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DEFINITION OF THE ENERGY TERRITORY:

MODELIZATION OF THE URBAN AREA EQUILIBRATING THE PRODUCTION AND CONSUMPTION OF ELECTRIC ENERGY

2014-2015

Project
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Modelization of the urban area equilibrating the production and consumption of electric energy

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AVERTISSEMENT

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FORMATION PAR LA RECHERCHE ET PROJET DE FIN D'ETUDES EN GENIE DE L'AMENAGEMENT

La formation au génie de l'aménagement, assurée par le département aménagement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme et de l'aménagement, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir-faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,

Accroître la capacité des ingénieurs en génie de l'aménagement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de fin d'études (P.F.E.), situé en dernière année de formation des élèves ingénieurs. Cet exercice correspond à un stage d'une durée minimum de trois mois, en laboratoire de recherche, principalement au sein de l'équipe Ingénierie du Projet d'Aménagement, Paysage et Environnement de l'UMR 6173 CITERES à laquelle appartiennent les enseignants-chercheurs du département aménagement.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement

Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne les mémoires à partir de la mention bien.

REMERCIEMENTS

Je tiens en premier lieu à remercier Mindjid MAIZIA, directeur de ce projet de fin d'études, pour son aide durant la réalisation de ce travail.

Je souhaite également à remercier Gaëtan Palka, pour sa disponibilité et les conseils apportés.

Mes remerciements vont également à tous ceux qui m'ont aidé, et notamment Matthieu Cadoul pour Matlab©, et Nicolas Noël pour la représentation sous ArcGis©.

SUMMARY

1 Introduction

1.1 Stakes

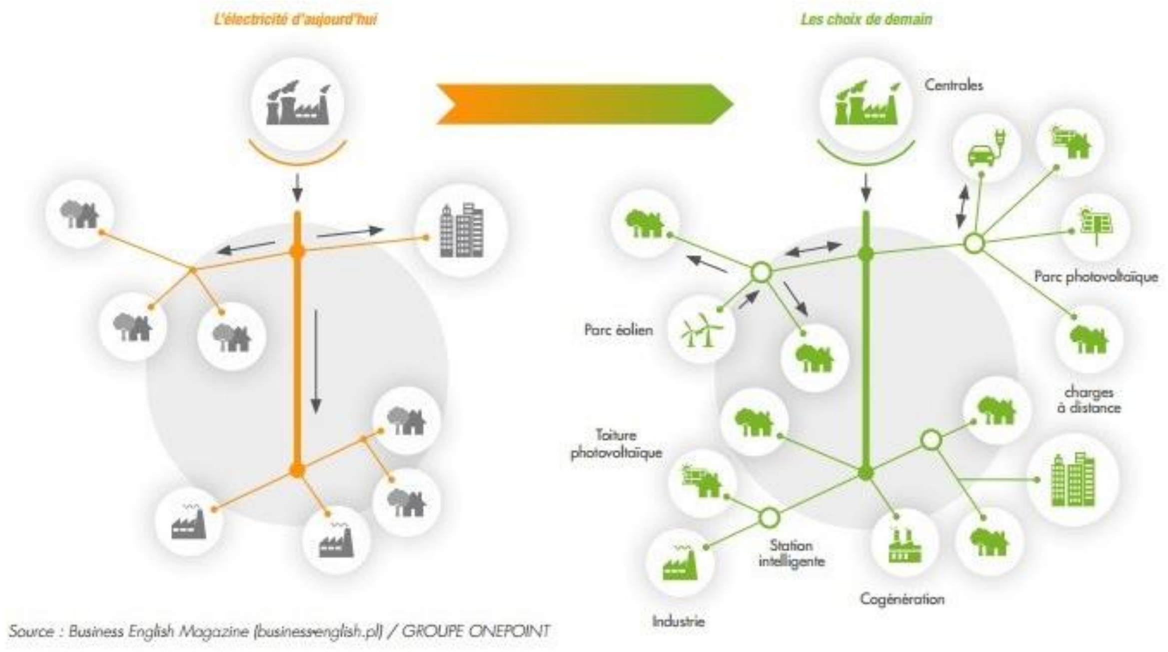
1.1.1 Energetic stakes

The French electric system is based on a centralization of the production resources: the production of the centrals is collected at regional or national level and then distributed over the entirety of the territory. The network has therefore been conceived to transport the energy from the centralized points of production towards the different locations of consumption. It can be divided in three parts:

- The national transport network transports energy over long distances. Depending on their production capacity, the production centrals are either connected to the regional or national network.
- The regional networks of repartition feed the distribution networks (the energy is divided amongst the different regions depending on their needs).
- The distribution network distributes the energy to the final clients (buildings, electricity consumers). Their structure is arborescent.

The energy flows in the regional and national networks can be bidirectional, unlike the distribution network, which is always unidirectional.

Figure 1: Tomorrow's electric network



Source : Business English Magazine (businessenglish.pl) / GROUPE ONEPOINT

The electricity produced is gathered at regional or national level, in order to be distributed again, even though the renewable energy centrals are spread over the territory. In the future, the network could be thought at a more local level, local centrals producing for local consumption and the surplus being integrated into the national grid (see Figure 1). The distribution network would then need to be bidirectional.

The current centralization of the production is due to the fact that the electricity is a non-storable energy: to distribute it directly at a local level, the consumption of the buildings (consumption points) must be even with the production to avoid losses. If the consumption is inferior to the production, the surplus of energy will need to be stored. However, its stocking involves that it be transformed in another type of energy (hydraulic, chemical…), and these transformations have a cost. Therefore it would be more interesting to use the energy produced by distributing it directly into a local network.

Moreover, the transport of electricity is submitted to losses. These are mainly located on the distribution network: the energy lost on this network is estimated at 6% of the energy transported. This contributes to the idea that the consumption points should be closer to the sources of production.

1.1.2 Regulatory stakes

The European Union wishes that buildings constructed in the State Memebers after 2018 will be « zero energy » buildings, producing as much energy as they consume. A smart European network (with captors for electricity, heating…) should be set to allow consumers to use energy in a more controlled way.

The « Grenelle Environnement » plans that energy positive buildings (produce more than they consume) will become the norm starting from 2020 for the construction of new residential buildings (this is to be considered at a neighborhood scale).

This involves to re-think the structure of the energy distribution network (which is unidirectional).

1.2 Objectives and problematic

The objectives of this study is to observe, through a concrete case, the evolution of the energy territory, here defined as the urban area where the renewable centrals production (distributed locally) and buildings consumption are even.

For the production to be distributed locally (instead of centralized in the regional or national network) and therefore to be able to represent the energy territory and its evolutions, several criteria must be respected:

- The production of each renewable central must be identified dynamically (depending on the time)

- The electric consumption of the surrounding buildings must be modelized in a dynamic way

- These two first hypothesis must fit: the production curve must at all-time *t* be superior to the buisldings' consumption curve.

On this study, we will consider that the electricity is transported as the crow flies, without considering the characteristics of the electric network which would be needed to transport the energy locally.

The problematic of this project, which will serve as a guideline, is the following:

Could the electrical energy produced by renewable solar and wind modes (local production) be devoted to local consumption rather than reinstated to the national grid?

2 State of the art

In the literature, different approaches are used to define the energy territory.

First of all, some considerations concern the terminology[1].The term “energy territory” can have three significations:

- Ideal conception: the neighborhood is considered for its components and performances. The characteristic the most considered in this approach is the autonomy of the neighborhood (self-sufficient neighborhood, which produces what it consumes).
- Operational conception: an area is chosen where the aim will be to improve the energetic performances (buildings, networks, transports…)
- Evaluative conception of legitimation: the performances of the neighborhood considered are evaluated, without regard to the surrounding ones, the efficiency intern of the neighborhood must be proven.

In this case study, the approach considered would be closes to the ideal conception. Indeed, the aim is to determine, considering the performances and components of the territory, how the autonomous territory (supplied by renewable energy resources) would evolve.

Other publications have a more physical approach. It is the case for several case studies, such as the one of Thasos, in Greece[2], or the one lead in Nordic conditions[3]. However, even if these studies focus on specific neighborhood, their considerations are rather economic and politic than energetic. Indeed, they try to determine, depending on the capacity of production and on the network size, the tariffing of the energy produced, and for the case of a consumption even with the production, the tariffing of a local consumption, and how to regulate these pricings.

They also focus on the performances specific to the neighborhood (if we relate them with the first three definitions proposed, their approach is closest to the operational conception).

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[1] Souami Taoufik, *Conceptions et représentations du territoire énergétique dans les quartiers durables*, Flux, 2009/2 n° 76-77, p. 71-81.

[2] J.C. Mourmouris, C. Potolias, *A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece*, 2013.

[3] Janne Hirvonen, Genku Kayo, Sunliang Cao, Ala Hasan, Kai Sirén, *Renewable energy production support schemes for residential-scale solar photovoltaic systems in Nordic conditions*, 2015.

3 Methods

3.1 General method

The aim of this study is to observe a concrete case of evolution of the attribution of the centrals' production to the buildings, depending on their consumption. The evolution of the shape of the territory covered by the centrals' production is interesting depending on the hours of the day and night. It can also vary depending on the seasons.

To achieve this degree of precision, data of buildings' consumption and centrals' consumption per hour are necessary.

For the case study chosen here, which is the **region Centre**, in France, this type of data (per hour) is available for the entirety of the region through the Eco2mix database (RTE France). The study will focus on the following renewable energies: the solar and wind production.

This database indeed provides the total regional solar production, wind production and consumption per hour. However for the study, the format is per hour and per solar or wind central, or building.

Collecting the data necessary and therefore calculating the production per central per hour and the consumption per building per hour will constitute the first step of the work. For this step, we will use different softwares: ArcMap© and an add-on to MATLAB©: toasterSystem©[4].

The second step will be the modelization of the energy territory with the data collected. For this step, we will use MATLAB, and use an algorithm of affectation.

3.2 Database

In order to modelize the energy territory, we will require different data:

- The X,Y coordinates of the buildings and their consumption per hour
- The X,Y coordinates of the renewable centrals and their production per hour

3.2.1 Buildings data

<u>Data sources:</u> *BD TOPO, IGN 2014 ; IRIS Contours, IGN 2014 and Eco2mix, RTE, 2013.*

X,Y COORDINATES

Due to the large number of data (1 824 661 buildings in the Region Centre according to the BD TOPO, IGN 2014), the data will be gathered per IRIS[5]. In The Region Centre, there is a total of 2 234 IRIS (IGN, 2014). The X,Y coordinates considered will be the centroid of each IRIS.

