Biomass district heating systems: a solution for the directive 27/2012/EU

Víctor M. Soltero[a], Ramón Velázquez[b] Ricardo Chacartegui[b], Monica Carvalho[c], José A. Becerra[b]

[a] *Department of Engineering of Design, University of Seville, Seville, 41011, Spain.* vmsoltero@us.es
[b] *Department of Energy Engineering, University of Seville,. Seville, Spain.*
[c] *Federal University of Paraíba, Department of Renewable Energy Engineering, Center of Alternative and Renewable Energy. João Pessoa, Brazil.*

Abstract

One of the key aspects regulated by Directive 27/2012EU is the efficiency of cooling and heating, and this directive suggests that district heating and cooling (DHC) systems should be implemented after mandatory studies are carried out: i) cost-benefit analysis for each new electricity generation facility; and ii) best usage of waste heat in industrial facilities located in the proximities. By December 2015, all member states of the European Union will have to report to the European Commission, reporting on the possibility of implementing DHC systems. However, due to the technical difficulties discussed herein, a complementary approach to the EU Directive is required to achieve the established goals in a reasonable period of time. In this paper, the authors discuss the possibility of implementing district heating in Spain from economic, social and environmental sustainability perspectives. This study focuses on municipalities with less than 10,000 inhabitants, using biomass as fuel, and taking into account weather conditions and most suitable techniques to achieve the sustainability objectives defined. Sensitivity analyses were carried out with variables related to cost-benefit: installed heat power, energy demand, load factor, type of fuel, operational cost, etc. These variables were adequately adapted to involve consumer centers that range from single-user level to municipalities, for different climate zones in Spain. The methodology was applied to three different locations in Spain: A, B and C, with respective building densities 0.4 m^2/m^2, 0.6 m^2/m^2 and 0.8 m^2/m^2. Significant reductions in CO_2 emissions were obtained along with and energy savings. The results demonstrated the relevance of the methodology for evaluating DHC systems. Among the results presented, there is a prediction of potentially 4000 tonnes of avoided CO_2 emissions per year and energy savings of approximately 20% in one of the locations. Economic viability was demonstrated for locations type B and C with higher building densities, where at least 1500 equivalent annual hours are required to demonstrate the viability of the heating network. Application of the methodology to the evaluation of feasible district heating systems for small- and intermediate- sized locations, as proposed herein for Spain, yields potential energy savings of 14,000 TJ and reduction of annual CO_2 emissions by 5.5 millions of tonnes. The results of this project not only provide a methodology for the evaluation of the possibilities of heating and cooling networks in Spain, but also provide guidelines for future similar evaluations in other regions with biomass resources.

Keywords:
District heating; Biomass, CO_2 emissions; Energy savings; Heat demand; CHP.

1. Introduction

More than 40% of the overall energy consumed in Europe is destined to the generation of heat (domestic, industrial purposes); the cooling demand follows an increasing, exponential trend [1]. District energy systems (DES) use a central source (instead of several individual systems) to supply energy services to multiple buildings, and offer significant opportunities for the achievement of energy savings and reduced environmental impacts [2]. An extremely flexible technology, DES can virtually utilize any fuel: waste energy, renewable sources, combined heat and power (CHP), geothermal energy exploitation, solar collector fields, city waste incinerators, or any combination [2,3]. Lund *et al.* [4] mention that a reduced use of fossil fuels could be achieved through DES, with the introduction or expansion of CHP systems (better fuel efficiency), inclusion of heat pumps, utilization of industrial waste heat, and even by displacing fossil fuels with residual resources such as waste or several biomass fuels. A centralized, local thermal energy system that produces heat and/or coolth (district heating and/or cooling system) and distributes the energy service throughout a community (or several buildings) has significant potential to contribute to the solution of energy-related challenges of modern society [5]. The use of this technology can provide valuable advantages, such as: improved energy efficiency, reduced environmental impacts, fuel flexibility, security of supply and convenience for users [5-7]. CHP and district energy do not require significant financial incentives to be launched in the market [8]. Additional 400 million tonnes of CO_2 can be saved annually, with the expansion of district heating and cooling (DHC) across 32 European countries - this corresponds to a reduction of 9.3% in CO_2 emissions [9].

Throughout the years, some countries have strategically invested in CHP and district networks as powerful tools to meet wider energy and environmental objectives [8]. Since the 1300's, district energy systems have been utilized in Europe, and nowadays, Northern European countries are the main users [5]. Many countries located in high latitudes already have a district heating market penetration between 30% and 50%, with Iceland reaching 96% [10]. According to COGEN [9], there are currently more than 5000 district network systems in Europe, with district heat reaching a share of 10% of the heating market; more than half of the European market is located in Northern and Eastern Europe.

Among the conclusions of the European Council in February 2011 [11], it was highlighted that the objective established by the European Council in June 2010 [12], should be achieved: increase energy efficiency by 20% until 2020. Until the moment, this objective does not seem to be a real possibility. Already in 2001, the IPCC [13] presented an overview of important examples of energy efficiency improvement technologies and indications of associated emission reduction potentials and costs. Technological opportunities exist (although underexploited) for improvements in energy efficiency, which could include a more widespread use of DES.

