Energy concepts for utilization of solar energy in small and medium cities: the case of Chambéry

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Abstract

In this paper, a part of the results of a study realised in Chambéry to develop the use of solar energy in small and medium European cities is presented. This analysis is based on the evaluation of the solar potential of the city, then a balance of saved energy and reduced emission is established. In the second part of the paper an application on a specific area of the city is realised by considering the technical feasibility and the specific constraints of the site. In the end, an economic appraisal is done to demonstrate the interest of the renewable energy use in small and medium cities.

1.- Introduction

Cities are presently the environment for 75 % of the European population. Furthermore, these concentrate about 80 % of the energy consumption of European Community in an area of just about 10% of the total area of the EU. The aim of this study is to promote the development of renewable energy and biomass for a large scale utilisation in small and medium cities in order to reduce the emission of CO_2, NO_x,CO and SO_2. The project is managed by the European Union (APAS,1996) and concerns three cities : Regensburg (Germany), Larissa (Greece) and Chambéry (France). It is important to observe the difference of style, traditional and climatic conditions in these three cities.

In this paper , we will focus our analysis on two points. The first one concerns the solar potential of Chambéry. Two potentials are considered, the theoretical one and the practical one. The analysis of the two potentials and the quantity of energy saved by solar DHW production will permit the estimation of the amount of reduced emissions. The second point is an application on a specific area of the city which will permit to define a low emission island. On this island an economic appraisal is done.

2. - Solar Potential for the City of Chambéry

2.1 - Method

The term « solar potential » is used here as a surface which could be equipped with solar collectors or others solar units because it is possible to easily convert this information into solar energy production when specific solar productivty is known.
The investigation is limited to the residential sector because it is difficult to have reliable data for the others sectors.
The first aim of this analysis is to estimate the repartition of building categories able to contribute efficiently to solar potential. Five different areas have been defined from specific data related to the different building types (Figure 1).

The second aim is the evaluation of the theoretical and the technical solar potential of the city. The main results of this analysis are shown in Table 1.

The distribution of the areas is the following :

- Area (1) contains only the parts of the city with a high density of buildings as Chambéry le Haut and the sectors of Biollay, Covet and Paradis. Few individual houses are located in these area;
- Area (2) contains the downtown with the historical protected sector;
- Area (3) contains 85 % of buildings and 15% of individual houses;
- Area (4) contains 50 % of buildings and 50% of individual houses and area (5) contains 100% of individual houses. They correspond to the peripheral areas of the town.

The total population living in these five areas is 54 000 inhabitants. The total surface of all areas is 21,12 km^2

Some hypothesis were considered in this analysis :

- the ratio "Sroof/ Sflo" is the ratio of the roof surface on the net floor area. The values of this ratio are shown on the forth column of Table 1. For tilted roofs, this ratio is equal to the projected roof surface, divided by the cosinus of the roof slope (around 30°), on the living surface .

- it was considered that only horizontal roofs and tilted roofs having an orientation comprised between South East and South West could be equipped with solar collectors. For tilted roofs, the orientation factor (f_1) is equal to 0.25 while its value is equal to 1 for horizontal roofs.

-The availability factor (f_2) takes into account the presence of various equipment on the roof (chimney, fan,.....).

-Excepting tilted roofs where solar collectors and the roof are at the same level, the installation of solar collectors with a slope of 45° will not permit the use of all horizontal roof surfaces. Thus, for horizontal roofs we consider an arrangement factor (f_3) equal to 0.4.

2.2 -Theoretical Potential

The solar theoretical potential, expressed in terms of available surface, is the roof surface corrected by the product of the three factors mentioned here above ($f_1.f_2.f_3$). This potential for the whole city is equal to 137 000 m2. (column 9 of Table 1).
The reduction of this potential by shading due to surrounding environment is very low. Figure 2 shows that this reduction exceeds rarely 5% of the total solar irradiation. and a mean value of 2% seems to be representative for the north part of the town. The south part is not affected.

