3rd International Scientific Conference on Energy and Climate Change

7-8 October 2010
Athens, Greece

PROCEEDINGS

Day 2 : 8 October 2010

Session 4 : Renewable Energy Sources

Model based investigation of biomass utilization paths for different regions in Germany, Sweden and Chile

Frank SCHWADERER, Patrick BREUN, Magnus FRÖHLING, Frank SCHULTMANN

Tel: +49-721-608-4458
e-mail: frank.schwaderer@kit.edu

Address
Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT)
Hertzstr. 16, Building. 06.33, 76187 Karlsruhe, Germany

Abstract
Various biomass utilization paths are currently being discussed and developed in order to substitute fossil resources and reduce climate relevant emissions. This causes the need of adequate instruments for the economic assessment of these paths in a local context. Such an assessment has to account for different plant locations, layouts and sizes which affect investments as well as material and energy flow costs. Most of the existing approaches in literature focus on plants for electricity production, regard only one stage of the supply chain or do not consider multiple locations and economies of scale. In contrast, in this contribution, locations and capacities are determined simultaneously by calculating investments as well as material and energy flows endogenously in an integrated model. The model is formulated as a mixed integer optimization problem and the calculations base on data for biomass availability, investments, biomass acquisition, transportation as well as auxiliary material and energy costs.
The model is applied to exemplary regions in Germany, Sweden and Chile. The considered utilization paths are a pelletizing production chain consisting of grinding, drying, pelletizing and cooling and a BtL (Biomass-to-Liquid) production chain characterized by the steps grinding, drying, pyrolysis, gasification and synthesis. The focus lies on the integration of regional conditions into the model and the comparison of the results for different regions.

Keywords: Renewable Energy Sources, Competitiveness and cost efficiency

1. Introduction

Biomass can be used for different processes and to obtain different products. Various biomass utilization paths are currently being developed, analyzed and discussed. Beyond the technical development, researchers, politicians and decision-makers from industry have a great interest in the economic assessment of potential implementations. In this context the main questions are:

- What will production costs for a certain utilization path in a region be?
- Is it possible to produce the biomass-based products competitively?
- Which investments can be expected?
- What plant sizes should be realized?
- How many production sites are reasonable?
- What is better, a central plant or a decentralized concept with transportation of intermediate products?

In this contribution an approach for the assessment of biomass utilization paths in a local context is presented and applied to three different regions in Germany, Sweden and Chile for a pelletizing and a BtL process chain. The work is organized as follows: In the first chapter the requirements for the strategic assessment and planning of biomass utilization paths and relevant literature in this context are discussed.

In the second chapter the applied approach for the regional assessment of utilization paths is presented. The approach has three main steps: the techno-economic assessment of the considered utilization paths, the modeling of regional framework conditions and the calculation of cost-minimal structures, locations and capacities for the utilization paths in certain regions. The application of the first step to the selected regions will be presented in chapter 4, the second step in chapter 5 and the last step in chapter 6. The work is closed with a summary and conclusions.

2. Requirements for strategic planning and assessment of biomass utilization paths

Treatment of biomass takes place in several consecutive process steps. First steps are size reduction like crushing or grinding and drying. Intermediate steps can e.g. be extraction, conversion, pyrolysis or separation processes. These can e.g. be followed by gasification, fermentation, refining or synthesis. When intermediate products can be transported, it is possible to realize production steps at different locations. This may especially be economically reasonable when intermediate products have higher densities than raw materials.

The establishing of new plant locations is connected to capacity planning. Normally, plants with higher capacities can produce with lower costs per unit due to lower specific investments. These economies of scale have to be considered when deciding about the number and capacities of plants. As economies of scale depend on the single process unit, a techno-economic assessment of each unit is required. Mass flows must be known in order to estimate capacities as well as transportation and mass flow depending costs.

Conversion processes require energy, but may also deliver waste energy or by-products which can be utilized energetically. These energy surpluses can e.g. be used for drying the biomass or in order to provide electricity. Alternatively, biomass can be burned in order to provide thermal energy. As a result, the question of plant size and structure of the production system is also related to the provision of energy and thus energy flows.

The available types, mass and distribution of biomass depend on regional conditions, such as land use, type and intensity of agriculture and forestry, local climate and supply windows. Furthermore, humidity of the biomass and spatial distribution strongly influence the mentioned questions. This holds also for the availability of the road and electricity network and possible plant locations as well as the location of possible consumers.

In literature, contributions can be found which cover some of these requirements. Often scenario analysis is used to compare different configurations (e.g. Tatsiopoulos and Tolis (2003)). Some approaches base on Geographical Information Systems (GIS) in order to find locations in connection with the estimation of transportation costs and identification of biomass potentials (e.g. Kappler et al. (2009), Noon and Daly (1996) or Voivontas et al. (2001), Panichelli and Gnansounou (2008)). Other works apply linear or mixed integer mathematical programming to calculate locations and capacities but do not consider economies of scale (Freppaz et al. (2004), Leduc et al. (2008)) or define the locations ex ante (Frombo et al. (2009)). Further contributions consider nonlinear functions and economies of scale for only one plant (López et al. (2008), Rentizelas and Tatsiopoulos (2009)).

In this paper a systematic approach is presented which reaches both, the integration of local framework conditions into the planning and assessment approach as well as the consideration of technical and economical specification of the considered utilization paths. The impact of regional framework conditions is investigated by consideration of three different regions.

3. Approach for the regional assessment of utilization paths

In this section the approach for the regional assessment of biomass utilization paths is outlined briefly. The application for pellet and BtL production is discussed in detail in the following chapters.

The approach is illustrated in Fig. 1 and comprises three main steps. The first focuses on the techno-economic assessment of the considered utilization path. The second step aims at determining framework conditions in the considered region. The third step contains the calculation of a cost-minimal structure of the biomass utilization path, number of locations as well as capacities, basing on the data of the first and second step. This optimization is carried out with a mixed integer optimization model[6]. The main characteristics of the model are described in the following.

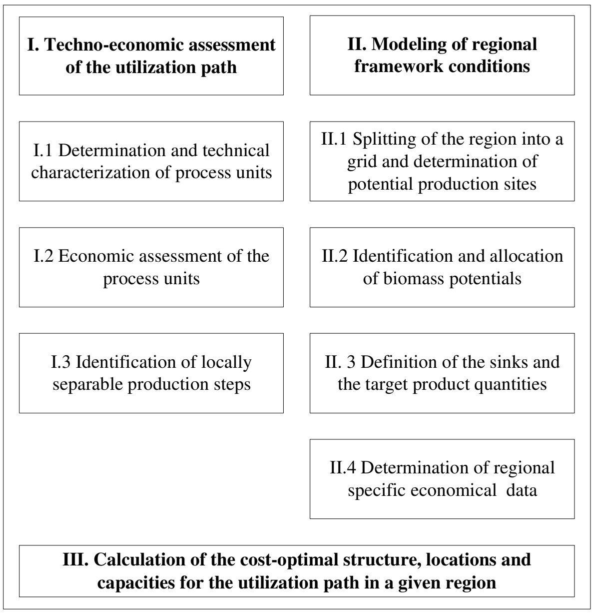

Fig. 1: Approach for the regional assessment of utilization paths

The techno-economic assessment of step I starts with the identification of the single process units and their technical characterization (step I.1). This includes the determination of factors β modeling the material conversion of biomass into main and by-products by the process units. These factors can be obtained from literature or by mass flow modeling and simulation. As a result, mass flow transformation processes are described as follows:

$$m^{Output\ flow} = \beta \cdot m^{Input\ flow} \qquad (1)$$

The input material flow is either the output flow from the previous process unit or the biomass which is delivered to a certain location, expressed as summation over biomass delivery from different sources in the considered region.

Thermal and electric energy demands for each process unit are required in order to model the energy supply for each production site. Basing on the specific demands the total energy consumption at each production site can be calculated. Energy can be provided either by buying electricity from the network, by using parts of the biomass within a burner or by using and transforming waste energy. This can accrue through exothermic reactions or energetically usable by-products and can be transformed e.g. by aggregates like steam and gas turbines. Energy balances are

[6] For a detailed description and formulation of the model see (Schwaderer et al. 2010).

formulated for each production location and each aggregate in order to ensure that the input energy flows correspond to the output energy flows under consideration of specific degrees of energy efficiency.

The economic assessment of the process units (I.2) aims at the determination of the investments. Generally, the investment I_0 can be estimated or found in literature for a certain base capacity C_0. Assuming a scale exponent R, the investment I_1 for a certain capacity C_1 can be approximated as described by equation (2).

$$I_1 = I_0 \cdot \left(\frac{C_1}{C_0}\right)^R \qquad (2)$$

Fig. 2 illustrates this relationship. In a mixed-integer optimization model this can be approximated piecewise linearly by introducing supporting points which represent certain capacities and approximating investments by linear interpolation between these points (compare Fig. 2)[7].

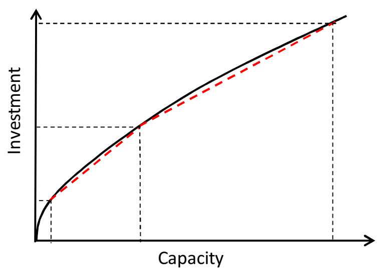

Fig. 2: Investment as function of the capacity and linear approximation

Despite the expenditures for the process units, the investment consists of direct subitems like pipes, electricity supply, isolation, instruments, measurement and control systems and indirect subitems like licenses, storing during erection, engineering, construction period interests, hold ups or start up. The subitems are estimated depending on the investment for the process units (compare e.g. Remmers (1991) and Chauvel (2003)).

Step I.3 of the techno-economic assessment is related to the identification of locally separable production steps which consist of a group of consecutive process units which can be operated independently at a stand-alone location. This especially requires that the intermediate product can be transported.

The second part of the applied approach consists of the modeling of regional framework conditions. In doing so, the considered region is split into a grid and for each cell of the grid the available biomass and the coordinates of the center are calculated with a Geographical Information System (GIS) (step II.1). The centers are assumed to be the sources of the biomass. Biomass can be delivered from these sources to the production sites which have to be connected to the road system and the electricity network.

The available biomass is estimated depending on the area where the biomass growths or accrues. The rate of yield is estimated basing on annual growth and mortality rates of the plants and rates for the generation of the relevant plant parts (e.g. wood residues) which are considered for utilization (step II.2). Furthermore, the sinks for the final products have to be defined as well as the target product quantities (step II.3).

The fourth step of the regional assessment is the determination of regional specific economic data. This comprises transport distances from the sources to the potential production sites, between the production sites and from the production sites to the sinks. As geographical features like lakes or mountains as well as the existence of roads are determinant, distances representing the existing road network are calculated in this contribution. Fig. 3 shows an example for a road distance between two possible production sites in Sweden.

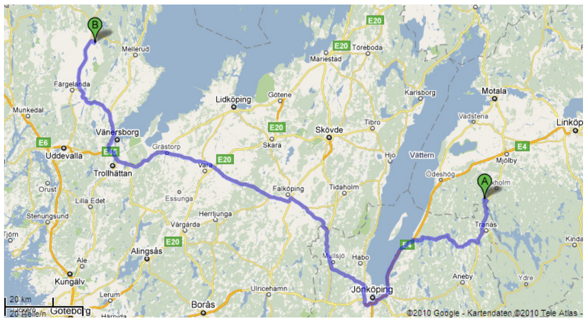

Fig. 3: Example transportation route (Distance 307 km) (Source: Google Maps)

Basing on the distances and mass and distance dependent cost factors, the transportation costs for biomass, intermediate and final products can be calculated. Further cost categories which are considered for cost minimization are acquisition costs for biomass, investment depending costs (e.g. amortization, interests) and costs for electric energy, auxiliary materials and residues.

Basing on the data of the first and second step, the cost-minimal number and capacities of the plants are calculated with a mixed-integer optimization model. This computes mass and energy flows at and between the production locations endogenously as outlined above. Investment estimation is carried out within the model for each process unit at each production location in order to calculate investment depending costs.

