	640	140	52
Dry flow (m3/s)	0.24	0.612	1.92	0.42	0.156
P (kW)	**48**	**122**	**384**	**168**	**78**
Channel	1,5	< 1	> 5	3	5
Long. (deg)	105°16'30"	105°41'20"	106°03'45"	105°46'15"	106°06'30"
Lat. (deg)	17°59'10"	17°37'40"	17°13'50"	17°06'30"	17°04'40"

Table 18: Selected hydro potentials in Khammuane province

[19] 136.97 US$/bbl as of 10th July 2008
[20] Cf. CAP REDEO Hydro & Biomass report

Biomass Site	A	B	C	D
District	Boualapha	Xaibouathong & Mahaxai	Xebangfai	Mahaxai
Long. (dec)	105.8232	105.4995	105.2165	105.2552
Lat. (dec)	17.2370	17.2635	17.1315	17.3389
Type of residue	Rice husks	Rice husks	Rice husks	Rice husks
Estimated residue production (T/year)	1250	850	240	400
Collected from	22 rice mills	57 rice mills	16 rice mills	20 rice mills
Energy output from biomass only (MWh/year)	550	350	110	180
Capacity(kW)	**99**	**67**	**19**	**32**

Table 19: Selected biomass potentials in Khammuane province

Given seasonality characteristics in the region, the sites have been sized at 1,5 times average capacity, with 75% availability of biomass over the year.

The map below displays identified sites location and their respective assessed capacity:

