Bioenergy for District Heating and Cooling Systems

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Abstract**—** The present paper refers to District Heating (DH) and District Cooling (DC) technology, approached from a different angle, when bio energy is encouraged to replace energy that originates form fossil resources. The article reflects on the standard features of the district heating and district cooling and on the way the system is going n terms of evolution throughout their subsequent development stages. It is highlighted why this novel approach in offering heat and cold to the inhabitants represents a key infrastructure as a European efficient resource energy system for today and for the future, under the circumstances of controlling the CO_2 emission. The paper concludes with conclusions regarding the district heating and district cooling flexible infrastructure that can support a wide rage of renewable energy sources on large scale.

Keywords**—** district heating and cooling, renewable energy sources, energy.

I. DH and DC Background and Targets

THE DH and DC theory based on the fundamental idea of using local heat, cold and fuel sources that under normal circumstances would be lost or remain unused. Another essential feature is that it provides a flexible infrastructure able to integrate a wide range of (renewable) energy sources. Heating and cooling are responsible for more than 50 % of total final energy consumption in the European Union. [1]

At present, with approximately 86 % of heat deriving from a combination of recovered heat, renewable energy and waste resources, modern district heating and cooling comes very close to fulfilling its fundamental idea in practice. Since heating causes most of the energy consumption in buildings in most of Eastern Europe countries, the introduction of a low carbon fuel for heating can significantly affect their region's emissions. DH, which is already an important source of heating in many European countries such as Denmark, Austria, Sweden, Finland, Czech Republic and the Netherlands, not only offers excellent opportunities for reducing environmental pollution, but also for saving energy. DH has been proved to be much more energetically efficient that traditional individual heating systems, as well as a major contributor to greenhouse gases emissions reduction in many countries. It is an extremely flexible technology which can make use of any fuel including the utilization of waste energy, renewable and, most significantly, the application of combined heat and power (CHP). Replacement of fossil fuel with wood fuel would typically reduce net CO_2 emissions in the process by over 90 % (assuming that the wood supply is managed in a sustainable way). Energy crops can be grown to meet the needs of the market and provide a secure long-term resource.

Currently, there are differences in the state of district heating and cooling technology throughout Europe; therefore the timeframes in the novel approach represent the final, pan-European state of technological achievement. In the most advanced schemes progress is much faster, but as the older systems are upgraded, innovations can be applied wherever there are networks.

Information on how to make cost-effective energy savings, as well as providing stimulus for consumers to act, can be effective in changing perceptions and encouraging action, identified in following directions [2]:

- information to citizens on issues such as how to reduce energy consumption in homes, through, for example, efficient lighting and heating and sensible purchasing decisions;
- information to industrial customers; and
- information to energy-efficiency experts and service providers to ensure that a network of such well-trained experts exists and functions well in all Member States.
- Two main action should be taken:
- education and training, and
- national regulatory authorities

Thus, it should not be difficult to convince consumers of the fact that by relatively simple measures, the average European household can save a significant amount in its spending, which is especially important for households spending a large share of their budget on energy.

Challenged by climate change, the need to secure sustainable economic growth and social cohesion, Europe must achieve a genuine energy revolution to reverse present-day unsustainable trends and live up to the ambitious policy expectations. A rational, consistent and far-sighted approach to heating and cooling is key for ensuring such transformation. While overlooked by policy discourse for years, the heating and cooling sectors are major players on the energy market, responsible for more than half of total final energy consumption and a significant share of European greenhouse gas emissions.

It is clear that heating and cooling – and more specifically the most optimal forms of it – should figure prominently in national, European and international climate change and energy policy strategies for the decades to come. [3]

District Heating and Cooling (DHC) has proven to be a major contributor to Greenhouse Gas (GHG) reduction in many member countries and recognition of DHC's importance is growing. In fact, many countries where it is established are renewing their commitment to DHC as they find new ways to use the technology to reduce environmental impacts. DHC facilitates linkages between supplies that are environmentally desirable and end users that could not otherwise make use of those energy sources.

DH not only offers excellent opportunities for reducing environmental pollution, but also for achieving the goal of saving energy. It is an extremely flexible technology which can make use of any fuel including the utilization of waste energy, renewable and, most significantly, the application of combined heat and power (CHP). It is by means of these integrated solutions that very substantial progress towards environmental targets, such as those emerging from Kyoto can be made.

