REDEO
RURAL ELECTRIFICATION
DECENTRALIZED ENERGY OPTIONS

EC-ASEAN Energy Facility
Project Number 24

REPORT FOR ACTIVITY 4

APPLICATION OF THE REDEO TOOL TO THE KAMPONG SPEU PROVINCE IN CAMBODIA

JULY 2005

Disclaimer

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1 Objectives of the REDEO case study on Kampong Speu Province

The objective of this case study is neither to provide a definitive masterplan for rural electrification nor to define projects that should be implemented or cancelled. It is only to gather in a same study indicators on potential projects. The systematic approach of REDEO permit to consider all options: thermal or renewable, centralized or decentralized… But more analysis on more data would be necessary to build a true electrification masterplan.

The final outputs of this case study are projects, about which we give the following elements:

- investment cost
- number of persons supplied
- life-cycle cost of kWh
- other indicators on impact on development and environment.

Whereas energy policy in Cambodia is based on private sector, our analysis is often lead from a public point of view. The global life-cycle cost of kWh (total investment, operation and maintenance discounted costs divided by number of kWh sold all over a computation period), which is often used in our studies, illustrates this logic. We do not focus on profits, but on the best way to reach an objective: a large electrification rate in Kampong Speu Province by year 2020.

However, this approach is totally consistent with a policy based on private investment in so far that it can define some areas where private sector must be encouraged and other areas where a public management is more advantageous.

As we focus on a public approach, this study doesn't take existing REEs into account, neither do anyway some national policies concerning grid extension.

2 CLUSTERING

2.1 Objective of the module

The REDEO approach is to contribute to sustainable development by providing electricity in the zones where it is the most needed and the most relevant. Thanks to several indicators such as population, education and health facilities, employment and road access, the tool compute a so-called “Index of Potential for Development” (IPD) for each locality. According to this Potential of Development and to other criteria defined by the user (administrative situation, minimal size of population), the tool defines the Centers with High Potential for Development (CHPD).

All the other localities (OL, meaning “not CHPD”) situated in the neighborhood of a CHPD are clustered with it. The notion of “neighborhood” is defined as follows: each OL is clustered with the nearest CHPD, if the distance is inferior to a maximal distance given as input by the user. Then a cluster of villages is considered as a point. The tool works at the cluster scale.

Classic electrification scenarios focus on the most profitable areas or only follow main roads. This way is likely to increase the gap between developed and less developed or remote localities. The definition of CHPDs is a way for the user to define differently the target areas. In the “electrification scenarios” module, this study aims at supplying all the clusters defined by the CHPDs. The selection process of CHPDs is thus a way to reach land use planning objectives.

2.2 Definition of CHPDs

The Index for Potential for Development (IPD), is based on the Human Development Index (HDI).

The Human Development index is composed by three indicators:

- One health indicator: life expectancy
- One education indicator: composed by literacy rate and rate of children going to school
- One economical indicator: growth internal product per inhabitant.

For each of these three indicators, a number between 0 and 1 is given, so that the repartition of the values taken by each country is correct and occupied the whole interval. For example for the life expectancy a country gets 1 if its life expectancy is 85 years, it gets 0 if it is 25 years. For GIP per inhabitant, it gets 1 if log(GIP/inh)=log(40000) and it gets 0 when log(GIP/inh)=log(100) with a logarithmic scale (in order to have a good repartition).

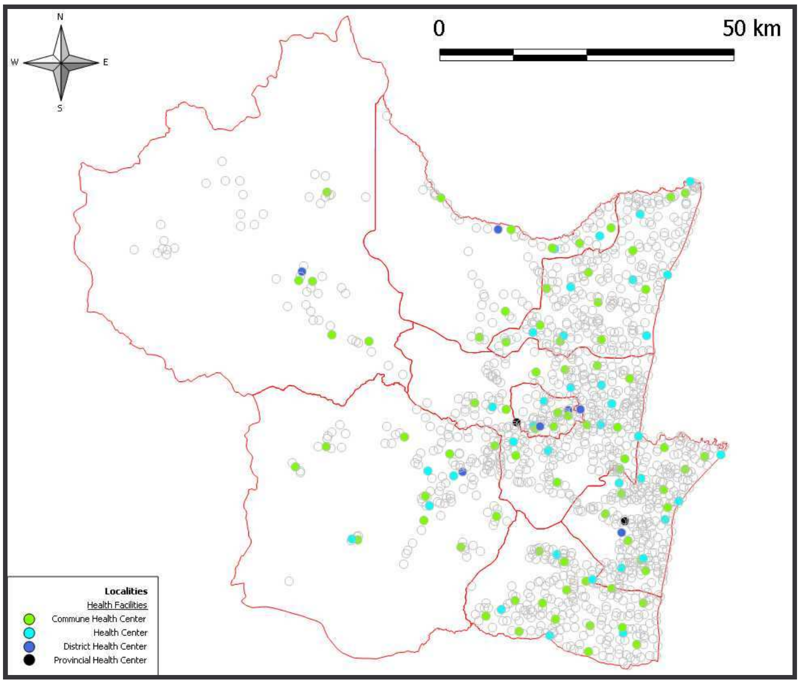
Then the HDI of a country is the arithmetical average of these three index.

We adapted this indicator to frequently available data at the locality scale in South-East Asia. In REDEO tool in general, the user have the possibility to accept predefined criteria for PDI or to define himself an indicator based on available data.

For Kampong Speu Province, our IPD is based on the following aspects:

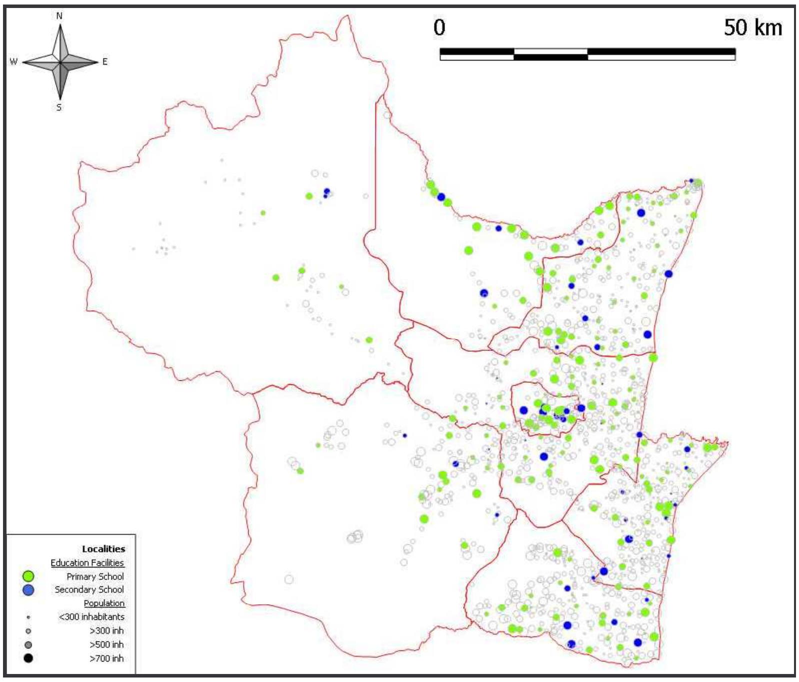
- health
- education
- accessibility
- employment rate

- **health**: our GIS database gives for each locality if it has a health center and what kind it is: Province hospital, Referral hospital, Operationnal District, District hospital, Health Center Communal Health Center or nothing. Concerning health, the computation of IPD doesn’t take other elements into account such as the number of beds or of doctors because these data are not frequently available or such as life expectancy because this has no meaning at the locality scale…



Map 1: Health infrastructures in Kampong Speu Province

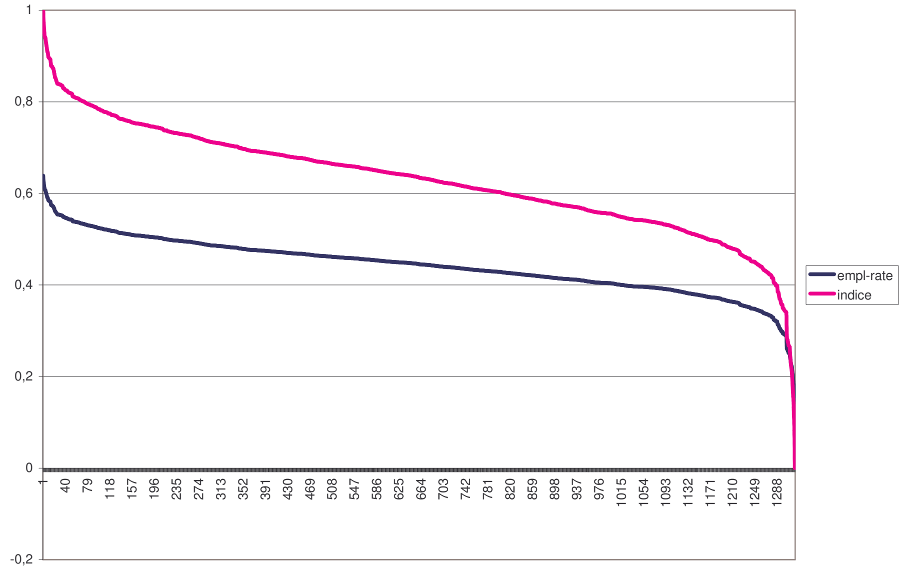
- **education**: For each locality, the GIS database says if it has a secondary school, a primary one or nothing. We used this indicator, whereas lots of others were available, such as literacy rate, rate of people having gone to school, etc… We consider only the presence of schools because it is an indicator available everywhere and because it reveals an important role of the locality in the neighborhood.



Map 2: actual and planned primary and secondary schools in Kampong Speu Province

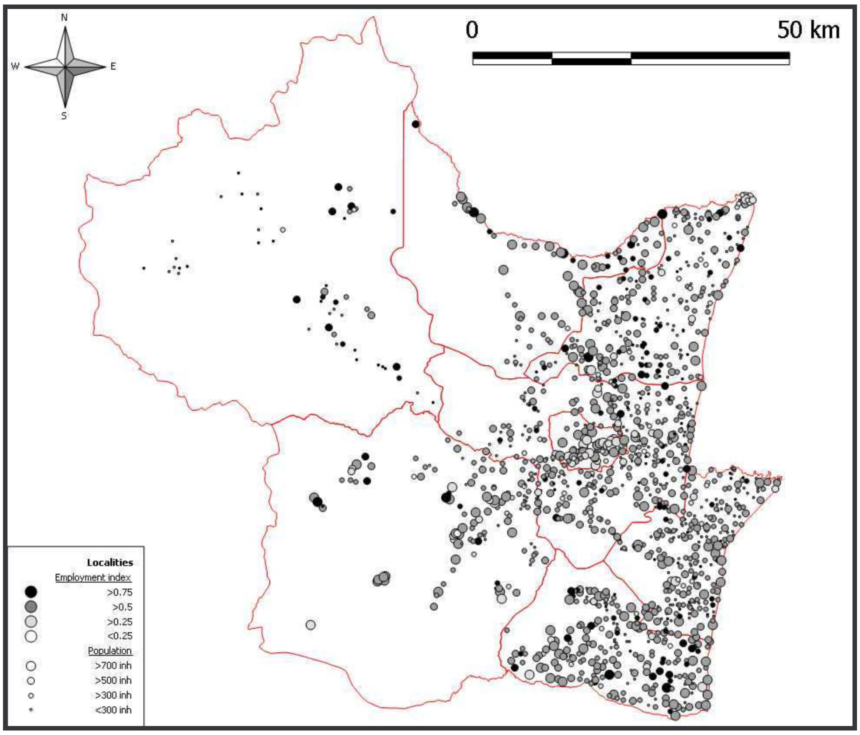
- **employment rate :** We use figures from the WinR+ databasen that comes from last national census (200). For each locality, it gives the number of employed people, which we divide by the population of the locality. Obtained rates go from 0.2 to 0.6. We translate those figures as explained in the following figure to get indexes from 0 to 1.

Figure 1: economical index in function of employment rate of the locality



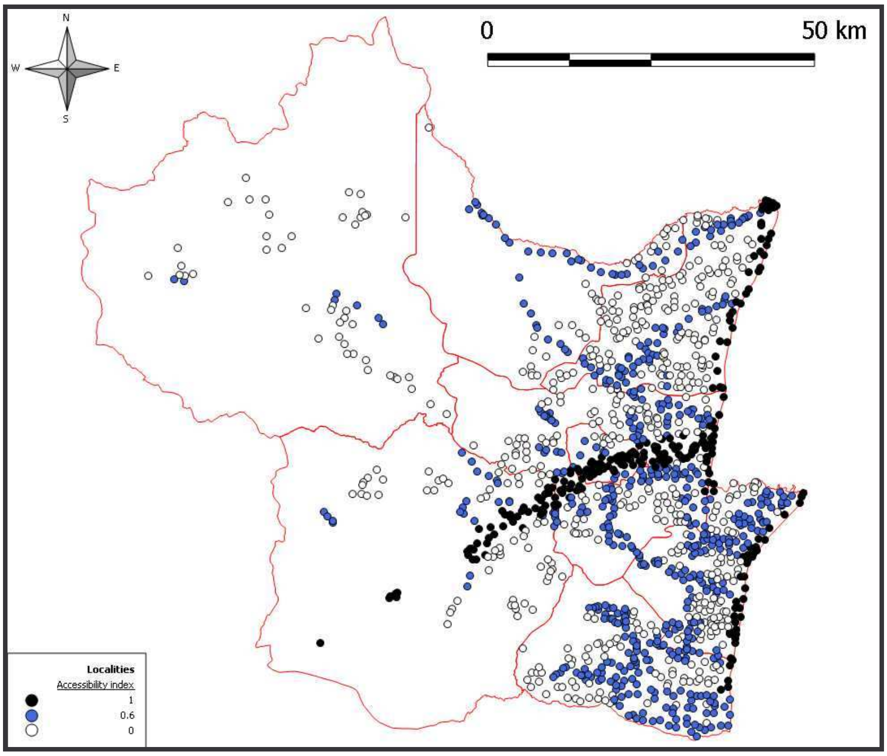
It means that a locality with an employment rate of 50% in our database will get an index around 0.75.