The comparison of the X,Y coordinates of the IRIS will permit to localize them in comparison to the position of the centrals, and therefore distribute the power generated according to the proximity of the IRIS to the central.

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[4] Mindjid Maïzia, ToasterSystems, Application for Model Design, 2014, Polytech Tours

[5] "*Ilots Regroupés pour l'Information Statistique*", referring to a size of 2000 inhabitants per division of the grid

This first data will be provided by the BD TOPO of IGN, as well as the shape file “Contours IRIS” provided by the IGN (data 2014).

BUILDING CONSUMPTION

In France, the average of energetic consumption per private housing is of 196kWh/m²/year in 2008 (including 156 kWh/m²/year for heating and hot water). The energetic efficiency of housings improved of 24% between 1990 and 2008. For all-electric housings (heating, hot water…) the average energy consumption in 2012 is of 16565kWh/housing[6].

If we consider the housing as being all-electric (heating included), the equation used to determine the consumption depends on different variables: ΔT (difference of temperature between the inside and outside), Senv (surface envelope), Ubat (isolation factor), Q (ventilation debit), As (sun supply), Ai (intern supply) and ρ (air density).

$$\mathrm{C} = \frac{(\mathrm{D\,env} + \mathrm{D\,vent}) - (\mathrm{As} + \mathrm{Ai})}{\rho} = \frac{(\Delta\mathrm{T} * \mathrm{S\,env} * \mathrm{ubat} + 0.34\,\mathrm{Q}\Delta\mathrm{T}) - (\mathrm{As} + \mathrm{Ai})}{\rho}$$

However, considering the data available from the BDTOPO, which includes the ground surface and height of the buildings, we will do an approximation of the electric consumption of the region Centre buildings per hour per livable volume.

This average of the square meter consumption per hour in the Region Centre will then be applied to the buildings livable volume of each building considered.

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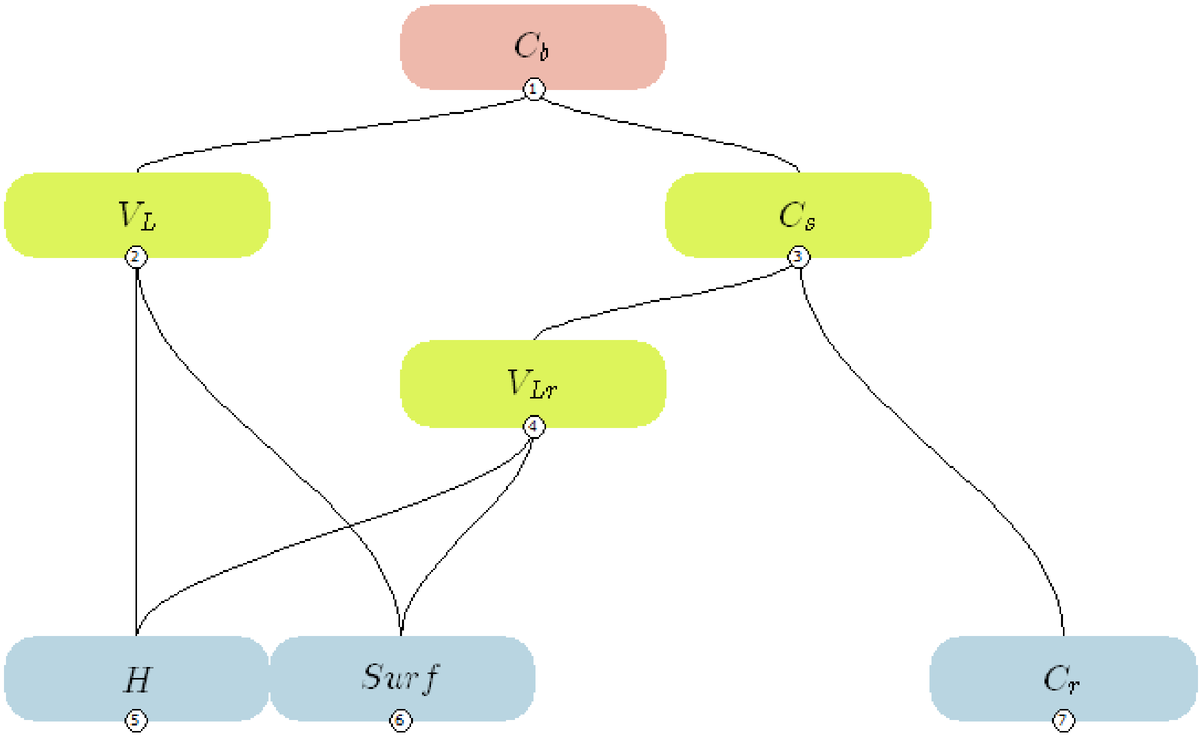
[6] ADEME, Building key figures 2013, CEREN source

System 1: Estimation of the building consumption per hour



N°	Name	Definition	Unity	Equation
1	C_b	Building consumption per hour	kW	$C_b = C_s \times S_L$
2	C_s	Medium consumption per square meter in an hour	kW/m^2	$C_s = Cr \times 1000 \times V_{Lr}$
3	V_L	Livable volume of the building	m^3	$V_L = H \times Surf$
4	V_{Lr}	Total livable volume of the region’s buildings	m^3	$V_{Lr} = \sum H \times Surf$

N°	Name	Definition	Unity	Size	Data source
5	H	Height of the buildings	m	$0 \leq H \leq 50$	BD TOPO, IGN
6	Surf	Ground surface of the buildings	m^3	$10 \leq Surf \leq 11\,519$	BD TOPO, IGN
7	C_r	Buildings regional consumption per hour	MW	$2091 \leq C_r \leq 8031$	Eco2mix, RTE France

Since we gather the buildings’ data per IRIS, the database will include the sum of the height and the sum of the surface of the buildings per IRIS. The consumption calculated through this process will therefore be an estimation of the total consumption per IRIS.

3.2.2 Wind centrals data

<u>Data sources:</u> *TheWindPower (builders' informations), DREAL Région Centre and Eco2mix, RTE 2013.*

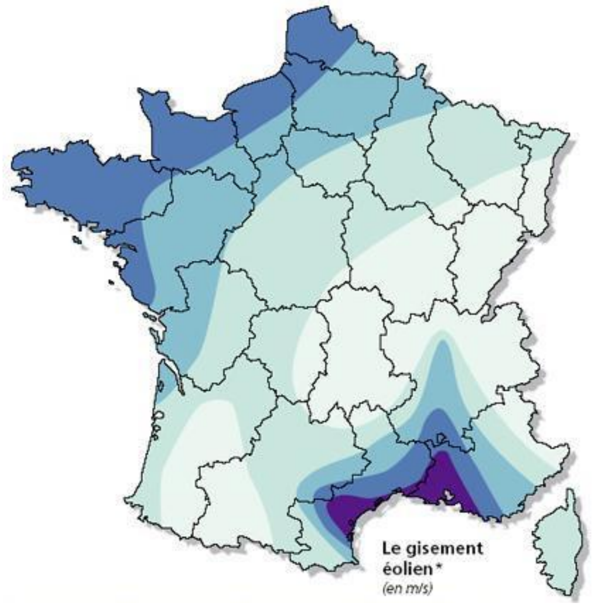
X,Y COORDINATES

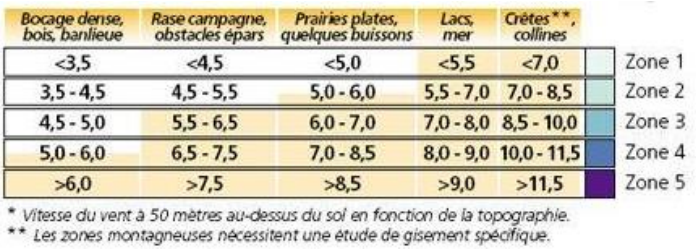
The X,Y coordinates of the wind centrals are provided by the DREAL Centre[7], which proposes directly the layer exploitable on ArcGis©.

WIND PRODUCTION

The wind potential is estimated at 30kWh for the whole planet and between 5 and 50kWh/year for the exploitable earth surface. In France, the exploitable wind resources are about 70 kWh/year on land and 500kWh/year offshore. It is therefore higher than the present consumption of electricity (about 400kWh/year). However, this production is highly fluctuant and can hardly be predicted, which implies stocking energy.

Figure 2: Wind speed in France (m/s)





Bocage dense, bois, banlieue	Rase campagne, obstacles épars	Prairies plates, quelques buissons	Lacs, mer	Crêtes**, collines		
<3,5	<4,5	<5,0	<5,5	<7,0	▢	Zone 1
3,5 - 4,5	4,5 - 5,5	5,0 - 6,0	5,5 - 7,0	7,0 - 8,5	▢	Zone 2
4,5 - 5,0	5,5 - 6,5	6,0 - 7,0	7,0 - 8,0	8,5 - 10,0	■	Zone 3
5,0 - 6,0	6,5 - 7,5	7,0 - 8,5	8,0 - 9,0	10,0 - 11,5	■	Zone 4
>6,0	>7,5	>8,5	>9,0	>11,5	■	Zone 5

* Vitesse du vent à 50 mètres au-dessus du sol en fonction de la topographie.
** Les zones montagneuses nécessitent une étude de gisement spécifique.

Source: http://www.acteurdurable.org/grand-eolien.html

The wind production depends mainly on the wind speed, as well as the turbine characteristics. The mechanic power retrieved from a wind turbine can be written with the following equation[8]:

$$P_{turbine} = \frac{1}{2} \times \mathrm{C_p} \times \rho \times \pi \times \mathrm{R_P}^2 \times \mathrm{V_w}^3$$

With $\mathrm{C_p}$ the aerodynamic coefficient of the turbine (translate the capacity of the device to recuperate the wind energy), ρ the air density, $\mathrm{R_P}$ the blades radius and $\mathrm{V_w}$ the wind speed.

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[7] Schémas éoliens départementaux - http://www.centre.developpement-durable.gouv.fr/carte-des-sites-eoliens-en-region-centre-a369.html

[8] Olivier Gergaud, *Energy modeling and economic optimization of a hybrid wind/photovoltaic system coupled with the grid and associated an accumulator*. Electric power. Ecole normale supérieure de Cachan - ENS Cachan, 2002.

