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Recent Researches in Environment, Energy Systems and Sustainability

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Proceedings of the 8th WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development (EEESD '12)

University of Algarve, Faro, Portugal, May 2-4, 2012

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Potential forest biomass and energy production at the regional scale: the case of maritime pine (*Pinus pinaster* Ait.) in the district of Bragança, Northeastern Portugal

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Abstract: - Bragança is a district of low population density and low energy demand. It has, however, a relatively large forest area. These facts lead to the formulation of the hypothesis that yearly biomass production in the district of Bragança can provide the energy required for some sectors of the economy trough simple and efficient conversion in heat and/or electricity. In this paper we analyzed regional annual biomass yield in maritime pine stands, the most conspicuous forest type in the area, and confronted it with energy demand from the industry, domestic and services sectors. The analysis was performed in a spatially explicit way taking spatial variability of productivity and forest area into account. Biomass was calculated from allometric models based upon inventory data. Biomass energy content was converted into total thermal energy and electricity. Results indicated that biomass is indeed a relevant potential source of energy in the region. Maritime pine alone can annually potentially provide near 49 % of final energy demand in the district of Bragança or 84% of final energy demand of the domestic, industry and services sectors. Also, biomass yield is able to offer 60% of all the electricity demand in the district of Bragança. Carrazeda de Ansiães, Vimioso, Torre de Moncorvo, Freixo de Espada à Cinta, Vinhais e Mogadouro can be self sufficient in this form of energy.

Key-Words: - Woody biomass for energy, maritime pine, *Pinus pinaster*, Bragança, Portugal

1 Introduction

Woody biomass for energy plays an important role in renewable energy strategies and planning at several scales. Biomass presents advantages over other sources of energy, such as a neutral CO_2 balance, a low contamination risk, the possibility of regional or national self-sufficiency and socioeconomic development at the local scale. Many areas of the world offer large amounts of this cheap and safe source of energy which makes it at least reasonable to admit that the interest for biomass as a source of energy will increase considerably in the short run [1].

In spite of the relatively large percentage of the country covered with forests and their relatively high productivity, energy production from biomass remains underexploited in Portugal. Biomass provides just 12% of the primary energy consumed in Portugal, mainly for heat production. In other European countries these figures are relatively higher, e.g. Latva (24%), Finland (21%), Sweden,

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(19%), Denmark (15%) or Austria (14%) [2]. Portuguese pulp and other forest related industries are for some time energetically self sustainable based on forest biomass. National energy strategies strongly support the development of energy production from biomass. The results have been, however, modest. For example, the 2006 energy strategy was centred in 15 relatively large power plants (2-3MW to 9-10MW) spread over the country planned to be in operation in 2011. Due to economical constrains related to biomass local/regional availability and market prices, these plants were not attractive enough for investors and only a few have been built. The 2010 energy strategy follows the previous guidelines and additionally requires that by 2020 plants rely upon biomass from dedicated crops. More recently, biomass demand for energy purposes has increased in Portugal due to the fast growth of the pellets industry in the North and Center of Portugal although almost all the production is exported to northern countries where it is used to produce energy.

Smaller power plants, conceived at the city or municipality level, can be of major interest in areas where energy consumption is limited and offer an eventually more efficient way of producing and using energy from biomass. At this scale, energy self-sufficency is also hypothetically achievable, but biomass evaluations of supply and demand are rare.

Although firewood represents 27% of all energy consumption in the district of Bragança [3], the use of biomass for energy is in an early stage of development. Firewood is used mainly in rural areas for heating and cooking in open fireplaces in a inefficient way. Fireplaces are also common in cities, where they are used for direct house heating although the use of closed burners in integrated housing heating systems has been increasing. Particular small dimension industries and services, e.g. bakeries, restaurants, also use frequently woody biomass. More recently pellet boilers start being commercialized but no information on the scale of use of these systems is still available. Final energy consumption in 2005 in the district was of 1.23 toe/inhabitant, lower than 1.84 toe/inhabitant, the national average but increased in near 33% over the last decade mainly due to a 100% increase in electricity [3]. Fossil fuels represent 55% of all energy consumption in the district. Around 51% of the energy consumption occurs at the building scale [3].