Presently, the ‘Three Es’ of balanced policy making are: (i) Energy security, (ii) Economic development , (iii) Environmental protection. DHC is a key technology for helping to deliver these aspirations. Specifically, it is a mature technology that already delivers low carbon heating and cooling for many towns and cities. It allows heat that would otherwise be wasted to be recycled; it also provides a network for the effective use of low and zero carbon renewable sources of energy. The use of locally available waste heat and the use of renewable heat energy contribute to energy security. This is due not only to inherent energy efficiency, but also through the fuel. [3]

II. About DH and DC

District heating and cooling form a technological concept based on thermodynamics comprising infrastructure for delivering heating and cooling services to customers. It is named also tri-generation.

District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating. The heat is often obtained from a cogeneration plant burning fossil fuels but increasingly biomass, although heat-only boiler stations, geothermal heating and central solar heating are also used, as well as nuclear power. District heating plants can provide higher efficiencies and better pollution control than localized boilers. Cogeneration (also combined heat and power, CHP) is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. It is one of the most common forms of energy recycling.

Figure 1 brings data concerning why the overall picture of Europe’s unsustainable use of heat is striking. The reasons are: (i) From primary energy supply to energy end use more than half of total European primary energy input is wasted; (ii) Most of this waste occurs in the form of heat; (iii) Around 60 % of total energy end-use takes place in the form of heat. Data are based on Ecoheatcool, Example year of 2003, covering covers EU 27, Iceland, Norway, Switzerland, Croatia and Turkey.

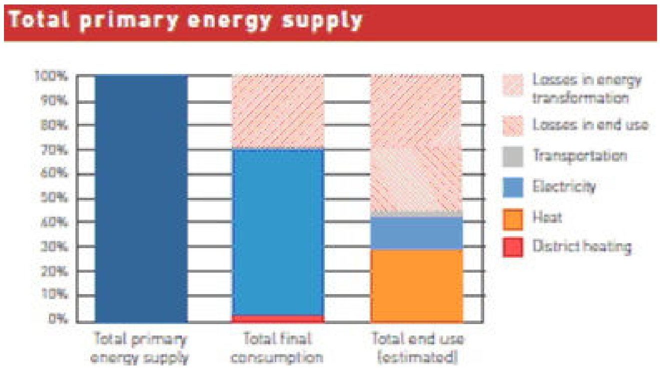

Fig.1 Europe’s unsustainable use of heat, by 2003, according ECOHEATCOOL

Conventional power plants emit the heat created as a by-product of electricity generation into the natural environment through cooling towers, flue gas, or by other means. By contrast CHP captures the by-product heat for domestic or industrial heating purposes, either very close to the plant, or especially in Scandinavia and Eastern Europe, as hot water for district heating with temperatures ranging from approximately 80 to 130 °C. This is also called Combined Heat and Power District Heating or CHPDH. According to latest research, District Heating with Combined Heat and Power - CHPDH is the cheapest method of cutting carbon, and has one of the lowest carbon footprints of all fossil generation plants.

Europe has actively incorporated cogeneration into its energy policy via the CHP Directive. In September 2008 at a hearing of the European Parliament’s Urban Lodgment Intergroup, Energy Commissioner Andris Piebalgs is quoted as saying, “security of supply really starts with energy efficiency.” Energy efficiency and cogeneration are recognized in the opening paragraphs of the European Union’s Cogeneration Directive 2004/08/EC. This directive intends to support cogeneration and establish a method for calculating cogeneration abilities per country. The development of cogeneration has been very uneven over the years and has been dominated throughout the last decades by national circumstances. [5]

The European Union currently generates 11 % of its electricity using cogeneration. However, there is large difference between Member States with variations of the energy savings between 2 % and 60 %. Europe has the three countries with the world’s most intensive cogeneration economies: Denmark, the Netherlands and Finland.

Other European countries are also making great efforts to increase their efficiency. Germany reported that at present, over 50 % of the country’s total electricity demand could be provided through cogeneration. So far Germany has set the target to double its electricity cogeneration from 12.5 % of the country’s electricity to 25 % of the country’s electricity by 2020. The UK is also actively supporting combined heat and power with the goal to achieve a 60 % reduction in carbon dioxide emissions by 2050.

The opposite of DH is DC. Working on broadly similar principles to district heating, district cooling delivers chilled water to buildings like offices and factories needing cooling. In winter, the source for the cooling can often be sea water, so it is a cheaper resource than using electricity to run compressors for cooling. [6]

The Helsinki district cooling system uses otherwise wasted heat from summer time CHP power generation units to run absorption refrigerators for cooling during summer time, greatly reducing electricity usage. In winter time, cooling is achieved more directly using sea water. The adoption of district cooling is estimated to reduce the consumption of electricity for cooling purposes by as much as 90 per cent and an exponential growth in usage is forecast. The idea is now being adopted in other Finnish cities. The use of district cooling grows also rapidly in Sweden in a similar way.