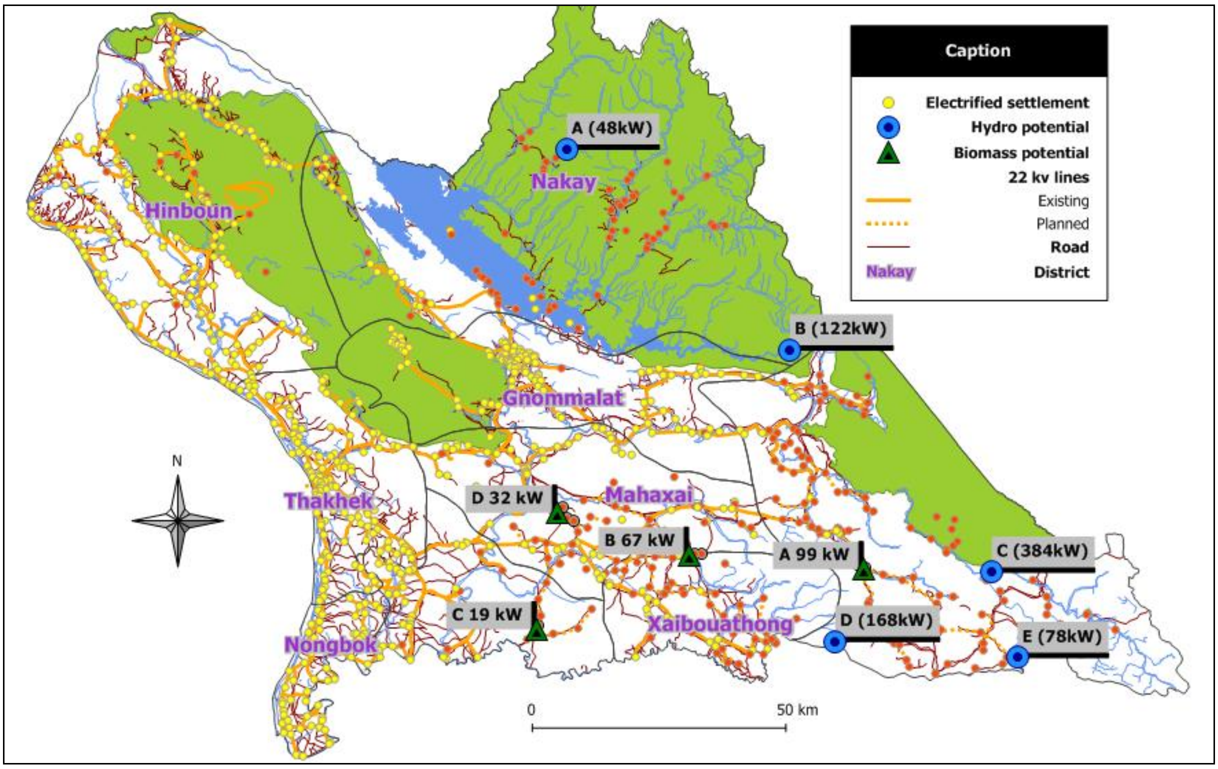


Figure 30: Hydro and Biomass potential sites

6.3 Projects identified

Results are presented in synthetic form. Detailed results are provided in Appendix.

6.3.1 Hydro projects

Site A (48 kW)

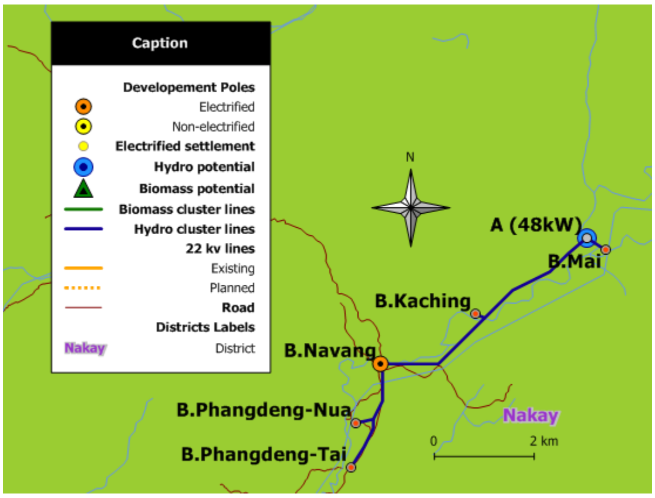


Figure 31: Cluster built from hydro site A

Levelized cost of kWh is almost the same in both isolated and grid-integrated configuration.

But depending on funds availability, connecting the cluster to the grid would enable to satisfy the 18% of the demand that the hydro power plant could not assume over the planning period.

Site A card	***Mode***	**Isolated**	**Grid integrated**
▪ Power: 48 kW	kWh levelized cost	0.26 $/kWh	0.24 $/kWh
▪ Settlements: 5	MV lines length	8.4 km	36.9 km
▪ Population: 836	Investment (year 1 & 2)	563 240 $	1 257 408 $
▪ Dev. Poles supplied: **B.Navang**	% of the demand not satisfied over the planning period	18%	0%

Site B (122 kW)

When looking at things on a rural electrification point of view, relevancy of exploiting site B could be discussed as villages that could benefit from it are located close to existing MV lines, and should be therefore connected to the grid in the foreseeable future. However, MV lines are ending in this region (Eastern part of the province), with high voltage losses, and low available capacity. Site B could represent an opportunity to partly offset MV lines voltage losses by injecting power into the grid (net-metering), with a levelized cost of kWh much more attractive (0.10 $/kWh compare to 0.24 $/kWh in isolated mode) .