In this paper we analysed the potential supply of energy from biomass from maritime pine (*Pinus pinaster*) stands in the Bragança district and evaluated it in terms of the percentage of energy demand in the economic sectors where energy from biomass can be used with available technology. We addressed the following research questions at the regional scale: i) how much energy can be produced from sustainable supply of maritime pine biomass? ii) What proportion of energy consumption can be covered by energy from biomass, i.e, is self-sufficiency achievable? iii) What are the prospects for biomass energy production and use in the near future in the Bragança district?

2 Methods

We roughly compared maritime pine woody biomass supply and energy demand in the district of Bragança to evaluate the degree of biomass based energy self-sufficiency in the region. For that we modeled annual biomass yield at the regional scale from existing maritime pine stands inventory data and collected statistics of energy consumption per sector of the economy in the district. Final comparisons were made directly between total primary energy and electric energy that can be generated from the annual biomass supply and the demand in energy in general or in the domestic, industrial and services sectors.

We followed some assumptions that although in part unrealistic permit to evaluate of the potential role of biomass in energy production and use in the region. We assumed that maritime pine biomass grown in the district was used in energy production only. We also assumed the conversion of biomass in energy (heat and electricity) centralized in plants located in industrial/commercial districts that are usually located in the capitals of the municipalities.

2.1 Study area

This study was conducted in the district of Bragança, Northeast of Portugal, 6608km² in area. Administratively the district is comprised of 12 municipalities. Current population (2011) is 136,252 inhabitants (148,883 in 2001) near 45% of which in the capitals of the municipalities (Table 1). These urban areas exhibited population growth in the last decade contrarily to the rural parishes that lost a significant percentage of their population [4]. Climate is generally Mediterranean with strong Continental, Atlantic and Mediterranean influences according to altitude.

Forests occupy approximately 191,000ha (29%) of the district area. Other major land use classes are agriculture (35%) and shrublands (34%). There is a

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high diversity of forest types in the district but maritime pine, *Pinus pinaster*, forests are dominant (56,850ha, 34% of the forest area), followed by deciduous oak species (44,185ha, 26%), chestnut, other softwoods, cork oak, eucalyptus, other hardwoods and holm oak [5]. According to the National Forest Inventory [5], productivity for maritime pine is 1.4 dry ton/ha.yr in the northern part of the district and 3.4 dry ton/ha.yr in the south.

Table 1: Population in the district of Bragança by municipality. Source: [4].

Municipality	Population
Alfândega da Fé	5104
Bragança	35341
Carrazeda de Ansiães	6373
Freixo de Espada à Cinta	3780
Macedo de Cavaleiros	15776
Miranda do Douro	7482
Mirandela	23850
Mogadouro	9542
Torre de Moncorvo	8572
Vila Flor	6697
Vimioso	4669
Vinhais	9066
Total (District)	**136252**

2.2 Maritime pine cover mapping

Land cover cartography was based on open access sources, namely the 2007 level II of the Land Use/Land Cover data (COS2007) of the Portuguese Geographic Institute [6] and available free of charge in vector format. Although the production of these LULC coverages is totally supported by public funding, IGP charges absurd amounts of money for data more detailed than level II. This hierarchical level, comprised of 15 LULC classes, combines all forest types in a single "Forest" class which is insufficient for the purposes of this work. To solve this limitation we photo-interpreted, individually, all the areas classified as "Forest" in the COS2007 level II coverage in order to obtain land units of the "Coniferous" and "Mixed" forest classes. For this we used orthorectified aerial imagery from 2007 in normal color format (ArcGIS Map Service: http://servicesarcgisonline.com).

2.4 Forest biomass supply

Forest biomass annual yield was estimated from biomass and stand density models based on inventory data. We used data on diameter at breast height (dbh), tree height (h), age (t), number of trees per ha (N) and basal area per ha (G) from 33 sampling plots of the 2005-2006 National Forest Inventory [5] corresponding to maritime pine stands in the district of Bragança.