In the following section the techno-economic assessment is carried out for two example processes, a pelletizing and a BtL process.

4. Techno-economic assessment of the example utilization paths (I)

[7] E.g. Nemhauser and Wolsey (1988).

4.1. Determination and technical characterization of process units

(A) Pelletizing process

Fig. 4 shows a possible process flow diagram of the production chain for the production of pellets (compare Mani et al. (2006) and Thek and Obernberger (2004)).

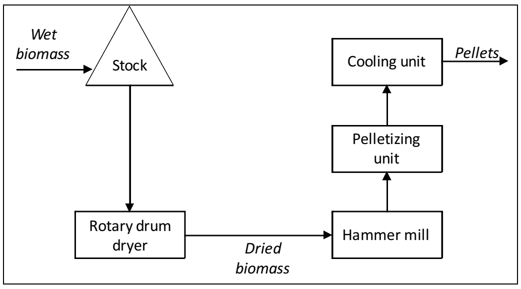

Fig. 4: Process units of the pelletizing production chain

Biomass is prepared decentralized via mobile chipping to gain particle sizes suitable for transport and stocked in the woods. A directly heated rotary drum dryer is the first process unit. The required heat is provided by combustion of a certain fraction of the delivered biomass.
After the drying operation the biomass has to be crushed further in order to obtain a particle size suitable for pelletizing of about 3.2 to 6.4 mm. This is done by a hammer mill.
Consecutively, the ground biomass is compacted in the press mill to form pellets. With this mechanical densification a pellet density of about 1,000 to 1,200 kg/m^3 can be obtained, whereas the bulk density ranges between 550 and 700 kg/m^3. Sometimes additional binders and stabilizing agents are used to reduce the pellet springiness and to increase the pellet density and durability. Since biomass from woody plants contains high fractions of lignin, which acts as glue under high pressure, the usage of binders and stabilizing agents can be neglected.
After the pelletizing process, the obtained product has a temperature of 70°C to 90°C due to the extrusion and material pre-heating. The cooling unit as the last process unit hardens the pellets and ensures that the end product leaves the plant with ambient temperature.

Tab. 1: Material conversion parameters for wood with 35 % humidity

Process unit	β [t output/t input]	E_{el} [MWh/ t input]
Drying	0.745	0.02
Size reduction	1.000	0.1325
Pelletizing	1.000	
Cooling	1.000	

Tab. 1 displays the material conversion factors β for the mentioned process units, whereas the electric energy demands are given in MWh. For drying the input flow wet biomass is relevant, while the values of the latter three process units base on the mass of dried biomass. The values stem from Hamelinck et al. (2003) and company estimations.

The necessary thermal energy for drying and therefore the required amount of biomass for incineration depends on the mass of evaporated water.

(B) BtL process

Fig. 5 shows a possible process flow diagram of the production chain for the production of Fischer-Tropsch (FT) fuel (compare Kerdoncuff (2008) and Hamelinck et al. (2004)).

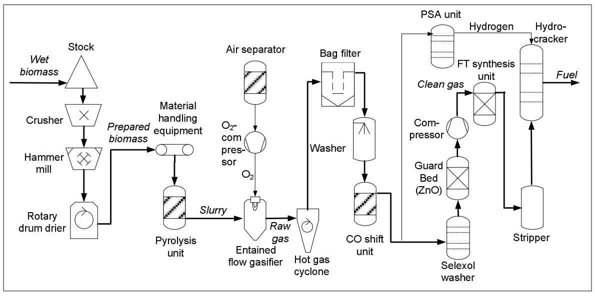

Fig. 5: Process units of the BtL production chain

Biomass is delivered coarsely shredded and stocked due to seasonal fluctuation. The first process units are a crusher and a hammer mill for further size reduction. Depending on the water content the biomass is dried in a rotary drum dryer which can be heated directly by burning biomass or indirectly by using waste surpluses of other process units.

The prepared biomass is the input for the pyrolysis unit, where it is firstly preheated and mixed with hot sand and then heated within 1 sec to 500°C. This results in a thermal degradation of chemical bonds and a vaporization of the remaining water. The obtained slurry consists of pyrolysis oil and coke, the pyrolysis gas can be energetically utilized.

The slurry is gasified with dioxygen in an entrained flow gasifier. The required thermal energy is generated by partial combustion of the slurry. O_2 is provided by an air separator and oxygen compressor. A slag occurs as a by-product of the gasification. Afterwards, the gas is cleaned and conditioned. Coarse dust is separated via a hot gas cyclone and the fine dust fraction through a bag filter. Via the washer alkali, halogen and nitrogen compounds are removed from the gas flow.

During Fischer-Tropsch synthesis one mol carbon monoxide reacts with two mol hydrogen in order to build hydrocarbon chains of different lengths. This proportion between CO and H_2 is adjusted by the CO shift unit with water steam. A part of the conditioned gas is fed into a PSA (pressure swinging adsorption) unit to separate hydrogen required for the hydrocracking of long hydrocarbon chains from FT synthesis (waxes). The selexol washer separates CO_2 from the gas. Hydrogen sulfide is removed from the gas within a ZnO guard bed. The clean synthesis gas is converted to hydrocarbons with different chain lengths using a fixed bed reactor with a cobalt catalyst causing an exothermic process. The synthesis products are separated into condensation water, gas and a liquid fraction consisting of wax, diesel and gasoline by a stripper. The gas can be further used energetically.

Tab. 2: Material conversion parameters for wood with 35 % humidity

Process unit	β [t output/t input]	E_{el} [MWh/ t input]
Size reduction	1.000	0.02647
Drying	0.745	
Pyrolysis	0.72	0.135
Gasifier	0.480	0.2604
Cyclone	0.983	
Bag filter	0.995	
CO shift	1.148	
Selexol washer	0.415	
Guard bed	1.000	
FT Synthesis and stripper	0.747	

Tab. 2 shows the material conversion factors β for the process units. They are obtained by material flows analysis (Kerdoncuff (2008)). Furthermore, the electric energy demands of the process units are given in MWh, for size reduction and drying per ton of biomass input, for the pyrolysis per ton of prepared biomass and cumulated for the other process units per ton of slurry input. Pyrolysis gas is utilized to provide thermal energy for the pyrolysis. Thermal energy is furthermore required for drying and depends on the energy demand per ton of evaporated water. Thermal energy surpluses of the synthesis and the synthesis gas can be used for drying instead of burning biomass or in order to produce electricity for internal purposes or for the electricity network.

4.2. Economic assessment of the process units

Tab. 3 displays an extract of the economic data for the investment estimation of selected process units.

Tab. 3: Investment data for selected process units of the BtL and the pelletizing production chain

Unit	I_0	C_0	R	A	R^A
Grinding	0.48 M €	33.5 t/h	0.6	0.33	-0.82
Drying	8.5 M €	33.5 t/h	0.8	0.33	-0.82
Pyrolysis	7.52 M €	70 MW	1	0.33	-0.82
Gasifier	90.1 M €	78 t/h	0.7	0	1
CO shift	12.2 M €	8.82 kmol/h	0.65	0.81	1
Guard bed	240 T €	8 m³	1	2	1
FT synthesis	17 M €	208 t/h	1	0.3	1
Pelletizing	470 T €	5 t/h	0.8	0.33	-0.82

This comprises the base investment I_0 for the base capacity C_0, the scaling exponent R and the factor for direct subitems A . R^A is a further scaling exponent which is applied on the factor A . The factor for indirect subitems is assumed to be 0.5. The data bases on Hamelick et al. (2004) and Henrich and Dinjus (2003). The technical units of the capacities are transformed in order to estimate the capacity depending on the input material flow.

4.3. Identification of locally separable production steps

Regarding the pelletizing process, two separable production steps can be executed at different locations. As transportation of biomass by truck is limited by weight it is possible to transport higher volumes of dried biomass compared to wet biomass. Thus, a separation of the drying unit on the one hand and the hammer mill, pelletizing and cooling unit on the other hand has to be taken into account. A further separation of the latter process steps is not reasonable as neither a loss of mass nor an energy densification takes place.
For the Btl production chain three production steps are identified. The first step consists of the process units for size reduction and drying. The second step is the pyrolysis process. The obtained slurry is transportable and has a much higher energy density than biomass. The process units from gasification to product separation form the third production step. A separation into more steps is not possible due to the gaseous intermediate products and a complex interconnection of energy flows in order to ensure the right input temperatures and pressures.

5. Modeling of regional framework conditions in Germany, Sweden and Chile (II)

5.1. Main characteristics of the regions

The outlined approach is applied to three different regions in Germany, Sweden and Chile. Each region has a total surface of about 110,000 square kilometers (compare Tab. 4).

Tab. 4: Characteristics of the considered regions

	South Germany	South Sweden	Aysén in Chile
Surface [km²]	106,303	114,190	106,982
Inhabitants	23,254,921	4,583,815	91,492
Density [Inh./km²]	219	40	1
Communes	3,157	167	10

In Germany the selected region covers the federal states of Baden-Württemberg and Bavaria. These are located in the south of Germany and bounded by France in the West, Switzerland and Austria in the south and the Czech Republic in the east. In the following we call this region South Germany.

In Sweden the south of the country is considered, too. The region covers approximately 10 counties and ends a few kilometers southern of Stockholm. As a result, the region is mainly bounded by Middle Sweden and a small part of Norway in the north-west and apart from that by the North and Baltic Sea.

Aysén del General Carlos Ibáñez del Campo, shortly Aysén or the XI region of Chile is located in the southern part of Chile. It is bounded by the X region in the north, by the XII region in the South, by Argentina in the east and the Pacific Ocean in the west.

The regarded regions strongly differ in terms of population. South Germany is most densely populated with 17 cities of more than 100,000 inhabitants and 3,157 communes in total. In comparison, South Sweden has one-fifth of the South German inhabitants per square kilometer, 7 cities bigger than 100,000 and 167 communes. In contrast, Aysén has less than 100,000 inhabitants in total, whereby 80 % of them are living in 7 cities with between 1,400 and 50,000 inhabitants. 45% of the entire surface of Aysén is covered with forest, which is mainly native forest. The rest of the region is covered by snow and glaciers (17 %), grasslands and bushes (12 %), wetland (11 %) and areas without vegetation (11 %).

5.2. Splitting the regions into a grid and determination of potential production sites (II.1)

In this section 20 potential production sites in each region are defined and the regions are divided into grids, whereby each cell has a standard edge length of 35 km. Cells, which have a resulting surface of about less than the half of a cell with this edge length, e.g. due to borders or lakes which cross the cells, are united with adjacent cells in order to prevent high computing times.

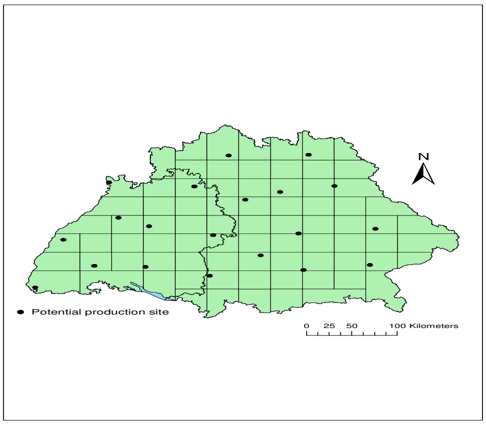

Fig. 6: Grid and potential production sites in South Germany

With the exception of the Lake Constance in the south the regarded region in Germany features no geographical or political circumstances which have to be considered when dividing the region into a grid. The resulting grid consists of 80 cells and is illustrated in Fig. 6. The 20 potential production locations are marked with black spots. The Alpes in the south of Bavaria permit potential production sites in this area. The *Black Forest* and further uplands (e.g. *Swabian and Franconian Jura*) influence the situation of the potential production sites, too.

The South of Sweden includes two bigger and thousands of smaller islands which are all excluded before gridding the region (compare Fig. 7). Moreover, Sweden has numerous lakes and rivers. The biggest (*Vänern, Vättern, Roxern, Glan* and *Hjälmaren*) are respected within the grid which then consists of 77 cells. The 20 potential production sites across the country correspond to cities or villages and have access to the network of rural roads.