The value of the power coefficient Cp depends on the turbine's rotation speed and the wind speed. It can be expressed as a function of λ, the specific speed. λ is the rapport between the peripheral speed on the blades' end and the wind speed:

$$\lambda = \frac{R_P \times \Omega}{V_w}$$

Ω is the angular speed of rotation of the turbine.

The Cp can also be considered as the coefficient of maximal energy, which as been determined by the the Betz limit[9] as:

$$Cp = \frac{16}{27} \approx 0{,}59$$

From this equation of the mechanic power of a turbine, we can calculate the production per central if we have the characteristics of the centrals (number of wind turbines, blades radius of the turbines…) as well as the wind speed received per a turbine per hour. However, we lack this last data: the data available at a format per hour is the data of regional wind production.

Therefore, we consider an average value of wind per hour for the entirety of the region. The average wind speed will be calculated thanks to this equation, for each hour:

$$P_r = \sum_i Pcent_i = \sum(n_{Ti} \times \frac{1}{2} \times C_p \times \rho \times \pi \times {R_{Pi}}^2 \times {V_w}^3)$$

$$P_r = \frac{1}{2} \times C_p \times \rho \times \pi \times {V_w}^3 \times \sum(n_{Ti} \times {R_{Pi}}^2)$$

$$V_w = \sqrt[3]{\frac{P_{regio}}{\frac{1}{2} \times C_p \times \rho \times \pi \times \sum(n_{Ti} \times {R_{Pi}}^2)}}$$

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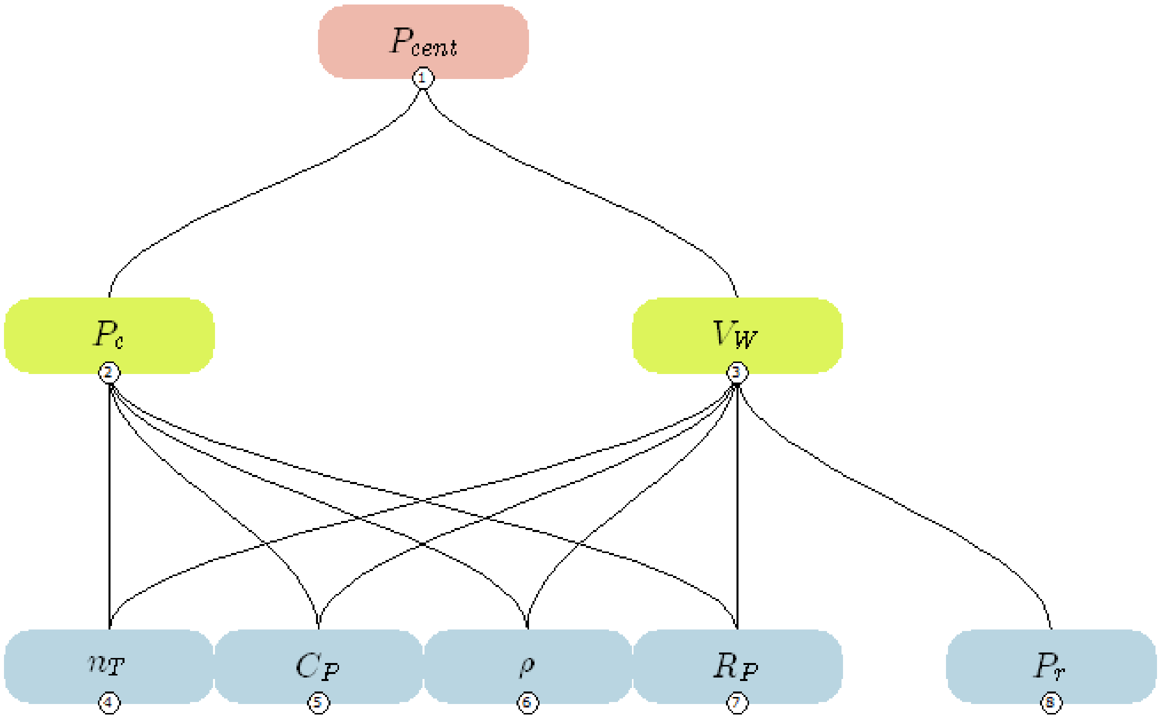
[9] Demonstration of the Betz limit - http://eolienne.f4jr.org/demonstration_limite_betz

System 2: Estimation of the wind centrals production per hour - O. Gergaud



N°	Name	Definition	Unity	Equation	
1	P_{cent}	Wind centrals production per hour	kW	$\mathrm{Pcent} = \mathrm{Pc} \times \mathrm{V_W}^3$	
2	Pc	Hypothetic power produced by a central with a wind of 1m/s	kW	$\mathrm{Pc} = \frac{1}{2} \times \rho \times \pi \times \mathrm{C_P} \times n_\mathrm{T} \times \mathrm{R_P}^2$	
3	$\mathrm{V_W}$	Wind speed	m/s	$\mathrm{V_W} = \sqrt[3]{\frac{\mathrm{P_r}}{\frac{1}{2} \times \rho \times \pi \times \mathrm{C_P} \times \sum(\mathrm{R_P}^2)}}$	
N°	**Name**	**Definition**	**Unity**	**Size**	**Data source**
4	n_T	Number of turbines		$2 \leq n_\mathrm{T} \leq 17$	Constructors' website
5	$\mathrm{C_P}$	Aerodynamic coefficient		$\mathrm{C_P} = 0{,}59$	Bertz method
6	ρ	Air density	$\mathrm{kg/m^3}$	$\rho = 1{,}25$	
7	$\mathrm{R_P}$	Blades radius	m	$40 \leq \mathrm{R_P} \leq 58$	Constructors' website
8	$\mathrm{P_r}$	Regional wind production per hour	MW	$0 \leq \mathrm{P_r} \leq 1949$	Eco2mix, RTE France

3.2.3 Solar centrals data

Data sources: *Builder's syndicate; EDF-Région Centre 2012 and Eco2mix, RTE 2013.*

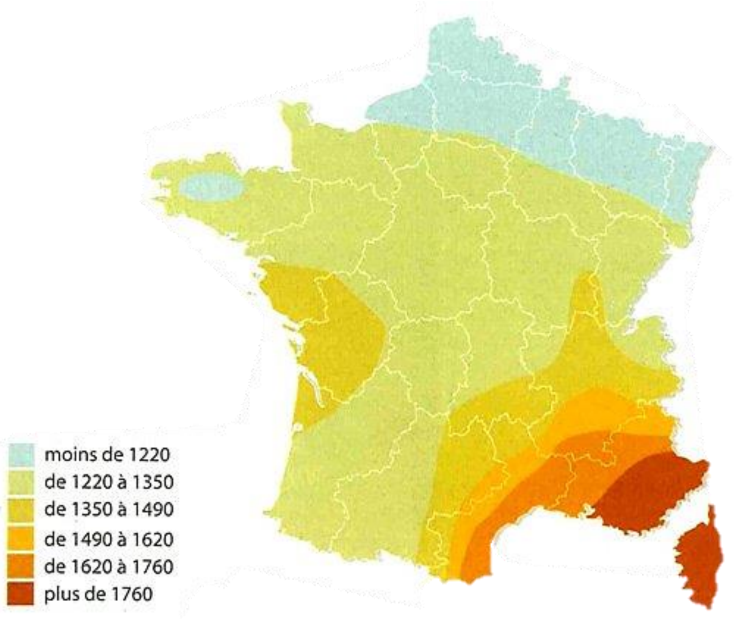
X,Y COORDINATES

The localisation of the solar centrals of the Region Centre is provided by EDF, on its rapport for the energetic transition in Région Centre[10]. The X,Y coordinates will then need to be found for these localizations (and converted to the right system of coordinates) before being added to ArcGis©.

SOLAR PRODUCTION

The sun rays represent a very important renewable energy resource, from far the highest. The energy received on earth varies, per square meter, between 1100 and 2300kWh/year. In France the variation is between 1200 and 1800 kWh/an (3,2kWh to 5kWh per day on average, depending on the latitude (see Figure 3).

Figure 3: Power of the sun rays in France (kWh/m²/year)



Source: ADEME

The photovoltaic panels permit to transform the sun light in electric energy. The photovoltaic production depends on the intensity, the period of sunlight and the position of the panel in comparison to the sun. Therefore, at midday, the sun delivers about 1kW/m² of rays on a captor placed perpendicularly to its rays.

The power produced by a solar panel can be written with the following equation[11]:

$$Psurf \; = Asurf \times factiv \times G_T \times ncell \times ninvert$$

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[10] Débat national sur la transition énergétique – Région Centre, EDF, 2013 - http://www.regioncentre-valdeloire.fr/files/live/sites/regioncentre/files/contributed/docs/avenir-region/transition-energetique/contribution-ecritte-edf.pdf

[11] M. Mandalaki, S. Papantoniou, T.Tsoutsos, *Assessment of energy production from photovoltaic modules integrated in typical shading devices*, 2014.

With A_{surf} the surface of a panel, f_{activ} the part of the surface with active photovoltaic cells, G_T the total of radiations received by the panel, n_{cell} the conversion efficiency from the sun rays to the cells and n_{invert} the efficiency of the conversion in energy.

The same method as the wind speed estimation will be used for the solar radiations: we consider an average of radiations, even on the region Centre.

Therefore, we have:

$$P_{regio} = \sum_i Pcent_{\mathrm{i}} = \sum_i Asurf_{\mathrm{i}} \times factiv_{\mathrm{i}} \times ncell_{\mathrm{i}} \times ninvert_{\mathrm{i}} \times G_{\mathrm{T}}$$

$$G_{\mathrm{T}} = \frac{P_{regio}}{\sum_i (Asurf_{\mathrm{i}} \times factiv_{\mathrm{i}} \times ncell_{\mathrm{i}} \times ninvert_{\mathrm{i}})}$$

The data available for the region Centre solar centrals does not include the different efficiency coefficients, but the constructors' websites presents a general efficiency coefficient depending on the technology of the panels, the conversion coefficient (n_{conv}).

Therefore G_T becomes:

$$G_{\mathrm{T}} = \frac{P_{regio}}{\sum_i (Asurf_{\mathrm{i}} \times factiv_{\mathrm{i}} \times nconv_{\mathrm{i}})}$$

Moreover, the surface of the panels is not provided either. In order to determine this variable, we will use the peak power of each central, data provided by the centrals' administrator website.