Quadratic mean diameter (dg) was computed from N and G and used to estimate aboveground average tree biomass (BT, in dry tons) from the biomass model of Montero [7]:

$$BT = e^{-3.00347} \times dg^{2.49641} + \varepsilon \quad (1)$$

Biomass was estimated at the stand level by multiplying average tree biomass by stand density. Given that density is a parameter whose variability is uncontrolled since it depends mostly upon factors related to the life/management history of the stand, and therefore can't be modeled, we assumed for the purpose of this research that density changed naturally over time according to a density model [8] (under the 2 × 2m tree spacing adjustment):

$$\ln N = 13.634 \quad 1.897 \ln dg + \varepsilon \quad (2)$$

where N is the stand density and dg the quadratic mean diameter of the stand.

Biomass Mean Annual Increment (MAI) was calculated by dividing Biomass at the stand level by stand age (t). Although MAI is age dependent, this was the best possible simple estimate of biomass growth that was possible to derive from the inventory data available. Stand age of the sample plots ranged from 12 to 36 yrs.

MAI was later spatially modeled at the region level (Fig.1) using a geostatistical approach (ordinary kriging based upon an omnidirectional variogram spheric model established for a lag distance of 12000m and 7 lags). Biomass mean annual increment estimates locally were assigned to each maritime pine polygon in the cover map.

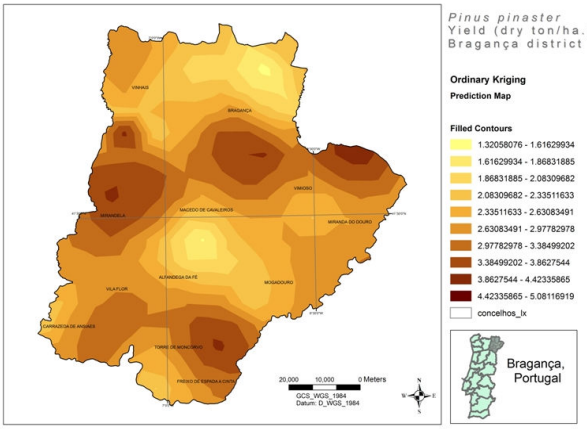

Fig. 1: Estimation of mean annual increment (dry ton/ha.yr) at the region level for maritime pine.

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This methodology allows the calculation of biomass produced annually in maritime pine stands in the district. It is not a landscape biomass growth and yield model since it does not assumes explicitly the dynamics of individual stands, but just a model of the annual average biomass yield obtained sustainably.

2.3 Energy demand and self-sufficiency

Energy demand was estimated based on official 2009 consumption data available from the Portuguese energy authority (Direcção Geral de Energia e Geologia (DGEG): http://www.dgge.pt/) and [3]. Data was gathered for the 12 municipalities and later organized by source and economic sector. We used data of electricity consumption (kWh), and oil products (in tons) and natural gas sales (10^3Nm^3). For firewood consumption we used data from [3]. The economic sectors considered were: i) agriculture, ii) domestic, iii) industry and commerce, iv) services, v) construction and vi) transportation. Energy was converted in Joule and kWh to make comparisons among sources and uses possible. The methodology is described in detail in [9].

The comparison between energy harnessed from biomass and energy demand was done considering both total demand and energy demand in the domestic, industry and services sectors. The concept of self-sufficiency used here is simply the ratio between energy from the biomass and energy demand.

3 Results and discussion

3.1 Energy from biomass

The 89,000ha of maritime pine stands in the district of Bragança have a potential production of 231,695.6 dry ton/ha.yr and a total energy content of 4,171TJ (Table 2). Considering an efficiency rate of 85%, a common rate in commercial large scale boilers, this amount represents 3,545TJ available for use by communities through simple thermal conversion (e.g. boilers). The same amount of biomass can potentially generate 255MWh of electric energy (22% efficiency, calorific value of 18GJ/ton and 7200h of power plant operation per year) (Table 2). Bragança, Mogadouro, Torre de Moncorvo e Carrazeda de Ansiães are the municipalities with higher yearly availability of biomass and potential energy from biomass (Table 2). Bragança municipality, from the existing 16,353ha of pine forests, is able to provide at least 554TJ or to generate 40GWh of electricity per year from the biomass. In Alfandega da Fé, the municipality with lower biomass yield, these figures are 111.8TJ and 6.8GWh, respectively.

Table 2: Forest area, energy content and electricity potentially generated annually from maritime pine biomass in the district of Bragança per municipality. Conversion to electricity based on an efficiency of 22%, calorific value of 18 GJ/ton and 7200h of power plant operation per year.