This potential might be used for DHW and PV applications. For the city of Chambéry, the PV potential has not been studied in detail because in France this technique is currently not used, according to the particularity of the French electricity production; for this reason, we did not neither analyse the possibility of putting PV cells on the vertical walls.

2.3 - Practical Solar Potential

The optimal surface to cover DHW energy requirements with a ratio of 95% in the best cases and 30% in average is 0.7 m^2/inhabitant (MACH, 1990). This condition leads to a practical solar potential equal to 37 700 m^2.

The practical DHW solar potential is the minimal value between the theoretical solar potential and the optimal surface as defined here above. For Chambéry this potential is thus equal to 37 700 m2 (column 12 of table 1).

The solar productivity of a DHW solar installation is equal to 450 kWh/m2/a at Chambéry (see section 3.2). Consequently, the practical DHW solar energy production is equal to 17 GWh/a which corresponds to 0.3 MWh/a per inhabitant. This value is equal to 5% of the present global energy consumption of the residential sector.

Remark 1 : By the difference between the theoretical DHW potential and the practical DHW potential, we could obtain the available surface of the roofs which could be devoted, theoretically, to PV applications. So, a theoretical PV solar energy production is defined as the product of this available surface by the PV solar productivity, estimated at 100 kWh/m^2/a for Chambéry. This potential is equal to 10 GWh/a.

Remark 2 : We have studied the solar potential related to the heating of individual houses to be build in the future at Chambéry. We have chosen the « Direct Solar Heating Floor » technique» (DSHF is a heating floor connected with solar collectors and with an auxiliary heating system) because it is the only technique compatible with an economic objective if solar collectors are used for heating and DHW production together. In these conditions, the solar productivity of a DSHF system is 310 kWh/m^2/a. The annual number of projects is around 40 and the solar collector area is equal to 15 m^2 per house (for an average net floor area of 120 m^2). The future practical solar energy production for individual houses heating at Chambéry will be about 200 MWh/a.

For the heating of new buildings, the same technique or another equivalent solar technique are not still economically available and this case is not analysed. We will consider for these future buildings only DHW solar production.

Table 1 : Calculation of the theoretical and the practical DHW solar potential [m^2]

Area (1)	Distribution (2)	Net floor .Area. **Sflo** [m^2] (3)	**Sroof/Sflo** (4)	Roof Surface **Sroof** [m^2] (5)	Orient. factor (**f1**) (6)	Availab .factor (**f2**) (7)	Arrangt .factor (**f3**) (8)	**Sth :** Theoritical Solar Potential [m^2] (**Sroof.f1.f2.f3**) (9)	Inhabitants (**Inh**) (10)	**Sn**: Needed DHW Solar collectors Surface [m^2] (**0,7*Inh**) (11)	Practical DHW Solar Potential [m^2] **Min[Sth;S]** (12)
1	Chby le Haut Biollay Covet+Paradis Houses	197657 93111 67284 4604	0,373 0,274 0,22/cos30	74000 25500 17000	1 1 0,5	0,5 0,5 0,5	0,4 0,4 1	14800 5100 4250	8800 3600 2115	6160 2520 1480	6160 2520 1480
2	Downtown - protected sector Houses	*753200* *-181600(*)* 4749	0,25/cos30 (**)	165000	0,5	0,1	1	8250	2900	2000	2000
3	Buildings (85 %) Horiz.roof (1/4) Tilted roof (3/4) Houses (15 %)	 124000 370000 80226	 0,3 0,3/cos30	 37000 128000	 1 0,5	 0,5 0,1	 0,4 1	 7400 6400	17300	12100	12100
4	Buildings (50 %) Horiz.roof (1/4) Tilted roof (3/4) Houses (50 %)	 42000 125000 161363	 0,3 0,3/cos30	 13000 43000	 1 0,5	 0,5 0,1	 0,4 1	 2600 2150	6500	4500	4500
5	Houses (100 %)	36363									
	Total houses (2800 houses)	287243	1/cos30	331680	0,5	0,7	1	116100	12785	8940	8940
								137150 [m^2]	54000		37700 [m^2]