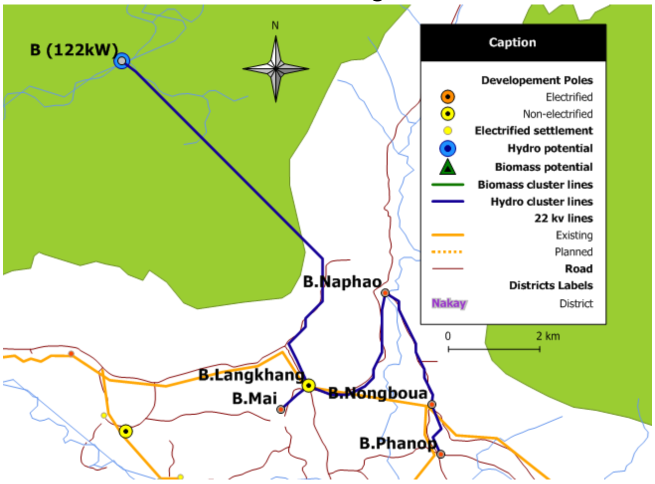


Figure 32: Cluster built from hydro site B

<table>
<tr><td rowspan="5">Site B card
▪ Power: 122 kW
▪ Settlements: 5
▪ Population: 1 774
▪ Dev. Poles supplied: none</td><td>Mode</td><td>Isolated</td><td>Grid integrated</td></tr>
<tr><td>kWh levelized cost</td><td>0.24 $/kWh</td><td>0.10 $/kWh</td></tr>
<tr><td>MV lines length</td><td>17.7 km</td><td>17.7 km *</td></tr>
<tr><td>Investment (year 1 & 2)</td><td>1 187 504 $</td><td>2 180 210 $</td></tr>
<tr><td>% of the demand not satisfied over the planning period</td><td>16%</td><td>0%</td></tr>
</table>

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

<u>Site C (384 kW)</u>

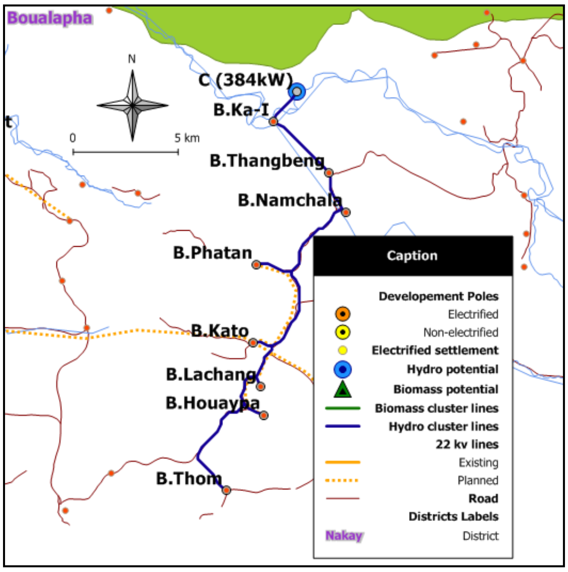


Figure 33: Cluster built from hydro site C

Site C should definitely be considered as an opportunity for net-metering. Required investment for grid-integrated configuration is almost exactly the same than in isolated mode (slightly increased because of the needed connexion protections), as the Cluster crosses a planned MV lines, with a levelized cost of kWh much more attractive. Moreover, the hydro power plant can satisfy the whole demand of targeted villages by the planning horizon, for which peak demand will not reach the estimated capacity by 2020, allowing to continuously inject power into the grid. As Site B, Site C is an opportunity to partly offset MV lines voltage losses in South-East of the province.

<table>
<tr><td rowspan="5">Site C card
▪ Power: 384 kW
▪ Settlements: 8
▪ Population: 1 014
▪ Dev. Poles supplied: none</td><td>Mode</td><td>Isolated</td><td>Grid integrated</td></tr>
<tr><td>kWh levelized cost</td><td>0.64 $/kWh</td><td>0.04 $/kWh</td></tr>
<tr><td>MV lines length</td><td>29.5 km</td><td>29.5 km*</td></tr>
<tr><td>Investment (year 1 & 2)</td><td>2 160 210 $</td><td>2 170 210 $</td></tr>
<tr><td>% of the demand not satisfied over the planning period</td><td>0%</td><td>0%</td></tr>
</table>

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

Site E (78 kW)