The employment rate component of our IPD for Kampong Speu Province is as follows:



Map 3: Employment index for Kampong Speu Province

- **accessibility**: We found important to take access conditions into account, as it is an economical factor of development and as electrification and maintenance of a system are easier to do in a reachable locality. One GIS layer concerns roads in Kampung Speu Province. The database gives the type of each road. We consider villages situated on main roads, as explained in table 5:



Map 4: accessibility index

The IPD used for this case study is based on the following data:

Health infrastructure	index	nb of localities
Province hospital	1	1
Referral hospital	1	1
Operationnal District	0,8	1
District hospital	0,8	7
Health Center	0,6	36
Communal health center	0,4	74
nothing	0	1199

Education infrastrucure	index	nb of localities
Secondary school	1	31
Primary school	0,6	207
nothing	0	1081

Road	index	nb of localities
hard surface or two lanes	1	231
loose surface road	0,6	537
no permanent road	0	551

Map 5: Coefficients for IPD computation in Kampong Speu Province

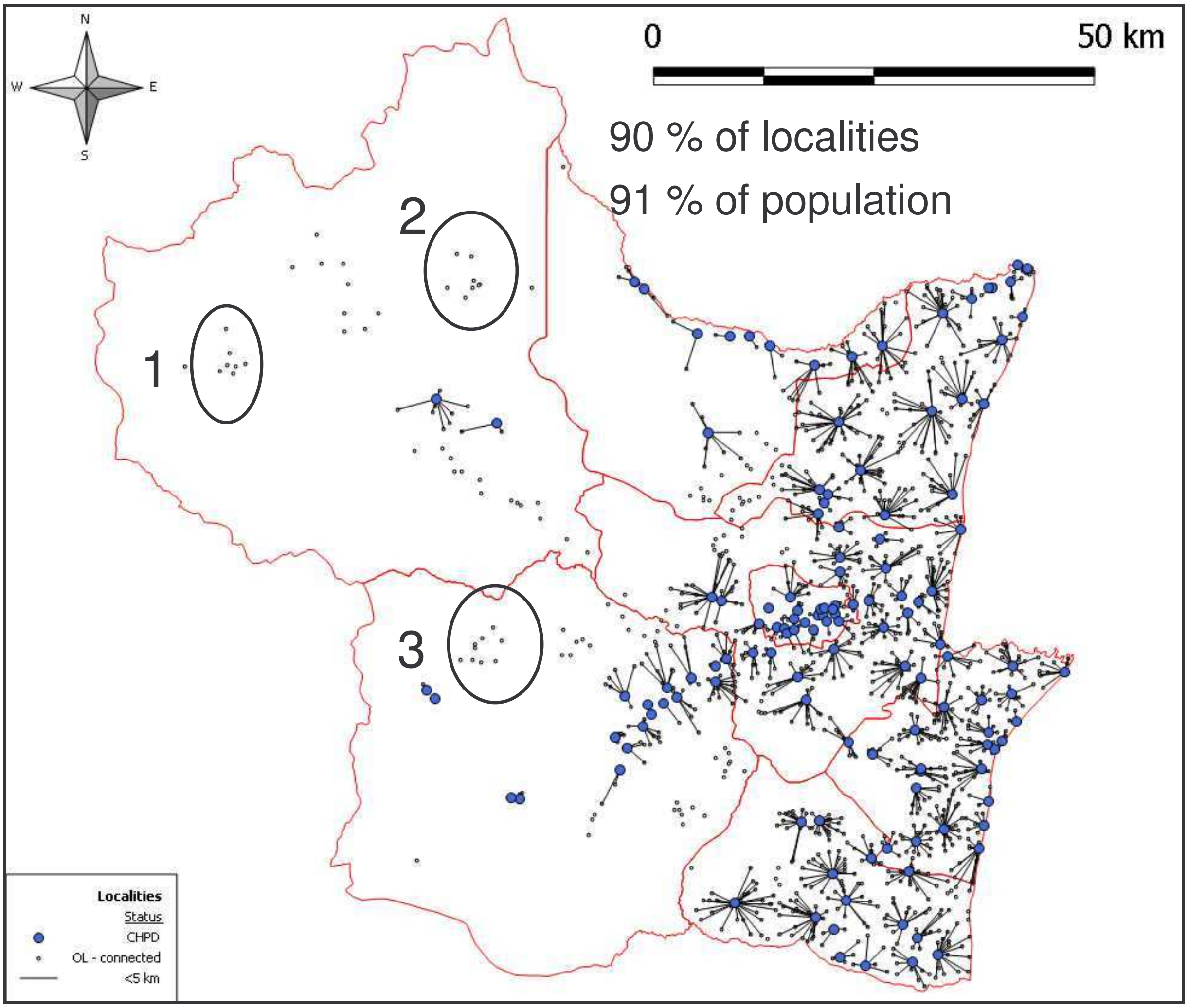
The IPD is the arithmetical average of these four index values (health, education, employment, accessibility).

After having computed IPD, the tool gives to the 10% localities with highest IPD the status of CHPD. As Kampong Speu Province counts 1319 localities, 132 localities are CHPDs. Then each other locality (OL) is linked to the nearest CHPD, if it is closer than a **cut-off distance : 5 km**.

2.3 Results, remarks and improvements

2.3.1 First results

The following map presents the first results:

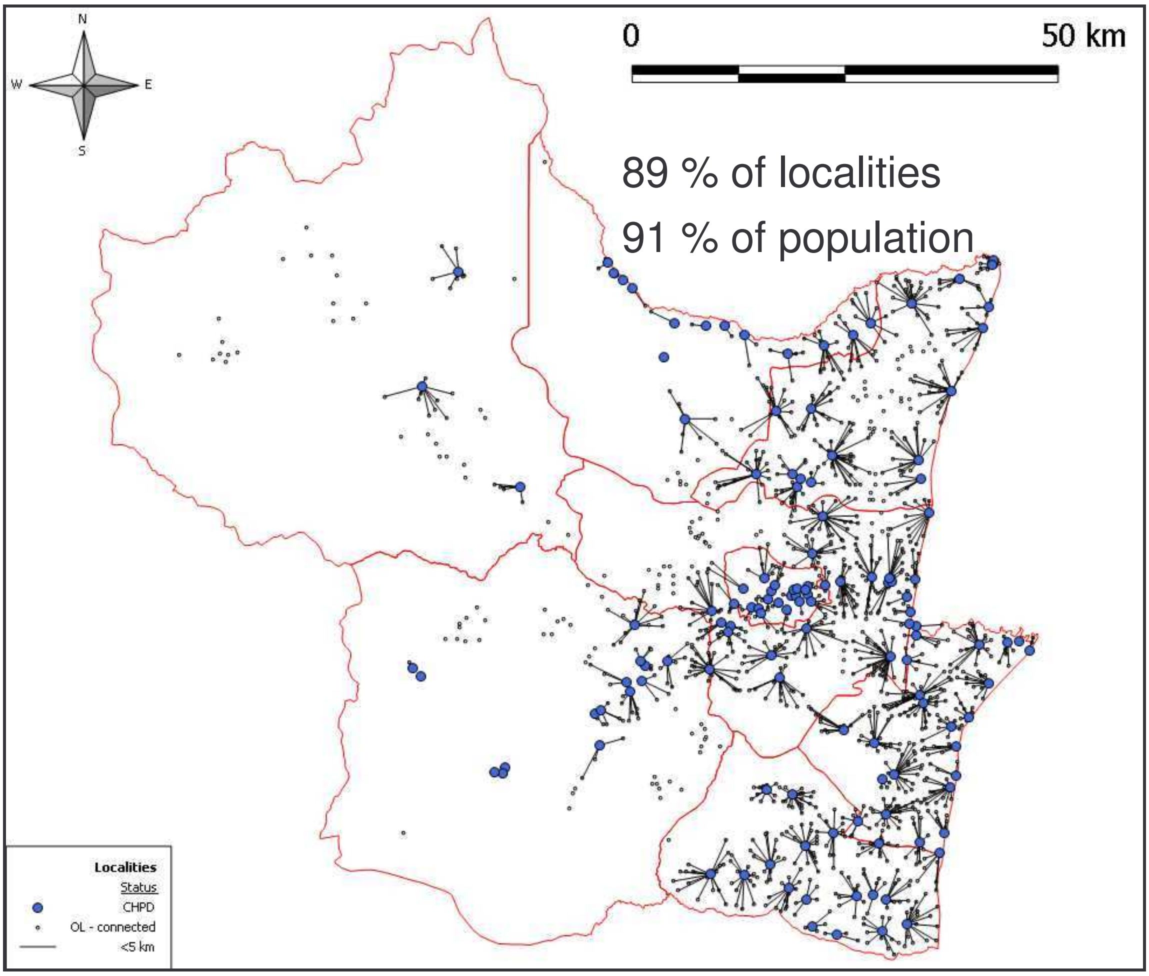


Map 6: First clustering with cut-off distance of 5 km

- The repartition of CHPD is interesting. In this example, the population of CHPDs (10% of localities) represents only 14% of the Province total population, but the rate of population situated at least at 5 km of a CHPD is 91%.
- The spatial repartition is not very satisfying. The western part of the province is very poorly considered.
- Of course, it is possible for the user to choose manually new CHPDs, for example in areas 1, 2 and 3. But we can also improve the selection process of CHPDs in order to have a better repartition. That is what is done in next paragraph.

2.3.2 Only big localities are CHPDs

First, one population criteria is added: each locality that counts less than 500 inhabitants can not be a CHPD. The following situation is thus obtained:

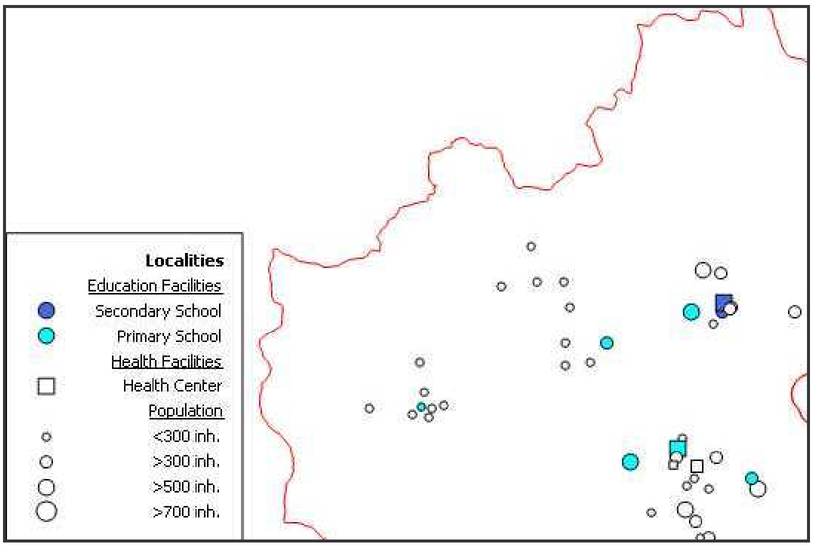


Map 7: Clustering - CHPD have more than 500 inh., cut-off distance=5km

The changes are not very important. The same population is concerned (91%). The repartition is better.

2.3.3 "Agglomerations" improvement

Figure 2: north-western area



A zoom on the north-western part of the Province reveals the presence of clusters of villages representing a relatively important population (around 1000 people in each cluster) and health or educational facilities in a cluster but not all in the same village. These "natural" clusters are not selected by our process because any village alone has not enough infrastructures to be selected as a CHPD. This is a problem that is likely to occur frequently, health infrastructures for example are often built in the outskirts of a locality.

To answer this problem, before computing IPDs, we can use a preliminary algorithm that aggregates localities when they are very close. (eg 1 km)

This algorithm has a double aim:

- To avoid that an important group of very close localities has no CHPD.
- To take infrastructures located in the outskirts of a locality into account.

The objective is not to consider a group of close localities as a single big locality, which would considerably and artificially change the repartition of CHPD.

For each "natural cluster" of localities (defined such as distance to the nearest locality is lower than 1 km), we give to the group biggest locality the added characteristics of the group's localities (addition of health and education index, average of economical index, maximum of access index). Thus this biggest locality have more chance to be selected as a CHPD… Then, after selection of CHPDs, we cancel these modifications.

The following figure gives an example of this approach: A, B, C, D and E are localities forming together a "natural" cluster. A is the biggest of these localities.