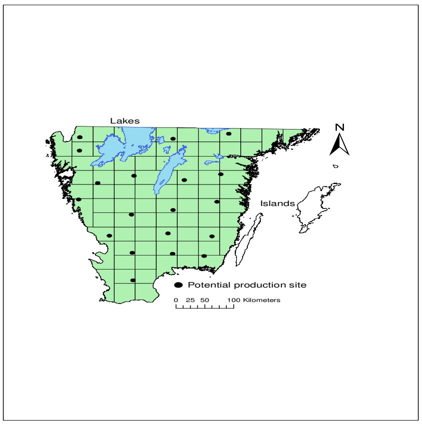

Fig. 7: Grid and potential production sites in South Sweden

43 % of the native forest in Aysén are national parks, national monuments or reservations and are protected by the *Sistema de Nacional de Áreas Silvestres Protegidas del Estado* (SNASPE). As no forest operation is allowed in SNASPE protected areas (marked by stripes in Fig. 8), they are excluded for further considerations. This applies also for islands and areas which are only accessible via SNASPE areas. Gridding of the remaining area leads to 45 cells.

The mountain chain of the Andes, a high number of rivers and lakes and the absence of a fully developed road network have to be considered when defining 20 possible production sites. The production sites are selected close to main roads near to cities or colonies in plain areas to ensure suitability for construction. As 98.4 % of the population in Aysén is connected to the electricity network, it is assumed that no additional power lines have to be installed.

5.3. Identification and allocation of biomass potentials in the regions (II.2)

Europe holds significant amounts of usable biomass, especially forest residues, industrial by-products, straw and maize residues and potential energy crops (Ericsson and Nilsson (2005)). In this study forest and straw residues are considered in South Germany and South Sweden. These are the most important biomass resources already available. Industrial by-products are not considered due to inhomogeneity and potential contamination with toxic substances.

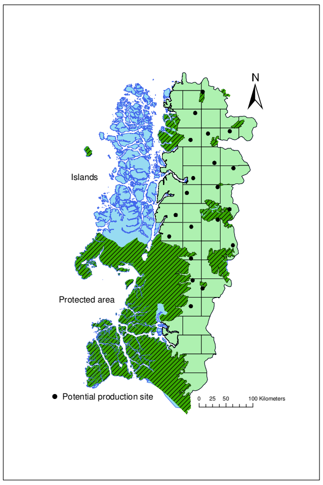

Fig. 8: Grid and potential production sites in Aysén

In order to estimate the biomass potentials, the Corine Land Cover vector data of the European Environment Agency is utilized (EEA (2010)). The total forest area serves as a basis for the estimation of the residual forest wood, corresponding to the Corine-categories broad-leaved forest, coniferous forest and mixed forest. For the estimation of residual straw the land cover category non-irrigated arable land is utilized.

Basing on Kappler (2008) and FFE (2006), 58% of the arable land in South Germany is assumed to be grain fields. Basing on data of the Sweden Statistic Agency (SCB (2010)) the arable land for spring and winter wheat, rye, spring and winter barley, oats, triticale and mixed grain is about 986 km². The share of arable land of the total area of Sweden is due to EUROSTAT (2010) 6.4 %. This results in 37.5 % grain fields of the arable land in Sweden. The yields in tons per hectare and year are assumed to be 5.5 for South Germany (Kappler (2008)) and 3.51 for South Sweden (SCB (2010)). In order to calculate the usable amount of residual straw, a residue generation ratio for straw to cereal grain of 1.3 is assumed (Ericsson and Nilsson (2005), Hall et al. (1993)) which is multiplied with 0.22 in order to account for animal feeding and litter for soil stabilization.

For residual forest wood it is assumed that 0.72 tons per hectare of forest accrue per year regarding both, South Germany and South Sweden (basing on Kappler (2008)). The underlying total areas and the resulting biomass potentials for residual straw and residual forest wood are displayed in Tab. 5.

In Aysén some parts of the native forests are cultivated. 96.2 % of the wood used for industrial production is processed by 18 sawmills in the north of Aysén. Additionally, 525,000 m³ of firewood are extracted every year. Besides SNASPE protected areas in Aysén, every forest operation has to be registered by the National Forest Corporation (Corporación Nacional Forestal, CONAF) which follows a very restrictive policy. Against this background and basing on an annual forest growth rate of 5 m³ and an annual mortality rate of 3 m³, it is assumed that annually 2.56 tons of wood per hectare can be utilized, which is 3.5 times more than estimated for Europe[8].

Tab. 5: Forest and grain areas and biomass potential

	South Germany	South Sweden	Aysén, Chile
Grain [km²]	16,712	5,325	-
Fraction grain of total surface	16 %	5 %	-
Residual straw [T t/a]	2,613	535	
Forest [km²]	38,120	60,342	48,155
Fraction forest of surface	36%	53%	45%
Fraction protected area of forest	-	-	43%
Biomass from forests [T t/a]	2,712	4,360	3,645

Basing on the outlined data and the grids defined in the previous section for each region, the biomass potential for each cell in the grid is calculated. The results for South Germany are displayed in Fig. 9 as available biomass in tons per square kilometer for each cell. It can be observed that residual forest wood is first of all available in the south and in the north-east. Residual straw concentrates on the center of Bavaria (right part of Fig. 9).

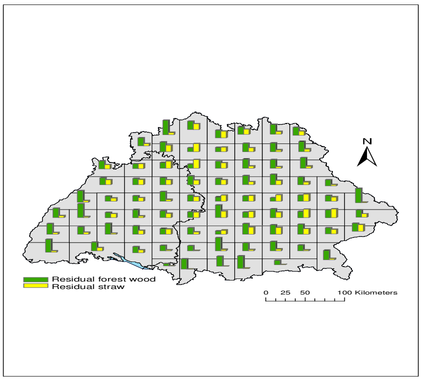

Fig. 9: Considered biomass potential in South Germany [t/km²]

In South Sweden residual forest wood is available more or less equally distributed all over the region with exception of the populated south (compare Fig. 10). Residual straw is marginal and primarily available in the north near the two lakes. The potentials in Aysén concentrate in the north and north-west of the region (Fig. 11). The higher areas of the Andes have no vegetation.

[8] Information from researchers at the *Unidad de Desarollo Tecnológico (UDT)* in Concepción, Chile.

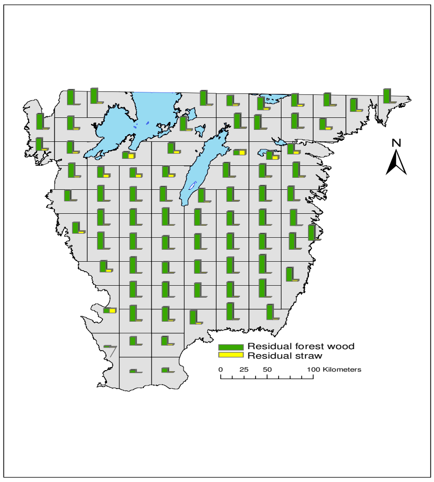

Fig. 10: Considered biomass potential in South Sweden [t/km²]

Tab. 6 contains the assumed moisture contents of the considered biomass types. For Germany and Sweden it is assumed that residual forest wood has 50 % water content and is dried during stocking at fresh air to 35 % (Kappler (2008)).

Tab. 6: Moisture content of the biomass

Moisture content	South Germany	South Sweden	Aysén in Chile
Wood, fresh	50 %		60 %
Wood, matured	35 %		60 %
Residual straw [T t/a]	15%		-

Fig. 11: Considered biomass potential in Aysén, Chile [t/km²]

For the native forest of Chile a water content of 60 % is assumed (Hamelinck et al. (2003)) and due to poor drying properties within the damp climate in Aysén, no natural drying is expected. For residual straw a water content of 15 % is assumed (Kappler (2008)).

5.4. Definition of the sinks and the target product quantities in the regions (II.3)

For South Germany and South Sweden it is assumed that the produced biofuel is consumed by the population in these regions. The number of inhabitants in each cell of the grids defined in section 5.2 is estimated basing on the population in each commune and an allocation of communes to the cells of the grid. Then, each cell is modeled as sink and it is proposed that, corresponding to the share of inhabitants which are allocated to one cell, an equal part of the total fuel amount has to be transported to the cell.

As Aysén is only little populated it is assumed that the total amount of the final products (pellets and biofuel) is exported. Hence, the port of the region, which is situated in Puerto Aysén, is the only sink.

Tab. 7: Target production quantities

	South Germany	South Sweden	Aysén in Chile
Pellet scenario [t]	-	-	20-400 T
Biofuel scenario [l]	400 m	400 m	200 m

The total amounts of products which are specified in each scenario are given in Tab. 7. The pellet production scenario is only investigated for Aysén as this technique is already well established in Chile and seems to be the most promising for a prospective realization. The annual production rate is varied between 20,000 and 400,000 tons to demonstrate the impact of the modeled framework conditions on locations and capacities. The BtL scenario is calculated for all regions to investigate the influences of the different regions on the optimal solution. The assumed annual production rates are about 70 % of the biofuel which could be produced when the total biomass potentials of the regions (compare Tab. 5) would be utilized. The gap accounts for the utilization of biomass to recover energy for drying.

5.5. Determination of regional specific economic data (II.4)

In this section the most relevant economic data is given. Tab. 8 displays the specific transportation costs. The costs split in a parameter depending solely on the mass and a parameter depending on mass and distance. For Germany and Sweden the costs are taken from Kappler (2008). The parameters for Chile base on a linear regression on transportation costs for different distances in Aysén (given in INFOR (2004)). The difference between Chile and Europe goes back to the much worse condition of the road network in Aysén.

Tab. 8: Mass and distance dependent transportation costs

Biomass		Europe	Chile
Wood (general)	Fix [€/t]	2.34	4.60
	Var. [€/(t*km)]	0.13	0.2
Straw (15% H_20)	Fix [€/t]	12,92	-
	Var. [€/(t*km)]	0,15	-
Liquid	Fix [€/t]	1,9	4.57
	Var. [€/(t*km)]	0.08	0.13

As the native wood in Aysén is not fully cultivated and the road network is characterized by few roads, road construction has to be considered. This is approximated by assuming that a road from the point of source of biomass is constructed to the existing road network when biomass of the corresponding cell is utilized. The costs for the construction of roads consist of amortization, interests and maintenance. The investments comprise machinery (roller, excavator) and the costs for fuel consumption. It is assumed that no costs emerge for construction material, since the earth of the native forest can be used to build the roads. This leads to road construction costs of annual 2.620 €/km.

In order to avoid that the model calculates solutions which lead to an unrealistic frequency of truck arrivals and departures at a certain location, the number is limited to 20 per hour for all production locations in all considered regions. The approximation of the number of truck arrivals and departures at a certain location bases on the maximum masses which can be transported under consideration of limitation of driving at weekends and empty drives.

Tab. 9 displays further cost parameters. The costs for biomass acquisition in Germany and Sweden base on Kappler (2008). They depend on costs for labor, interests, amortization for machines and storage. The costs for Chile base on precise calculations for the costs for fuel, lubricant, material consumption, amortization, maintenance and interests for the machines and salary for workers for the tasks extraction and comminuting.

Tab. 9: Important cost parameters

Cost category		Europe	Chile
Wood acquisition	[€/t dry substance]	83	45.13
Straw acquisition	[€/t dry substance]	63	-
Investment depending costs (BtL)	[% of investment]	15.5	15.1

It is assumed, that the annual costs for interests, amortization, maintenance and repair, assurance, taxes, administration and labor depend on the total investment at a certain production location. The factors are given in Tab. 9, too. The smaller investment depending costs in Chile represent the lower wage level of South America. For the pellet process higher investment depending costs are assumed (25.6 %). The costs for auxiliary materials, electricity and disposal of waste for the BtL process are taken from Kerdoncuff (2008).