It is expected that by 2010, following targets are to be reached:

- A voidance of 9.3 % of all European CO_2 emissions by district heating,
- Additional 40 – 50 million tones of annual CO_2 reductions by district cooling,
- Decrease of primary energy consumption with 2.14 EJ (595 TWh) per year, corresponding to 2.6 % of entire European primary energy demand,
- 25 % share of renewable energies in district heating,
- Reduced European energy import dependency with 4.45 EJ (1236 TW h).

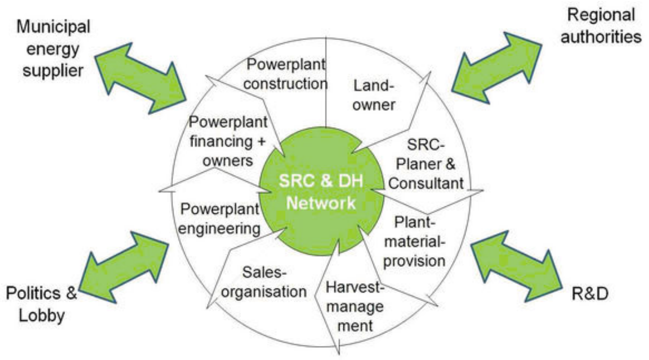

Fig.2 Target groups and key actors necessary for the connections for a sustainable bio disctrict heating system (according to the BIOHEAT IEE project)

As Figure 2 indicates, a lot of cooperation and will and economic and ecologic liaisons and constrains must act for turning into reality a concept of cogeneration (or tri-generation) based on bio energy input, as being a novel solution. Specifically DH, a significant source of heating in many European countries, could benefit from the use of biomass as combustible. The energy efficiency of DH is much higher than in the case of traditional individual systems, and it can be fed by any kind of fuel. Therefore, the combination of this technology together with a sustainable, secure, renewable and harmless combustible such as biomass, could contribute to generate heat in a very efficient way and to reduce CO_2 emissions significantly. This represents a feasible solution for the heating problems encountered in Eastern Europe, where the application of biomass for this purposes is not as extended as in other European countries.

In combination with relatively low emission values the utilization of wood potentials in biomass fuelled ORC plants is the most reasonable alternative for energy generation from wood (Maraver et al., 2009). However, the technology is rather new and practical experience is required to assess the real efficiency and reliability. Problems still occur due to changing fuel quality and ineffective combustion control systems. A major challenge is to obtain stable operating conditions with varying biomass quality. [7]

III. THEORETICAL BACKGROUND FOR TRIGENERATION BASED BIOMASS

This part focuses on the thermodynamic study of two different configurations for a CHPC, or tri-generation, system based on biomass combustion. The optimization analysis has been mainly based on the calculation of the exergy efficiency corresponding to the overall tri-generation system. CHPC (Combined Heat, Power and Cooling) plants are one of the most promising alternatives for distributed generation and taking advantage of biomass resources. In such systems, there are no important resources requirements and the seasonal efficiency of the conversion is increased thanks to both the high efficiency of the overall system and the large operation period. [8]

The profitability can also be boosted by the diversification of the products (heating, cooling and power generation) offered by the facility, which promotes the penetration of the technology in the market. Different systems can be used to cover cooling and power demands using heat from biomass combustion. Therefore, the first step in a tri-generation system design has to be the determination of the best configuration in terms of thermodynamic integration of all devices and the optimization of the overall energy efficiency. However, it is also important to notice that in real case applications energy demands have special characteristics that involve changes in the optimal theoretical configuration.

Maraver indicates that a conversion system consists of a biomass boiler (BB), of a given power output, the power generator is an Organic Rankine Cycle (ORC), because of its ability to generate combined heat and power from low temperature applications, and the cooler is a simple effect Absorption chiller (AC). To carry out the thermodynamic optimization, two configurations for a tri-generation system based on solid biomass combustion have been analyzed. Both configurations present the same technical characteristics (heating, cooling and electricity productions) but they differ in the manner that the devices are assembled: in the first configuration the ORC, the AC and a heat exchanger are "in parallel" (Figure 3) and in the second configuration the same devices are "in cascade" (Figure 4).

The results from the thermodynamic assessment are depicted in [8]. They reveal that Option 2 ("in cascade") has higher exergy efficiency (ψ) than Option 1 ("in parallel").