Municipality	Forest Area (ha)	Energy Content (TJ)	Electricity (GWh)
Alfândega da Fé	2775.0	111.8	6.8
Bragança	16353.1	651.9	39.8
Carrazeda de Ansiães	9227.2	422.4	25.8
Freixo de Espada à Cinta	3522.6	197.8	12.1
Macedo de Cavaleiros	6163.6	273.0	16.7
Miranda do Douro	2830.3	155.9	9.5
Mirandela	7590.4	399.7	24.4
Mogadouro	11253.7	504.7	30.8
Torre de Moncorvo	8678.1	452.0	27.6
Vila Flor	5383.9	272.7	16.7
Vimioso	6151.3	327.2	20.0
Vinhais	9094.8	401.5	24.5
TOTAL	89,024.0	4170.5	254.9

3.2 Energy demand

Demand of energy in the district based on consumption show that diesel, firewood and electricity are the forms of energy with higher use summing to 78% of all the energy consumed (Table 3) with regional variation (Table 4). Domestic is the sector with higher consumption (37% of all sectors combined) followed by transportation (25%) and services (13%) (Table 5). Domestic, industry and services, the sectors that can use energy from biomass (either thermal or electricity), are responsible for 58% of the total energy consumption in the district (Table 3) in spite of variations among municipalities (Table 5).

Table 3: Final energy consumption in the Bragança district by form and sector. Sources: DGEG and [3].

	Sector (TJ)							Consumption by form of energy
Form of Energy	Agr.	Dom.	Ind.	Serv.	Constr.	Transp.	Total	
Electricity	47.89	613.50	102.51	741.97	13.79	0.83	1520.49	21.0%
Gas	0.38	176.32	12.61	57.08	1.12	1.32	248.84	3.4%
Natural Gas	0.00	98.43	44.11	110.67	8.73	1.03	262.97	3.6%
Diesel	335.24	15.51	204.29	18.76	233.65	1379.93	2187.38	30.3%
Gasoline	0.00	0.00	12.61	0.00	5.93	306.71	325.25	4.5%
Other	1.11	0.04	22.96	14.15	578.06	110.27	726.59	10.1%
Firewood	0.00	1759.21	195.47	0.00	0.00	0.00	1954.68	27.0%
Total	384.62	2663.01	594.55	942.62	841.29	1800.09	**7226.19**	
Consumption by sector	5.3%	36.9%	8.2%	13.0%	11.6%	24.9%		

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Table 4: Final energy consumption in the Bragança district by municipality for some forms of energy. Notice that total values per municipality include other forms not shown. Sources - DGEG and [3].

	Forms of energy TJ (%)				
Municipality	Electricity	Diesel	Gasoline	Firewood	Total
Alfândega da Fé	44.7 (31.4)	32.5 (22.8)	13.69 (9.6)	46.99 (33)	142.39
Bragança	440.44 (19.7)	659.93 (29.5)	114.2 (5.1)	491.34 (22)	2233.38
Carrazada de Ansiães	57.53 (14.5)	99.53 (25.1)	19.63 (5)	130.69 (33)	396.04
Freixo de Espada à Cinta	37.59 (35.1)	20.8 (19.5)	1.73 (1.6)	35.3 (33)	106.96
Macedo de Cavaleiros	171.79 (28.1)	180.71 (29.5)	15.96 (2.6)	177.54 (29)	612.22
Miranda do Douro	108.38 (21.4)	218.62 (43.1)	16.41 (3.2)	147.14 (29)	507.36
Mirandela	270.12 (20.1)	443.52 (32.9)	82.37 (6.1)	350.19 (26)	1346.88
Mogadouro	109.42 (17.5)	172.47 (27.6)	17.21 (2.8)	193.4 (31)	623.88
Torre de Moncorvo	79.8 (12.9)	171.23 (27.6)	15.63 (2.5)	192.03 (31)	619.45
Vila Flor	78.08 (29.9)	82.29 (31.5)	10.03 (3.8)	78.38 (30)	261.27
Vimioso	45.44 (36.9)	31.96 (26)	3.68 (3)	35.67 (29)	123.00
Vinhais	77.2 (30.5)	73.83 (29.1)	14.72 (5.8)	76.01 (30)	253.36
District of Bragança	1520.49 (21.0)	2187.38 (30.3)	325.25 (4.5)	1954.68 (27.1)	7226.19

Table 5: Final energy consumption in the Bragança district by municipality and sector. Sources - DGEG and [3].