6. Calculation of the cost-minimal structure, locations and capacities for selected scenarios in the regions (III)

In this section the results from step III, which is the model based calculation of cost-minimal structures, locations and capacities, are presented for the considered scenarios. The input for the calculations consists of the data and assumptions presented in the previous chapters.

6.1. Results for the pellet scenario in Aysén

Pellet production in Aysén is considered for capacities from 20,000 to 400,000 tons of pellets per year. The results show that the two identified productions steps are never separated and the plants are installed in the north of the region.

Up to a capacity of 140,000 tons a plant is operated at location 10 (compare Fig. 12). This location is near to Puerto Aysén and near to the cell *H* which has a high biomass density (compare Fig. 12 and Fig. 11).

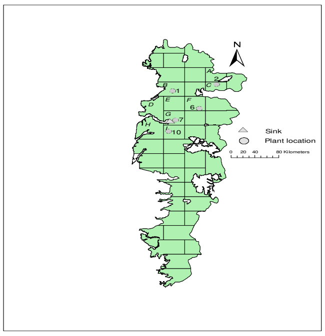

Fig. 12: Pellet plant locations in the North of Aysén

Fig. 13 shows that the total production costs decrease with the increasing capacity of this plant from 118 € per ton of pellet to 109 € per ton of pellet. This results from economies of scale which determine the investment depending costs (compare Fig. 14).

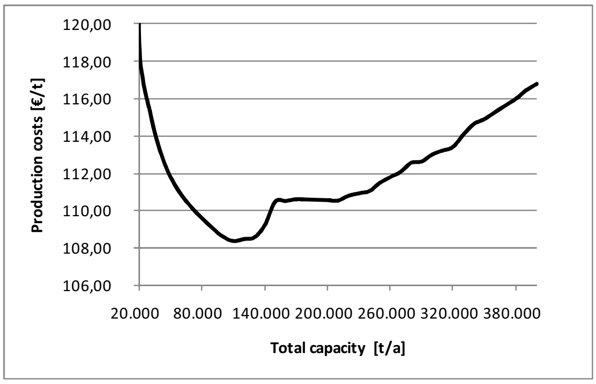

Fig. 13: Production costs for the pellet production in Aysén

Although a further increase of the plant size would be possible, a pellet production of more than 140,000 t leads to another plant location in order to save transportation costs. The second plant is installed at location 7, Puerto Aysén, which is also the location of the port. Production costs rise as the new plant has a lower capacity. For this plant biomass is firstly used from cell G, then also from *D* and *E* which leads to increasing transportation costs. As this plant is nearer to the sink, transportation costs for the pellets decrease.

A total production capacity of more than 280,000 pellets per year leads to a third plant which is installed at location 1. This plant's capacity rises up to 47,500 tons, then a further plant is installed at location 2. The plant at location 1 uses biomass from cell B, the plant at location 2 from A and C, where huge amounts of biomass are available. With a total production of 400,000 pellets a fifth plant is installed at location 6.

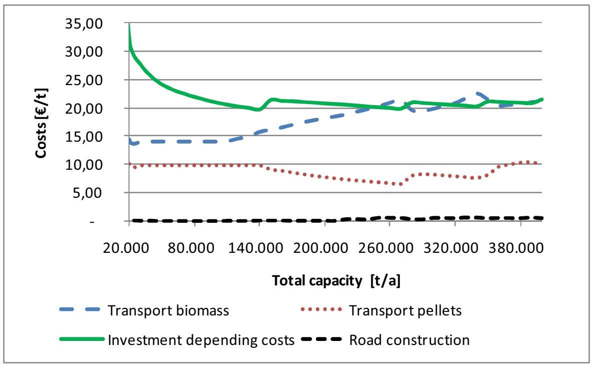

Fig. 14: Transportation and investment depending costs

As a summary, this scenario shows that the number of plants, locations and capacities depend on the availability of biomass, the closeness to the sink, economies of scale and transportation costs for biomass and products. Beside this, the mentioned factors influence the overall costs and lead to higher pellet production costs in Aysén than in other parts of Chile with already existing pelletizing plants. In the next section, the more complex BtL production chain is assessed under consideration of these relationships in all three regions.

6.2. Results for the BtL scenarios in South Germany, South Sweden and Aysén

Fig. 15 illustrates the results for South Germany. The structure of the production network consists of two independent systems. The plant in the south-west of the region at location 4 consists of all three production steps of the BtL production chain: a plant for the biomass preparation including drying, a pyrolysis plant and a gasification and synthesis plant. The plant processes only residual forest wood with a capacity of 707.163 tons. This biomass stems primarily from the Black Forest and its surroundings. Energy surpluses of production step 3 are utilized for drying the biomass and providing the electric energy, a little energy surplus of 72,615 MWh is sold to the public electricity network.

The second part of the production system has a decentralized structure. A gasification and synthesis plant at location 17 processes the total amount of slurry produced in 10 different pyrolysis plants. Plant 17 is the only to reach the maximum number of allowed truck transports.

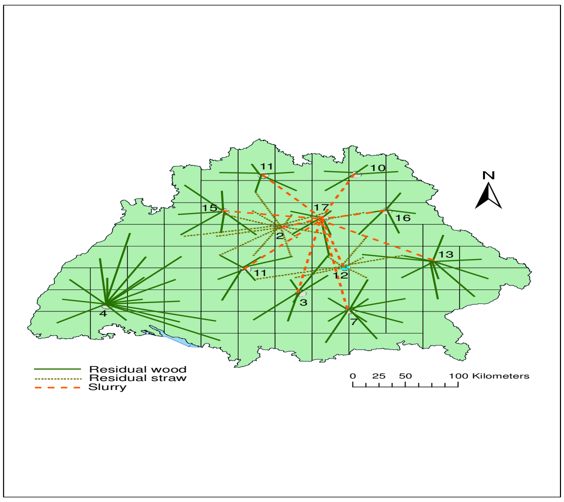

Fig. 15: Model results for South Germany

All pyrolysis plants are installed together with plants for biomass comminution and drying. Nine of this plants process residual forest wood. The smallest one is directly installed at location 17, the rest in a circle around this location using the residual forest wood from wood-intensive regions. At location 2 and 12 residual straw is processed in the part of South Germany with the largest potentials (compare Fig. 9). Five pyrolysis plants have a capacity between 82,000 and 102,000 t slurry, four plants between 115,000 and 162,000 and two between 194,000 and 251,000. At location 17 huge amounts of energy surpluses can be converted into electric energy and sold (688,752 MWh). The other plants of this system all require electricity from the public network (between 28,112 and 49,983 MWh). The drying of the biomass is realized by burning 64,742 tons of residual wood.

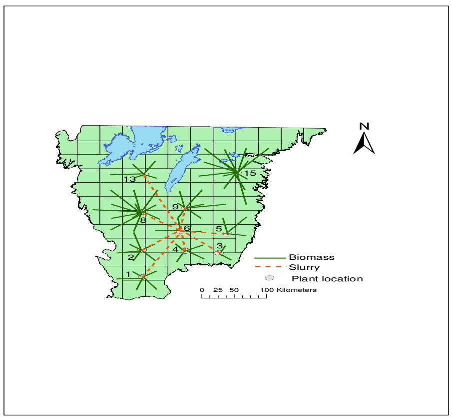

Fig. 16: Model results for South Sweden

Comparing these results with South Sweden (see Fig. 16) it can firstly be observed that in Sweden no residual straw is utilized. Furthermore, there are two plant locations less than in South Germany and three plants which meet the upper limit for truck transportation (6, 8 and 15). Analogously to South Germany the production network consists of two parts. At location 15 biomass from the area between the lakes and the Eastern coast is prepared, pyrolyzed, gasified and synthesized. The other plants form a decentralized production system with a gasification and synthesis plant at location 6 in the center. Biomass preparation and pyrolysis is never separated, too. But, in Sweden a very big pyrolysis plant is installed at location 8 which processes about 30 % of the biomass. In comparison the plants in the south are smaller which may be due to the small amounts of available biomass there.

The biomass potentials in the north of the region considered in Sweden are not utilized. This is most likely explained by the lakes which make this region difficult to access and also prevent the installation of bigger plants without transporting biomass from more distant cells. Regarding energy, more than five times of thermal energy surpluses can be utilized for drying the biomass because the drying plants installed at the site of the synthesis plants are bigger. At the same time more thermal energy is required because no residual straw is utilized. As a result, clearly less electric energy is sold to the public electricity network. But also less electric energy has to be bought at the decentralized locations as two locations less are operated and as the overall capacity of the decentralized plants is smaller.

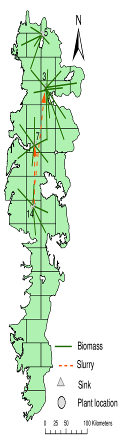

Fig. 17: Model results for Aysén in Chile

Finally, Fig. 17 illustrates the result for the Chilean scenario. Here, only four production sites with three gasification and synthesis plants at location 3, 5 and 7 are calculated. Location 14 delivers slurry to location 3 and 7, which are both restricted by the transportation limitation. Each of the three synthesis plants is supplied with slurry from a pyrolysis plant installed at the same location. The region in the south of Aysén is not part of the production network. Reasons are the great distance to the sink near location 7 and the poor infrastructure in these area as well as the higher biomass potentials in the north. Regarding the capacities, plants 3 and 7, which are located near to the sink make up nearly 80 % of the total capacity of the production network. The thermal energy demands in Chile are higher compared to Germany and Sweden due to the higher water content of the biomass. As a result, it is cheaper to use waste heat from synthesis for drying and accept a more central structure with higher transportation costs. Biomass is only burned at location 14 to provide energy (compare Tab. 10).

Tab. 10 shows further cost categories for each scenario per ton of produced biofuel. Due to the assumptions in section 5.5, biomass acquisition is cheapest in Aysén. The higher transportation costs for biomass in South Germany compared to Sweden go back to the utilization of residual straw. As the number of decentralized pyrolysis plants is the highest in South Germany, the transportation costs of slurry per ton of biofuel are the highest, too, and accordingly the lowest in Aysén. Biofuel transportation costs may be lowest in South Germany due to the big and relatively equal distributed population. The higher investment depending costs in Chile result from higher investments for drying the biomass and lower capacities for the single gasification and synthesis plants which leads to less economies of scale. Regarding electric energy, the selling in South Germany and Sweden overcompensates costs for purchasing electric energy, whereas in Chile energy surpluses are mostly utilized for drying the biomass and in total costs for buying electricity accrue.

In total the considered scenarios deliver cheapest production costs in Sweden and about 3 % higher costs in South Germany. The highest production costs result for Aysén.

Tab. 10: Costs for the BtL scenario in the considered regions

[€/t biofuel]	South Germany	South Sweden	Aysén
Biomass acquisition	430.1	418.5	326.2
Transportation:			
Wet biomass	137.5	105.9	261.5
Slurry	54.1	44.5	19.5
Biofuel	14.5	16.5	21.8
Road construction	-	-	5.5
Investment depending	664.0	659.8	780.9
Water and waste water	24.2	24.2	24.2
Slag disposal	1.0	0.8	1.3
Electric energy	-37.9	-22.4	21.8

Total costs	1,287.5	1,247.8	1,457.1

Summary and conclusion

In this contribution an approach for the assessment of biomass utilization paths in a regional context is presented. It bases on the one hand on a detailed techno-economic characterization of the utilization paths, particularly regarding energy and material flows and estimation of investments. On the other hand relevant regional framework conditions are modeled. Major features are a GIS-based estimation and allocation of biomass potentials and the regarding of existing road networks.

The main part of this contribution is the application of this approach to three different regions in Germany, Chile and Sweden. Two utilization paths are considered: a pelletizing and a BtL process. Regional characteristics like the existing road network or the need for construction of new roads, possible production locations and sinks of the product as wells as economic data are considered.