Initial Situation (all these localities are very close)

	Education	Health	Eco	Acces	Pop	IPD
A	0,6	0	0,35	0	251	0,95
B	0	0	0,24	1	236	1,24
C	0,6	0	0,32	0	75	0,92
D	0	0,6	0,35	0,6	110	1,55
E	0	0	0,68	0	68	0,68
Global IPD if the localities were considered as one:						
Agg.	0,6	0,6	0,34	1	740	2,54

Report of the obtained IPD in A's data

A	0,6	0,6	0,34	1	740	2,54
B	0	0	0,24	1	236	1,24
C	0,6	0	0,32	0	75	0,92
D	0	0,6	0,35	0,6	110	1,55
E	0	0	0,68	0	68	0,68

SELECTION OF CHPD

A	CHPD	2,56
B	OL	1,24
C	OL	0,92
D	OL	1,55
E	OL	0,68

or

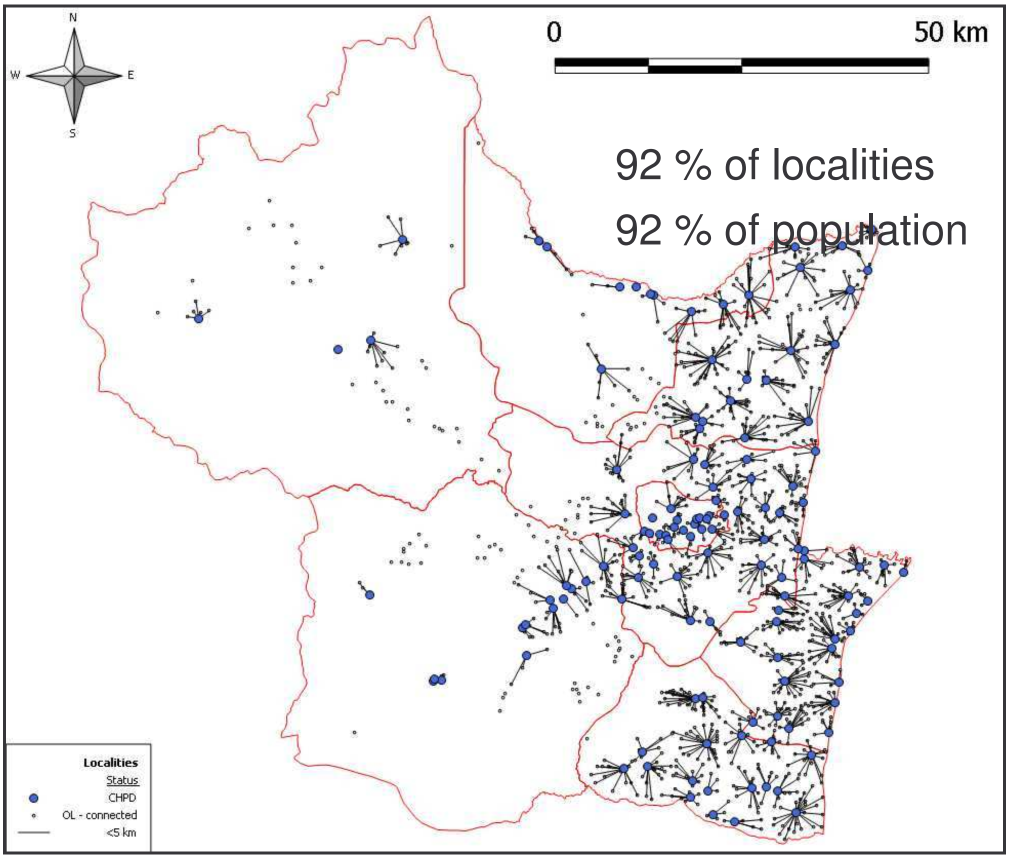
A	CHPD	2,56
B	OL	1,24
C	OL	0,92
D	CHPD	1,55
E	OL	0,68

Return to initial situation for clustering and load forecast

A	0,6	0	0,35	0	251	2,54
B	0	0	0,24	1	236	1,24
C	0,6	0	0,32	0	75	0,92
D	0	0,6	0,35	0,6	110	1,55
E	0	0	0,68	0	68	0,68

The following map presents results obtained by this method.

Figure 3: Clustering with "agglomerations" improvements and pop(CHPD)>500 inh.



The repartition is better. We will consider this situation as initial situation for load forecast and electrification scenarios. Some details on the population concerned by this clustering are given in next part.

3 LOAD FORECAST

3.1 Model and inputs

The model is relatively simple. As said in introduction, the aim of this case study is not to manage a precise analysis of future demand to dimension systems but to obtain figures that corresponds to existing forecasts to make a global analysis.

As no economical analysis is done, we do not focus on tariffs. Our economical indicators are investment costs and life-cycle kWh costs. So only the global values of energy demand are interesting for this study. Consequently, there is no need to build a model based on precise categories of customers.

Furthermore the more a model is complex and supposed to approach reality, the more each parameter has to be carefully studied. We use average values for energy consumption at the locality scale. Thus, as coefficient are rather few, this is easy for the user to adapt them in order to obtain the same results than deeper studies.

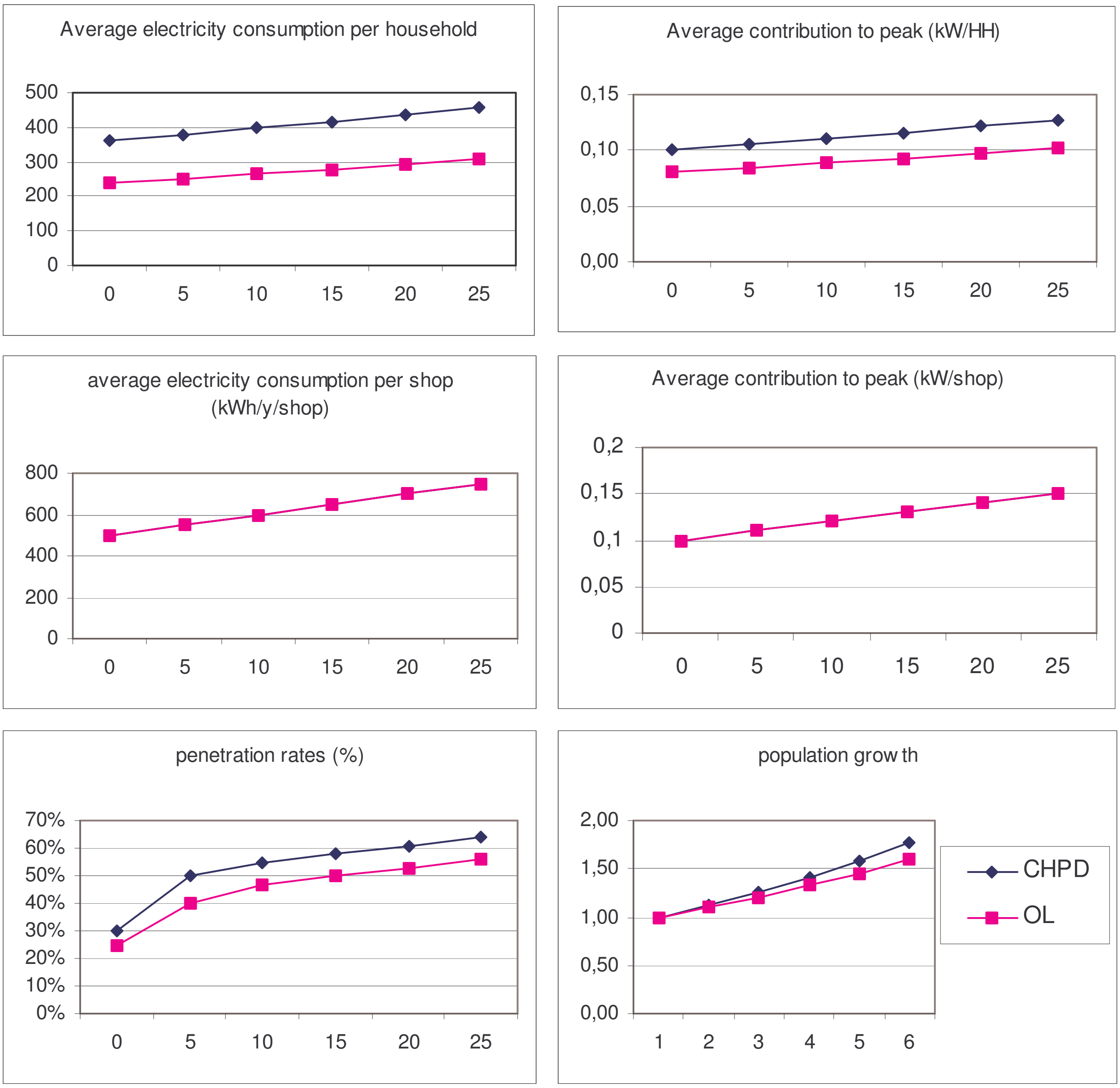
Concerning residential energy consumption, our model is based on average values. Only two categories are considered : people in CHPDs or in OLs. The inputs are presented in next paragraph. Concerning non-residential energy consumption, health and education infrastructures are taken into account. In addition to that, a default value is given for public energy consumption in each locality in function of its status (CHPD/OL).

3.1.1 Residential and small shops load forecast

The parameters used for load forecast in Kampong Speu Province are as follows:

	Parameter	Unit	CHPD	OL
residential	Average electricity consumption by household - year 00	kWh/year/household	360	240
	Average electricity consumption by household - year 05	kWh/year/household	378	252
	Average electricity consumption by household - year 10	kWh/year/household	397	265
	Average electricity consumption by household - year 15	kWh/year/household	417	278
	Average electricity consumption by household - year 20	kWh/year/household	438	292
	Average electricity consumption by household - year 25	kWh/year/household	459	306
	Average contribution to peak demand - year 00	kW/household	0,10	0,08
	Average contribution to peak demand - year 05	kW/household	0,11	0,08
	Average contribution to peak demand - year 10	kW/household	0,11	0,09
	Average contribution to peak demand - year 15	kW/household	0,12	0,09
	Average contribution to peak demand - year 20	kW/household	0,12	0,10
	Average contribution to peak demand - year 25	kW/household	0,13	0,10
	penetration rate - year 00	%	30%	25%
	penetration rate - year 05	%	50%	40%
	penetration rate - year 10	%	55%	47%
	penetration rate - year 15	%	58%	50%
	penetration rate - year 20	%	61%	53%
	penetration rate - year 25	%	64%	56%
	Population growth rate	%	2,30%	1,90%
small shops	Average electricity consumption by shop - year 00	kWh/year/shop	500	500
	Average electricity consumption by shop - year 05	kWh/year/shop	550	550
	Average electricity consumption by shop - year 10	kWh/year/shop	600	600
	Average electricity consumption by shop - year 15	kWh/year/shop	650	650
	Average electricity consumption by shop - year 20	kWh/year/shop	700	700
	Average electricity consumption by shop - year 25	kWh/year/shop	750	750
	Average contribution to peak demand - year 00	kW/shop	0,1	0,1
	Average contribution to peak demand - year 05	kW/shop	0,11	0,11
	Average contribution to peak demand - year 10	kW/shop	0,12	0,12
	Average contribution to peak demand - year 15	kW/shop	0,13	0,13
	Average contribution to peak demand - year 20	kW/shop	0,14	0,14
	Average contribution to peak demand - year 25	kW/shop	0,15	0,15
	Average number of small shops by 100 inhabitants	shops/100 inh	1	0,5
	penetration rate for shops	%	80%	80%

Table 1: Parameters used for residential load forecast and their values



- The average consumption per household and contribution to peak are matching those currently reported by EDC in Kampong Speu Province.
- The number and average consumption of shops are only raw estimates.
- The penetration rate is only expected and corresponds to classic scenarios in developing countries.
- The expected global population growth rate corresponds to forecasts from last census in Cambodia (2000). Different growth rates for CHPDs and OLs have been considered to take population flows from rural to urban areas into account.

3.1.2 Non-residential load forecast

3.1.3 Infrastructures

Public consumptions are computed from data on hospitals, schools and administrative status that we have in the GIS database, and which contain comes from last census (2000).

	Contribution to peak (kW)	Electricity consumption (kWh/y)
Provincial health center	2	7000
District health center	5	17500
Health center	10	35000
Communal health center	20	70000
Classroom	0,1	200
other (for a CHPD)	12,5	35000
other (for an OL)	4	14000

Map 8: Hypothesis for non-residential consumptions

3.1.4 Industrial consumption

REDEO tool gives the possibility to the user to take all other kinds of energy consumption into account. The user has to define a column in the database localities table and to indicate the energy consumptions corresponding to the possible values of this column.

This possibility is really fundament if we consider that electricity is a way to encourage development. Indeed, local industries, that are the basis of local economy, need cheap and good quality electricity services. If we do not consider them for planning electrification, development is seriously checked.