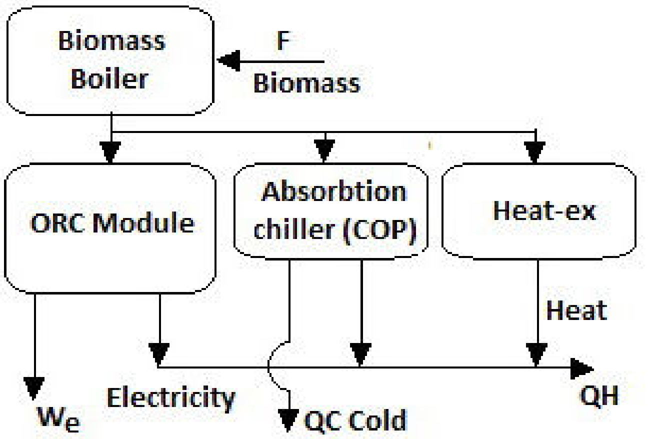

Fig. 3 "In parallel" trigeneration system, Option 1 [8]

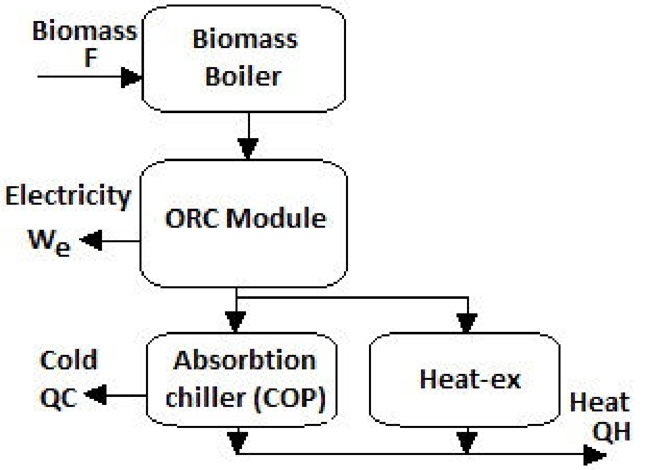

Fig.4 "In cascade" trigeneration system, Option 2 [8]

According to Lizarraga and Feng [9][10] exergy efficiency is defined by the following expression (Equation 1), where Ψ is exergy, W_e represents the electric work output and B_{QN}, B_{QC} and B_F respective exergy of the heat production, the cold production and the fuel input:

$$\Psi = \frac{W_e + B_{QN} + B_{QC}}{B_F} \qquad (1)$$

It is also important to compare both configurations according to their Electric Equivalent Efficiency (EEE), defined by Equation 2. EEE is a parameter specified in the Spanish legislation.Its calculation gives a reference value to compare every cogeneration or polygeneration system and to assign the corresponding premium that is added to the normal electricity sale price:

$$EEE = \frac{W_e}{F - \frac{QH}{\mathrm{Ref_H}} - \frac{QC}{\mathrm{Ref_{COP}}}} \qquad (2)$$

Although additional work is needed to deeply understand the influence of all parameters of each device constituting the tri-generation system, the general results (Table 1) show that tri-generation systems "in cascade" present higher exergy efficiency than the corresponding "conventional" systems with the same generation characteristics (We, QH and QC). Thus it is proved that this type of combined generation systems of heat, cold and electricity are thermodynamically more interesting than stand-alone generation systems. Tri-generation "in parallel" has no thermodynamic interest due to the lower exergy efficiency in comparison with "conventional" generation. It is also important to notice the relation between electric equivalent efficiency and exergy efficiency, in other words, low Ψ involves low Electric Equivalent Efficiency (EEE).

Table.1. Thermodynamic Optimization analysis (Ψ and Ψ_C are the exergy efficiency of the trigeneration and equivalent stand-alone systems, respectively)

Trigeneration system	Ψ (%)	Ψ_C (%)	EEE (%)	EEE_{min} (%)
Option 1	6-7	9-10	14-15	27
Option 2	22-23	18-19	47-48	27

A good solution is indicated by the configuration in figure 4, according which the system will produce heat and cooling in the two separated periods, i.e. winter and summer.

At present, with approximately 86 % of heat deriving from a combination of recovered heat, renewable energy and waste resources, modern district heating and cooling comes very close to fulfilling its fundamental idea in practice. District heating, figuratively and literally speaking, provides the pipeline for connecting these heat losses with the heat demands, thereby reducing energy losses and the total volume of primary energy needed in the energy system. District heating thus turns losses into opportunities thereby truly achieving more with less. District heating (Figure 5) and district cooling (Figure 6) represent the most suitable energy solutions for satisfying urban heat and cold demands.

By means of combined heat and power, which boost the efficiency of thermal power generation from an average 45 % up to 90 %, or by directly channeling surplus heat from other sources into the network, district heating enables waste heat to be recovered and used to satisfy existing heat demands. Use of surplus heat also averts further primary energy losses from individual boilers. These features make district heating into a unique ally in the movement to reduce primary energy use and increase the efficiency of the entire energy system. This is precisely why district heating received a great boost in various countries during the oil crisis of the 1970's. The other major benefit of district heating is that it can use a wide variety of difficult to handle, local energy sources that are less efficiently and cost-effectively deployed in individual applications.