The peak power corresponds to the maximum power that can be produced by a central for STC conditions, which are the standard test conditions. These conditions consider a repartition of the sun rays of type AM = 1,5, incident sun rays on the photovoltaic cells of 1000W/m², and a temperature of 25°C. The central peak power corresponds to the equation:

$$\mathrm{C_{PP}} = Asurf \times factiv \times G_{\mathrm{Tstc}} \times ncell \times ninvert$$

The total effective surface of the central is therefore of:

$$Asurf \times factiv = \frac{\mathrm{C_{PP}}}{G_{\mathrm{Tstc}} \times ncell \times ninvert}$$

$$Asurf\text{-}eff = \frac{\mathrm{C_{PP}}}{G_{\mathrm{Tstc}} \times nconv}$$

With G_{Tstc} =1000W/m².

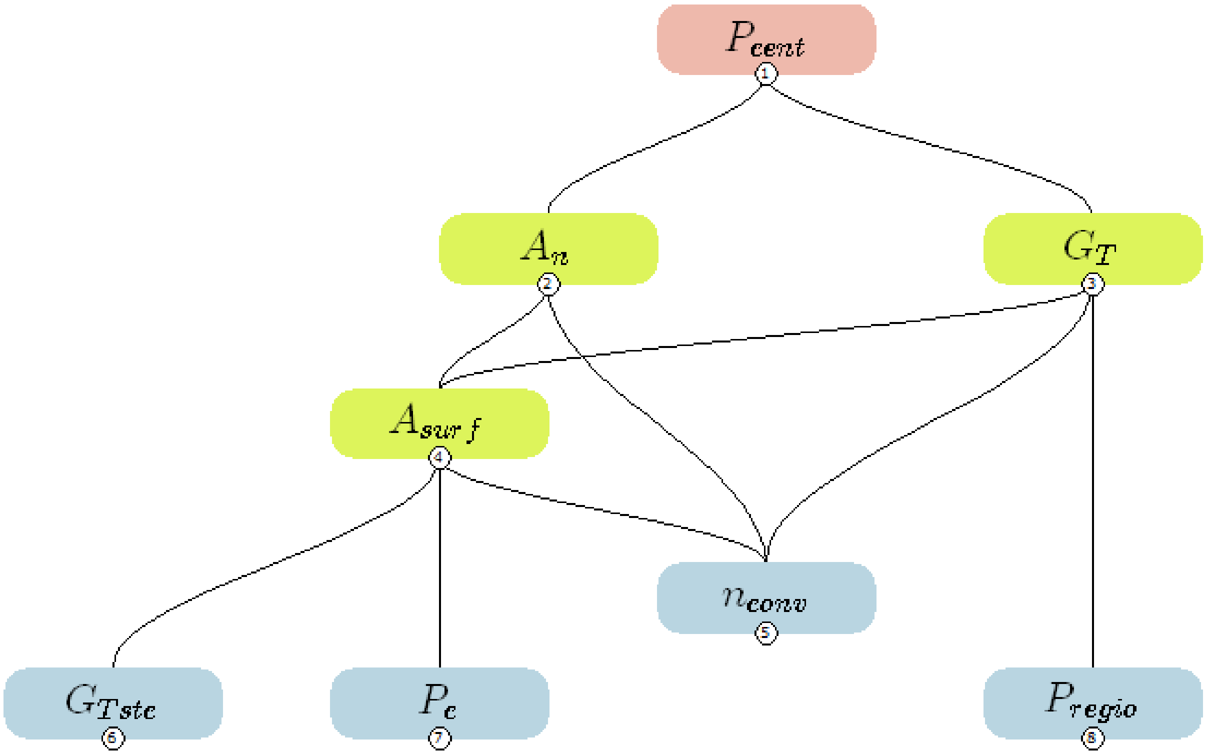
Finally, if we consider the first expression and modify it with the previous specifications, we have:

$$Pcent = Asurf \times factiv \times G_{\mathrm{T}} \times ncell \times ninvert$$

$$Pcent = Asurf\text{-}eff \times G_{\mathrm{T}} \times nconv$$

$$Pcent = Asurf\text{-}eff \times G_{\mathrm{T}} \times nconv$$

System 3: Estimation of the solar centrals' production per hour - M. Mandalaki, S. Papantoniou, T.Tsoutsos



N°	Name	Definition	Unity	Equation
1	P_{cent}	Solar centrals production per hour	kW	$P_{cent} = A_n \times G_T$
2	A_n	Hypothetic efficient surface	m^2	$A_n = A_{surf\text{-}eff} \times n_{conv}$
3	G_T	Total of radiations received per hour	kW/m^2	$G_T = \frac{P_{regio} \times 1000}{\sum(A_{surf\text{-}eff} \times n_{conv})}$
4	$A_{surf\text{-}eff}$	Total surface of the central's panels	m^2	$A_{surf\text{-}eff} = \frac{P_C}{n_{conv} \times G_{Tstc}}$

N°	Name	Definition	Unity	Size	Data source
5	n_{conv}	coefficient		$0,12 \le n_T \le 0,14$	Constructor's website
6	G_{Tstc}	Total of radiations received per hour on STC conditions	kW/m^2	$G_{Tstc} = 1$	
7	P_C	Peak power of the central	kW	$40 \le R_P \le 58$	Constructor's website
8	P_{regio}	Regional solar production per hour	MW	$0 \le P_{regio} \le 1949$	Eco2mix, RTE France

3.3 Matlab©

Once the production and consumption data is collected, the next step is to attribute, per hour, the buildings to the centrals which supply them in electric energy.

In order to affect the buildings to the centrals, we will use the software Matlab©, and an algorithm of affectation[12]. The code used is the one following:

```
[DistanceCentraleBuildingTriee,BuildingIndex]=sort(DistanceCentraleBuilding);
BuildingIndex=BuildingIndex';
```

We order the buildings according to their proximity to the centrals

```
affectation=zeros(size(BuildingConsumption));
```

At the beginning the buildings are not attributed to any central so affectation equals 0

```
centraleId=0;
CentraleProduction=CentraleProductionInitiale;
```

Residual production of the centrals, at the beginning it equals the effective production (calculated earlier)

```
for h=1:length(CentraleProduction)
```

A la première heure

```
  for i=1:numel(CentraleProduction)
    centraleId=centraleId+1;
      if centraleId>min(size(CentraleProduction))
         centraleId=1;
      end
```

Central analyzed

```
  b=BuildingIndex(i);
```

Building analyzed

```
    if affectation(b,h)==0
```

If the building considered is not attributed to a central,

```
    r=CentraleProduction(h,centraleId)-BuildingConsumption(b,h)
```

the algorithm checks that the residual production can cover the consumption of the building.

```
              if r>=0
affectation(b,h)=centraleId;
```

If it can,
the building considered is attributed to the central analyzed.

```
CentraleProduction(h,centraleId)=r;
              end
    end
```

The building consumption is retrieved from the central’s residual production.

```
     if sum(CentraleProduction(h,:))==0
        break
     end
  end
end
```

If all the central’s production is used, the algorithm stops.

The final result will be a matrix of lines corresponding to the IRIS and columns corresponding to the hours. The cells will be filled with either zeros, if the IRIS is not attributed to any central at this hour, or the number of the central the IRIS is attributed to at this hour.

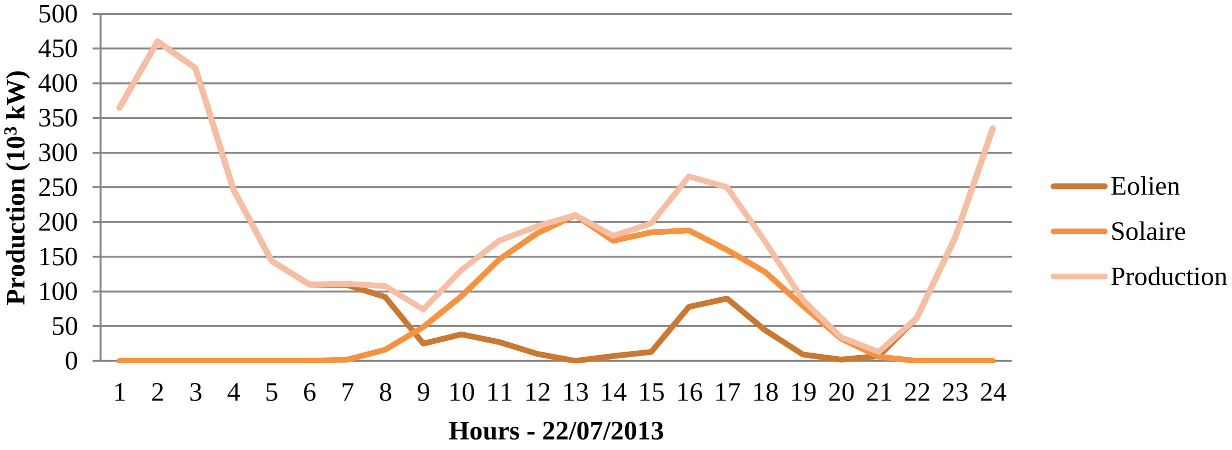
---

[12] Affectation Algorithm, Mindjid Maïzia, Atelier Nice, Polytech Tours, 2015.

In order to represent the energy territory, the difference between production and consumption has been calculated. The following analysis will be based on three days: a day presenting an average difference, a day with the highest difference (smallest energy territory), and a day with the smallest difference (largest energy territory).