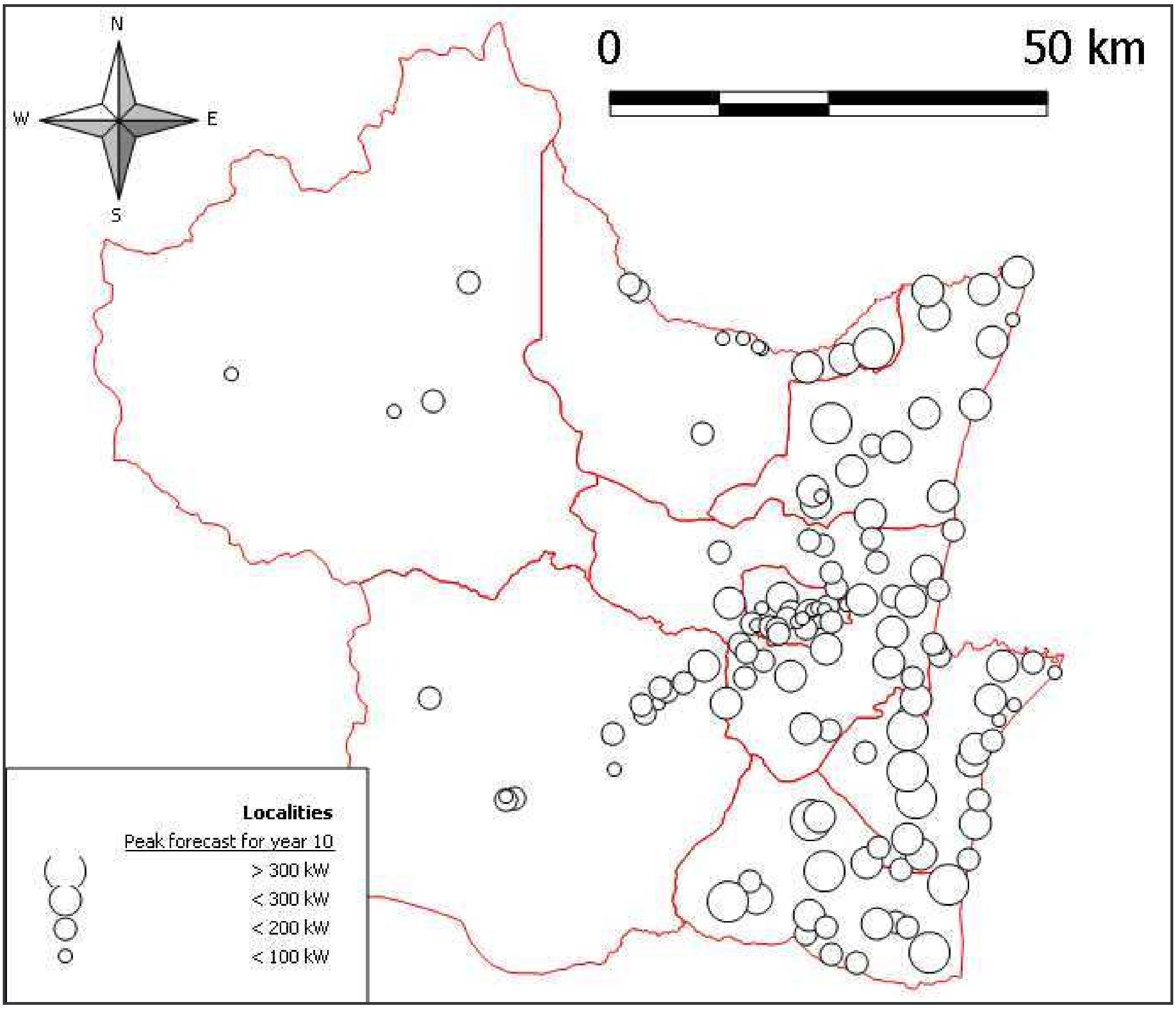
However, this has not been done for this case study by lack of data on small enterprises.

3.2 Results

The obtained figures are not effective values based on electrification scenarios: the peak demand forecast is the **potential peak demand if all the localities of all the clusters are considered**. But they doesn't consider that all households are supplied because a households penetration rate is used to obtain these figures.

Then the load forecast at the cluster level is computed as the sum of the load forecasts in the corresponding localities.

The following map represents the results of clustering and load forecast:



Map 9: Peak demand forecast by year 10

District	Peak Demand forecast (MW)			Energy consumption forecast (GWh/y)		
	year 0	year 10	year 20	year 0	year 10	year 20
Aoral	0,3	0,4	0,5	1,2	1,6	2,1
Basedth	3	4,1	5,3	11,5	15,8	20,6
Chbar Mon	1,5	2,1	2,6	5,8	7,9	10,4
Kong Pisei	3,3	4,2	5,3	12,2	16	20,1
Odongk	2,9	3,9	4,8	11,1	14,7	18,5
Phnum Sruoch	1,4	2	2,6	5,4	7,6	10,1
Samraong Tong	3,8	5	6,2	14,3	18,8	23,7
Thpong	1,1	1,5	2	4,3	6	7,9
TOTAL	**17,4**	**23,2**	**29,4**	**66**	**88,6**	**113,4**

Table 2: Potential load forecast for Kampong Speu Province

The increasing of electricity demand can be explained by three main reasons:

- increasing of penetration rate (around 30% by year 0, around 60% by year 20)
- increasing of average individual energy consumption (+5% per year)
- increasing of population (2.3% per year for CHPDs, 1.9% for OIs)

District	Cluster avg peak demand forecast			Cluster avg population	population concerned	total population	% of pop concerned*
	year 0	year 10	year 20				
Aoral	41	54	67	995	7961	15182	52%
Basedth	90	125	161	3300	108930	106976	102%
Chbar Mon	40	54	69	1225	46566	40680	114%
Kong Pisei	79	103	128	2228	91358	98265	93%
Odongk	95	125	156	2943	91257	98901	92%
Phnum Sruoch	50	70	91	1697	47542	69033	69%
Samraong Tong	80	105	131	2392	112476	117765	96%
Thpong	62	86	111	2178	39215	43260	91%
TOTAL	**67**	**90**	**114**	**2120**	**545305**	**590062**	**92%**

*Rk : As some localities can be connected to a cluster in an other district, some rates can be more than 100%

Table 3: Other data by district

The table reveals that :

- the districts where clusters have the highest average electricity consumption are not the most urban districts (Chbar Mon and Kong Pisei) as we could have expected. This is explained by the fact that in rural areas CHPDs are sparser. Thus each CHPD covers a wider area than in urban districts.
- Six on the eight districts of the Province, representing around 90% of the population, have a very high rate of population in villages concerned by this clustering.
- Around 45000 persons, representing 55% of the population of the Province, are not concerned by this clustering. The main part of these people are in Phnum Sruoch district (21500 people) and Aoral District (7000 people).
- For all these populations, photo-voltaic and pico-hydro systems are particularly relevant, as they are not likely to be electrified by other systems.

District	Peak Demand forecast (W/inhabitant)			Energy consumption forecast (kWh/y/inhabitant)		
	year 0	year 10	year 20	year 0	year 10	year 20
Aoral	38	50	63	151	201	264
Basedth	28	38	49	106	145	189
Chbar Mon	32	45	56	125	170	223
Kong Pisei	36	46	58	134	175	220
Odongk	32	43	53	122	161	203
Phnum Sruoch	29	42	55	114	160	212
Samraong Tong	34	44	55	127	167	211
Thpong	28	38	51	110	153	201
TOTAL	32	43	54	121	162	208

Table 4: Electricity consumption per person

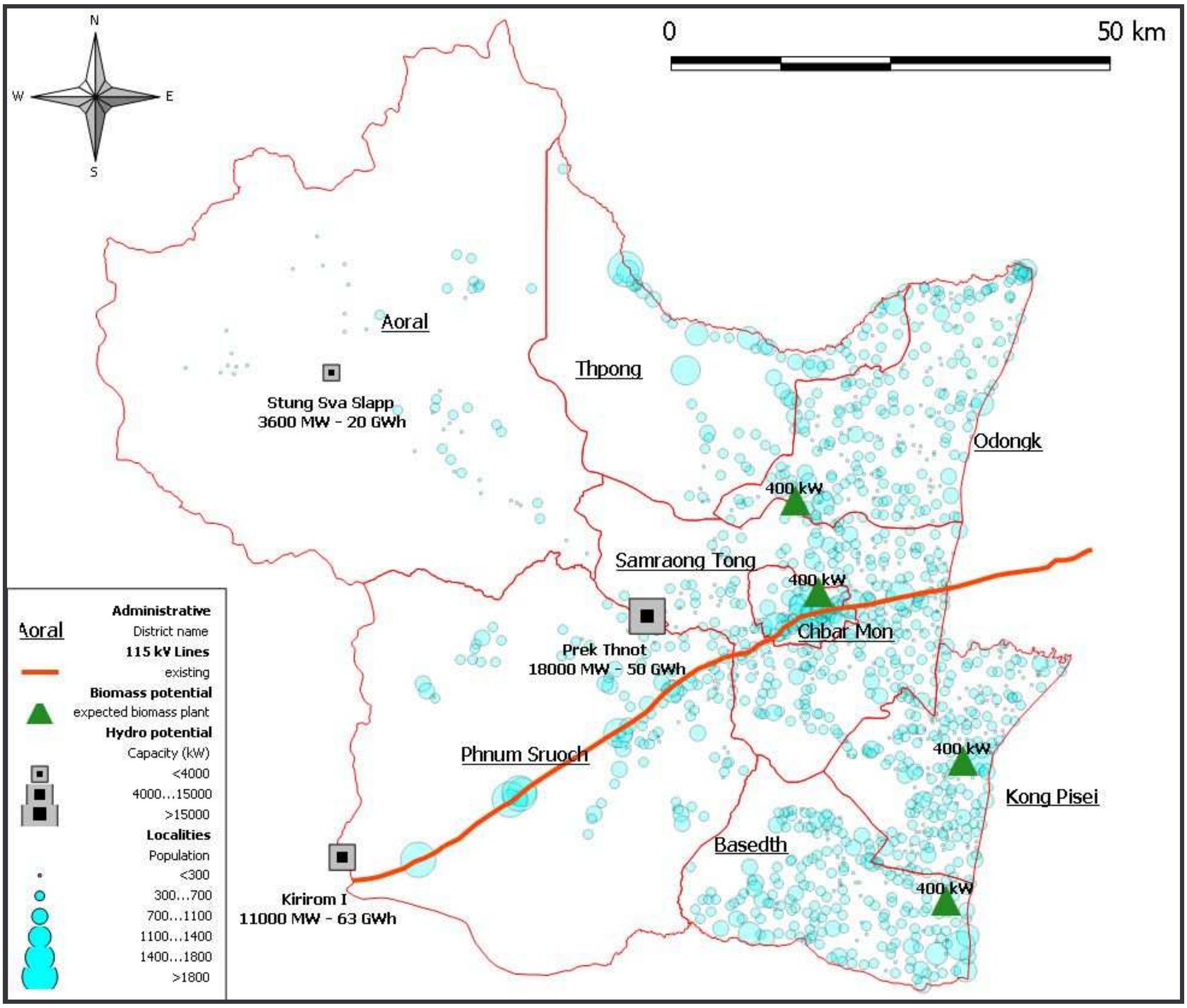
The district with the highest individual energy consumption is Aoral District, whereas it is the most rural district. This can be explained by the following reasons:

- Statistics on Aoral District are maid on a very small sample.
- Localities in Aoral District are very sparse. Consequently, each CHPD is connected to very few localities : one fifth of clustered localities are CHPDs in Aoral District, whereas this rate is around one ninth for the whole province. It doesn't necessary mean that the results are contrary to the reality: we can understand that a CHPD in a rural area have infrastructures that concern a little population. Consequently the energy consumption per inhabitant (which includes public consumptions) can be higher than in urban areas.

After Aoral District, Chbar Mon and Kong Pisei districts with the highest individual electricity consumption forecasts.

4 PRODUCTION OPTIONS

The following map shows our hypothesis for production options in Kampong Speu Province, that are going to be presented in this chapter:



4.1 Main grid installations

4.1.1 Transmission lines

- The only transmission line going through Kampong Speu Province links Kirirom I hydropower plant to Phnom Penh.

4.1.2 Substations

- This case study considers that the 115/22 kV substation in Kampong Speu is commissioned and that no other will be implemented in Kampong Speu Province.

4.1.3 Power availability

- Considering that Kirirom I capacity is about 12 MW and considering that it is mainly built to supply Phnom Penh, we infer that only 2 MW are available to supply Kampong Speu Province.
- We guess that Kirirom II and III will be commissioned by year 2010. This will give 2 MW more available for Kampong Speu Province.
- The total capacity of national grid for Kampong Speu Province by year 2020 considered in this study is: **4 MW**.

4.1.4 KWh from the main grid price

- Power available in Kampong Speu can be produced by different technologies in different places:
  - Produced in Phnom Penh: Electricity production cost is around 8 UScents/kWh in Phnom Penh and 13 UScents/kWh in provincal towns. [1] We consider that the cost of kWh produced in Phnom Penh and available in Kampung Speu is : **9 cents/kWh**.
  - Produced in Kirirom hydro plant: kWh cost is estimated to **2 cents/kWh**, if Kirirom hydropower plant produces 70 GWh/y for an investment cost of 29 M$ and a life duration of 30 years.
  - Imported from Vietnam: If import tariff is around 5 cents/kWh (as said in [2] p15) and if we consider a transport cost of 0.3 cents/kWh and 30% losses, we obtain **7 cents/kWh.**
  - Produced in Kampong Speu: around **10 cents/kWh**.

- As all these costs are very different and as the main part of power produces anywhere is for Phnom Penh, we can roughly consider that the kWh cost in Kampong Speu is an average of these prices.
- For our study, we will consider a cost of **7 USc/kWh**.
- As this cost is hard to evaluate, a sensibility analysis will be done.