The pellet process is applied to Chile. The investigation of different production volumes shows that production locations and capacities are determined by the availability of biomass, transportation costs as well as economies of scale and the sink. The results of the BtL utilization path show that there is a great impact of the regional framework. It can be observed that geographic characteristics like the Black Forest in South Germany or the lakes in Sweden have an impact on the placement of production sites and the structure of the production network. Different number of plants and capacities are calculated for the three regions. Particularly in Chile, where the basic conditions are very different to Europe, a big variation compared to South Germany and South Sweden is observed. The poor conditions and the small number of roads and the higher humidity of the biomass overcompensate lower wages and lead to more synthesis plants. Regarding production costs, the model delivers the lowest costs for South Sweden, followed by Germany and Aysén in Chile.

To sum up, calculation costs for different scenarios are calculated which allows answering the question of competitiveness. At the same time, investments are estimated and a promising regional concept regarding the structure of the production system, number and locations of production plants and plant sizes in the regions is calculated.

References

Chauvel, A., Fournier, F., Raimbault, C., 2003. "*Manual of process economic evaluation*". Paris.

EEA, 2010. "*Corine Land Cover 2006 seamless vector data*", European Environment Agency, available at: www.eea.europa.eu/data-and-maps.

Ericsson, K., Nilsson, L.J., 2005. *"Assessment of the potential biomass supply in Europe using a resource-focused approach"*, Biomass and Bioenergy, Issue 30, p 1-15.

EUROSTAT 2010, "Land use 2007", Eurostat, available at: www.eep.eurostat.europa.eu.

FfE, 2006. "Biomassenutzung *in Bayern – Potentiale und Techniken für die Stromerzeugung*", Study, Forschungsstelle für Energiewirtschaft

Freppaz, D., Minciardi, R., Robba, M., Rovatti, M., Sacile, R., Taramasso, A., 2004. "*Optimizing forest biomass exploitation for energy supply at a regional level*". Biomass and Bioenergy 26, 15–25.

Frombo, F., Minciardi, R., Robba, M., Rosso, F., Sacile, R., 2009. "*Planning woody biomass logistics for energy production: A strategic decision model*". Biomass and Bioenergy 33, 372–383.

Hall, D.O., Rosillo-Calle, F., Woods, J., 1993. "*Biomass for energy: supply prospects*". In: Johansson, T.B., et al., Renewable energy – sources for fuels and electricity. Island press, p 593-651.

Hamelinck, C., Suurs, R., Faaij, A., 2003. "*International bioenergy transport costs and energy balance"*. University of Utrecht.

Hamelinck, C., Faaij, A., den Uil, H., Boerrigter, H., 2004. "*Production of FT transportation fuels from biomass; technical options, process analysis and optimisation and development potential*". Energy 29, 1743–1771.

Henrich, E., Dinjus, E., 2003. „*Das FZK-Konzept zur Kraftstoffherstellung aus Biomasse*". In: Internationale Tagung Biomassevergasung 1.-2. Oktober 2003, Leipzig.

INFOR, 2004. *„Propuesta de una metodología para el estudio de la oferta de le eña en Coyhaique y Puerto Aysén"*. Instituto Forestal, Santiago, Chile.

Kappler, G.O., 2008. "*A system-analytical study on the emergence and supply of energetically usable remnant straw and forest residues in Baden-Württemberg – a location analysis related to the Karlsruhe bioliq®-concept*". Scientific Report FZKA 7416, Forschungszentrum Karlsruhe.

Kerdoncuff, P., 2008. *„Modellierung und Bewertung von Prozessketten zur Herstellung von Biokraftstoffen der zweiten Generation"*.Karlsruhe.

Leduc, S., Schwab, D., Dotzauer, E., Schmid, E., Obersteiner, M., 2008. "*Optimal location of wood gasification plants for methanol production with heat recovery*". International Journal of Energy Research 32, 1080–1091

López, P., Gal´an, S., Reyes, N., Jurado, F., 2008. "*A method for particle swarm optimization and its application in location of biomass power plants*". International Journal of Green Energy 5, 3,199–211.

Mani, S., Sokhansanj, S., Bi, X., Turhollow, A., 2006. "*Economics of Producing Fuel Pellets from Biomass"*. Applied Engineering in Agriculture 22, 3, 421-426.

Nemhauser, G., Wolsey, L., 1988. "*Integer and combinatorial optimization"*. John Wiley and Sons, USA.

Noon, C., Daly, M., 1996. "*GIS-based resource assessment with BRAVO*". Biomass and Bioenergy 10, 101–109.
Panichelli, L., Gnansounou, E., 2008. "*GIS-based approach for defining bioenergy facilities location: A case study in Northern Spain based on marginal delivery and resources competition between facilities*". Biomass and Bioenergy 32, 289–300.

Remmers, J., 1991. „*Zur Ex-ante-Bestimmung von Investitionen bzw. Kosten für Emissionsminderungs-techniken und den Auswirkungen der Datenqualität in meso-skaligen Energie-Umwelt-Modellen*". Karlsruhe.

Rentizelas, A., Tatsiopoulos, A., 2009. "*An optimization model for multi-biomass trigeneration energy supply*". Biomass and Bioenergy 33, 223–233.

SCB 2010, "*Use of arable land by municipality and crop, Year 1981, 1985, 1989-1995, 1999-2007"*, Statistiska centralbyrân, available at: www.sccd.scb.se.

Schwaderer, F., Fröhling, M., Rentz, O. and Schultmann, F., 2010. *„A techno-economic capacity and location planning model for a multi-stage biofuel production chain"*. Manuscript submitted for publication. Paper presented at the 24th European Conference on Operational Research *("Facility location planning for a multi-layer biofuel production chain")*. July 11-14, 2010, Lisbon, Portugal.

Tatsiopoulos, I., Tolis, A., 2003. "*Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods"*. Biomass and Bioenergy 24, 199–214.

Thek, G., Obernberger, I., 2004. *"Wood pellet production costs under Austrian and in comparison to Swedish framework conditions"*. Biomass and Bioenergy 27, 671–693.

Voivontas, D., Assimacopoulos, D., Koukios, E., 2001. "*Assessment of biomass potential for power production: a GIS-based method*". Biomass and Bioenergy 20, 102–112.

Romania's depleted oilfields geothermal potential

Dr.eng., Batistatu Mihail-Valentin
"Petroleum – Gas University "of Ploiesti, Faculty of petroleum Engineering – Scientific Secretary
(Corresponding Author)
Tel: +40244573171
Fax: +40244575847
E-mail: mbatistatu@mail.upg-ploiesti.ro,
mihail_batistatu@yahoo.com
Petroleum-Gas University of Ploiesti, No.39 Bulevardul Bucuresti, Ploiesti, jud. Prahova, Romania
Dr. Eng., Ion Malureanu
"Petroleum – Gas University "of Ploiesti, Faculty of petroleum Engineering
E-mail: imalureanu@upg-ploiesti.ro
Petroleum-Gas University of Ploiesti, No.39 Bulevardul Bucuresti, Ploiesti, jud. Prahova, Romania

Abstract: Romanian oilfields are exploited since the middle of the 19th century. In this period (more than 150 years) have been drilled more than 71000 wells with depths between a few hundred meters up to more than 7000 m. Many of them are abandoned without recovering the casing which is steel in good condition. So a reentry to these wells is relatively easy and not expensive. Analyzing the distribution of geothermal gradient values on Romania's teritory we emphasis some areas as eastern border of Pannonian Basin and central zone of Valachian Platform with abnormal temperature gradients until 6,5 -6,8°C / 100 m. So, we may encounter, in the deep wells, temperatures until 150 - 200°C.Also even the petroleum reservoirs are depleted there are unexploited water reservoirs some of them having abnormal high pressure gradients. Opening these water bearing reservoirs we will obtain eruptive hot water resources able to provide important amounts of thermal energy for heating and/or electrical power. Cooled water can be injected in the same or subjacent/superjacent reservoirs naturally heated and selectively exploited.

Key words: thermal anomalies, temperature, pressure, gradients, well, water, reservoir.

Introduction
Geothermal energy represents an important resource which, in favorable conditions, may be economically used for domestic and/or industrial purposes. The main attributes of this energy are its renewable potential, worldwide spreading and environment friendly character. Even in the zones where thermal flux and temperature gradients are relatively small at a certain depth we will meet high temperatures and fluids able to assure a thermal flow.

Based on these conditions we may see that one important cost of thermal energy obtaining is related with wells' drilling. When these wells already exists it is obvious that the the necessary effort for obtaining thermal energy is smaller.
Romania, one of the firsts petroleum producing countries has an impressive number of wells drilled in the last century some of them at big depths, which are now deactivated, able to be used to extract hot water from the deep layers in order to obtain thermal energy at small production costs.

Geological frame.
Romania's teritory is structured in two main geostructural areas (Sandulescu 1984), the labil one represented by the Carpathians orogenic domain (central western zone) and a stable, consolidated one

represented by neighboring platform zones (P.Mo., D.B., P.N.D., P.M.) as is shown in the figure bellow.

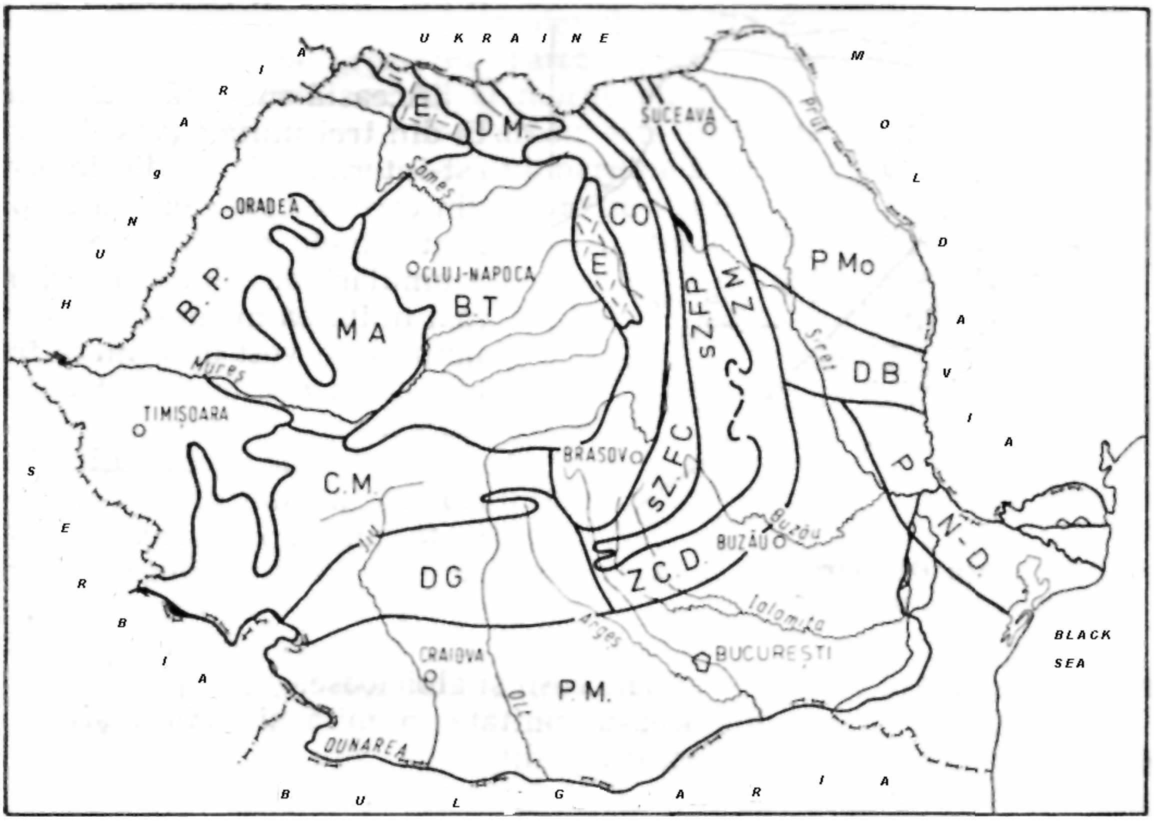

Fig.no.1. Romania's main geological units: P.Mo. – Moldavian Platform, D.B. – Barlad Depression, P.N.D. – nodr Dobrudja, P.M. – Moesian Platform, E. – Neogene Volcanic Chain, C.O. – Oriental Carpathians, C.M. Southern Carpathians, M.A. – Western Carpathians, sZ.F.C. – Inner, Cretaceous, Flisch, sZ.F.P. – Outer, Paleogene, Flisch, Z.C.D. – Diapiric Folds Zone, D.G. – Getic Depression, B.P. – Pannonian Basin (Romanian area), B.T. – Transilvanian Basin, D.M. – Maramures Depression. (after Beca and Prodan 1983).