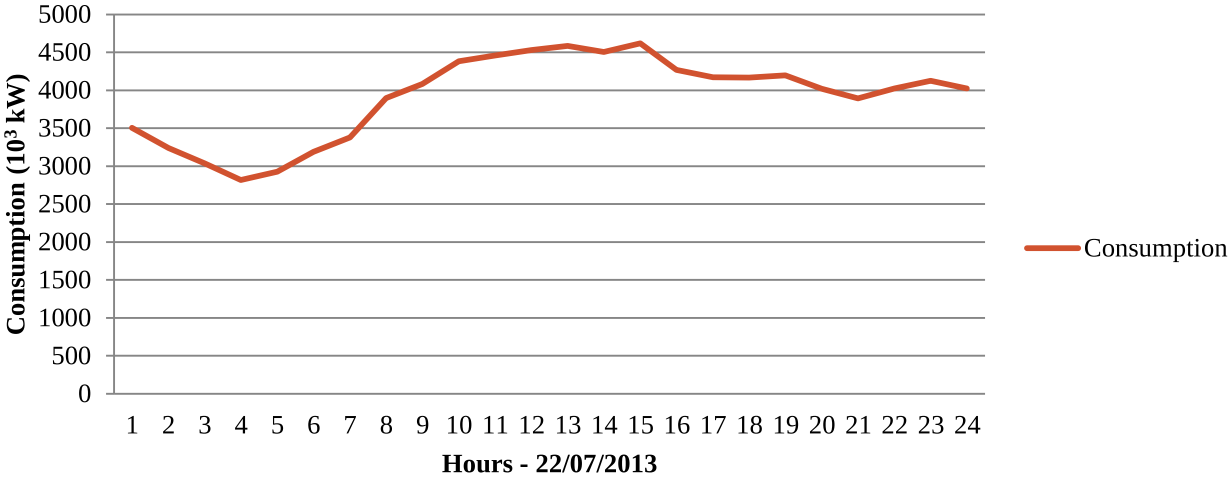
4.1 Medium energy territory – 22/07/2013

Graph 1: Energy production on the 22/07/2013



The solar production begins around 09:00 and finishes around 21:00. The wind production, as expected, is irregular and hard to predict. Here it knows a peak between 02:00 and 03:00, when there is almost no consumption.

Graph 2: Energy consumption on the 22/07/2013



On this day, the consumption stays rather regular. It rises after 05:00 and slightly slows down after 16:00. The data considered here is gathered during a summer, and it influences the electricity consumption, which is generally lower in summer, and has more obvious peaks of consumption.

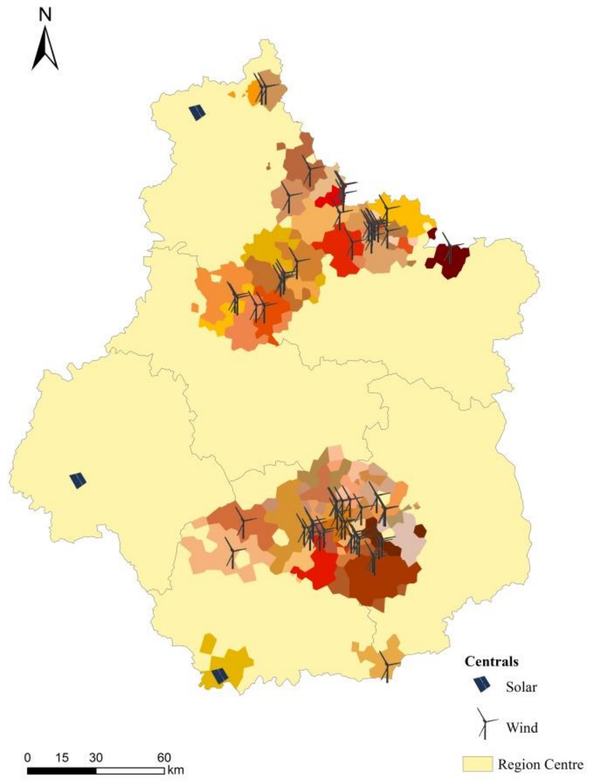


Figure 4: Energy territory of the centrals at 03:00 the 22/07/2013

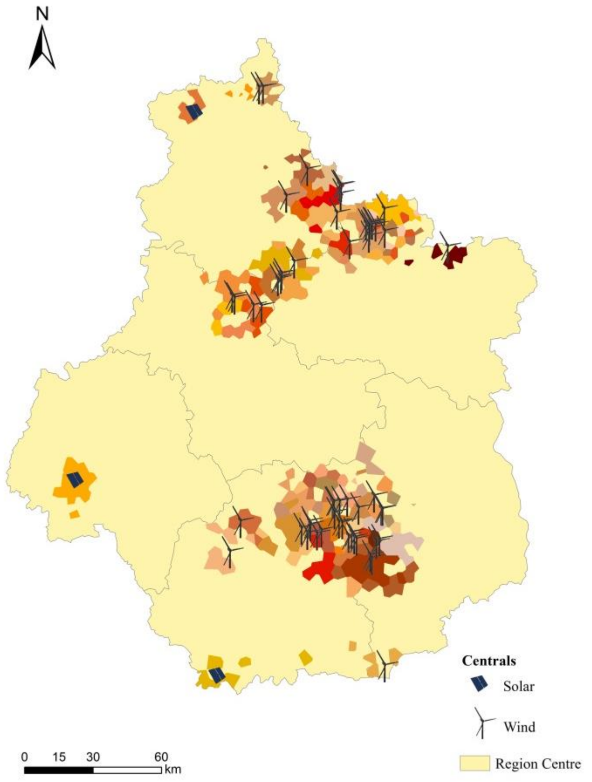


Figure 5: Energy territory of the centrals at 08:00 the 22/07/2013

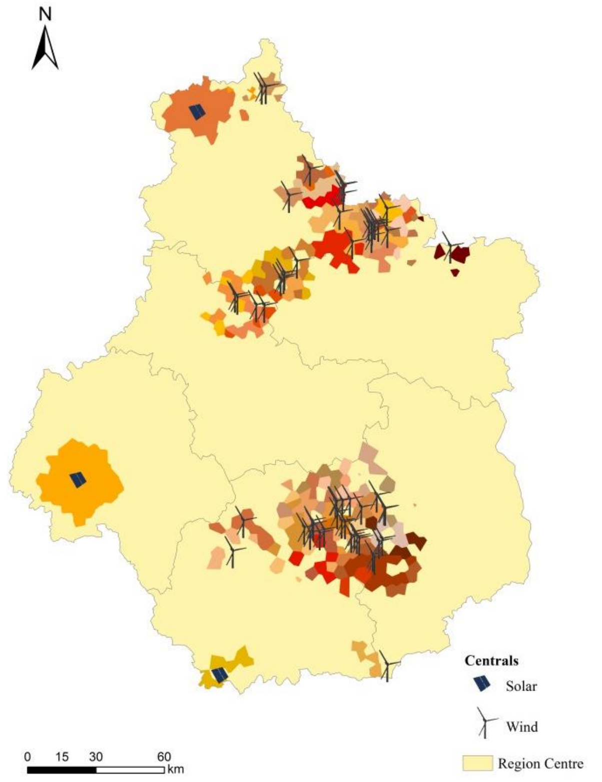


Figure 6: Energy territory of the centrals at 16:00 the 22/07/2013

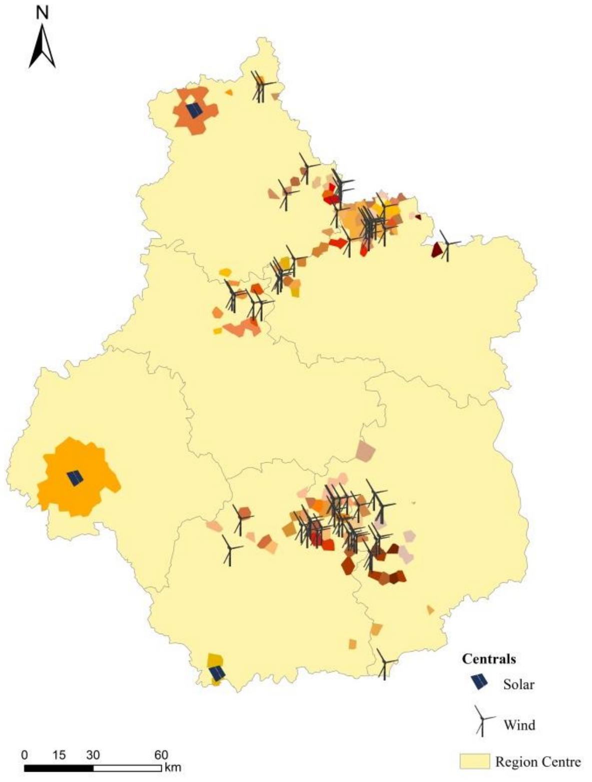


Figure 7: Average energy territory of the centrals at 19:00 the 22/07/2013

The maps above represent a representation of the energy territory covered by the centrals of the Region Centre at different hours of the day. Each IRIS supplied by the production in renewable energy has been attributed a color corresponding to the central supplying the energy (the Annex 1 presents the centrals of Region Centre and their ID).

On the maps (Figure 5 and 6 in particular), we can observe that some isolated IRIS have their consumption covered by a central, while some IRIS closer to the central are not attributed. This means that consumption of the closer IRIS was too important to be covered by the central's production. The remaining energy was then attributed to a further IRIS, with a lower consumption at the hour considered.

Moreover, some centrals see the IRIS surrounding them attributed to further centrals, despite the sorting depending on the distance between centrals and IRIS. The central (3) (solar central of Chaillac, Indre) for example has the surrounding IRIS attributed to the wind central (4). It implies that their production could not cover the consumption of closer IRIS, and had to be delivered further away from their location.

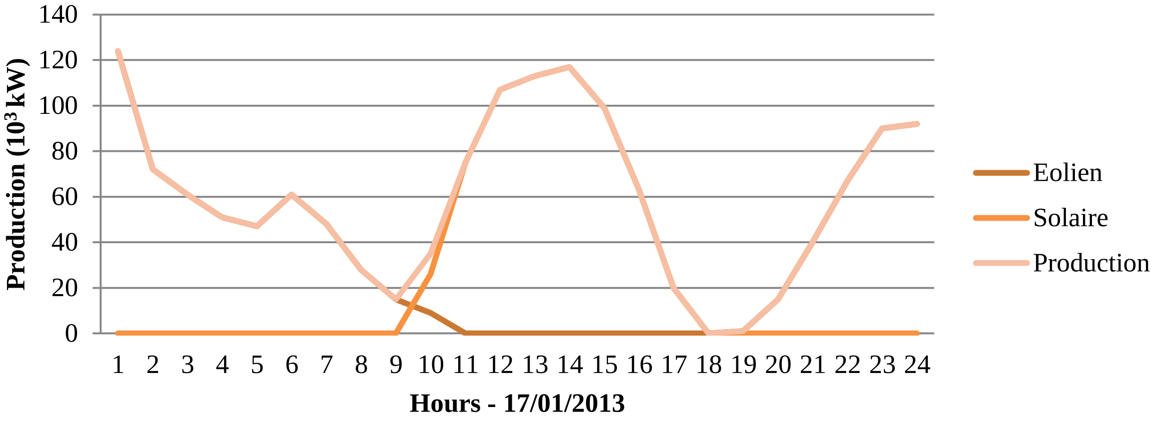
The average difference between regional production and regional consumption, in 2013, is a deficit of -4111.10^{3}kW/hour. An example of the energy territory covered for this average difference is given at 19:00 on the 22/07/2013 (Figure 7). The production covers the consumption of 182 IRIS, or 86 423kW. There is however produced energy not attributed to any IRIS that could be inserted into the national network (Table 1).