4.1.5 Construction costs for main grid installations

- We have no specific data on transmission lines and transformers costs in Kingdom of Cambodia. We made the following hypothesis, based on similar data in neighboring countries:
  - MV line cost : $9000/km
  - Transformer cost: $6000

4.2 Diesel plant

- REDEO tool will compute production costs from diesel options thanks to a catalog of costs and technologies given by the user.
- As we don't have such a catalog, the following model has been used for this study:

investment cost	33000 + 630 x installed capacity
life duration	7 years
Operation and Maintenance	annually 2% of investment cost
fuel cost	$0,1 per kWh

Table 5: standard costs used for diesel option

- The evaluation of diesel plants investments costs is very raw. It has be chosen such as bulk production is cheaper than little production but it doesn't consider a database of technologies or of plant models with precise characteristics. In our model, the investment costs in function of installed capacity are as follows:

capacity	investment cost	price/kW installed
50 kW	64500 $	1290 $/kW
100 kW	96000 $	960 $/kW
200 kW	159000 $	795 $/kW
500 kW	348000 $	696 $/kW
1000 kW	663000 $	663 $/kW

Table 6: corresponding investment costs depending on capacity

4.3 Hydro plants

We should keep in mind that results given by the REDEO tool can only be considered as departure points for true feasibility studies. Indeed, the question of hydro plants dimensioning is a very difficult one which is not treated by REDEO. However, the tool gives an idea of the zones that can be mainly supplied by hydro plants energy.

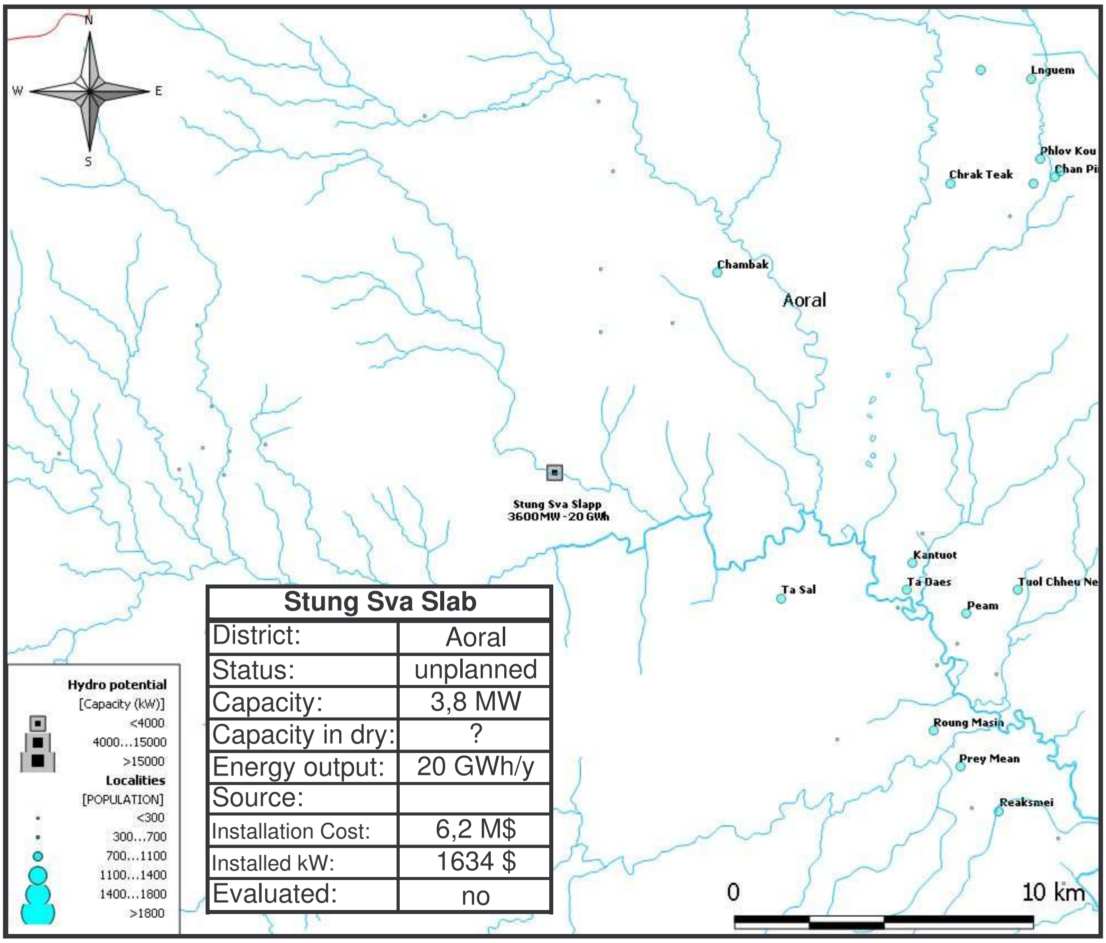
The REDEO approach concerning hydro plants dimensioning is relatively simple: For each potential site, the user has to precise:

- an estimation of investment cost
- an estimation of potential capacity
- an estimation of annual energy output.

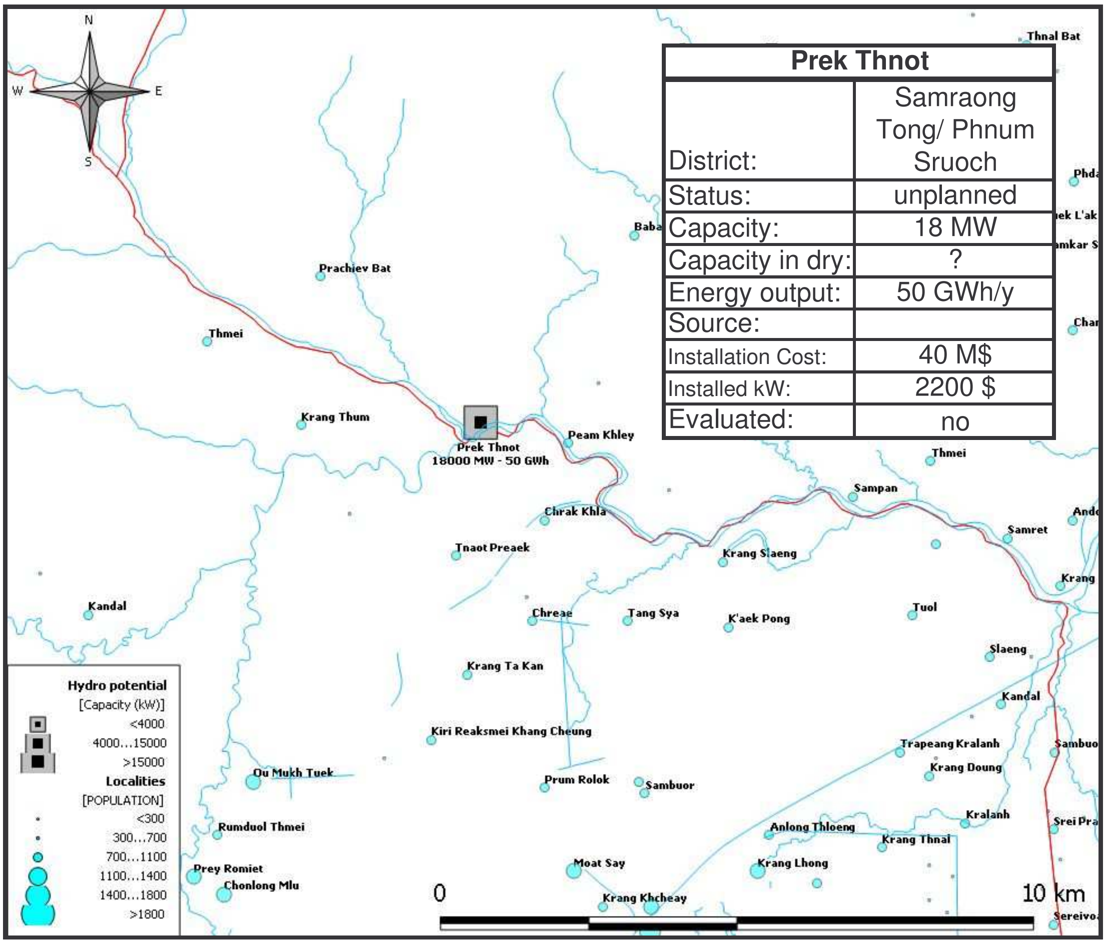
The following table shows actual and potential hydro sites in Kampong Speu Province:

N°	Site name	district	localisation	status	(to be) installed capacity	Energy output	source	Estimed installation cost	price of the installed kW	evaluation
1	**Kirirom 1**	**Phnum Sruoch**	**not in KPS Province**	**built**	**11 MW**	**70 GWh/y**	**-**	-	-	-
4	**Stung Sva Slab**	**Aoral**	approx.	**unplanned**	**3,8 MW**	**20 GWh/y**		**6,2 M$**	**1634 $**	**yes**
5	**Prek Thnot**	**Samraong Tong/ Phnum Sruoch**	approx.	**unplanned**	**18 MW**	**50 GWh/y**	**[4]**	40 M$	2200 $	no

- The column "evaluation" says whether or not we have a cost given by an evaluation study.
- As Kirirom stations are planned to be connected to Kampong Speu and Phnom Penh through the 115 kV line crossing the Province, we cannot consider them as potential decentralized options.
- We miss data on costs too. Given figures are only raw estimates.
- We were not able to localize precisely the potential sites for Stung Sva Slab and Prek Thnot plants. The following maps shows the expectations made for this study:



Stung Sva Slab	
District:	Aoral
Status:	unplanned
Capacity:	3,8 MW
Capacity in dry:	?
Energy output:	20 GWh/y
Source:	
Installation Cost:	6,2 M$
Installed kW:	1634 $
Evaluated:	no



Prek Thnot	
District:	Samraong Tong/ Phnum Sruoch
Status:	unplanned
Capacity:	18 MW
Capacity in dry:	?
Energy output:	50 GWh/y
Source:	
Installation Cost:	40 M$
Installed kW:	2200 $
Evaluated:	no

4.4 Biomass

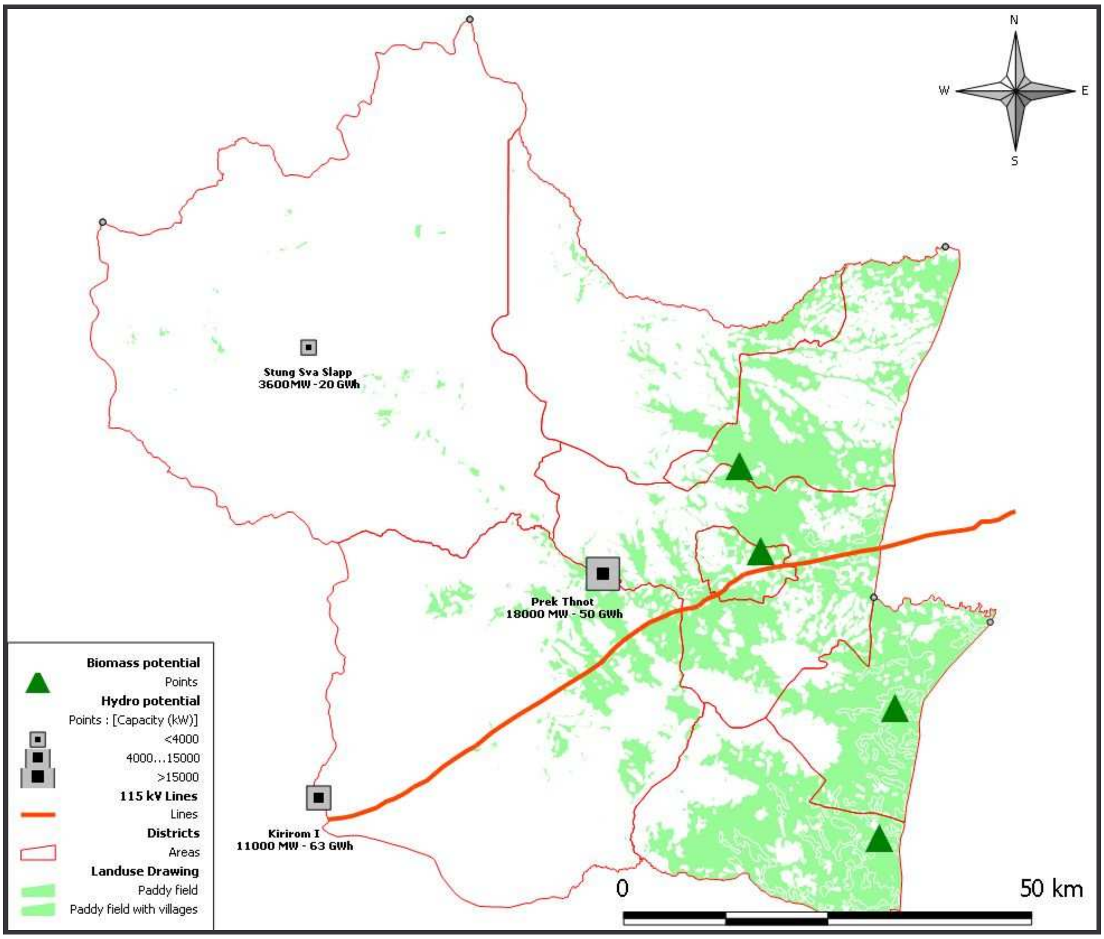
- In South-East Asia, Power can be produced from the following natural components:
  - Rice husk and straw
  - Cane trash and bagasse
  - Palm Oil residues
  - Animal Wastes
  - Urban Municipal Waste
  - Tapioca production
  - Wood processing and plywood industries
  - Energy crops