Because the purpose of this work is to emphasis mainly the favorable zones/conditions for geothermal energy exploitation we selected the areas characterized by higher temperatures and significant thermal flow. In order to accomplish this task we appeal to the Romania's geothermal map (fig.no.2) which indicates that the promising geological units are Moesian Platform and Pannonian Depression.

Moessian Platform formations consists of a crystalline basement a sedimentary cover with a variable thickness from less than 1000 m to more than 7000 m (Mutihac et al 2004). According geological data with the 3000 m depth temperature distribution we may see that the higher temperatures are placed in the central zone of the platform north of Videle oilfield where the temperature exceed 130°C.We also meet smaller but significant "warm" zones as Bals, Bordei Verde, Central Dobrudja. The origins of these anomalies are connected with the uplifted zones of the basement (fig.no.3) and the existence of an important plutonic body in the western-central part of the platform (fig.no.4).

Even if the thermal flux has a moderate value, around 50 – 60 mW/square meter/year the good thermal conductivity of the crystalline igneous and/or methamorphic rocks provides enough energy for these anomalies.

Another important factor is the existence of porous permeable rocks containing fluids water/hydrocarbons, some of them up to 15 – 20% porosity and also good permeability up to500 mD

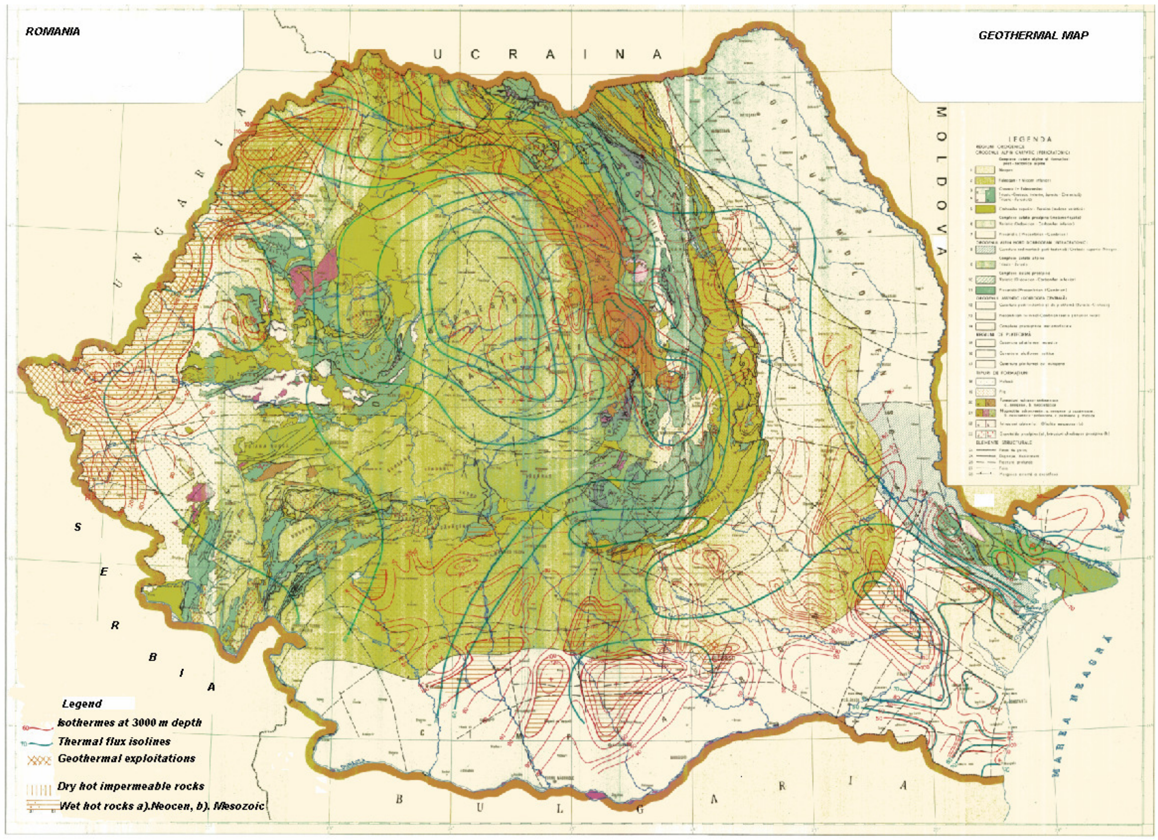

Fig. no. 2. Romania's geothermal map (after Romanian Institute of Geology and Geophysics – 2001)

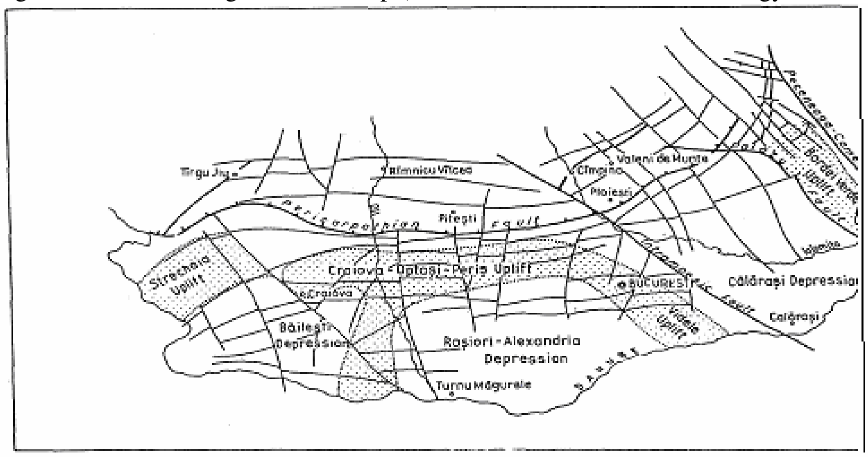

Fig.no.3. Tectonic sketch of Moesian Platform (after Dicea 1991)

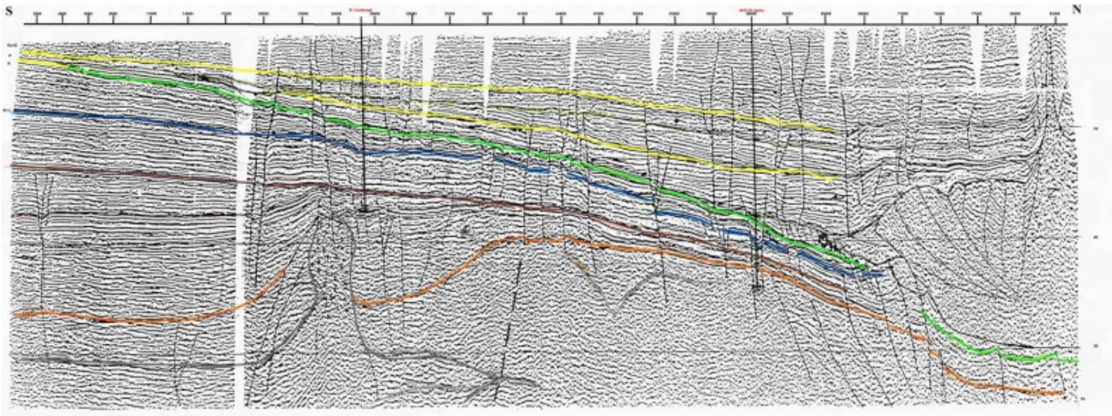

Fig.no.4. Synthetic seismic profile through the central part of Moesian Platform and neighboring Molasse Zone emphasizing the existence of a magmatic intrusion.

As well as it concerns the oil/gas fields at the level of Moesian platform territory occur more than 200 petroliferous structures, placed to depths between 1000 – 5000 m, exploiting reservoirs of Devonian up to Pliocene age. They are carbonated and sand/sandstones reservoirs. These oil/gas accumulations are/were exploited by more than 7500 wells many of them suspended or abandoned.

Another more important area for geothermal anomalies is the Pannonian Basin. Situated in the western part of Romania's territory it represents only the eastern border of this basin the rest developing far to the west. It is also formed by a crystalline basement and sedimentary cover.

The basement presents more uplifted and subsided blocks forming horst and grabens. The subsided zones functioned as subbasin areas where, mainly in the Neogene time existed sedimentary sub-basins with thicker deposits which generated important oil and gas amounts.

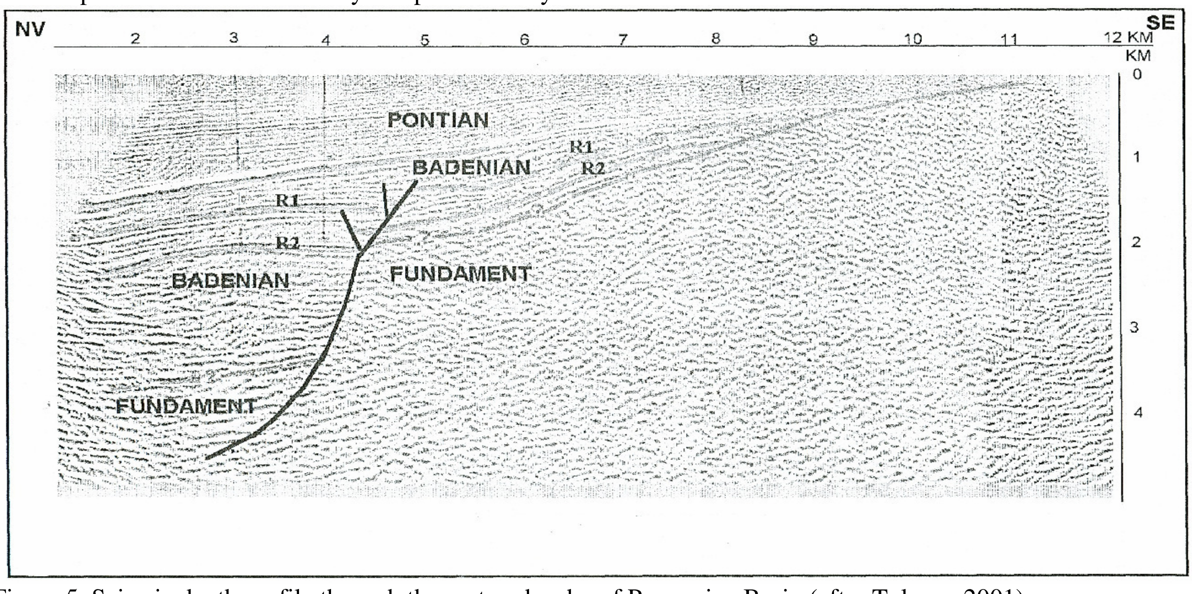

Fig.no.5. Seismic depth profile through the eastern border of Pannonian Basin (after Tulucan 2001)

The whole basin is dipping towards west the sediments thickness varying from less of a hundred meters on the eastern border to more than 6000 m in the central part.

The heat flow is related with the existence of a complex basement faults system which enhances both thermal flux and geothermal gradient. As is shown in fig.no.2., at 3000 m depth, temperature may exceed 150°C, Mainly in the southern and northern parts of the Romanian sector. For instance on Grabet structure, the temperature measured in the wells around 3500 m was about 180°C corresponding to a temperature gradient around 5°C/100 m. ON other geological structures, with a thinner sedimentary cover temperature gradients may exceed 6 – 6.5°C/100 m, but the maximal temperature measured in the wells is smaller because of the wells' depth.

In the studied area we may encounter more than 120 petroliferous structures (Tulucan 2001) exploiting sedimentary and crystalline reservoirs placed at depths from 100 up to 4000 m. These oil/gas accumulations are/were exploited by more than 4500 wells many of them suspended or abandoned.