The third major benefit and part of the vision of the next tendencies is regarding the sustainability of the system. As energy for district heating is generated centrally and on large scale, it can for instance integrate combustible renewable that are difficult to manage in small boilers. This includes most combustible renewable such as wood waste, straw and olive residues, and also waste sources like municipal waste and sewage sludge. Various bio-fuels, geothermal, solar and wind resources can be effectively integrated into the district heating network by means of different techniques.

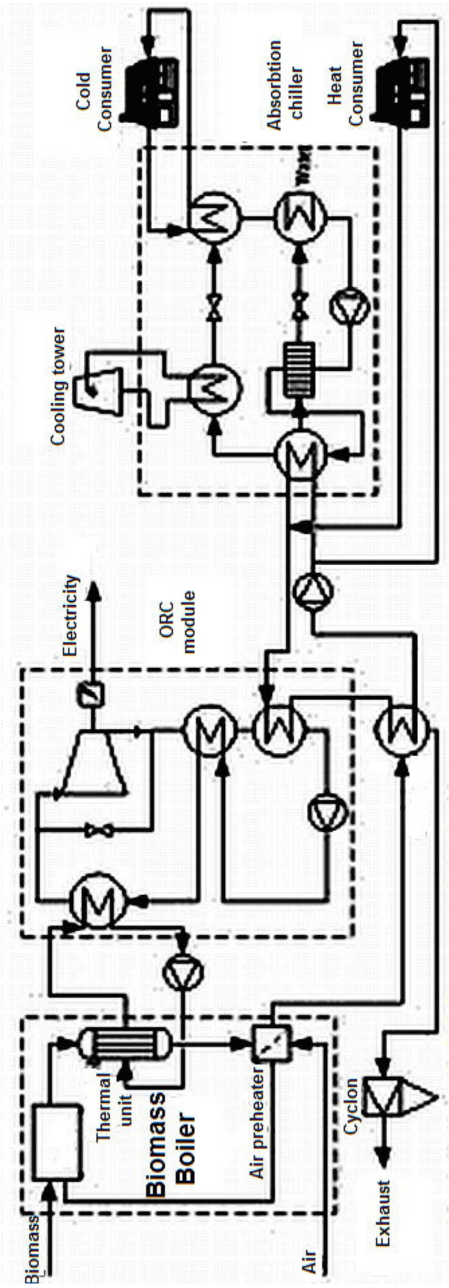

Fig.4. Configuration for combined production of heat/cold and electricity [10]

Fig.5. District heating vision by 2020 [1]

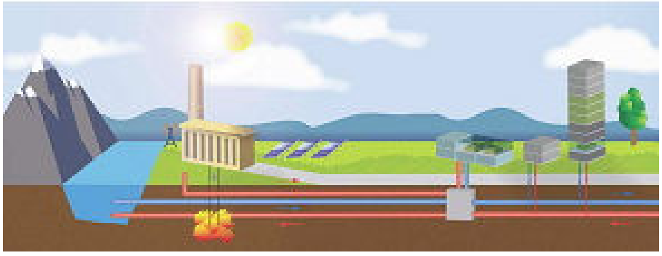

Fig.6. District cooling vision by 2020 [1]

Just as for district heating, the main idea of district cooling is to use local sources that otherwise would be wasted or remain unused, in order to offer the market a competitive and highly efficient alternative to traditional cooling solutions. In district cooling systems, cold water at a temperature of around 6°C circulates through buildings achieving effective cooling. The rise in cooling demands is attributable to rising ambient temperatures, greater comfort expectations, the perception that cooling contributes to higher productivity, and the increase in internal loads of electronic equipment. In existing district cooling systems, 40 to 60% of the cooling demands are process related with a climate independent base load of 15 %. Space and process cooling is moving quickly from luxury into necessity and represents an exponentially growing market. This has remained relatively unnoticed by policy planners, partly because cooling needs are traditionally being met by electrical air conditioners, hiding the cooling element in the building's overall electricity consumption. Due to this superior efficiency substantial primary energy savings can be achieved. District cooling can reduce cooling related electricity consumption by up to 80% compared with a conventional system. This because production is far less based on electricity and the electrical chillers employed are more efficient due to benefits of scale. In Europe 44 % of total water consumption is used for cooling purposes in energy production, primarily in thermal power plants. Decreasing water availability in parts of southern Europe, coupled with the increasing trend of satisfying cooling demands by electrical air-conditioning devices, may pose a serious threat to water supply in the region.