(*) the italic characters refer to ground surface and not to living surface

(**) We suppose that only 25% of the *ground surface* is occupied by buildings in this area

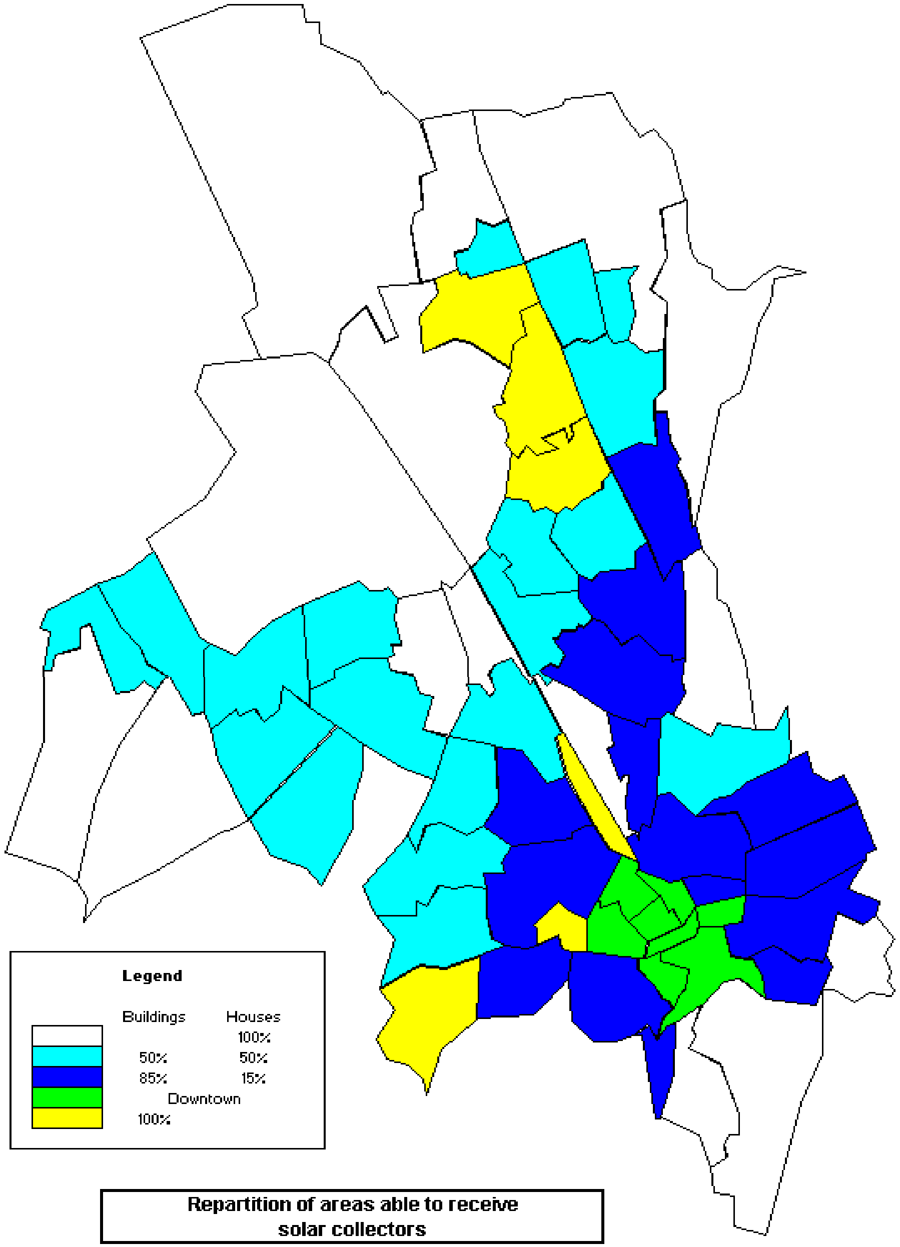

Figure 1

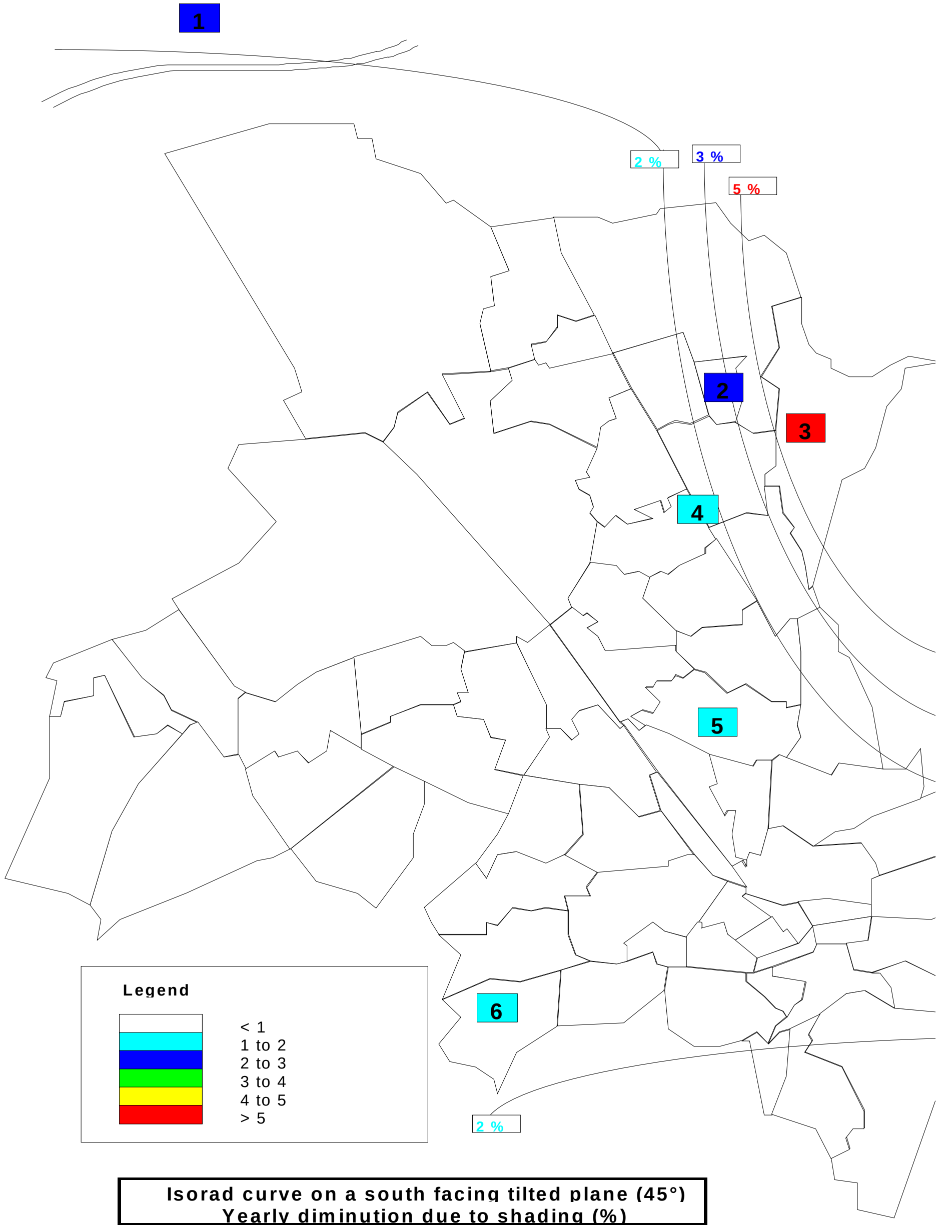

Figure 2

2.4 - Energy Saved by Solar DHW Production

It is assumed that the available surfaces which can be equipped with solar collectors for solar DHW production and the different consumed energies for a classical DHW production are identically distributed over the entire town of Chambéry. This hypothesis avoids to know exactly what sort of energy is substituted by solar energy at a precise location. We have to know only the percentages of the repartition of the different energy consumption and the corresponding efficiency of DHW production.unit

Table 2 gives the results of primary energy savings. They are not very precise and correspond only to an average value for the town.