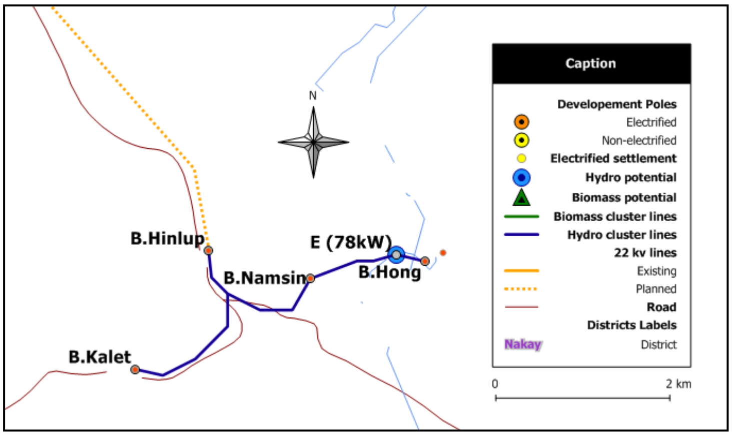


Figure 34: Cluster built from hydro site E

Same observations than for Site C can be made. Cluster built from Site E is in the vicinity of a planned MV lines and grid-integrated configuration should be considered (villages 100% demand would be satisfied by the power plant by 2020, with a capacity still above the peak demand at the end of the planning horizon).

Site E card	*Mode*	Isolated	Grid integrated
▪ Power: 78 kW	kWh levelized cost	0.31 $/kWh	0.05 $/kWh
▪ Settlements: 4	MV lines length	4,8 km	4,9 km
▪ Population: 526	Investment (year 1 & 2)	494 714 $	506 144 $
▪ Dev. Poles supplied: none	% of the demand not satisfied over the planning period	0%	0%

Site D (168 kW)

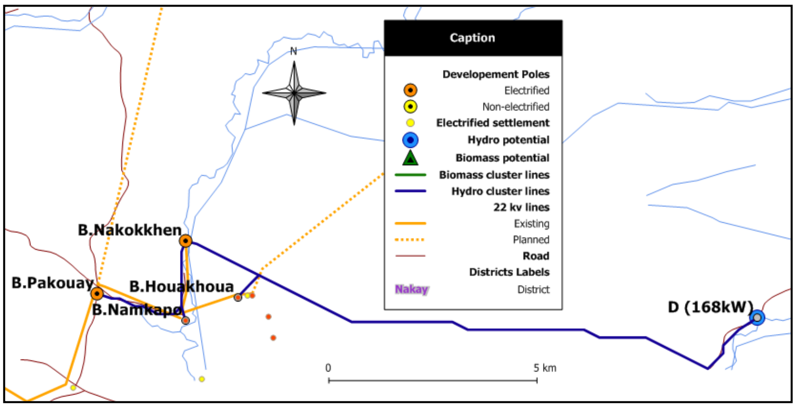


Figure 35: Cluster built from hydro site D

Site D should also be considered in gird-integrated configuration to both satisfy the 8% demand that the hydro power plant could not supply over the planning period and inject excess electricity into the grid when possible.

Site D card	*Mode*	Isolated	Grid integrated
▪ Power: 168 kW	kWh levelized cost	0.25 $/kWh	0.08 $/kWh
▪ Settlements: 4	MV lines length	19,8 km	19,8 km*
▪ Population: 1 864	Investment (year 1 & 2)	1 384 834 $	1 394 834 $
▪ Dev. Poles supplied: **B.Nakokkhen + B.Pakouay**	% of the demand not satisfied over the planning period	8%	0%

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

6.3.2 Biomass projects

Results are presented in synthetic form. Detailed results are provided in Appendix.

Site A (99 kW)