- In Kingdom of Cambodia, all these technologies are poorly developed. However, as RE is a long-term issue, we have to consider the areas were biomass plants are likely to be interesting.
- Almost all these technologies, only the rice paddy is **clearly available** in Kampong Speu Province. The land-use layer of the GIS map doesn't give any data on other possibilities. However biogas systems already exist in Kampung Speu and biomass plants based other fuels can be very interesting too.
- As the east part of the Province is mainly occupied by rice plantations, we can consider that there is a potential for biomass. According to the GIS land-use layer, rice plantations represents more than 140000 hectares. If we consider a yield of one ton of paddy per hectare and an availability of 50% of this paddy, we have 70000 tons of paddy of which we can use rice husk.
- Characteristics of biomass plants based on rice husk are collected in the following catalog corresponding to the "production options" module" output:

Parameter category	Parameter	Unit	Manifold name	type		
CROP AND RESIDUE PRODUCTI	Crop residue: production ratio (%)	%	ResProd	Percentage	22%	22%
	Residue Name	-	ResName	Text	Rice husk	Rice husk
	Residue availability (%)	%	ResAva	Percentage	locally dependant	locally dependant
	LHV	MJ/kg	LHV	Integer	13	13
	Moisture content	%	Mois	Percentage	8	8
	Residue preconditioning	-	ResPrecond	Text	no treatment	no treatment
	Minimum Total Crop Production	Tonne	MinCropProd	Floating Point (single)	0	195000
	Maximum Total Crop Production	Tonne	MaxCropProd	Floating Point (single)	195000	-
	Conversion process	-	ConvProc	Text	**<2MW**	**>2MW**
	Electricity production per tonne of crop	KWh/tonne	ElecProdCrop	Floating point (single)	100	100
	Plant efficiency	%	Efficency	Floating Point (single)	30%	30%
	% of days operating in a year	%	DaysOper	Percentage	100%	100%
TECHNOLOGY	Life time	Year	LifeTime	Integer	20	20
	Time to Commissioning	Years	TimeCommiss	Integer (Years)	3	3
	Investment cost	$/kW	InvestCostkW	Floating Point (single)	1750	1450
COSTS	O&M	$/kWh	OMCost	Floating Point (single)	3,24	3,24
	Fuel cost	$/kg	FuelCost	Floating Point (single)	locally dependant	locally dependant
OTHERS	Potential employees	-	PotEmp	Integer	3	10

Table 7: Characteristics of biomass systems based on rice residues

- We have no idea of the rice residue cost in Kampong Speu Province. This cost is locally dependant and the actual use of these residues have to be taken into account. However, the price of rice residues after milling process is not high because the use of rice husk for biomass plants avoid using land for rice husk disposal, avoid the risk of wild rice husk burnings.
- If rice husks are burned through efficient suspension boilers, they produce a good quality ash containing a high silica content that can be sold to electronics or steel industries. The price of this ash can be around $200/ton, corresponding to $40/ ton of rice husk or $8 / ton of paddy. But all these figures are only raw estimations that should be adapted to the local context.
- As we have no data on the localization of agro-industries, we defined four fictive potential sites for biomass power plants, each of 400 kW, as follows:



Map 10: renewable energy production options in Kampong Speu Province

5 ELECTRIFICATION SCENARIOS

5.1 General Ideas

The aim of the REDEO tool is to provide to the user good indicators for electrification planning. It is neither to do a complete economical or financial study nor to determine precisely the power flows in a future network. It is to propose a set of projects and their main characteristics:

- life cycle kWh cost
- initial investment
- Annual expenses if any
- Indicators on Environment and Development.

To build this set of projects, REDEO follows two approaches:

- one based on renewable energy options
- one based on national grid extension and diesel plants options

These indicators will permit the user to build a preliminary framework for electrification planning and to determine which projects should be deepened by feasibility studies.

5.2 Hydro plants

5.2.1 Methodology and input

For each potential hydro plant, REDEO determines an area with a potential peak demand forecast by year 10 corresponding to potential installation capacity of the plant.

One consequence of this dimensioning is that other technologies are needed to provide a continuous and good quality service. Indeed, in dry season, the plant cannot supply the same area than in rainy season. Furthermore, the demand is very increasing and the plant can only answer to half of the peak demand by year 20. REDEO tool doesn't give estimation of costs engendered by this additional technology (mainly diesel).

To determine the area supplied by the plant, REDEO tool uses a very simple algorithm: the nearest cluster is connected. While plant capacity is enough, the nearest cluster from the set "plant + already connected cluster" is connected. This way is not the most effective. Indeed, we can imagine an optimal situation connecting far localities that are very near each others and not connecting some localities closer to the plant but in an other direction. We prefer to keep this solution because it is more satisfying in a land use planning perspective.

The input used for the computation of costs are as follows:

Figure 4: General Parameters for hydro plant costs computation

tranformer price	6000	$
lines km cost	11000	$
computation period	15	years
hydro plant life duration	25	years
discount rate	0,08	

As plants life duration is higher than computation period, a residual value is given to the plant at the end of the computation period. This residual value is determined with a linear rule: the residual value at year

15 is equal to ten twenty-fifths of the initial value. Discounted residual value is then deduced from investment cost

5.2.2 Results

The following maps represents the areas of which potential peak demand by year 10 corresponds to hydro plant installed capacity.

Figure 5: Clusters supplied by Prek Thnot hydro plant

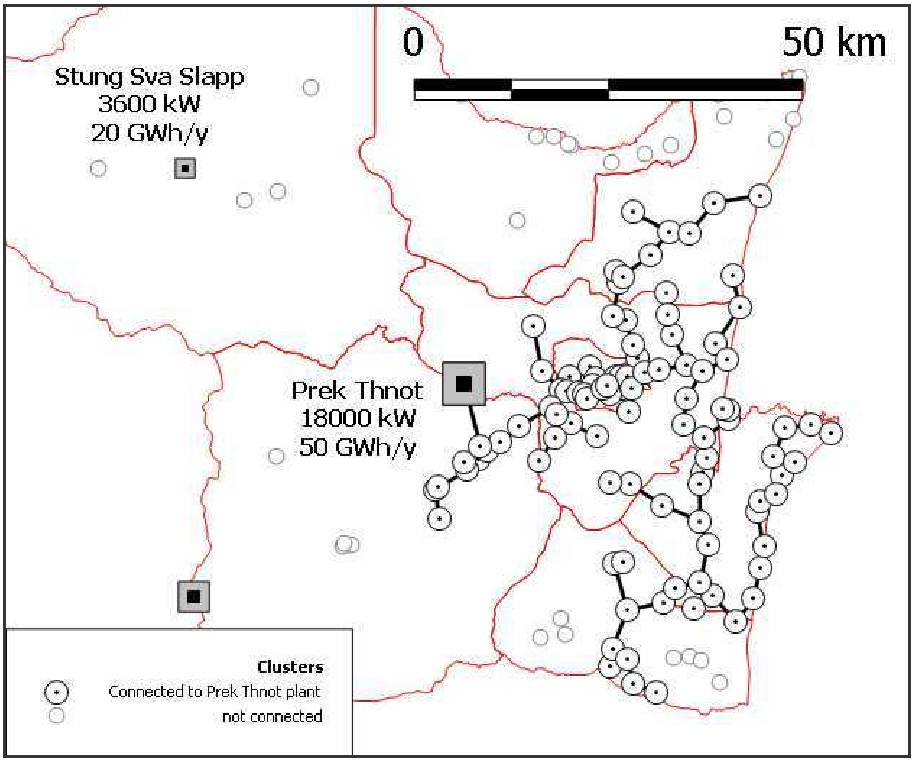
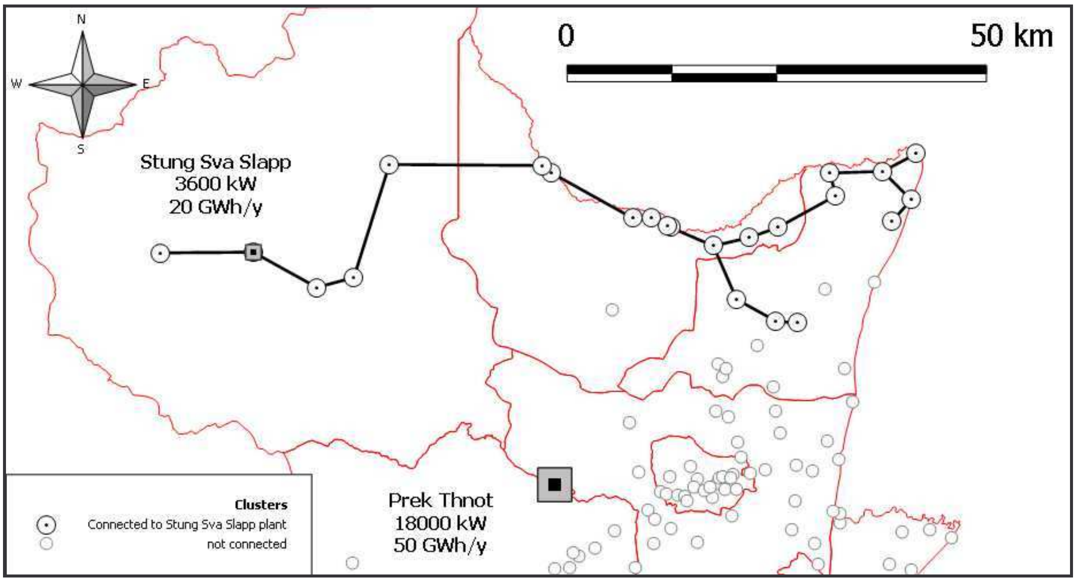


Figure 6: Clusters supplied by Stung Sva Slapp hydro plant



Prek Thnot		
kWh sold (years 0 to 14)	942748655	kWh
Investment Cost	40000000	$
Residual Value (year 15)	16000000	$
Discounted Res Value	5043867	$
Investment - Disc Res Val	34956133	$
annual O&M Costs	800000	$/y
total discounted O&M costs	6880000	$
Production expenses	41836133	$
Production Cost	**4,438**	USc/kWh
distribution lines length	287	km
Investment Cost	3157000	$
Transfo investment costs	642000	$
Residual Value of (10) and (11)	1181324	$
Investment - Disc Res Val	2617676	$
total discounted O&M costs	590359	$
Distribution & transfo Cost	**0,466**	USc/kWh
TOTAL AVERAGE kWh COST	**4,903**	**USc/kWh**
TOTAL INVESTMENT COSTS	**43 157 000**	**$**
Annual Capacity	**50000000**	**kWh**
Consumption year 0	50000000	100%
Consumption year 5	50000000	100%
Consumption year 10	50000000	100%
Consumption year 15	50000000	100%
Power capacity	**18000**	**kW**
Peak demand forecast year 0	13470	75%
Peak demand forecast year 5	15708	87%
Peak demand forecast year 10	17849	99%
Peak demand forecast year 15	19780	110%
Population concerned	**408 680**	**people**