Energy used by the DHW production unit	Repartition of energy consumption (%)	DHW Production unit's conversion efficiency	Primary energy Savings (MWh/year)
« District heating system »	41,4	0,8	8800
Fuel oil	19,1	0,62	5240
Natural gas	29,4	0,76	6580
Electricity	8,9	0,9	1680
Coal/Wood/Propane	1,2	0,68	300
Total	100		22600 MWh/year

Table 2 : Saved primary energy by Solar DHW Production in Chambéry

2.5 - Reduction of Emissions

Specific emissions of different combustible products used for heating are shown in Table 3. These values are obtained from BEHAR (1990) and CITEPA (1992) and are expressed in function of primary energy consumption.

Primary energy	Heavy Fuel Oil	Natural Gas	Fuel Oil	Propane	Coal	Wood
Heat capacity [kWh/kg]	11,1	11,9	11,9	12,8	8,3	4
CO2[kg/kg]	3,12	2,48	3,16	3,01	2,94	0
SO2[g/kg]	40	0	10	0	20	0
NOx[g/kg]	4	5,8	3,12	5	3	3
CO2 [g/kWh]	281	208	265	235	354	0
SO2 [g/kWh]	3.6	0	0.84	0	2,41	0
NOx [g/kWh]	0,36	0,49	0,26	0,39	0,26	0.75
eqCO2 [g/kWh]	335	281	305	294	408	113

Table 3 : Specific emissions of different combustible products expressed in grams per kWh of primary energy

To calculate the amount of specific emission expressed in terms of « equivalent CO_2 » value, we use the following equivalence coefficient :1"$eqCO_2$" for 1 "CO_2"; 0 "$eqCO_2$" for 1 "SO_2" and 150 "$eqCO_2$" for 1 "NOx" (GIES, 1990).
For the two particular cases of district heating system and electricity depending on several sort of primary energy, the following results were obtained (table 4) :

	District Heating System of Chambéry		Electricity (French mean conditions)		
Primary Energy	Heavy Fuel Oil	Natural Gas	Nuclear+ Hydraulic	Heavy Fuel Oil	Coal
% Primary En	13%	87%	80%	10%	10%
Prod.Efficiency	75%	75%	35%	35%	35%
Heat capacity [kWh/kg]	11,1	11,9	-	11,1	8,3
CO2[kg/kg]	3,12	2,48	0	3,12	2,94
SO2[g/kg]	40	0	0	40	20
NOx[g/kg]	4	5,8	0	4	3
CO2 [g/kWh]	290		182		
SO2 [g/kWh]	0,624		1,72		
NOx [g/kWh]	0,626		0,206		
eqCO2 [g/kWh]	384		213		

Table 4 : Specific emissions of District Heating System and Electricity

From the previous values of specific emissions and the values of saved primary energy by solar DHW production, we calculate the amount of avoided emissions related to this solar application (Table 5)

	Primary energy savings	CO2	SO2	NOx	EqCO2	CO2	SO2	NOx	EqCO2
	MWh/year	Specific emission [kg/MWh]				Total emission [t/year]			
Dist. Heat.	8800	290	0,624	0,626	384	2552	5,5	5,51	3380
Fuel Oil	5240	265	0,84	0,26	305	1388	4,4	1,4	1600
Nat. Gas	6580	208	0	0,49	281	1368	0,0	3,2	1850
Elec.	1680	182	1,72	0,206	213	305	3,4	0,35	360
Coal(1/3) Wood(1/3) Prop.(1/3)	300	196	0,8	0,47	272	59	0,24	0,14	80
Total	22600					5672	13,5	10,6	7270

Table 5 : Avoided emissions due to solar DHW production in Chambéry

In conclusion, with this approach, the possible reduction of emissions relating to the practical solar potential for DHW production in the entire town of Chambéry is equal to around 7300 tons per year of "eqCO2".