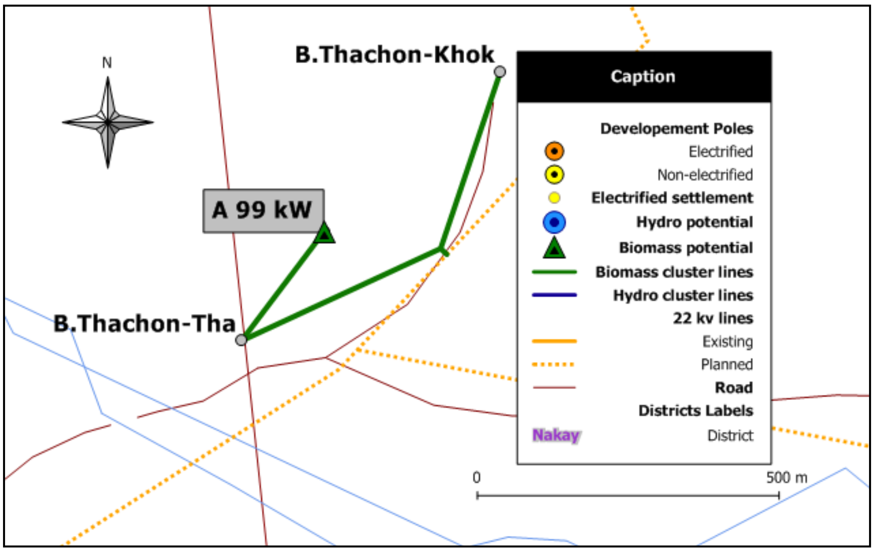


Figure 36: Cluster built from biomass site A

Integrating the site to the grid would imply increasing the investment cost only by 10 000$, as the site is close to the main grid. However, as all energy produced could be placed on the grid, the levelised cost will be reduced to 0,09 $/kW.

Site A card	***Mode***	**Isolated**	**Grid integrated**
▪ Power: 99 kW ▪ Settlements: 2 ▪ Population: 543 ▪ Dev. Poles supplied: none	kWh levelized cost	0,41 $/kWh	0,09 $/kWh
	MV lines length	0,9 km	0,9 km*
	Investment (year 1 & 2)	308 k$	318 k$
	% of the demand not satisfied over the planning period	0 %	0 %

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

Site B (67 kW)

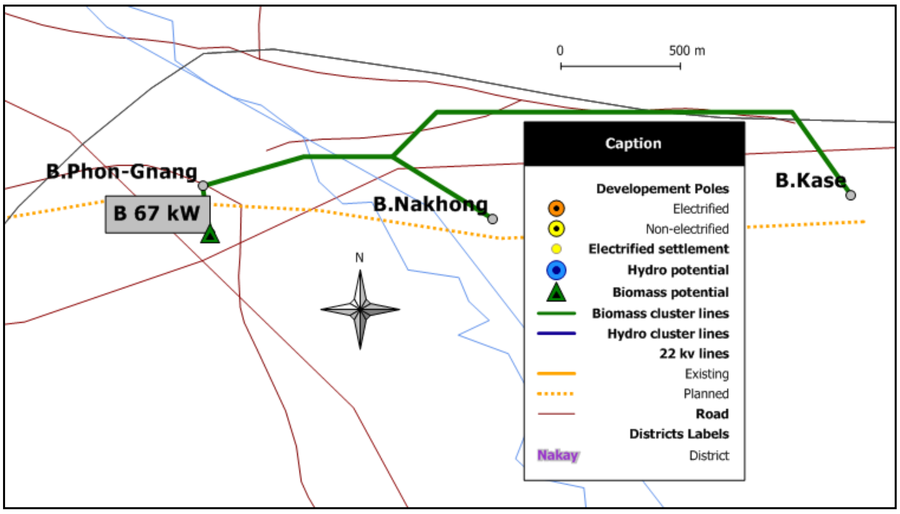


Figure 37: Cluster built from biomass site B

Integrating the site to the grid would imply increasing the investment cost only by 10 000$, as the site is close to the main grid. However, as all energy produced could be placed on the grid, the levelised cost will be reduced to 0,11 $/kW.