	Sector TJ (%)						
Municipality	Agriculture	Domestic	Industry	Services	Constr.	Transp.	Total
Alfândega da Fé	2.41 (1.7)	65.17 (45.8)	6.77 (4.8)	24.16 (17)	0.49 (0.3)	43.4 (30.5)	142.39
Bragança	74 (3.3)	755.75 (33.8)	184.49 (8.3)	388.63 (17.4)	135.5 (6.1)	695.01 (31.1)	2233.38
Carrazada de Ansiães	21.1 (5.3)	148.95 (37.6)	27.57 (7)	36.29 (9.2)	92.14 (23.3)	69.99 (17.7)	396.04
Freixo de Espada à Cinta	7.23 (6.8)	57.26 (53.5)	5.19 (4.8)	17.95 (16.8)	0.01 (0)	19.34 (18.1)	106.96
Macedo de Cavaleiros	44.86 (7.3)	262.48 (42.9)	66.54 (10.9)	92.69 (15.1)	39.67 (6.5)	105.97 (17.3)	612.22
Miranda do Douro	55.29 (10.9)	180.08 (35.5)	57.3 (11.3)	64.2 (12.7)	53.89 (10.6)	96.61 (19)	507.36
Mirandela	60.9 (4.5)	480.18 (35.7)	116.66 (8.7)	134.08 (10)	113.14 (8.4)	441.91 (32.8)	1346.88
Mogadouro	41.31 (6.6)	227.71 (36.5)	32.21 (5.2)	54.88 (8.8)	163.4 (26.2)	104.38 (16.7)	623.88
Torre de Moncorvo	11.56 (1.9)	214.01 (34.5)	41.5 (6.7)	38.16 (6.2)	233.53 (37.7)	80.68 (13)	619.45
Vila Flor	27.9 (10.7)	102.02 (39)	20.37 (7.8)	37.34 (14.3)	6.89 (2.6)	66.76 (25.6)	261.27
Vimioso	12.11 (9.8)	58.74 (47.8)	17.6 (14.3)	16.03 (13)	0.15 (0.1)	18.36 (14.9)	123.00
Vinhais	25.96 (10.2)	110.66 (43.7)	18.36 (7.2)	38.21 (15.1)	2.48 (1)	57.69 (22.8)	253.36
District of Bragança	384.62 (5.3)	2663.01 (36.9)	594.55 (8.2)	942.62 (13)	841.29 (11.6)	1800.09 (24.9)	7226.19

3.3 Energy self-efficiency

The annual maritime pine biomass production in the district of Bragança shown above (3.1) is a considerable source of energy in the region. The energy that can be obtained from this biomass through simple thermal conversion (85% efficiency) corresponds to 49% of all energy requirements in the region (Table 6). Considering that most of the energy in the area is used for heating, primarily in the industry, domestic and services sectors, and also that these sectors can immediately use energy from this source, maritime pine biomass is able to provide 84% of all the energy required in the district (Table 6). Particular municipalities are totally self-sufficient (Freixo, Vimioso and Vinhais) whether others are self-sufficient for the three selected sectors only (those before plus Carrazeda de Ansiães, Mogadouro, Torre de Moncorvo and Vila Flor). These total 7 out of 12 municipalities.

Considering electricity only, the annual biomass yield is able to supply 60% of the total demand in the district of Bragança (Table 7; Fig. 2). Among municipalities, Carrazeda de Ansiães, Vimioso, Torre de Moncorvo, Freixo de Espada à Cinta, Vinhais e Mogadouro, exceed self sufficiency (Table 7; Fig. 2). Electricity is used mostly in the domestic, industrial and services sectors (96%).

Table 6: Total final energy demand and final energy demand from the industry, domestic and services sectors and percentage of demand that can be covered by energy produced annually from maritime pine biomass in the district of Bragança (self-sufficiency) per municipality. Estimates do not consider the distinct forms of energy and are based upon an 85% efficiency.