Well data

As we mentioned before the potential geothermal areas interfere in many cases with the petroliferous structures. In these cases we have the possibility to use the existing wells mainly where they are placed on abandoned oilfields.

Comparing the wells' depth range with the temperature values and gradients we may assume that the minimum depth of the wells is about 3000 m. Well construction programs have, at this level, a 5 ½ or 6 5/8 inches steel casing, able to resist to formation pressure, cemented up to 1000 m or, on gasfield, up to the surface. Usually at this depth there is only one casing the intermediary casing (9 5/8" – 10 ¾") shoe being placed at a shallower level, about 2000 – 2500 m.

Another important benefit is that all the wells have at least a minimal investigation program, consisting in well log data, and production data as, pressures, debits, temperatures, cumulate production, etc. These data allow us to predict the main features of the potential geothermal exploitation.

In order to not interfere with petroleum exploitations we take into account the exploited depleted zones of the oilfields or entire depleted oilfields.

Main approach

Always until reaching the main objectives of a petroliferous structures, usually placed at a certain depth, the overlaying deposits crossed by the wells contains more porous permeable rocks forming water saturated reservoirs. Even when the petroleum accumulation is depleted the water bearing reservoirs preserve the initial pressure values which is at least equal with the normal hydrostatic pressure. The existence of well logs and/or drilling data (drilling rate, weight on hook, etc) enable us to estimate or even determine the formation pressure for these water saturated reservoirs. Also well logs interpretation calculates rocks porosity so we may estimate the aqvifer potential. Also the pressure values may be enhanced by gas injection especially now when carbon dioxide sequestration is an actual task for the world and mainly European countries.

Obviously the extracted water has certain salinity so we cannot use it directly so is necessary to take into account a heat change unit.

Another important aspect related with the oilfield activities is the existence of an infrastructure as roads, pipes, electricity etc.

Case study

In order to obtain a good match between the existing depleted oilfields and the possibility of developing a geothermal energy recovery unit we may correlate the next important features:

- Thermal flow,
- Temperature gradients,
- Wells'depth,
- Lithology,
- Pressure gradients,
- Oilfield exploitation stage.

As a result of these data correlation we choose the western part of Moesian platform in the zone of so called Craiova – Bals – Optas uplift where the basement is relatively up and also the depth of the wells is high. From this zone we selected Bibesti – Bulbuceni structure (fig. no. 6). It is positioned on the northern border of the Moesian Platform at the limit with the molasse zone (Getic Depresion). The wells crossed formations of Pliocene down to Paleozoic, Devonian .

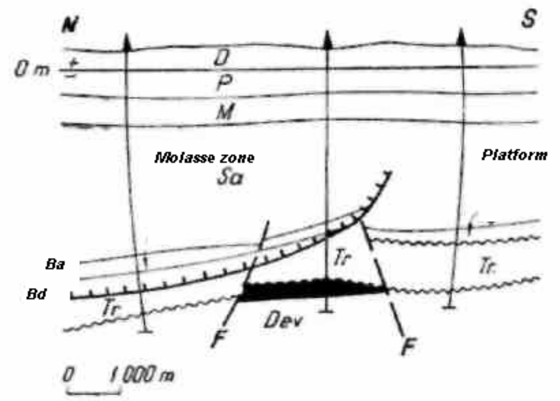

Fig.no.6. Bibesti – Bulbuceni structure geological section (after Beca and Prodan 1983 - modified)

Devonian deposits are consisting of dolomites and dolomitic sandstones. Discordant and transgresive they are covered by Permo – Triasic about 600 m thick consisting of continental sandstones "red formations” and carbonated deposits. Follow the Middle to upper Jurasic formations, thin and discontinuous. Mesossoic deposits are covered by a thick Neogene series (up to 3500 – 3800 m) developed in a detritic facies consisting of an alternance of sandstones, carbonate sandstones and marls which at the shallower level turn to sands and shales/clays deposits.

The main reservoirs are the Devonian and Permo – Triasic dolomites and sandsones, oil saturated and Sarmatian – Meotian sandstones, gas saturated. The reservoirs depth is from 4900 up to 1400 m.

The Paleozoic reservoirs had initially (at 4800 – 4700 m depth) an initial temperature, measured in the wells, of 142°C. Pressure values were initially about 500 barrs. Reservoirs porosity is about 9 – 11% and bulk producted volumes were about 100 cubic meter per day for a well. Water salinity is relatively small about 50 – 70 g/l and they are chloride-calcic type.

Also the lower Sarmatian deposits (about 3800 m depth) have a 125°C temperature and more than 400 barrs initial pressure.

From the well logs we depicted more water saturated reservoirs which probably preserved the initial temperature and pressure conditions both for Paleozoic and lower Sarmatian deposits. These reservoirs may provide an important water flow considering that each well may produce up to 100 cubic meters per day. At the surface extracted water temperature varies with the flow regime and may rich about 110°C.

The mentioned values are sufficient for heating water but they are not able to product stem capable to provide the function of a power plant. In this case we may use for a power plant a different propelling fluid with a lower vaporization temperature.

In the same time the selected structure is placed to a relative acceptable distance from a coal power plant so the produced carbon dioxide can be injected into the reservoirs in order to maintain or eve increase the initial pressure. In this way the cost will be smaller and the benefits higher.

Acknowledgments

Romania’s territory is divided in two main domains,Carpathian Orogenic Belt and the Platform zones.

Both domains have accurate petroliferous structures spreaded in different zones, depths and geological formations. They are exploited from more than 150 years so many oilfields are in the final stage of production or are already abandoned.

Regarding geothermal distribution parameters we may emphasize some distinctive areas with higher temperature and thermal flux values able to represent interesting zones for geothermal energy. The most important zones from this point of vue are placed In Moesian Platform and Pannonian Basin areas some of them being already exploited but not on a large scale and for industrial proposes. In the mentioned zones temperature gradients may rich more than 6°C / 100 m, after well measurements.

Also these zones are characterized by the existence of some important petroliferous structures so they benefit by the existence of many wells, some of them at great depths up to 5000 m. Ones of these structures are depleted or even abandoned . Although the water saturated reservoirs of these zones are not exploited and they preserve high pressures values.

Correlating the geothermal parameters values with reservoirs parameters we emphasize the potential zone for geothermal energy exploitation.

Bibasti – Bulbuceni oilfield is such a favorable zone because of its deep wells, high temperatures, up to 142°C, overpressured water saturated reservoirs and important flow rates, about 100 cubic meters per day for an well. These properties make it attractive for geothermal energy exploitation for water heating or even power plants in certain technological conditions. Also being placed in a coal mining zone, with coal based power plants it may achieve the role of carbon dioxide sequestration, increasing the benefits.

References:

Batistatu M.V., 2000, Determinarea valorilor gradienţilor de presiune fisurare şi temperatură ai formaţiunilor geologice (Determination of Pressure, Fracture and Temperature Gradients of Geological Formations); Ed. U.P.G.Ploieşti.
Beca C., Prodan D., 1983, Geologia zacamintelor de hidrocarburi (Hydrocarbons Accumulations Geology); Editura Didactica si Pedagogica; Bucuresti
Dicea O., et.al.(1991): Cadrul geologic de formare a acumulărilor de petrol şi gaze în principalele bazine de sedimentare din Romania. (Geological frame of oil and gas accumulations generation in the main sedimentary basins of Romania) oral presentation A.A.P.G. Huston
Mutihac V. , Stratulat M.I., Fechet R.M., 2004, Geologia Romaniei (Romania's Geology); Editura Didactica si Pedagogica; Bucuresti
Paraschiv D., (1975): Geologia zacamintelor de hidrocarburi din Romβnia (Hydrocarbons Accumulations Geology); Studii tehnico econimice seria A ;Bucuresti.
Paraschiv D., (1979): Platforma moesică şi zăcămintele ei de hidrocarburi (Moesian Platform and its hydrocarbons accumulations); Editura AcademieiR.S.R. ;Bucureşti
Sandulescu M., (1984): Geotectonica Romβniei (Romanias' Geotectonics); Editura tehnica - Bucuresti.
Tari G., et. al. (1996): Cimmerian and Alpinne Stratigraphy and structural evolution of the Moesian Platform (Romania/Bulgaria) ;A.A.P.G Memoires
TulucanA.D., (2001): Studiul geologic complex al Sectorului Românasc al Depresiunii Pannonicecu privire specială asupra capcanelor de hidrocarburi

Integration of renewable energy systems in buildings: a legal perspective

Marianna.I.ATHANASAKI [1] and Agis M.PAPADOPOULOS[2*]

[1]Attorney by Law, LLM

[2] Laboratory of Heat Transfer and Environmental Engineering School of Mechanical Engineering, Faculty of Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

*Corresponding Author: Professor Dr.-Ing., *Tel +30 2310 996015, Fax: +302310996012, e-mail:* agis@eng.auth.gr,

Abstract: Improving the energy efficiency of the building stock and integrating renewable energy systems in buildings, in particular in urban ones, is a major goal of the European Policy on Energy Efficiency. Implementing those measures in Greece, especially in multi-family buildings, is a complicated issue, the technical aspect being probably the most straight forward one to cope with. There are economic and financial issues and there are also social ones. A series of studies have highlighted the immense energy conservation potential, described the measures that enable its utilization and assessed the economics of a ten years' implementation plan.
Still, a series of legal issues are linked to the complicated property scheme of the great majority of urban, multi-family buildings. Changes in two legal fields are needed in order to have a realistic chance of implementing the renewable energy systems, as foreseen by the technical study: (a) The general building regulation has to be altered in certain paragraphs, in order to simplify the licensing procedure of retrospective installation of RES systems in buildings and (b) The decision making procedure in those multi owned properties has to be streamlined, in order to enable complete and integral, and therefore efficient and effective, renovation measures. Proposals in that direction will be discussed in the paper

Keywords: Renewable energy, buildings, legislation, procedures

1. Introduction

The European Directive on the Performance of Buildings (2002/91/EC), the implementation of which has become mandatory for all member states since January 2006, is the most recent in a long series of regulatory actions, aiming at the improvement of building's energy behaviour. This necessity to improve the buildings' energy behaviour became peremptory during the two oil crises in the 1970's, and was expressed in the effort to reduce the demands for heating, ventilation and air-conditioning, without endangering the living standards of the day. In these thirty years of intensified, systemic development in the field of energy design of buildings, a new, interdisciplinary scientific field was developed, reaching a stage of maturity in a fairly brief time period. It is characterized by an advanced, and experimentally well validated, theoretical background, by its incorporation in the syllabi of most engineering and architectural departments of Universities and, at least in many countries, by a flexible and fairly effective legislative framework. At the same time, the architects, engineers and constructors active in the field have access to powerful computational codes, to new generations of insulating materials, building components, such as glazing and HVAC systems, all of which enable the implementation of progressive solutions, besides having the side-effect of ensuring that fewer limitations are imposed on the architectural design. These developments are exemplified in the evolution of the buildings' energy behaviour in countries like Denmark or Germany, where average specific annual consumption dropped, from more than 300 kWh/m^2a in 1970 to less than 50 kWh/m^2a. Whatever the motive of conservation actions may be and despite the progress made, energy consumption in the building sector continues to constitute a major part of the worldwide annual final energy use. In Europe alone it exceeds 40%. (Papadopoulos, 2007).

2. Legal framework

The energy legislation

The Directive 2002/91/EC for the energy performance of buildings (Directive 2002/91 of the European Parliament and Council of the 16th of December, 2002 for the "Energy performance of buildings" (EC L1 of 4.1.2003)) has set a very specific series of goals:

- Reduction of thermal needs and energy loads on the basis of pre-defined goals.
- Use of higher density fuels and reduction of the compatible fuels use.
- Obligation of energy assessment study for each new-built construction.
- Energy inspection and issuing of energy certificates for newly built and existing buildings that are fully refurbished, and also for existing buildings that are to be sold or let.
- Obligation for the inspection of boilers and central air conditioning systems.