Site B card ▪ Power: 67 kW ▪ Settlements: 3 ▪ Population: 625 ▪ Dev. Poles supplied: none	***Mode***	**Isolated**	**Grid integrated**
	kWh levelized cost	0,36 $/kWh	0,11 $/kWh
	MV lines length	3,7 km	3,7 km*
	Investment (year 1 & 2)	359 k$	369 k$
	% of the demand not satisfied over the planning period	2 %	0 %

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

Site C (19 kW)

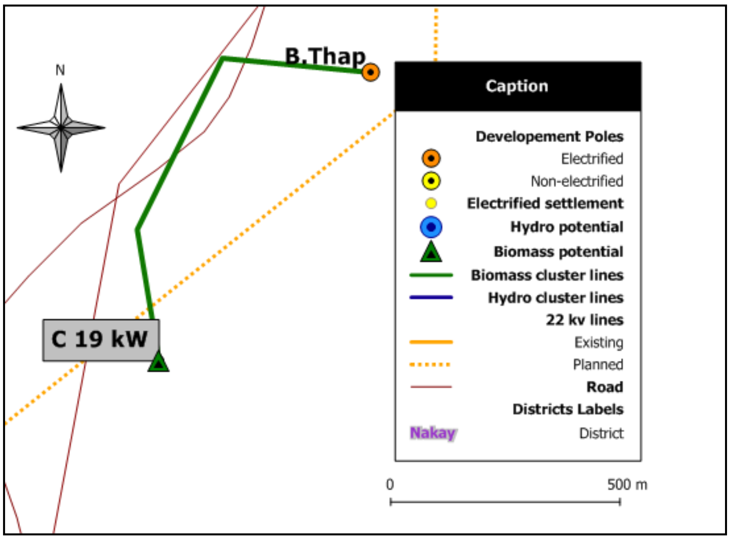


Figure 38: Cluster built from biomass site C

In the case of site C again, grid integration would only cost an additional 10 000$ with the advantage of reducing levelised cost to 23 cents / kWh, for the same reasons as above. Regarding the very low capacity of the site and therefore the percentage of demand not satisfied over the planning period, this project is not recommended in isolated mode.

Site C card ▪ Power: 19 kW ▪ Settlements: 1 ▪ Population: 658 ▪ Dev. Poles supplied: **B.Thap**	***Mode***	**Isolated**	**Grid integrated**
	kWh levelized cost	0,32 $/kWh	0,23 $/kWh
	MV lines length	1 km	1 km*
	Investment (year 1 & 2)	245 k$	255 k$
	% of the demand not satisfied over the planning period	73 %	0 %

* same value than in isolated mode since the cluster is crossing an existing or planned MV line

Site D (32 kW)

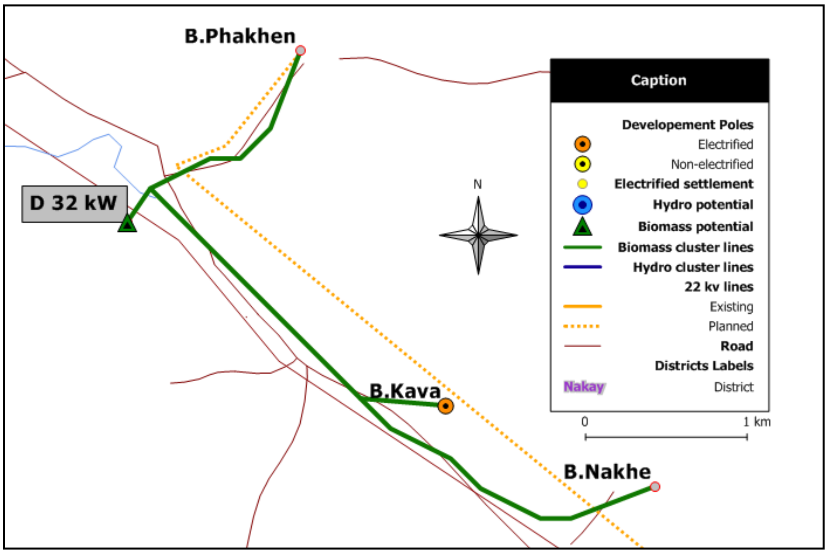


Figure 39: Cluster built from biomass site D

Integrating site D to the grid would increase the investment cost by 10 000$ with the advantage of reducing levelised cost to 23 cents / kWh, for the same reasons.