Municipality	Total Energy Demand (TJ)	Self-suffiency (%)	Energy Demand Ind+Dom+Serv (TJ)	Self-suffiency Ind+Dom+Serv (%)
Alfândega da Fé	142.4	66.7	96.1	98.9
Bragança	2233.4	24.8	1328.9	41.7
Carrazeda de Ansiães	396.0	90.7	212.8	168.7
Freixo de Espada à Cinta	107.0	157.2	80.4	209.1
Macedo de Cavaleiros	612.2	37.9	421.7	55.0
Miranda do Douro	507.4	26.1	301.6	43.9
Mirandela	1346.9	25.2	730.9	46.5
Mogadouro	623.9	68.8	314.8	136.3
Torre de Moncorvo	619.4	62.0	293.7	130.8
Vila Flor	261.3	88.7	159.7	145.1
Vimioso	123.0	226.1	92.4	301.1
Vinhais	253.4	134.7	167.2	204.0
TOTAL	**7226.2**	**49.1**	**4200.2**	**84.4**

Table 7: Electricity demand, potential electricity generation from the biomass and electricity self-sufficiency of annually produced maritime pine biomass in the district of Bragança per municipality. Estimates of electricity generation based on an efficiency of 22%, calorific value of 18GJ/ton and 7200h of power plant operation per year.

Municipality	Electricity Demand (GWh)	Electricity generation (GWh)	Electriticy Self-suffiency (%)
Alfândega da Fé	12.4	6.8	55.0
Bragança	122.2	39.8	32.6
Carrazada de Ansiães	16.0	25.8	161.6
Freixo de Espada à Cinta	10.4	12.1	115.8
Macedo de Cavaleiros	47.7	16.7	35.0
Miranda do Douro	30.1	9.5	31.6
Mirandela	75.0	24.4	32.5
Mogadouro	30.4	30.8	101.5
Torre de Moncorvo	22.2	27.6	124.6
Vila Flor	21.7	16.7	76.9
Vimioso	12.6	20.0	158.4
Vinhais	21.4	24.5	114.4
District	**422.2**	**254.9**	**60.4**

From the estimates above the role of biomass in potential energy strategies or scenarios at the regional scale seems quite significant. Although our estimates considered that all biomass was able to be used in energy generation and no economical analysis were included, the importance of this source of energy in a regional context seems relevant. Considering that maritime pine forest is just 34% of all the forest cover of the district the role of woody biomass in the district of Bragança

not just can be extremely important as it should support energy planning at this scale as well as at the municipality scale.

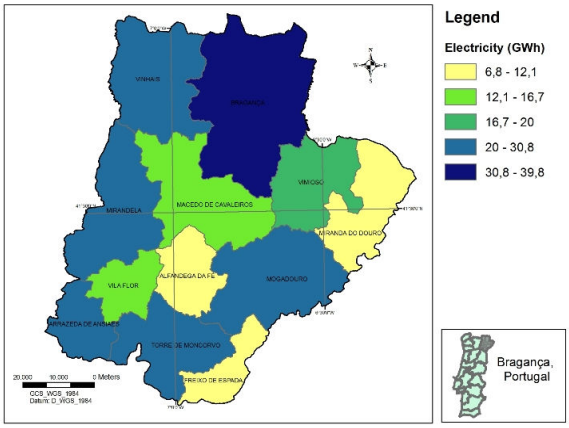

Fig. 2: Distribution of electricity potentially produced annually from maritime pine biomass in the district of Bragança by municipality.

4 Conclusion

Maritime pine biomass supplied annually in the district of Bragança is able to cover a relatively large amount of the final energy demand in the region.

The annual biomass yield of maritime pine is able to supply:

- 49% of all final energy requirements (as heat) in the district of Bragança,
- 84% of the final energy demand in the domestic, industry and services sectors,
- 7 out of 12 municipalities are self-sufficient for the domestic, industry and services sectors,
- 60% of all the electricity demand in the district of Bragança,
- more than 100% of electricity demand in Carrazeda de Ansiães, Vimioso, Torre de Moncorvo, Freixo de Espada à Cinta, Vinhais e Mogadouro.

Considering additionally that maritime pine represents just 1/3 of the total forest cover in the region, the prospects for the conversion and use of energy from woody biomass in the district of Bragança are very promising.

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