	22/07/13 3:00	22/07/13 8:00	22/07/13 16:00	22/07/13 19:00
Production (10^{3}kW)	422	108	266	88
Consumption intern to the energy territory (10^{3}kW)	310	102	259	86
Total energy remaining (10^{3}kW)	112	5	7	2

Table 1: Flows of energy on the 22/07/13

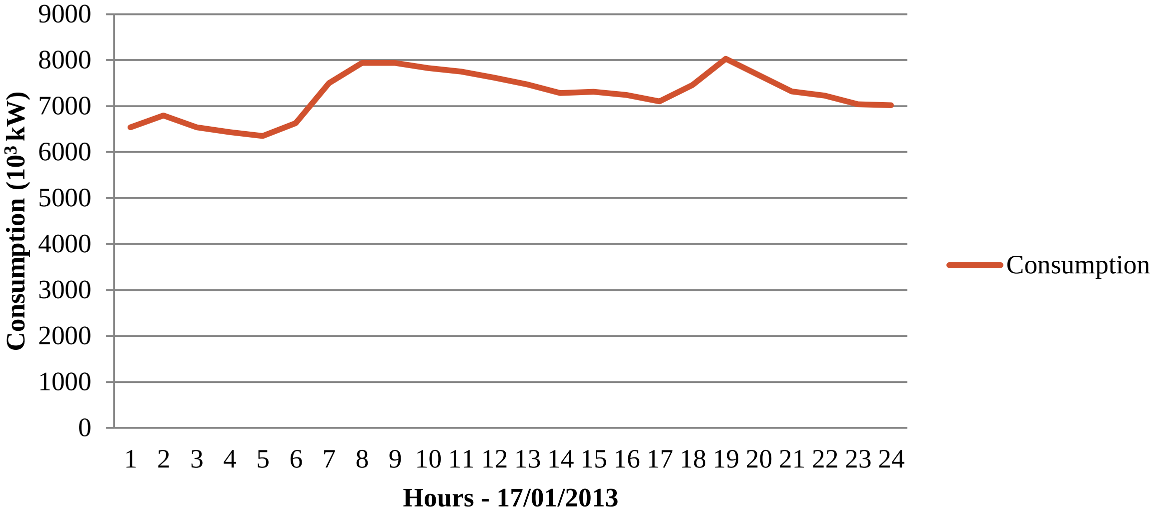
4.2 Minimum energy territory - 17/01/2013

Graph 3: Energy production on the 17/01/2013



On this day, the total production is lower than during any other day of the year 2013. It is even null between 18:00 and 19:00. There is a peak of production (due only to the solar production) between 14:00 and 15:00, which reaches 120.10^3kW. This figure is much lower than the average production of 2013, which is of 381.10^3kW/hour.

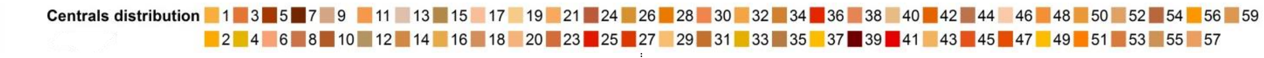
Graph 4: Energy consumption on the 17/01/2013



The consumption shows two main peaks: at 8:00 and between 19:00 and 20:00 it reaches 8000.10^3kW. This figure is much higher than the average consumption (4494.10^3kW/hour in 2013).

This low production and high consumption account for the largest difference between production and consumption of 2013: -8030.10^3kW of difference between the production and consumption at 19:00. The average difference in the Region Centre in 2013 is of -4111.10^3kW.

This large difference shows when representing the energy territory.



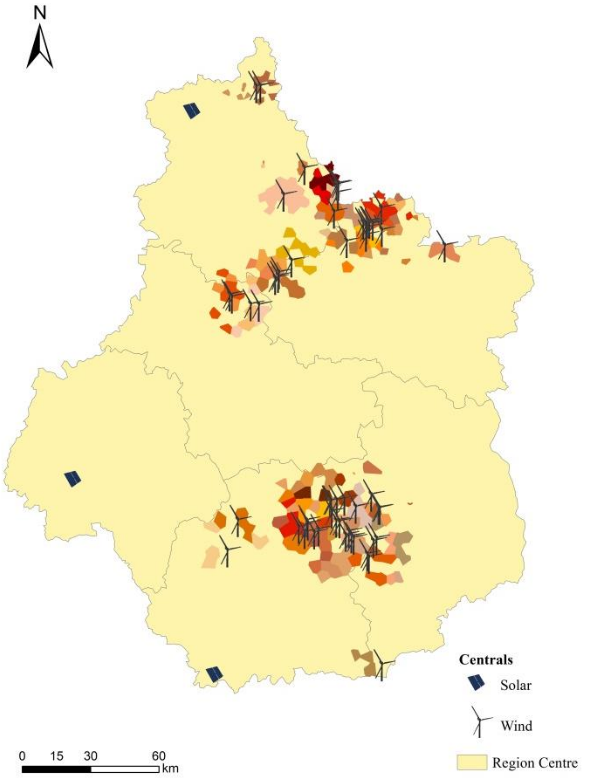


Figure 8: Energy territory of the centrals at 03:00 the 17/01/2013

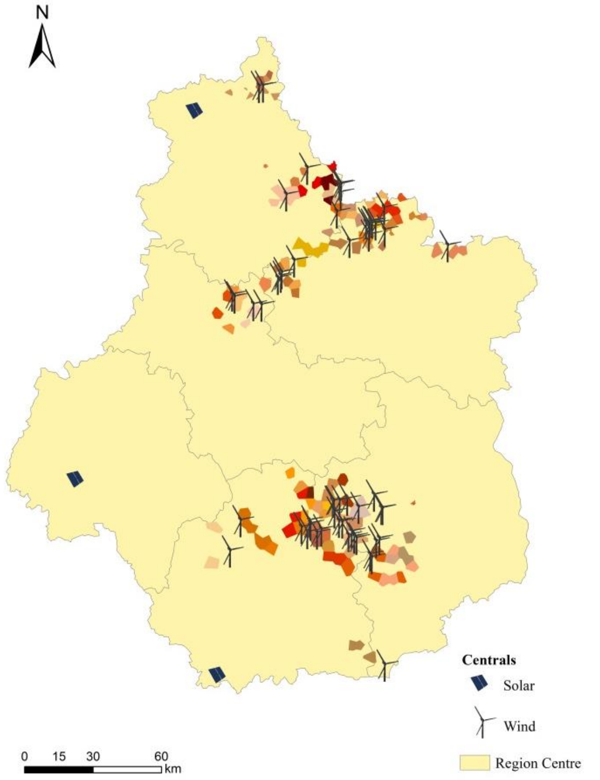


Figure 9: Energy territory of the centrals at 08:00 the 17/01/2013

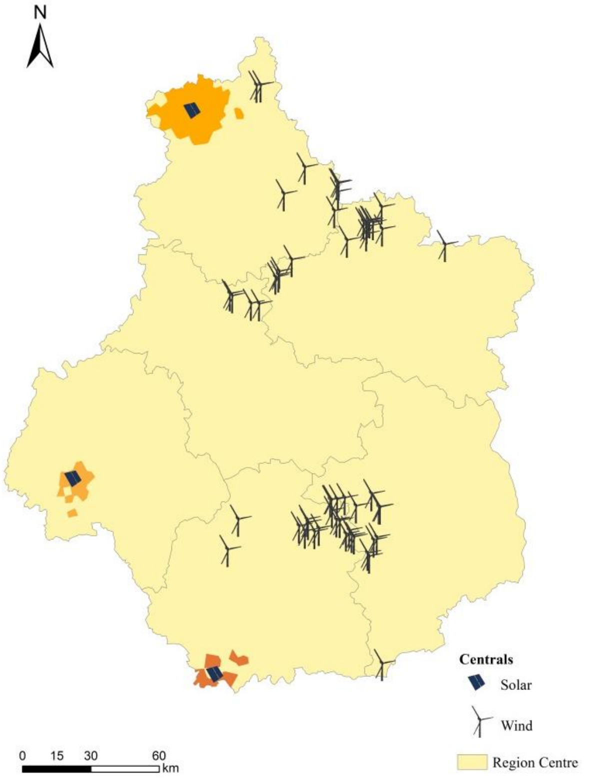


Figure 10: Energy territory of the centrals at 16:00 the 17/01/2013

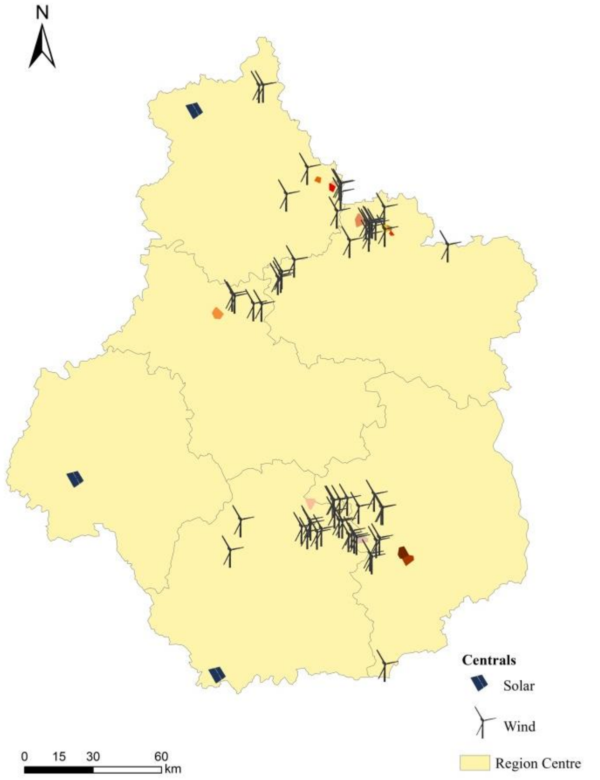


Figure 11: Minimum energy territory of the centrals at 19:00 the 17/01/2013

On the 17th January of 2013, the production of energy by the wind centrals was extremely low. At 16:00, it was even null: the only production of energy in Region Centre was due to the solar centrals. Coincidently, it is also the date of the highest consumption of the year: 8031.10^3kW/hour at 19:00. These factors account for the highest difference between production and consumption: -8030.10^3kW (the production at 19:00 is of 1.10^3kW/hour).