<table>
<tr><td rowspan="5">Site D card
▪ Power: 32 kW
▪ Settlements: 3
▪ Population: 896
▪ Dev. Poles supplied: B.Kava</td><td>Mode</td><td>Isolated</td><td>Grid integrated</td></tr>
<tr><td>kWh levelized cost</td><td>0,36 $/kWh</td><td>0,23 $/kWh</td></tr>
<tr><td>MV lines length</td><td>6,1 km</td><td>6,1 km*</td></tr>
<tr><td>Investment (year 1 & 2)</td><td>430 k$</td><td>440 k$</td></tr>
<tr><td>% of the demand not satisfied over the planning period</td><td>36 %</td><td>0 %</td></tr>
</table>

All the biomass projects identified are located close to planned MV lines. These potential sites could therefore be exploited as rural supply plants for the above listed villages until MV lines are commissioned. As for some hydro projects, net-metering would be then after a crucial issue to address to increase available capacity on the national grid or ensure energy back-up on for the biomass cluster.

6.4 What about remaining villages?

The identified projects would benefit to 48 villages, meaning that still 239 villages of the province remain without any supply solution.

Biomass settlements	**15**
Hydro settlements	**33**
Remote settlements	**239**

Table 20: Targeted and remote villages

PV technology is getting more and more widespread in Lao PDR[21] and could be an option for those villages. However, beneficiaries issue must be addressed: should households or community infrastructures be targeted first? Should the available funds not be very high, priority could be given to community infrastructures in the perspective of offering access to modern social services to all the population, without geographic distinction.

[21] For example, the Village Off-Grid Promotion and Support (VOPS) project has installed 3 750 Solar Home Systems (SHS) since March 2006. 5 750 additional systems are planned.

7 Conclusion

Results presented in this report highlight a common view of both countries regarding electrification development:

(i) carry out grid extension, depending on available investments

(ii) priority to renewable resources in areas not targeted by the grid

In many cases, integrated mode appears to be the best option to take the most advantage of local resources while offering the possibility to inject excess electricity into the grid. This configuration will obviously require from local authorities to set up power purchase modalities, that should facilitate private operators emergence.

Data bases on which rely the results presented here should be updated regularly, necessitating from technicians trained on GEOSIM© use to launch new simulation to update also planning results. These technicians are now in a position to replicate the approach to other provinces of Cambodia and Lao PDR.

The results provide possible guidelines and tools for policy makers to make their decisions in terms of access to the grid for renewables, purchase tariffs, ...

8 Appendix 1 – Changes since mid-term workshop

CAMBODIA

1. Main Parameters

	Previous value	Updated value
Households / km LV line	300	150
Population growth rate	2.5%	1.8%
Technical losses	20%	17%
Population classes*	3	4

*Additional class: very poor class

- income: < 1$ / day
- weight of 4th class: 34% in 2009, 25% in 2020 /
- 2009 consumption: 8kWh/month
- 2009 peak demand: 75W

2. Scenario 1

➔ *extension phases*

HV Lines from Vietnam in 2010

- Phase 1: 2009 – 2010
- Phase 2: 2011-2015
- Phase 3: 2016-2020

➔ *MV lines commissioning dates*

- Ponhea Kraek to Skun via Kampong Cham 2010
- Skun (Cheung Prey) – Phnom Penh (South West) 2016
- Kampong-Cham – Kratie (North East) 2016
- Kampong Cham to the North along the river to Stueng Trang 2016
- Kampong Cham to the South along the river to Srei Santhor 2016

LAO PDR

- Number of households per km of LV line: 23 ➔ 30
- Study of the possibility to connect hydro and biomass projects to MV network