Furthermore, across Europe, summer droughts are projected to be more severe, limiting the availability of cooling water and thus reducing the efficiency of thermal power plants. In cogeneration a large proportion of the heat that would have required cooling is transferred into the district heating network. This surplus heat can also be used to drive cooling equipment in district cooling systems. Although water is needed within the network it circulates in a closed circuit. District cooling offers a resource saving alternative to such developments. With chillers driven by surplus heat from district heating networks and with additional use of other, natural energy sources that would have remained unused without the district cooling system (like ground- river-, lake and sea water, snow and ice), district cooling is 5 to 10 times more energy efficient than electrical air-conditioning systems.

IV. MARKET ACTORS ON BIOMASS IN ROMANIA

The renewable energy sources represent a new market in Romania, with much less market actors than in the developed countries but with promising perspectives for the future. Unfortunately there is no developed RES industry in Romania today but only small-scale projects developed by research institutes or small companies.

Biomass is currently used only for heating purposes. 54% of the heat generation from biomass comes from wood-waste burning; in other words, 89% of the district heating and food preparation – in rural areas – is based on vegetal waste. About 70% of the remarkable firewood resources are currently utilized. Also the utilization rates of industrial by-products are quite good: almost 40% for solid by-products and over 80% for black liquors. The great amount of other biomass usage consists solely of straw.

Regarding the targets, in the last few years opportunities for biomass utilization have been developed as Romania has adopted the primary legislative framework for promoting renewable sources. The "Romanian Strategy for Renewable Energy Sources Utilization" provides the necessary framework, general principles for developing action program for renewable energy sources and sets targets for increasing reuse of waste, including wood and agricultural residues. Within the frame of this strategy, there are provided measures to take, which, through turning into account the biomass energy potential, should reach an equivalent consumption of about 3,347.3 toe until 2010, with an average energy output of 97.5 toe (1134 GWh). [15] In realizing bioenergy implementation different actors play different roles and can either boost or slow down the development.

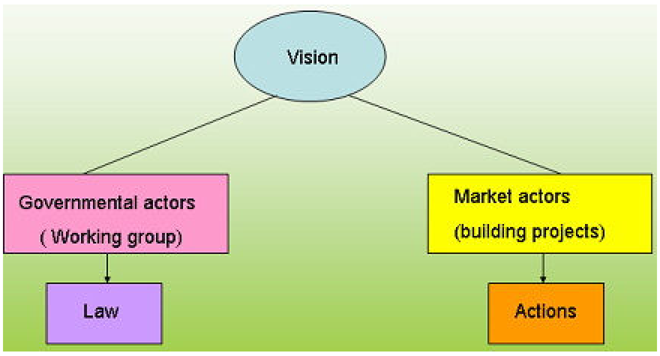

Fig.5. Role of different actors in Romania, in reference to the new vision [15]

The total area of the forests is about 63.700 km^2 of which 60 % in the mountains. The total volume of wood in the Romanian forests is about to 1.6 m3. The average annual growth of the forests is 33.000 thousand m3 per year. The exploitable potential is about 22.000 thousand m3 per year. Harvest time varies from species to species, being usually between 30 and 80 years. At harvest 25 ... 45% of the volume is in the form of scrap (in Romania in 2005: loss of 414,103 m^3 and 869,103 m^3 technological shell) and thus wood biomass is an important energy resource. According to data supplied by the National Institute of Wood, waste and sawdust shavings from wood exceed 1 million m^3 in present; estimating that in 2010 this amount will reach approx. 1.5 million m^3. [16]

Currently, 55% of forest fund are state-owned, 15% in public ownership of territorial administrative units, 11% forests are privately owned establishments and religious education, 8% of private forest ownership of legal persons and 11% forests to private individuals. [16]

Biomass differs from other alternative energy sources in that the resource is variable, and it can be converted to energy through many conversion processes. The suppliers may be divided according to the biomass resources:

- Forest products: wood, logging residues, trees, shrubs and wood residues, bark etc. from forest clearings;
- Agricultural waste, agricultural production wastes, agricultural processing wastes, crop residues,
- Agricultural crops for biofuels
- Municipal wastes: urban wood wastes, urban organic wastes,
- Industrial wastes: wood processing industry waste, mill wood wastes,
- Energy crops: short rotation woody crops, herbaceous woody crops, grasses, starch crops (corn, wheat and barley), sugar crops (cane and beet), forage crops (grasses, alfalfa and clover), oilseed crops (soybean, sunflower, safflower)

The biomass is used for heat production in small and medium size boilers. Until now in Romania there are no CHP plants (Combined Heat and Power) using biomass.