3- Low emission islands (Chambéry Le Haut) :

3.1- Basic situation

The area of "Chambéry le Haut" has some general interesting properties which makes it suitable for a "low emission island" :

- high density of population;
- homogeneous local geographical aspect;
- uniformity of the buildings (age, type, number of floors, etc.);
- building management by public authorities. This might induce the implication of local authorities in the promotion of solar energy use in Chambéry;
- this area corresponds to a specific kind of urbanism developed in the sixties and the population living there has a low income. So, the use of new technologies in a such context might have on the one hand a positive influence on social aspects and might be on the other hand an example which can be applied in many difficult suburb areas in France, in particular when a process of refurbishment is planned;
- at the present time, the heating and the DHW production are realised by a district heating system. The energy used for this system is mainly gas. Its efficiency (used energy/primary energy) for DHW production is about 0.8, with a specific emission of "eq CO_2" equal to 384 kg/kWh.

3.2- Technical concept for solar energy using :

We choose this sector to develop the use of solar energy permitting the production of DHW because it responds to a number of favourable technical conditions :

- the absence of shadow because all narrow buildings have the same height;
- the absence of shadow due to the far surrounding environment (the yearly reduction of solar energy is around 2%).
- the large available place to install the solar collectors because the roofs of all buildings are horizontal;
- production of centralised DHW already existing for each building;
- available location to install storage tanks for solar DHW production in technical premises.

The solar energy will be used only for the pre-heating of DHW. The solar system consists of :

- solar collectors oriented to the South with a slope of 45°. The needed surface is equal to 0.7 m^2 per inhabitant This value corresponds to the optimal surface obtained from a study realised in the City of Geneva (similar climatic conditions) by Macherel and Krebs (MACH, 1990);
- primary network linking the solar collector to a heat exchanger. This exchanger is connected to solar tanks by a secondary network. The ratio between storage volume and the collector surface is 0.05 m^3/m^2. The solar storage tanks are placed in the technical premises which contain also the terminal unit of the district heating system;

- The cold water is pre-heated in the solar storage tank and then its temperature is increased to the requested temperature by the existing DHW production system. The distribution of hot domestic water in each apartment is realised by the existing network.

We realised some modelling with a specific technical software considering the following data:

- optical and thermal characteristics of solar collectors;
- thermal and hydraulic characteristics of the network and the exchangers;
- climatic data of the area;
- storage volume;
- domestic hot water flow.

Obtained results permitted to define an average solar productivity of **450 kWh/a/m^2** for a solar DHW installation in Chambéry.

3.3- Energy savings

Number of concerned inhabitants : 8800
Total surface of solar collectors : 6160 m2
The energy savings are different if we speak about « primary energy » or about « useful energy » (or « useful heat ») which is the product of the primary energy by the production unit's conversion efficiency. In our case, as solar energy preheats domestic hot water instead of useful energy delivered by gas district heating system having an efficiency of 0.8,.the amount of saved energy is :

Useful energy :	2770 MWh(u)/a
Primary energy :	3460 MWh/a

The solar fraction in the total DHW energy consumption is around 38%.
As the irradiation on 45° tilted plane oriented to the South is equal to 1 310 kWh/a/m2, the efficiency of the solar DHW production is 34%.

3.4 - Reduction of Emissions

Table 6 below gives the results of the reduction of emissions in "Chambéry le Haut" due to the solar DHW production which realizes the preheating of the domestic water instead of the district heating system which becomes only an auxiliary system. The values of specific emissions are the same than those used in the paragraph 2.5. To calculate the emission in equivalent amount of CO_2, we consider 150 "eqCO_2" for a unit of NO_x.