As a matter of fact, the introduction of the aforementioned directive has two strategic objectives:

- To introduce a methodologically sound, holistic approach in the energy design of buildings
- To combine the commercial value of a building with its energy performance

The directive was harmonized into Greek legislation with Law 3661 – "Measures for the reduction of the energy use of buildings" Official Gazette 89/19th of May 2008. The Law foresaw the issue of the Regulation on the Energy Efficiency of Buildings (KENAK), which happened in April 2010, and in which five (5) thematic categories are distinguished:

1. Definition of minimum energy demands for energy performance
2. Calculation method for the energy performance of new-built and existing constructions
3. Issue of energy efficiency certificate
4. Boilers and air-conditioning systems inspection
5. Foresight for specialized and certified board of energy inspectors

The technical and economic aspects of the regulation's implementation have been discussed in a series of publications. Still, the successful implementation of the law and the regulation depends to a great extent on, sometimes hidden, legal issues. Un detail, the Regulation on the Energy Efficiency of Buildings (KENAK) foresees in Article 14, par. 1 and 3, the following:

"The Energy Certificate depicts the energy classification of the building. 3. When a property is been sold, the notary is obliged to mention the protocol number of the energy certificate in the contract and to attach a transcript of the certificate to the contract. Whenever a property is been let, the protocol number of the Energy Certificate has to be mentioned in the renting contract, be it a private one or one produced by a notary. The revenue service will not consider contracts with a valid Energy Certificate".

The civil legislation on property

Given the way in which Greek cities were built, with dense multi-storey, multi-family residential buildings, and the fact that more than 86% of the Greek families own their primary residence, the matter of whether the certification applies to a single apartment or to the whole building is of crucial importance. In article 6 par.4 of Law 3661/2008 is foreseen that:

"The energy certification of horizontal properties, as defined by Article 1 of Law 3741/1929 (OGG 4 Α΄) and properties according to Article 1 of Decree 1024/1971 (OGG 232 Α΄) is based on the common certification of the whole building, as long as it is a building complex with a commonly used heating system. The expenses for the certification will be covered by the owner or, if there are many owners, by each owner according to the percentage of their ownership."

From the above mentioned regulation it can be deduced, that in addition to the legal powers derived from the property ownership titles (power of disposition and power of exploitation: renting) a new typical regulation and limitation is introduced by KENAK, namely that selling of renting the property will be legally not possible as long as the property is not energetically certified.

On the other hand, in the cases where the property is horizontally divided and shared (i.e. the floors of a multi storey building) legal issues can, and are expected to, arise when one of the owners wishes to sell or let his property (p.e. an apartment). This presupposes the certification of the whole building, the cost of which has to be carried by all owners, according to the percentage to which each one's property corresponds.

In order to avoid the expected difficulties the legislator foresees that the participation of the co-owners in the expenses for energy certification is mandatory, a measure which is in accordance to the main clauses of Law 3741/1929 as well as with the broader attitude of the energy conservation policy implemented in the last years. Furthermore, this approach is compliant to the broader effort towards sustainable development and environmental protection, which is embedded in the Greek constitution. It that sense, it is in the legislator's line of approach to reduce formal and procedural obstacles and to enhance the application of the specific legislative act.

Hence, and in accordance to Article 5 of Law 3741/1929, each co-owner is obliged to contribute according to his share in the property, to the common financial burdens, maintenance costs, replacement and operational costs and any other changes necessary for the more efficient operation and use of the commonly used parts of the building. It is therefore self-evident that the participation of all co-owners in an expense directly imposed by the law such as the energy certification of a property, is obligatory, as it has evidently a direct or indirect impact, now or in the future, on all the co-owners of the building. This applies both to the energy certification process and to any possible energy conservation measures, which will eventually have to be introduced, given the fact that most of the ones included in the latter group have significant financial implications for the owners.

3. On the implementation of the legislation in practice

A good example for this is the retrospective thermal insulation of buildings. Considering the fact that the majority of the buildings constructed in Greece before 1980 were are not thermally insulated, the energy saving potential is significant, but so are the financial and regulatory problems to be overcome. The way in which cities were built in the '60s and '70s led to a situation whereby effective energy renovation measures are often leading to forbidding costs and unacceptable economic results, or at least so it seemed over the last decade. However, the inefficiencies in the thermal protection of the buildings' shells and in their heating systems were proven within the framework of a series of studies carried out in Greece. So was the average saving potential of 28% referring to the present condition and with realistic, practicable measures involved (Papadopoulos et al, 2002; Papadopoulos, 2008).

A further good example is the use of solar systems, both thermal and photovoltaics, in a centralized system, which is only reasonable in multistorey apartments. Active solar systems (ASS) and Photovoltaics (PVs) are the most widespread, and certainly the most well known RES system. They are by now a commonly accepted solution for covering specific energy demands in the case of the final consumer. These developments were assisted, to a large extent, by national and international policies, as well by a public interest for energy, and respectively operational costs, conservation. Still, the development of the branch at the end of the 2010's seems to move in two different directions. Some types of solar systems have become well-selling products in fairly mature markets. The development does seem less impressive, when it comes to the potential for the further evolution of the market and to the question whether some of the valid support policies are sensible, or just a convenient excuse for not improving the systems' cost-benefit performance. (Tsoutsos, 2001)At the same time, one cannot help but form the impression, that the development of other solar systems lacks momentum, be it because the academic and the industrial community shows little, interest focusing on other RES systems, namely those producing electricity, or because the public interest has become weaker. This can be easily highlighted by the results of a SWOT analysis (Strength – Weakness – Opportunity – Threat) considering the solar systems both as independent components, as well as according to their applications. A very brief description of these four issues, as they arise from the social-economic boundary conditions could lead to the following keywords presented in Table 1.

Table 1: SWOT analysis of the solar systems' sector

Strength	Weakness	Opportunity	Threat
Mature basic technology	Questionable efficiency of cheaper systems and applications	GHG emissions reduction agreements	Varying political support
Acquaintance of the public with the technology	Perceived or actual high initial cost and/or technical risk of certain systems	Will/fashion to go "green" as drive to sustainable development	Low and stable prices for conventional energy
Affordable initial cost	Inadequate technical support	Globalisation of technologies and markets	Externalities are frequently ignored
Attractive support schemes and measures	Complicated support schemes and measures Legal problems	Tightening of building performance standards	Traditionalism of a conservative and clustered building industry
	Lack of a branch-wide labelling and promotion campaign		Legislative and managerial barriers

The latest artificial increase in energy prices, due to taxation increase for fiscal reasons, is a very good reminder of how shortsighted the policy of neglecting to implement such measures was. Precious time and even more precious energy resources have been used up, whilst the energy saving mentality of the 1970's and 1980's faded, without any significant results. Residential and mixed-use buildings are particularly suitable candidates for an enforced application of energy renovation measures, as they form the bulk of the Greek building stock and also are significant energy consumers. These are the buildings, however, which as a rule have many owners, and are therefore interesting for this study. According to KENAK a simple majority of the owners, namely 50% + 1 vote considering their property ownership, is needed, in order to proceed with the implementation of the energy renovation measures in all commonly owned and used areas of the building. As such, Article 2, par. 1 Law 3741/1929 and Article 1117 of the Civil Legislation Code define the building's façade, the building's roof, the foundations, the courtyard, the skylights and ventilation ducts etc. In case of different opinions amongst the co-owners, and if no other legal obligations arise, intervention on the building's shell and its services are principally allowed if they improve the building's operational features and efficiency and if they do not imply disadvantage to any of the owners. This derives from a series of decisions by the Supreme Court (ΑΠ 827/2005 ΕλλΔνη 47, 178, ΑΠ 357/2006 ΕλλΔνη 47, 819) which form the legal base for such legal cases.

In practice it becomes clear that problems can, and most probably will, arise over time, especially when high budget renovation measures may become a subject of debate. If one of the co-owners refuses to participate to the expenses, then the other owners have the right to apply before court against the former so as to enforce the legally foreseen payments. This right is derived from the aforementioned Article 5 of Law 3741/1929, which makes it clear, that the claims for covering expenses such as the energy certification costs are purpose specific and are not influenced by other legal provisions (social, managerial, exploitation of property, unduly profit etc). The latter provisions are in this context to be considered only as supplementary and as long as they do not contradict the clauses of Law 3741/1929.

Differences amongst owners of whole floors, or single apartments in multistoried buildings, based on the legal background of the horizontal property ownership are to be judged according to the specific procedure at the local court of first instance, which is exclusively competent for this. The fact that court procedures are as rule time consuming, and also costly, will not necessarily make things easier.

4. Conclusions

The Directive on the Energy Performance of Buildings and its respective national transpositions provide a useful background for enforcing developments. The key issue for its effective application can, however, not only be the use of current technology and know-how, or the imposition a firm set of standards and regulations. It is connected with the adaptation of best practices in accordance with the national and local needs, legal aspects, social circumstances and financial boundary conditions.

The major percentage of the Greek building stock consists of multistorey residential buildings co-owned by many owners. This makes any common intervention, like the energy certification or the implementation of energy conservation measures, a delicate matter, as it presupposes the acquiescence of the owner's majority. This is not always easily achievable, especially as the Greek legal framework on property ownership is rather complicated. The new Regulation on the Energy Efficiency of Buildings and also the one on Renewable Energy Sources try to simplify procedures and enhance the implementation of energy conservation measures, but it remains to be seen in any case how this will be turned into practice.

Still, changes in two legal fields are needed in order to have a realistic chance of implementing the renewable energy systems: (a) The general building regulation has to be altered in certain paragraphs, in order to simplify the licensing procedure of retrospective installation of RES systems in buildings and (b) The decision making procedure in those multi owned properties has to be streamlined, in order to enable complete and integral, and therefore efficient and effective, renovation measures.

In any case, and beyond any legislative acts, a change in attitude is needed, if energy conservation and sustainable development are to become social values and not mere terms.

References

Casals X.G. (2006) "Analysis of building energy regulation and certification in Europe: Their role, limitations and differences", *Energy and Buildings*, vol.38, pp.381-392

Papadopoulos, A.M., Theodosiou, T. and Karatzas, K. (2002) "Feasibility of energy saving renovation measures in urban buildings: The impact of energy prices and the acceptable pay back time criterion", *Energy and Buildings*, vol.34, pp.455-466.

Papadopoulos, A.M., Oxizidis, S. and Kyriakis, N. (2003) "Perspectives of solar cooling in view of the developments in the air-conditioning sector", *Renewable & Sustainable Energy Reviews*, vol.7, No.5, pp.419-438.

RAE, Regulatory Authority of Energy, Synoptic report on the situation of the electricity market, 2004, Athens (in Greek)

RAE, Regulatory Authority of Energy, Internal report report on the electricity sector, 2005, Athens (in Greek)

Railio J. (2006) "EPBD: Influences on European standardization and on ventilation and air-conditioning industry", *REHVA journal*, vol.1, pp.19-23

Greek Law 3661 "Measures for the reduction of energy consumption in buildings", Official Journal of the Government of the Hellenic Republic, FEK 89/19 May 2008.

Regulation of energy efficiency in buildings, Official Journal of the Government of the Hellenic Republic, FEK 407/ 19 April 2010.

Papadopoulos A.M., Theodosiou T. and Karatzas K. (2002), Feasibility of energy saving renovation measures in urban buildings: The impact of energy prices and the acceptable pay back time criterion, Energy and Buildings, 34, 455-466.

Papadopoulos A.M. (2007), Energy cost and its impact on regulating the buildings' energy behaviour, Advances in Building Energy Research 1, 105-12.

Papadopoulos A.M. (2008), How is thermal insulation applied into practice? A field study, Proceedings of the 40th International Heating, Ventilation Air Conditioning Conference, Belgrade, Serbia, 02-04 December.

Tsoutsos T. (2001), Marketing solar thermal technologies: strategies in Europe, experience in Greece, Renewable Energy, Pergamon Press, vol. 26/1, pp 33-46