9 Appendix 2 – Kampong Cham

9.1 Socio-economic parameters

TECHNICAL PARAMETERS		
General		
Population year census	2 006	
Population Annual Growth	2.50%	
Number of people / Household	5.7	
Economics		
Discount rate for Economic analysis	10%	
Discount rate for Financial analysis	9.5%	
Foreign inflation rate	4.50%	
Local inflation rate	4.00%	
Power purchase price from Utility in base year	0.15	$US/kWh
Willingness to pay in base year	0.6	$US/kWh
Diesel		
Specific fuel consumption	0.33	l/kWh
Diesel genset and hydro losses	10%	
Genset safety margin	10%	
Maximum lifetime for all machines	5	years
Annual Diesel fixed O & M cost ratio	4%	
Maintenance discount ratio	10%	
Fuel transportation cost to	1.64%	$US/l
Fuel delivery cost per liter	0.02	$US/l
Diesel price (including VAT, taxes…)	164.85	$US/bbl
Hours of demand per day	10	h/day
Hydro		
Hydro equipments	3 000	US$/kW
Lifetime of SHP	30	years
Annual SHP O&M cost ratio	2%	
Use of Backup	YES	
Hours of Demand	24	h/day
Biomass		
Biomass equipments	1 350	US$/kW
Annual Biomass O&M cost ratio	10%	
Specific heavy fuel consumption	0.33	l/kWh
Heavy fuel price (including VAT, Taxes…)	83.46	US$/bbl
Use of backup		
Hours of demand per day	24	h/day
Local network		
Numbre of households/LV line km	300	
Internal settlements MV/LV length	10%	
MV distance coefficient	20%	
LV line km cost/km	15000	US$
MV line km cost/km	20000	US$
Low capacity meter price	50	US$
High capacity meter price	5000	US$
Lifetime of LV line	30	
Lifetime of MV line	30	
Lifetime of transformer	30	
System LV OM annual cost	0.5%	
MV OM annual cost	0.5%	
Transformer OM cost	0.5%	
Grid network		
Extension Grid Network		
HV system grid extension cost	20%	
Average MV line cost per km	20 000	
Cluster Network Connection		
Network Connection Cost	10 000	$US
Network Connection life time	30	Years
Network Connection O&M cost ratio	2%	

Miscellaneous		
Peak hours per day (/24)	4	hours
Average Annual personnel salary	120	$US
Operating cost ratio	50%	
Power house cost	15000	$US
Lifetime of power house	30	Years

Appendix 3 – Khammuane

9.2 Annex1: socio-economic parameters

SCENARIO PARAMETERS		
General		
Planning duration	12	years
Hydro & Biomass Cluster limit	30	km
TECHNICAL PARAMETERS		
General		
Population year census	2 005	
Population Annual Growth	2.20%	
Number of people / Household	6.0	
Economics		
Discount rate for Economic analysis	10%	
Discount rate for Financial analysis	9.5%	
Foreign inflation rate	4.50%	
Local inflation rate	6.00%	
Power purchase price by the Utility		$US/kWh
Power purchase price from Utility in base year	0.150	$US/kWh
Willingness to pay in base year	0.3	$US/kWh
Hydro		
Hydro equipments	3 000	US$/kW
Lifetime of SHP	30	years
Annual SHP O&M cost ratio	2%	
Use of Backup	NO	
Hours of Demand	24	h/day
Biomass		
Biomass equipments	1 350	US$/kW
Annual Biomass O&M cost ratio	10%	
Specific heavy fuel consumption	0.33	l/kWh
Heavy fuel price (including VAT, Taxes…)	83.46	US$/bbl
Use of backup	NO	
Hours of demand per day	24	h/day
Local network		
Numbre of households/LV line km	30	
Internal settlements MV/LV length	10%	
MV distance coefficient	20%	
LV line km cost/km	15 000	US$
MV line km cost/km	20 000	US$
Low capacity meter price	50	US$
High capacity meter price	5 000	US$
Lifetime of LV line	30	years
Lifetime of MV line	30	years
Lifetime of transformer	30	years
System LV OM annual cost	0.5%	
MV OM annual cost	0.5%	
Transformer OM cost	0.5%	
Miscellaneous		
Peak hours per day (/24)	4	hours
Average Annual personnel salary	211	$US
Operating cost ratio	50%	
Power house cost	15 000	$US
Lifetime of power house	30%	years