	Prim.energy. savings	CO2	SO2	NOx	EqCO2	CO2	SO2	NOx	EqCO2
	MWh/year	Specific emission [kg/MWh]				Total emission [t/year]			
District Heating	3460	290	0,624	0,626	384	1003	2,16	2,16	1330

Table 6 :Avoided emissions due to solar DHW production in "Chambéry le Haut"

3.5 - Economic appraisal

3.5.1-Evaluation of the Financial Support

We define the equivalent price of the solar energy [MAG 1990] as :

Average price Constant annuity (*) + annual maintenance and auxiliary costs (**)
of the solar kWh = --
yearly **saved** primary energy

(*) The annuity **Ca** of the investment refunding **C** (solar collectors, storage, hydraulic network and engineering) is supposed constant over **n** years and the interest rate **q** is 5 %. The formula used is :

$$Ca = C \cdot \frac{q(1+q)^n}{(1+q)^n - 1}$$

(**) The annual maintenance and auxiliary costs are 20 F/m^2 and 10 F/m^2(solar collectors).

To have a competitive price of solar energy compared to the price of fossil energy, it is necessary to have a financial support. The rate of this financial support is given by the figure 3 in function of the investment amount and the solar energy price.

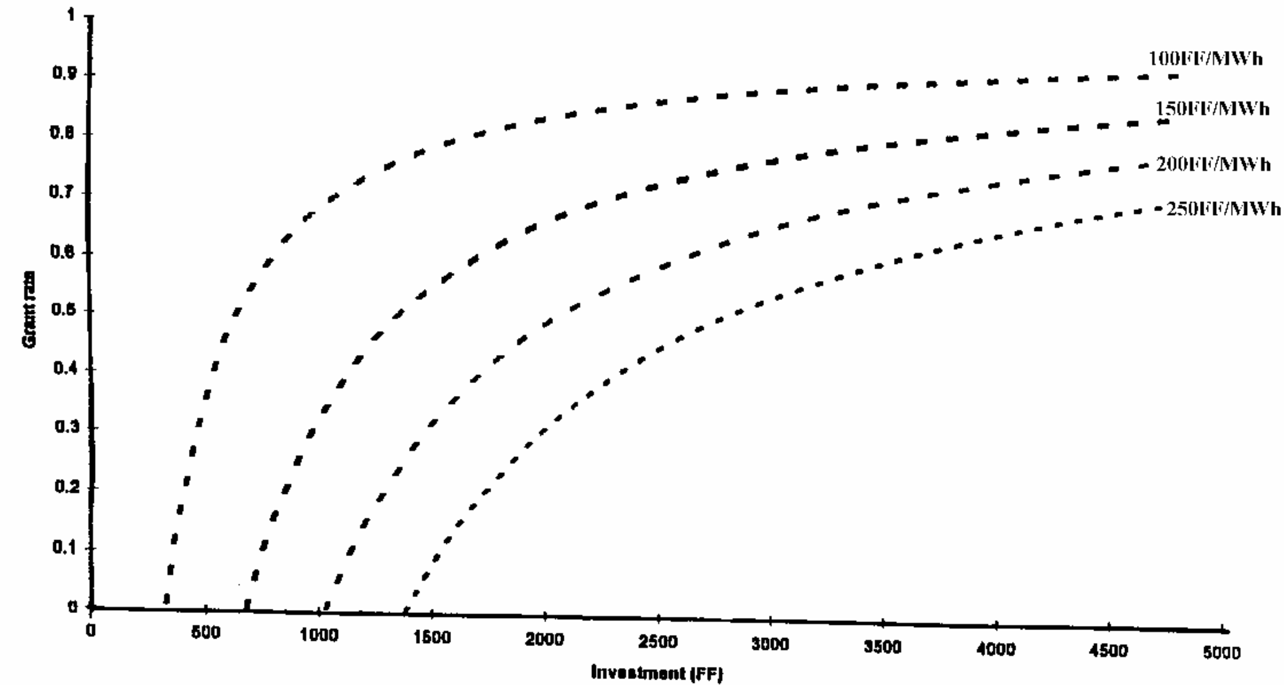

Figure 3 : Rate of financial support in function of the investment amount and the solar energy price

For example, an investment of 4500 F/m^2 (price corresponding to the present situation in Chambéry) leads to a financial support of :76 % if the price of solar energy is equal to 200 F/MWh.This percentage of financial support is high but it corresponds to a high investment as those available at the present time where only few m^2 of solar collectors are installed each year.