Table 8: Prek Thnot hydro plant costs

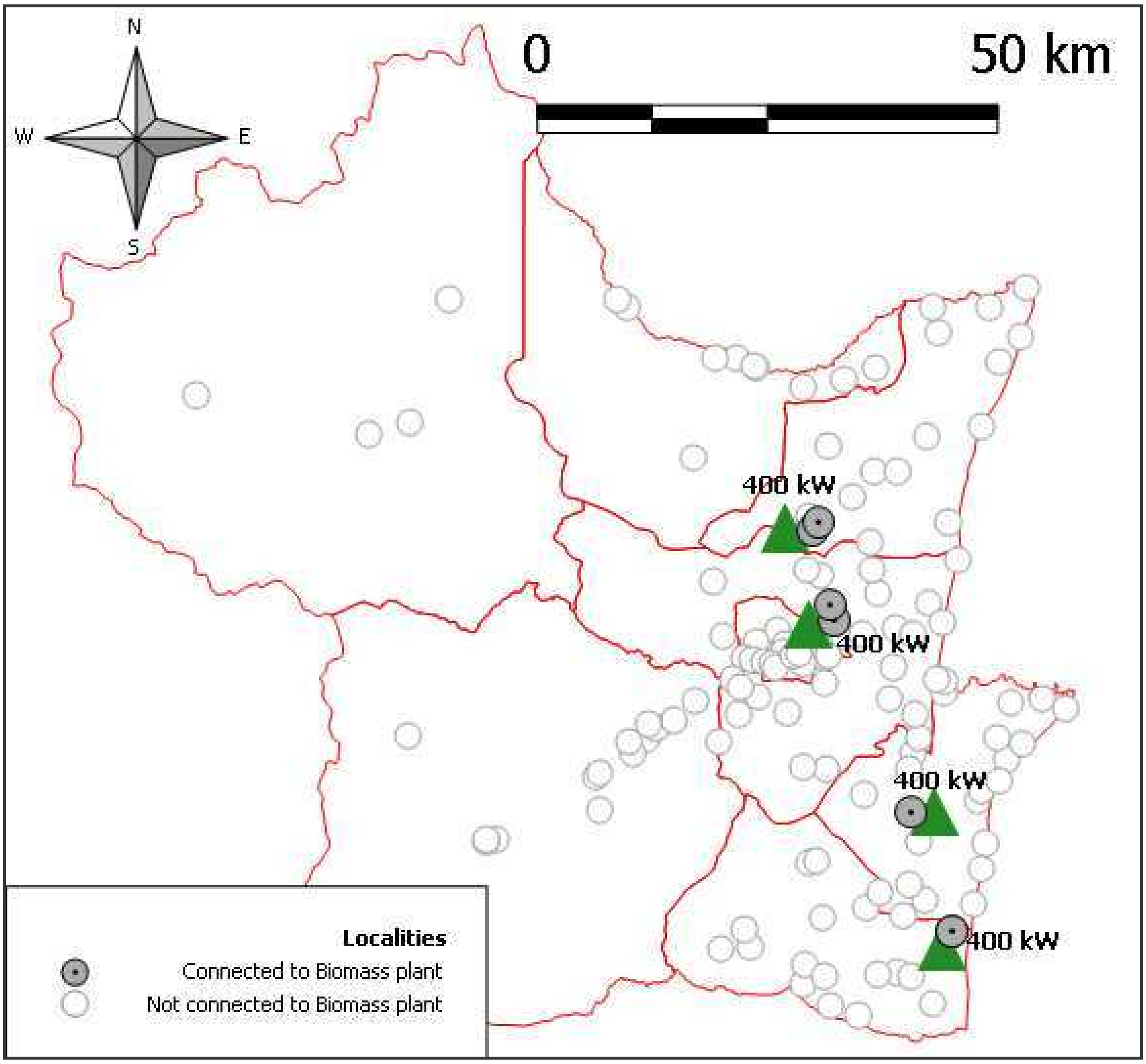
Stung Sva Slapp		
kWh sold (years 0 to 14)	201617224	kWh
Investment Cost	6200000	$
Residual Value (year 15)	2480000	$
Discounted Res Value	781799	$
Investment - Disc Res Val	5418201	$
annual O&M Costs	124000	$/y
total discounted O&M costs	1066400	$
Production expenses	6484601	$
Production Cost	**3,216**	USc/kWh
distribution lines length	132	km
Investment Cost	1452000	$
Transfo investment costs	132000	$
Residual Value of (10) and (11)	543327	$
Investment - Disc Res Val	1040673	$
total discounted O&M costs	271524	$
Distribution & transfo Cost	**0,920**	USc/kWh
TOTAL AVERAGE kWh COST	**4,137**	**USc/kWh**
TOTAL INVESTMENT COSTS	**7 652 000**	**$**
Annual Capacity	**20000000**	**kWh**
Consumption year 0	10798988	54%
Consumption year 5	12740413	64%
Consumption year 10	14534729	73%
Consumption year 15	16044766	80%
Power capacity	**3800**	**kW**
Peak demand forecast year 0	2837	75%
Peak demand forecast year 5	3329	88%
Peak demand forecast year 10	3815	100%
Peak demand forecast year 15	4248	112%
Population concerned	**89 673**	**people**

Table 9: Stung Sva Slapp hydro plant costs

- But one must keep in mind that these systems are not dimensioned to supply the corresponding areas with a continuous service. For example in the case of Prek Thnot Plant, hydrology doesn't permit to the plant to produce enough energy all along the year, whereas installed capacity is very high. We can see that as early as year zero, 100% of plant energy output is consumed…
- Even if Stung Sva Slapp table says that peak demand forecast by year 5 is only 88% of plant capacity, it doesn't mean that plant will be able to produce this power all along the year…

5.3 Biomass plants

The following map represents our four supposed places for biomass plants:



For example for the most northern biomass plant, we can do the following estimations:

fuel cost (rice husk)	10	$/paddy ton
retail value of ashes	8	$/paddy ton
electricity production	100	kWh/paddy ton
computation period	15	years
biomass plant life duration	25	years
discount rate	0,08	
kWh sold (years 0 to 14)	16684040	kWh
Investment Cost	**700000**	$
Residual Value (year 15)	280000	
Discounted Res Value	88268	
Investment - Disc Res Val	611732	
Fuel & OM costs	**2,324**	cts/kWh
Total discounted Fuel&OM costs	229395	
Production expenses	841128	$
Production Cost	**6,416**	cts/kWh
distribution lines length	3	km
Investment Cost	33000	$
Transfo investment costs	18000	$
Residual Value of (10) and (11)	12348	$
Investment - Disc Res Val	38652	$
total discounted O&M costs	6171	$
Distribution & transfo Cost	**0,343**	USc/kWh
TOTAL AVERAGE kWh COST	**6,759**	**cts/kWh**

But these estimations are very dependant on the fuel cost and on the retail value of ashes. The cost considered in the upper table is not the paddy cost, but the cost of rice residues corresponding to one ton of paddy. If we do not take the retail value of ashes into account, we obtain the following life-cycle kWh costs for biomass plants (Note: this figures correspond to simulations made with the most northern site, but the simulations on other sites are very similar.)

50 $	63,5	cts/kWh
10 $	16,2	cts/kWh
5$	10,3	cts/kWh
1$	5,6	cts/kWh

Table 10: life-cycle kWh cost for biomass plants in function of rice residues value (per ton)

5.4 Long Term grid extension and minigrids supplied by diesel plants

Main grid extension is often considered as the long term most interesting option, as bulk electricity production offers sometimes very cheap electricity. The objective of this first part is to determine the ideal extension of the grid if financial capacities were unlimited and if enough power is available from the national grid to answer the whole electricity demand.

The algorithm connects a cluster to the main grid if the total discounted expenses all over the computation period are lower in the case of a connection (investment costs for lines and transformer, kWh cost at the substation) than in the case of production by a diesel plant. Each locality is thus studied and connected if necessary and the grid thus spreads.

The following figures reminds the parameters used:

Figure 7: Parameters for long-term grid extension simulation

computation period	15	years
Discount rate	0,08	-
diesel plant life duration	7	years
Operation and Maintenance	2% of inv /year	
transmission line life duration	25	years
transmission line investment cost	11000	$/km
diesel plant investment cost	33000+630*Capacity(kWh)	$
fuel costs	0,1	$/kWh
transformer cost	6000	$
transformer life duration	25	years

- Even if our hypothesis for line costs are $9000/km, we take $11000/km for the simulation to take into account the fact that lines in the reality don't follow a straight line between two localities. In the future the user will be able to choose to consider the distance along roads between two localities or the distance following the straight line if data on roads grid are not available.
- For lines ant transformers, which life durations are longer then computation period, a residual value is taken into account with a linear rule: the residual value at year 15 is equal to ten twenty-fifths of the initial value. This residual value is then discounted and deducted from investment costs.
- Fuel costs are very hard to guess. 0.1 $/kWh is a high but prudent hypothesis.

Figure 8: Grid extension if kWh cost in Kampong Speu is 7 USc/kWh

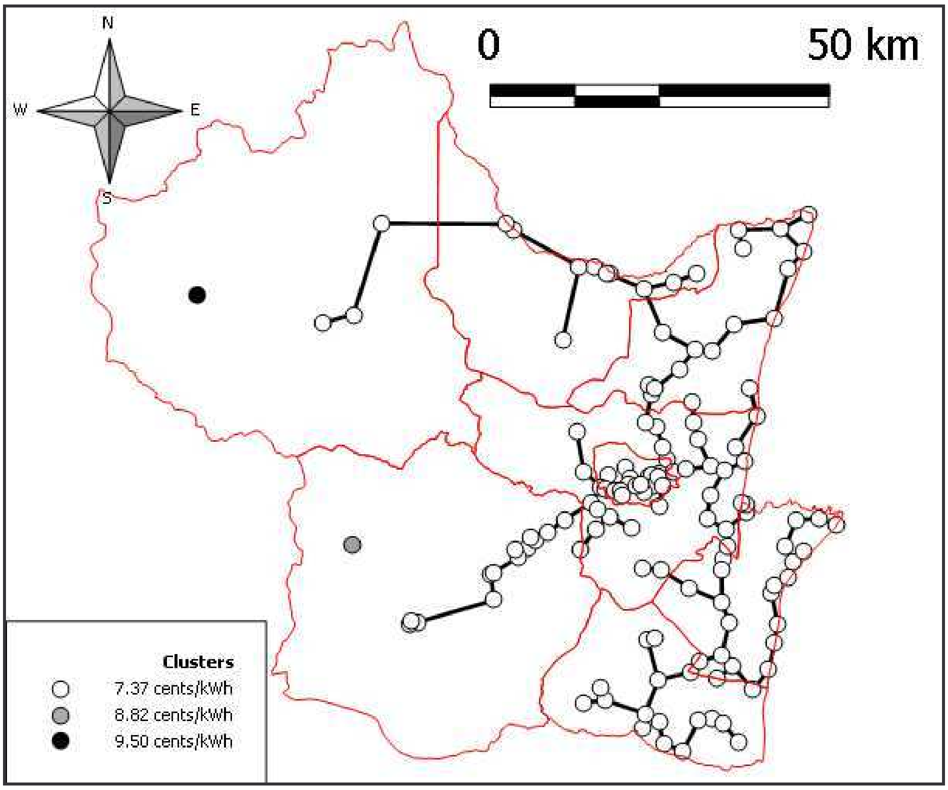
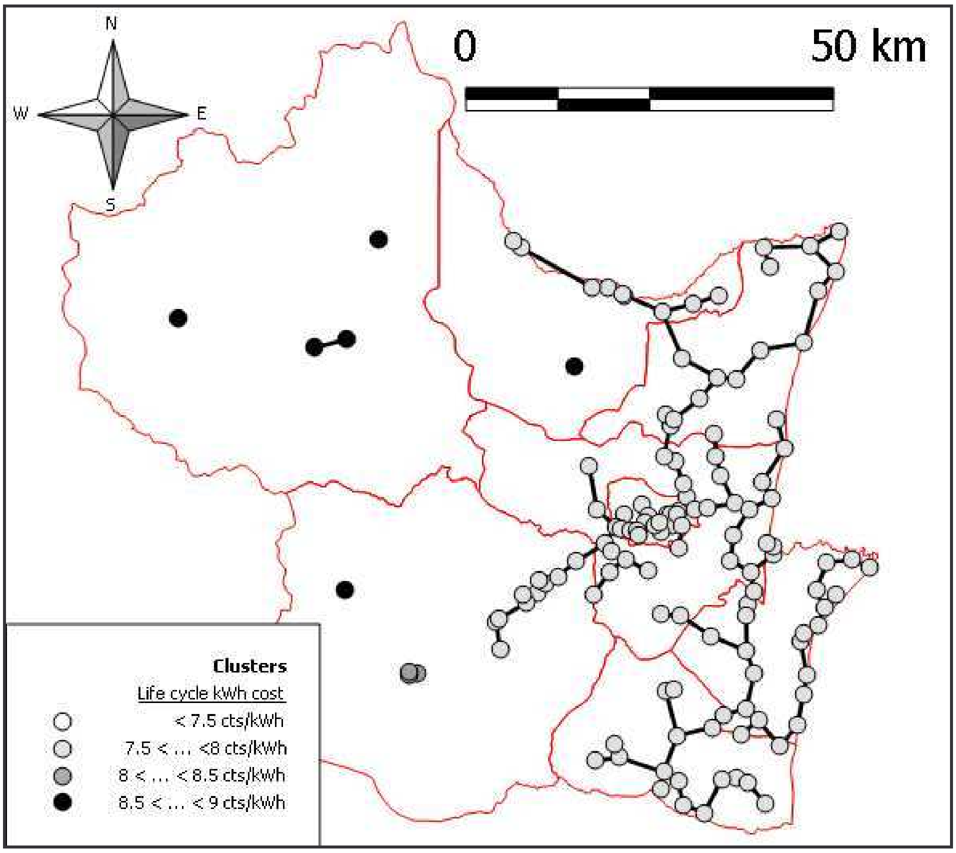


Figure 9: the same if kWh cost in Kampong Speu is 7.5 USc/kWh



- We notice that the solution configuration is very dependent on kWh cost in Kampong Speu substation. If we consider life-cycle cost, the competition between connection to main grid and decentralized grids is real. In fact the ratios "kWh cost in Kampong Speu" / "lines investments costs" and "kWh cost in Kampong Speu" / "diesel production costs" are very influent.
- However, this analysis has no reality because electricity demand in Kampong Speu Province is far higher than electricity available from the main grid. The connection to the grid is technically limited to a little part of the Province.
- The REDEO tool allows the user to choose the area that should be connected to the grid. The user can use several indicators such as:
    - IPD of localities
    - Population of localities
    - Distance to the substation…

- We choose to electrify Chbar Mon district in priority, because that is the hypothesis that corresponds the most to the reality.