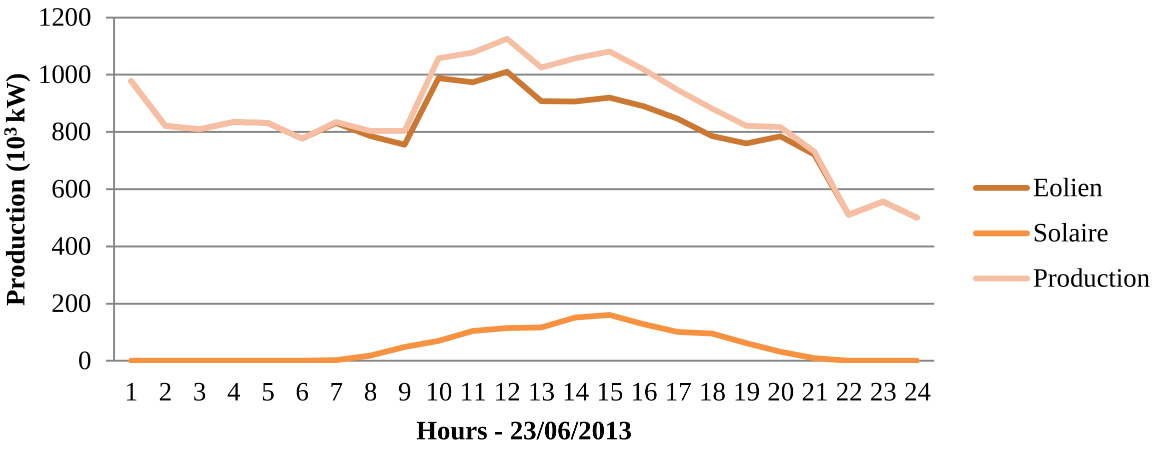
Therefore, the energy territory is extremely small: 12 IRIS covered, for a consumption of 250kW. Once again, produced energy has not been attributed (the production was not high enough to cover the total consumption of the IRIS).

	17/01/13 3:00	17/01/13 8:00	17/1/13 16:00	17/01/13 19:00
Production (kW)	61000	28000	63000	1000
Consumption intern to the energy territory (kW)	56725	24602	62805	250
Total energy remaining (kW)	4275	3398	195	750

Table 2: Flows of energy on the 17/01/2013

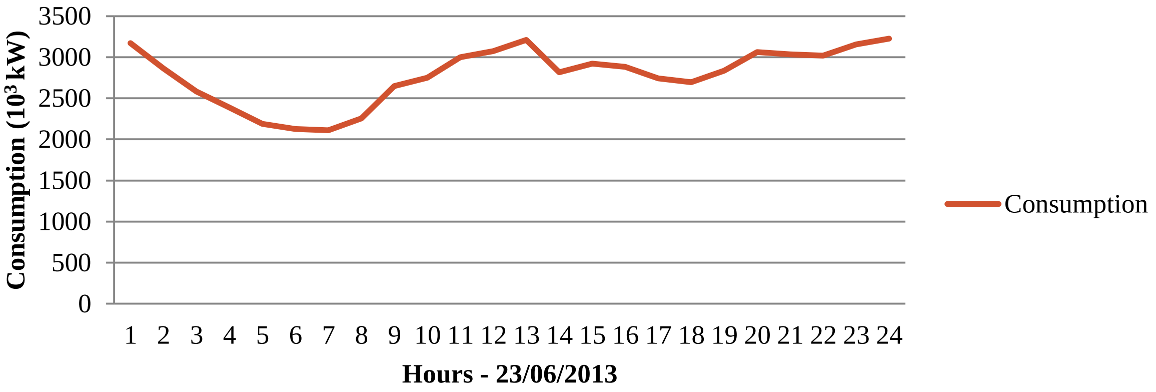
4.3 Maximum energy territory - 23/06/2013

Graph 5: Energy production on the 23/06/2013



The production on the 23rd of June 2013 is high: around 900kW/hour, much more than the average production of 381kW/hour in 2013. The production is almost constant at 800kW/hour between 02:00 and 09:00. It rises between 09:00 and 12:00, to know a peak of production above 1100kW/hour.

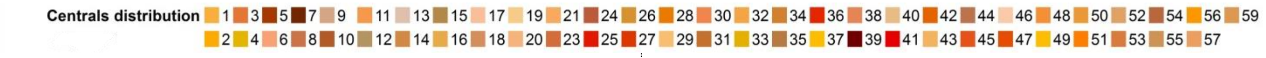
Graph 6: Energy consumption on the 23/06/2013



The consumption rises past 07:00, to reach a consumption of 3100.10^3kW/hour at 13:00 (average consumption of 4494.10^3kW/hour in 2013). It then decreases a little, before increasing again around 19:00.

This high production (for a medium consumption) accounts for the smallest difference between production and consumption of 2013: -1275.10^3kW of difference between the production and consumption at 07:00. The average difference in the Region Centre in 2013 is of -4111.10^3kW.

This small difference accounts for a widespread energy territory.



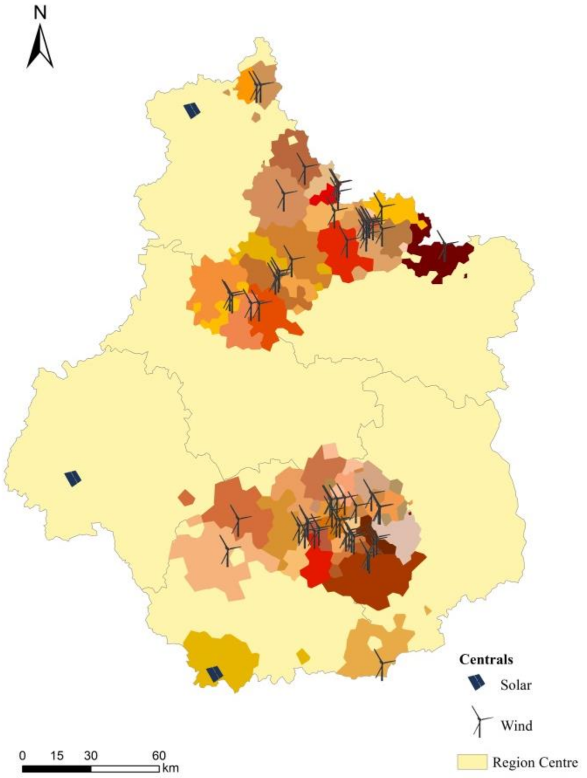


Figure 12: Energy territory of the centrals at 03:00 the 23/06/2013

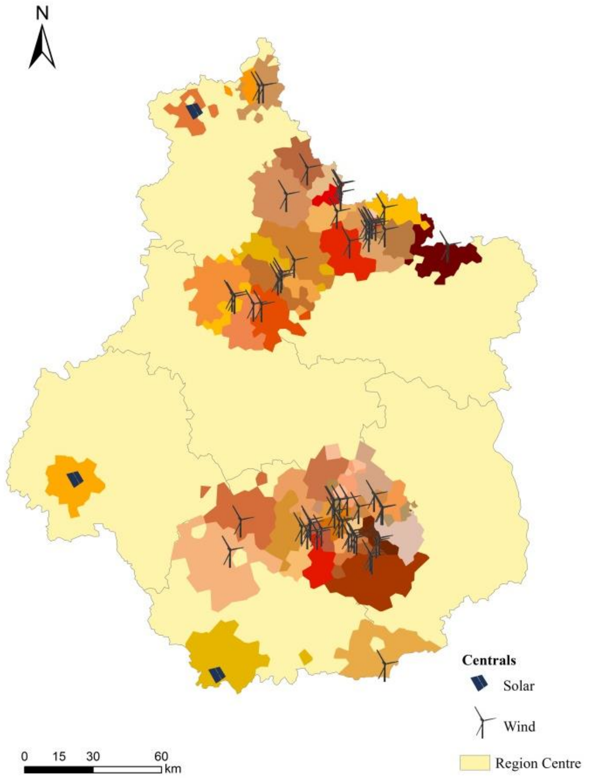


Figure 13: Energy territory of the centrals at 07:00 the 23/06/2013

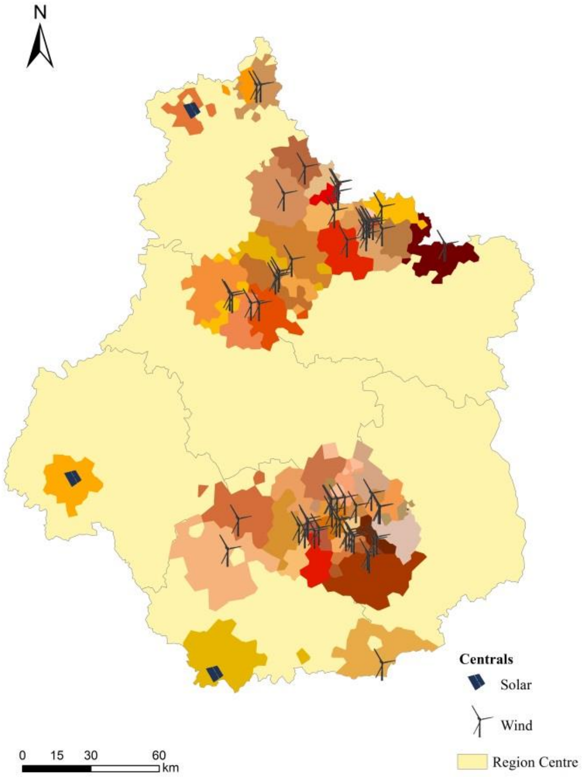


Figure 14: Energy territory of the centrals at 16:00 the 23/06/2013

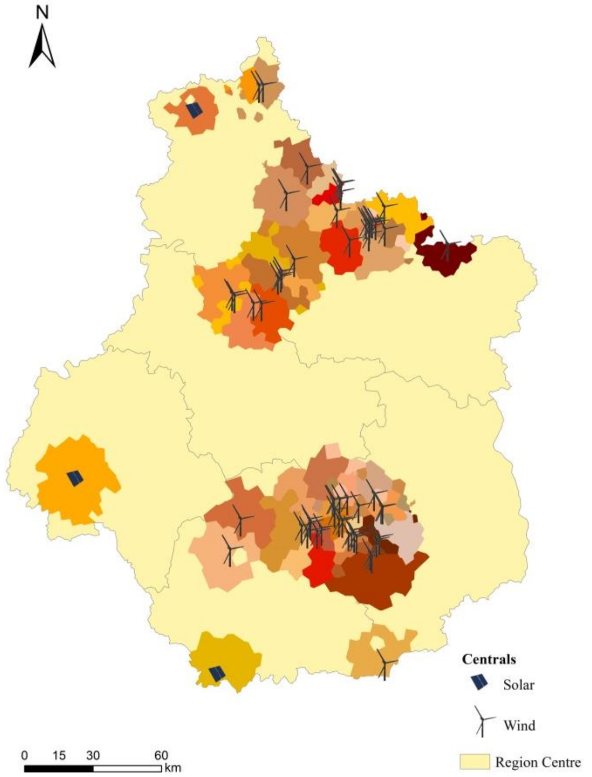


Figure 15: Energy territory of the centrals at 19:00 the 23/06/2013

Due to the rather small difference between regional production and regional consumption, the energy territory is one of the largest of 2013. At 7:00, the consumption is lower and the production of the solar centrals heightens, for a total difference of -1275.10^3kW/hour.