For an investment equal to 2000 F/m^2 the percentage of financial support is 50 % for a solar energy price of 200 F/MWh. This low amount of investment will perhaps corresponds to a future situation where solar energy will be widely used as in Austria (JILEK, 1995). But the development of solar energy is assumed to concern a large region like the Region "Rhône Alpes" which contain many big cities (Lyon, Grenoble, Valence...) and not one medium town like Chambéry.

To reduce the rate of financial support, two ways were explored :

- Reduction of annuities by a recovery of an "ecotax" on the emissions of fossil energy combustion;
- Take advantage of a large scale application of the same concept; for example in a development area like the Region "Rhone - Alpes"in France.

3.5.2- Balance of investment (Chambéry le Haut)

Hypothesis :

- About 6000 m2 of solar collectors are installed during 6 years
- The life time of solar collectors is 20 years
- Price of energy : 250 F/MWh (actual mean value)
- Constant annuity over 20 years related to an interest rate of 5 %

The results are given on the following tables.7 and 8. They are available only on the period between the end of installation (year 7) and the first restoring of the solar collectors (year 21) when there is not a dynamic aspect of the investment balance.

The balance is reached for rate of financial support about 70 % if investment is equal to 4500 F/m^2 (pessimist assumption) and about 30 % if investment is equal to 2000 F/m^2 (very optimist assumption).

Annual yields [FF]						3465 x 0.,25	866 kF
ii) CostsA : Capital Costs	Investment [FF]	Reduction by financial support [FF]	Life time [year]	Factor of annuity [%]	Annuity [FF]	Mainte-nance [FF]	Annual capital costs [FF]
Chby le Haut	28 MF	- 19.6 MF	20	0,08025	674 kF	123 kF	796 kF
Total A							796 kF
B : Operational Costs - personnel costs - energy costs - other costs							62 kF
Total B [FF]							62 kF
Total annual costs : A + B [FF]							858 kF
Annual yields minus total annual costs [FF]							8 kF

Table 7: Balance of investment for an investment of 4500 F/m2, a price of solar energy equal to 250 F/MWh and a rate of financial support equal to 70%

Annual yields [FF]						3465 x 0.,25	866 kF
ii) CostsA: Capital Costs	Investment [FF]	Reduction by financial support [FF]	Life time [year]	Factor of annuity [%]	Annuity [FF]	Mainte-nance [FF]	Annual capital costs [FF]
Chby le Haut	12.3 MF	- 3.8 MF	20	0,08025	682 kF	123 kF	805 kF
Total A							805 kF
B : Operational Costs - personnel costs - energy costs - other costs							62 kF
Total B [FF]							62 kF
Total annual costs : A + B [FF]							867 kF
Annual yields minus total annual costs [FF]							- 1 kF

Table 8: Balance of investment for an investment of 2000 F/m2, a price of solar energy equal to 250 F/MWh and a rate of financial support equal to 30%

4.- Conclusion

This analysis permits to give the following conclusions :

- Using of solar energy might be an opportunity to improve the life quality in difficult suburbs where local authorities have to manage energy distribution.
- The use of solar energy is a suitable approach to reduce emissions but it is still an expensive technique in France because this technology is not enough developed to permit the reducing of collectors and installations costs. To promote solar energy in medium city like Chambéry, it is necessary that this development will concern a large region like the Region "Rhône Alpes" where a global approach has to be elaborated to harmonize strategies in all cities of a region.
- Another possibility to accelerate the development of solar energy use might be grants offered either by the government or the European Union for clean technologies like solar energy.
- At the end we think that in France as in southern European countries, an important solar potential exists but this potential is not explored enough. While in countries with harder climatic conditions (Austria for example) the solar market is already in expansion.

Acknoledgements
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