The most suitable applications for heat producing facilities and CHPs are in:

- Small and medium size towns which have already a district heating plants that provide the town with heat and warm domestic water, using fossil fuels. The local district heating may be switched to biomass use.
- Small and medium size industries, producing within their technological process biomass waste, able to be used for the energy factory needs.

It is important to note that the energy crops may be used either for heat & power production, therefore the assumption on both areas should be correlated. In Romania there is a significant available land to dedicate to energy crops, producing raw material for power and heat technologies or for transport. The REFUEL project considers that the potential for dedicated energy crops may total 800 PJ/year. This estimation is based on the large agricultural land availability in Romania Today in Romania there are energy corps practically only for obtaining bio-fuels, and not for power or heating purposes.

Dedicated energy feedstock in the form of lignocelluloses crops represents a promising outlet to security of supply issues for future biomass production. Like the other biomass resources, they can be converted into virtually any energy form. However, their main advantage is that they can be developed to optimise key characteristics for energy applications and their sustained production can better ensure long term large-scale supplies with uniform characteristics.

Several tree species cover a wide range of ecological regions of Europe: [17]

- Poplar (Populus nigra, Populus euramericana cv rob, Populus alba, Populus tremula,

- Populusbalsamiferas Populus maximowiczii, Populus tomentosa, Populus euphraetica)
- Willow (Salix alba, Salix viminalis)
- Eucalypt (E. globulus, E. camaldulensis, E. viminalis)

The land availability for such crops is quite open in Romania, with low interferes with the land availability for agricultural crops or existing forests. A first step is to use the existing land covered by such “soft” wood forests for short-rotation woody crops as willows. In Romania, willows forests are found in the Danube and Danube Delta area, next to the other rivers area in Moldavia (e.g. Siret River). Some 200,000 ha of these forests are reported. [17]

Energy crops plantings are semi-permanent. Planting of energy crops typically requires four years for establishment and growth before the first harvest. Thereafter harvests are made every three years, for a total of seven harvests. Thus, e.g., a willow stand is expected to last for 22 years. Typical yields are in the range of 10 to12 oven-dry tons per hectare per year meaning 200 GJ/ hectare in average for each year. This results for Romania in a potential of 40 PJ/year primary energy in the form of already existing woody crops, or 950 ktoe/year. The assessment may be extended to also other species of trees developed on available land. Depending on the sharing quota of this available land with the crops for biofuels, the potential for energy crops for power and heat may go to several hundreds PJ/year. [18]

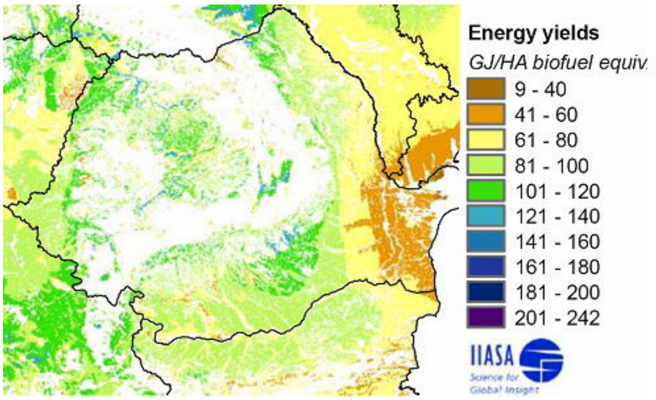

Fig.6. Potential energy yields of 1st generation biofuel feedstocks (cerereals, sugar crops, oil crops) [18]

The map in fig. 6 shows energy yields (in bio-fuel equivalent) of the best-yielding 1st generation biofuel feedstocks. They include a) oil crops (sunflower, rapeseed), b) cereals (wheat, maize, rye, triticale), and c) sugar crops (sugar beet, sweet sorghum).

V. Conclusions

It can be concluded that biomass tri-generation schemes in general have unique advantages for reducing environmental impacts in power generation. These technologies increase distributed electricity supplies while reducing both costs and emissions. Cogeneration systems and absorption chillers are among the most advanced technologies for energy savings, providing the most rational means of energy-management. Integrating these two technologies into a single tri-generation plant while, on the one hand it increases both plant complexity and initial investment costs, on the other, it greatly augments the advantages offered by each individual technology, providing a more malleable system which can meet the variable and complex energy needs of a defined application.

It is clear that heating and cooling – and more specifically the most optimal forms of it – should figure prominently in national, European and international climate change and energy policy strategies for the decades to come.

A smart energy exchange network (expected in the EU vision by 2030), allowing for optimal resource allocation between the multiple low carbon energy sources feeding into the system and various temperature demands of customers, as well *fully carbon neutral energy solutions through regional, integrated networks* (expected by 2050) are basically depending also on the EU strategy and *vision for DHC and their applications*.