Therefore, the energy territory counts 695 IRIS covered, for a consumption of 400.10^3kW. However, if the difference is the highest, the losses of renewable energy are higher than at 16:00 (more than half of the production is not used at 07:00). The energy territory at 16:00 is wider, the production supplying 743 IRIS, for a consumption of 597.10^3kW/hour.

	23/06/13 3:00	23/06/13 7:00	23/06/13 16:00	23/06/13 19:00
Production (10^3 kW)	809	835	1018	822
Consumption intern to the energy territory (10^3 kW)	442	400	597	502
Total energy remaining (10^3 kW)	367	435	421	320

Table 3: Flows of energy on the 23/06/13

5 Conclusion and study limits

The analysis of the results shows that the production, especially of wind centrals, is unpredictable. The consumption can be globally predicted (rush hours, peaks of consumption), but could be more accurately anticipated with regular plots.

Moreover, even though the production of the renewable centrals never covers the entirety of the consumption, there are always losses of energy produced, because the production cannot cover the total hourly consumption of the IRIS considered. The energy remaining would need to be gathered in the regional or national system to be distributed.

These disadvantages could also, in parts, be blamed on the limits of the method: indeed, since the consumption data has been gathered per IRIS, it is harder for the central to cover the total consumption of the IRIS area. Therefore, some IRIS are not attributed due to their too important high consumption. If considering the data per building, the modelization would be more precise, and the production could more easily cover the consumption of the buildings (the remaining energy would then be lower). Moreover, the IRIS is not attributed to the central if the the central cannot cover the totality of its consumption. For a production integrated in the local network, this specificity is not taken into account.

The method has others limits. For the production, only the centrals of Region Centre are considered, and not the small installations (photovoltaic panels on the roof, etc.). Their production is interesting, because to be profitable, their total production must be higher than the total consumption of the building that supports them. Their production can then cover the consumption of surrounding buildings.

Another limit is the accuracy of the building consumption: this estimation is based on the data available, and does not take into account several characteristics of buildings, such as the isolation. Both for the production and consumption, a plot of the flows of energy per central and building would have made this study more precise.

However, even if the integration of renewable energies in a local grid present difficulties, this distribution seems interesting. When considering the results, we can see that the territory covered is not negligible. Moreover, it can be justified by the following advantages:

- The centrals of production are located close to the points of consumption
- This proximity will limit the losses due to the transport of energy
- It would encourage to consider the renewable sources, which have no cost for the primary energy

In order to realize this transition from national to local network of energy, more accurate predictions of consumptions are needed. This first issue can be partly solved with the installations of smart meters, devices that can realize regular measures of the consumption data, and therefore supply more precise previsions of consumption. These devices can also include the production data of small installations. These data would permit to have knowledge of the needs of the network in real time.

The other issue that this transition will have to face is the character unpredictable of the production form renewable sources of energy. In order to compensate the difference between the renewable energy produced and the consumption, the traditional means of production will remain indispensable. They will then have to adapt their production to the variations of production of the renewable centrals.

This adaptability excludes the nuclear centrals, and would rather concern the hydraulic dams and thermic centrals. Even if these last ones are expensive and polluting, they would remain essential because of their high reactivity and adaptability.

The integration of this traditionally produced energy into the local network, and the integration of the remaining locally produced renewable energy into the regional or national network implies to transform the distribution grid into a bidirectional network.

This transition would change radically the status of renewable energy: they are nowadays considered as disturbers of the network, and would then be the regulators, the ones the traditional production is based upon. A local management would permit to regulate the traditional production according to the real time data collected from smart meters, and the real time production of renewable centrals. Overall, this transition implies firstly a better knowledge of the network, and ability to predict more accurately its needs.

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7 Illustration tables

8 Annexes

Annex 1: Centrals of the region Centre, 2012

	Central's name	Postal Code	Town
1	Ferme photovoltaïque d'Avon-les-Roches	37012	Avon-les-roches
2	Ferme photovoltaïque de Crucey-Villages	28120	Crucey-Villages
3	Ferme photovoltaïque de Chaillac	36035	Chaillac
4	Parc éolien Bois Ballay	18137	Mareuil
5	Champ éolien de Chéry	18064	Chéry
6	Parc chaussée césar sud	18066	Civray
7	Parc de Longchamp	18167	Nohant-en-Graçay
8	Parc des croquettes, parc des plantes	18190	Quincy
9	Parc de Forge	18198	Saint-Ambroix et Mareuil
10	Parc Les Coudrays	18237	Ste-Thorette
11	Parc les Mistandines	18237	Ste-Thorette
12	Parc Chaussée César Nord	18066	Civray
13	Parc éolien de Lazenay, Cerbois, Limeux-Les Trois Ormes	18044	Cerbois
14	Parc éolien de Massay II	18140	Massay
15	Parc éolien de Préveranges - Saint Saturnin	18234	Saint-Saturnin
16	Parc de Massay	18140	Massay
17	Parc éolien Le Moulin d'Emainville	28004	Allones
18	Parc éolien des Barbes d'Or	36125	Migny
19	Parc éolien des Rochers	36194	Saint-Genou
20	Parc éolien des Vignes	36195	Saint-Georges-sur-Arnon
21	Parc éolien des Pelures Blanches	36065	Diou
22	Parc éolien du pays d'Ecueillé Ligne Est (la Petite Pyramide)	36086	Heugnes
23	Parc éolien de Ménétréols et Lizeray Ligne Est	36098	Lizeray
24	Parc éolien de Ménétréols et Lizeray Ligne Sud	36116	Ménétréols-sous-Vatan
25	Parc éolien des Petites pièces et pièces de vignes	36097	Liniez
26	Parc éolien Les Tilleuls	36195	Saint-Georges-sur-Arnon
27	Parc éolien d'Aubigeon	36065	Diou
28	Parc éolien de Ménétréols et Lizeray Ligne Ouest Les Renardières	36116	Ménétréols-sous-Vatan
29	Parc de Binas - La Bruyère	41017	Binas
30	Parc éolien des Bornes de Cerqueux	45134	Epieds-en-Beauce
31	Le Bois Louis	45326	Tournoisis
32	Parc éolien du Sainbois	45326	Tournoisis
33	Centrale éolienne Patay	45248	Patay
34	Parc éolien de Pithiviers-le-Vieil	45253	Pithviers-le-Vieil

35	Parc éolien de Bazoches	45025	Bazoches-les-Gallera
36	Parc du Plateau Beauceron	45012	Audeville
37	Parc de Greneville-en-Beauce	45160	Greneville-en-Beauce
38	Parc éolien du Gâtinais	45303	Sceaux-du-Gatinais
39	Parc éolien des Gargouilles - CEGAR 1	28183	Gommerville
40	Parc éolien des Gargouilles - CEGAR 2	28183	Gommerville
41	Parc éolien des Gargouilles - CEVIN 1	28183	Gommerville
42	Parc éolien du Bois Cheneau	28025	Barmainville
43	Parc éolien des Quinze Mines	45080	Charmont-en-Beauce
44	Parc éolien de la Mardelle	45162	Guigneville
45	Parc éolien de la Vallée du Moulin	45162	Guigneville
46	Parc éolien de la Beauce Oratorienne (Bois Anchat)	41173	Ouzouer-le-Marché
47	Parc éolien des Mardeaux (Moisy)	41141	Moisy
48	Parc éolien des Pénages (Moisy)	41141	Moisy
49	Parc éolien de Pouzelas	36083	Giroux
50	Parc éolien de Cermelles	36083	Giroux
51	Parc éolien du Climat de Beauclair	45174	Jouy-en-Pithiverais
52	Parc éolien des Joyeuses	36195	Saint-Georges-sur-Arnon
53	Les Grandes Vallées	28317	Roinville
54	Parc de Germainville II	28178	Germainville
55	Parc de Germainville I	28178	Germainville
56	Parc éolien les Blés d'Or	36230	Vatan
57	Parc éolien le Mée	36230	Vatan
58	Parc éolien des Sauvageons (ex Vieux moulin)	45080	Charmont-en-Beauce
59	Centrale éolienne de Saint Jacques (ex Vieux moulin)	45080	Charmont-en-Beauce

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2014-2015

Definition of the Energy Territory:
Modelization of the urban area equilibrating the production and consumption of electric energy

Summary:

This study aims at defining the energy territory, which is the area which has its consumption covered by the production of a central. The case study observed here is the Region Centre, in France. The work exposed here consists in the estimation of the production of the centrals and consumption of the buildings of the Region Centre per hour, and the representation of the area equilibrating production and consumption. In order to do so, several softwares are used: Matlab©, ToasterSystem© and ArcGis©.
This project will also present conclusions in terms of adaptations of the electric grid, in order to conceive a distribution of energy that would no longer be generalized (national or regional) but local.

Keywords:
Energy territory, photovoltaic production, wind production, building consumption, modelization, electric grid