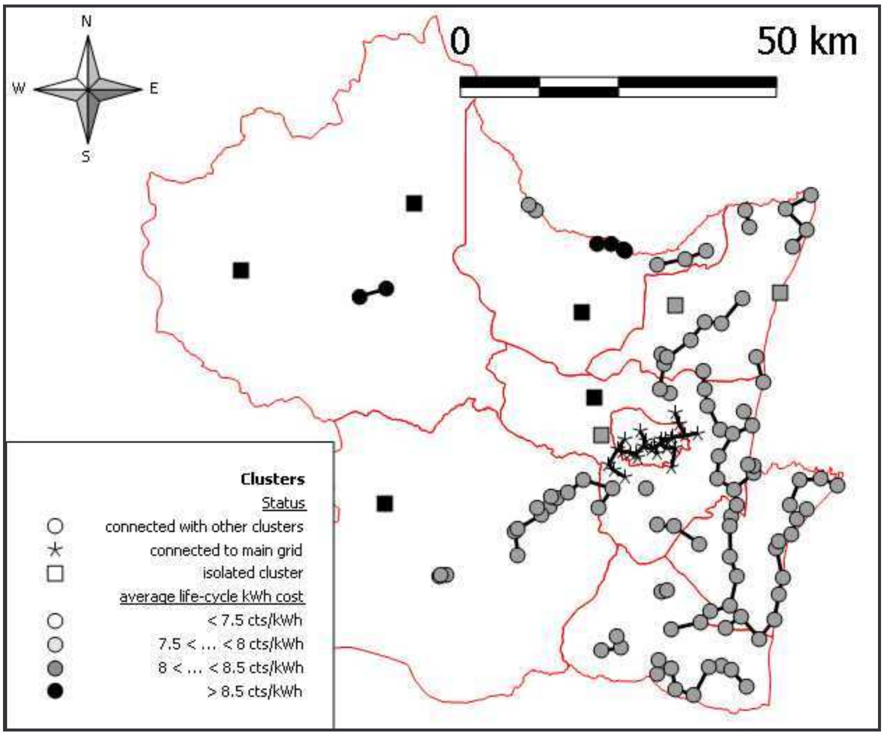
5.5 Isolated diesel grids

For all localities that are not likely to be connected to the national grid before 20 years, the alternative to renewable options are:

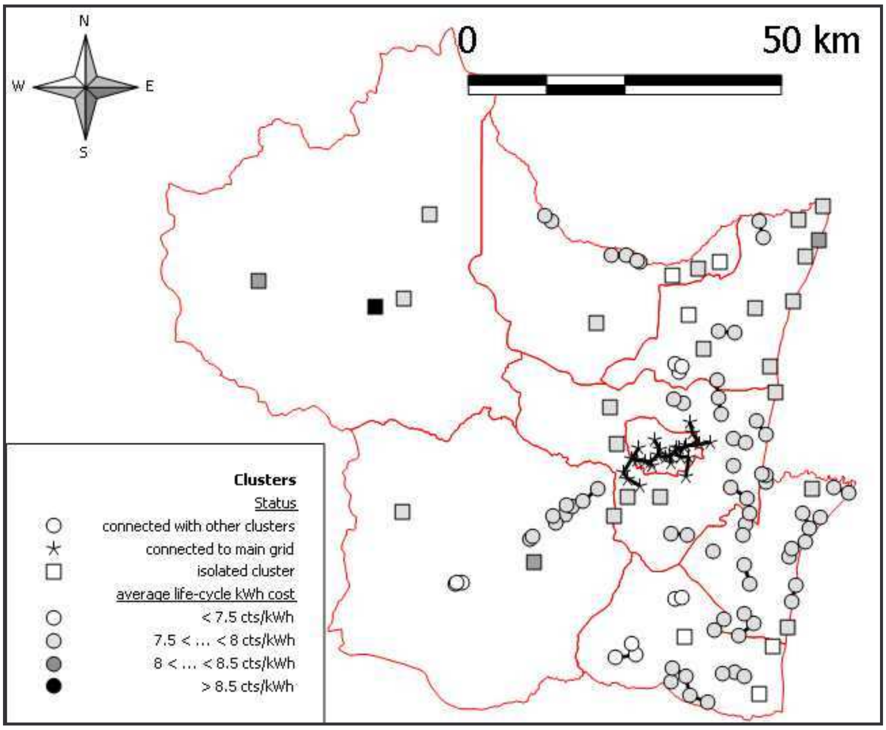
- isolated diesel plant
- clusters connected to form a minigrid supplied by a diesel plant.

To obtain the map showing which clusters should be considered alone and which clusters should be interconnected, we use an algorithm that connects clusters together if the connection improves the global situation in term of average life-cycle cost of kWh.

With our parameters, this algorithm gives the following results:



Map 11: Minigrids and isolated clusters if grid capacity is 4 MW by year 20



Map 12: The same if diesel plants investment costs are 33% cheaper

With our parameters, maps show that connecting clusters together is generally an economical solution. However, one must be very careful with these results because they are very dependant on lots of parameters, that should be better adapted to local context, such as:

- diesel plants investment costs
- fuel costs
- line costs.

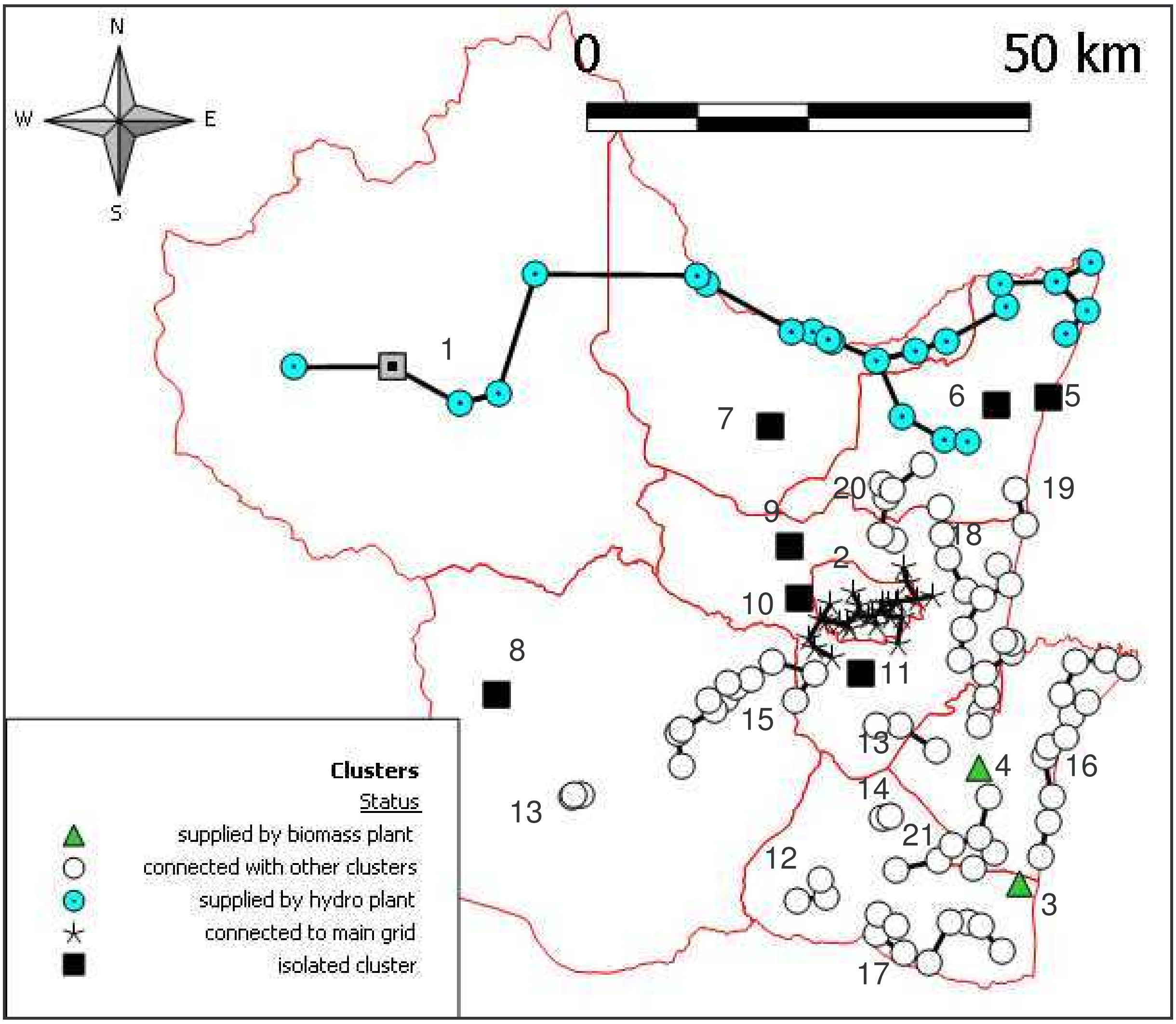
Furthermore, our model doesn't take line losses into account. That has no big consequences if localities are close each other but can be significant for the longest grids. That can be balanced by defining higher investment costs for transmission lines.

6 ECONOMICAL INDICATORS AND IMPACT ON DEVELOPMENT

6.1 Fictive scenario

The "electrification scenarios" module gave indicators on projects based on all our production options. The user can then build a scenario based on these projects. His choice can depend on available investment, political objectives, maybe national strategy…

We built a indicative scenario for Kampong Speu Province, which is summarized by the following map. The implementation of Stung Sva Slapp hydro plant seems very relevant, as it covers an area which is relatively far from the national grid. However, we must keep in mind that other systems are needed in addition of this hydro plant that will not be able to supply a continuous service throughout the year and which capacity will be exceeded by year 10.



Map 13: Fictive electrification scenario

6.2 Indicators by project

n°	technology	pop. covered	investment cost	kWh life-cycle cost	annual O&M costs (y0)
1	hydro	89 673	6 200 000	4,137	124 000
2	grid extension	71 845	557 500	7,19	11 150
3	biomass	9 228	700 000	6,754	20 119
4	biomass	5 905	700 000	6,8	21 670
5	isolated cluster	5 615	188 106	8,33	80 901
6	isolated cluster	6 879	206 376	8,34	89 989
7	isolated cluster	3 872	123 090	8,59	46 339
8	isolated cluster	2 789	97 764	8,82	32 338
9	isolated cluster	4 100	148 290	8,51	60 183
10	isolated cluster	6 087	226 158	8,47	101 367
11	isolated cluster	5 607	165 930	8,4	68 027
12	mini-grid	21 071	540 782	8,19	217 014
13	mini-grid	12 856	430 196	8,43	151 202
14	mini-grid	13 080	361 424	8,16	156 236
15	mini-grid	41 402	1 448 216	8,31	514 228
16	mini-grid	43 671	1 658 206	8,35	619 025
17	mini-grid	45 298	1 352 390	8,26	508 242
18	mini-grid	73 413	2 565 780	8,28	1 030 098
19	mini-grid	8 697	300 142	8,46	108 032
20	mini-grid	30 476	930 932	8,23	370 136
21	mini-grid	43 362	1 351 592	8,24	540 473
	TOTAL	544 926	20 252 874		4 870 770

Table 11: Main indicators on selected projects

- Kampong Speu Province counts around 590000 inhabitants, on which 544000 live in a locality concerned by our scenario. But that doesn't mean that 90% of population is going to be electrifies with such a scenario. Indeed the penetration rates for households are less than 30% at year 0 and around 60% at year 20…
- We notice that life-cycle kWh costs for all thermal systems are very similar. This is due to the fact that all localities are forecasted according to the same model and that if a locality's characteristics are very good (good load factor, bulk production…), it becomes attractive for other localities and it has more chance to belong to a decentralized grid.

6.3 Global indicators

Category	Sub-category	Indicator	Unit	Formulas	year 0	year 10	year 20
Impact on development	Status of electrificati	Households electrification rate	%	Nb of households being electrified / Total number of households	24%	45%	50%
		Localities electrification rate	%	Nb of localities being electrified / Total number of localities		92%	
	Impact on health	Percentage of health centers being electrified	%	Nb of health centres being electrified / Total number of health centres		93%	
		% of population having access to « electrified » health center	%	Nb of people in localities where closest health centre is electrified / Total population		96%	
		Mean distance to a non-electrified health center	Km	Sum of distance to a non-electrified health centre for all localities / Total number of localities		2,24	
		Mean distance to an electrified health center	Km	Sum of distance to a electrified health centre for all localities / Total number of localities		2,52	
	Impact on education	Percentage of schools being electrified	%	Nb of schools being electrified / Total number of schools		94%	
		% of population having access to « electrified » primary school	%	Number of people localities for which closest primary school is electrified / Total population		94%	
		Mean distance to a non-electrified primary school	Km	Sum of distance to a non-electrified primary school for all localities / Total number of localities		1,36	
		Mean distance to an electrified primary school	Km	Sum of distance to a electrified primary school for all localities / Total number of localities		1,70	

Table 12: impact on development indicators

- Given households electrification rates take into account population growth rates and penetration rates.
- Localities electrification rates and impact on health and education indicators are very satisfying.

7 CONCLUSION AND IMPROVEMENTS

This case study gives a first idea of REDEO decision aid tool possibilities. For Kampong Speu Province, it reveals that long-term better solution is based on combined using of all production options. Indeed, decentralized energy options are here sometimes economically very interesting options in comparison with thermal technology. Furthermore impact on environment and dependance from international context are lower.

The fact that localities situated in the neighborhood of CHPDs have systematically been taken into account can explain that potential demand forecast is rather high and that grid configurations are often interesting. Maybe an other approach only based on biggest cities would have given very different results. However, even if efforts have been done to promote local development, this aspect can considerably be improved by using a precise analysis of industrial potential of each secondary center. By considering those developing centers and by providing them continuous and good-quality electricity services, rural electrification planning can be an effective tool for economical policy and land-use planning.

Except this fundamental aspect, other things can easily be improved, as:

- Taking distance along roads into account
- Considering diesel plants investment costs better adapted to local context, and more generally having better estimates on all costs (kWh from national grid, diesel cost, rice residue costs...).
- Considering other technologies than rice residues for biomass plants
- Having better estimates on future industrial energy consumptions.

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