District Heating and Cooling is an integral part of the successful growth of CHP: heat networks distribute what would otherwise be waste heat to serve local communities.

Specifically, it is a mature technology that already delivers low carbon heating and cooling for many towns and cities. It allows heat that would otherwise be wasted to be recycled; it also provides a network for the effective use of low and zero carbon renewable sources of energy.”

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References

[1] DHC, “*District Heating Cooling – A vision towards 2020 – 2050*”, DHC+ Technology Platform material, May 2009, Brussels, http://www.dhcplus.eu/Documentation.html

[2] EC, “*Doing more with less — Green Paper on energy efficiency*”, European Commission document of Directorate-General for Energy and Transport, Luxembourg, Office for Official Publications of the European Communities, 2005 ISBN 92-894-9819-6

[3] IEA, “*District Heating and Cooling Including the Integration of CHP*”, IEA strategy document, IEA/CERT/EU/WP/(2004)9, August 2009, http://www.iea-dhc.org/download/

[4] J.R. Howell, R.O. Buckius, “*Fundamentals of Engineering Thermodynamics",* McGraw-Hill, 1987.

[5] M Cardu, I. Ionel and C. Ungureanu, “Ecological Aspects Concerning the Combustion of Lignite in Romanian Thermopower Plants”, *Energy Conversion and Management*, Vol. 46, 2005, pp. 1645-1654

[6] M. Cardu, I. Ionel and C. Ungureanu, “Combined nuclear and conventional plant, operating on hydrogen, according to Rankine cycle”, *Revue Roumaine Des Sciences Techniques Serie Electrotechnique et Energetique*, Vol. 52, part 1, 2007, pp. 105-120

[7] R. Strzalka, R. Ulbrich and U. Eicker, "Optimisation of combustion process in biomass-fuelled cogeneration plant", *Chemical Engineering Transactions*, Vol. 21, 2010, pp. 469-474
[8] D. Maraver, A. Rezeau, A. Sebestian and J. Royo, "Thermodynamic optimization of a trigeneration system based on biomass combustion", *Proceedings of the 17th European Biomass Conference*, Hamburg 2009, Germany, pp. 1368-1376
[9] J.S. Lizarraga and A.V.S. Baeza Aguardo, "Cogeneration with gas turbines for dryers and hot water boilers", *Heat Recovery Systems and CHP*, Vol. 15(3), 2005, pp. 319-325
[10] X. Feng, Y.N. Cai and L.L. Qian, "A new performance criterion for cogeneration system", *Energy Conversion and Management*, Vol. 39(15), 1998, pp. 1607-1609
[11] F. Popescu, I. Ionel and N. Lontis, Waste animal fats as renewable and friendly environmental energy resources, *WSEAS Transactions on Environement and Development*, Issue 7, vol. 6, ISSN 1790-5079, july 2010
[12] G. Trif-Tordai, I. Ionel and F. Popescu, Novel RES based Co-combustion technology, *WSEAS Transactions on Environement and Development,* Issue 7, Vol. 6, July 2010
[13] I. Ionel, F. Popescu, N. Lontis, G. Trif Tordai and W. Russ, "Co-combustion of fossil fuel with bio-fuel in small cogeneration systems between necessity and achievements", *11th WSEAS International Conference on Sustainability in Science Engineering, 27-29 May, Vol.2,* SSE'09, Timisoara, Romania, pp. 352, 2009
[14] S. Koenig and J. Sachau, "Sustainability of Biomass Energy Sources – Measurement and Regional Comparison", *WSEAS Transactions on Environment and Development*, EED'07, Spain, 2007.
[15] ENERO, "*Actor Analysis Biomass Romania*", Ref. BIORM08001, project report, developed by ENERO Romania and coordinated by SenterNovem, Netherlands, May 2009, available online at: http://www.enero.ro/proiecte/StudiiBiomasa/doc/Study%20on%20Actors_Biomass_Romania_2009.pdf
[16] JASPERS, "*Market Assessment of Romanian Energy Efficiency and Renewable Energy Schemes*", JASPERS project in ADRVEST report, 2007
[17] ENERO, "*Market Development Biomass in Romania. Survey: Scenarios study biomass Romania*", Ref. BIORM08003, project report, developed by ENERO Romania and coordinated by SenterNovem, Netherlands, September 2009, available online at: http://www.enero.ro/proiecte/StudiiBiomasa/doc/Study%20on%20Scenarios_Biomass_Romania_2009.pdf
[18] EIE, "*Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results*", REFUEL, EIE project, July 2007