Biomass has been in the spotlight, among the best available technologies for DHC, as it is regarded as a CO_2-neutral source. The CO_2 released from burning biomass is absorbed as part of the "biogenic" carbon cycle (plants absorb CO_2 through photosynthesis, and release it when decaying or burning); and this cycle does not release any new CO_2 into the atmosphere (carbon neutral) [14]. The use of biomass can be an important contribution to the renewable energy potential of DHC networks, and can be used directly in many of the existing facilities [1].

As high efficiency cogeneration and urban heating and cooling systems present a significant potential for the realization of primary energy savings, combining these technologies with biomass energy source is a sound, technically-safe step towards sustainability. However, in general, CHP and DHC remain underexplored in the European Union (EU). Member states have already started to carry out exhaustive and detailed assessments on the potential of these technologies [15-18].

The vision established by Directive 27/2012 [19], where Spain should make better use of the residual heat of new high efficiency cogeneration systems, is technically sound. However, implementation is difficult and the obtainment of results should not occur in a reasonable amount of time, due to the excess power installed in the peninsular electrical system as well as the deficit in tariffs that has led the legal framework to be unfavorable to the development of new cogeneration systems connected to the electrical grid.

The objective of this work is to discuss the implementation of biomass district heating in Spain, from economic, social and environmental sustainability perspectives. This study focuses on Spanish municipalities with less than 10,000 inhabitants, and takes into account weather conditions and the most suitable techniques to achieve sustainability objectives.

2. Current scenario for district heating, cogeneration and biomass heating networks in Spain

2.1. District heating and district heating and cooling networks in Spain

There is incipient interest in DHC in Spain. There are 240 urban heating and/or cooling networks, of which 202 are censed [20]. Each installation presents particular characteristics in function of the type of energy service offered (heat and electricity, only heat, or heat and coolth), of the type of client (industrial, residential), and of the type of primary energy employed (biomass, natural gas). The breakdown of percentages for District Heating (DH) and DHC users in Spain follows: 46.88% tertiary sector, 33.08% homes, and 20.04% industry [20]. When considering the absolute number of facilities, there is a trend towards DH systems (*i.e.*, only heat is generated), which predominate with 85% of systems installed [20]. Regarding power, of the total 1100 MW installed, 690 MW correspond to DHC installations, with DH systems responsible for only 37% of all installed power. This is due to the fact that large size installations usually produce heat and coolth, while small-sized systems only generate thermal energy in the form of heat. Globally, of the total power installed in distribution systems (1,109,30 MW), 71% corresponds to heat generation and 29% to coolth generation. The sum of all heating and cooling distribution networks installed in Spain is equivalent to 6.5 million m^2 (87,000 homes), with more than 30 km of networks [20]. These systems generate annual savings of 150,000 tonnes of CO_2 (consequence of 50% savings in the consumption of fossil fuels). Nowadays the penetration of DHC systems in Spain remains symbolic. With an average network length of only 1.5 km, it is clear that the supply of heat and coolth to urban nuclei was not the main motivation for the implementation of these systems.

2.2. Cogeneration in Spain

In Spain, the maximum electrical power demand in 2014 reached 38,948 MW, 3.3% less than the maximum value for 2013, and 14.3% less than the historical maximum. The installed power of the Spanish peninsular electrical system in 2014 was 102,259 MW, which was 122 MW (0.1%) less than in December, 2013. The most significant decrease was verified in carbon power plants, which reduced power by 159 MW, as a consequence of shutting down power plants [21]. The variations in power for the remaining technologies that constitute the generation park were nil or non-significant.

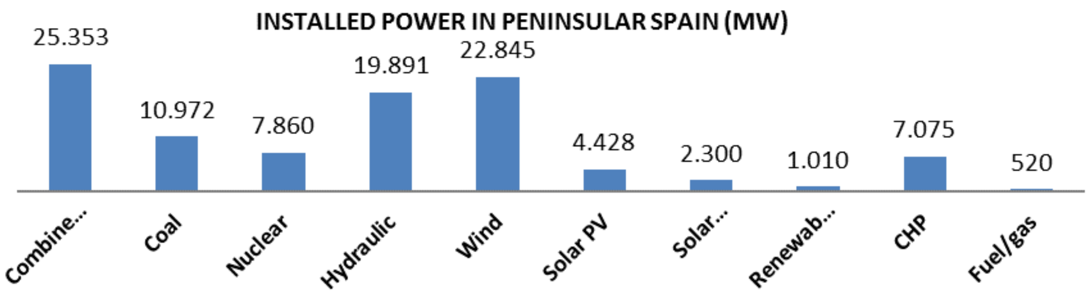

Fig. 1. Installed power in peninsular Spain, according to the type of technology, in 2014 [21].

The aforementioned circumstances, along with the fact that the coverage index of the electrical system is 1.4, which exceeds 1.1, has not favored the growth of cogeneration systems in recent years. Including non-renewable thermal and fuel/gas technologies, cogeneration represents 6.9% of the total power installed in the peninsula [21]. Figure 1 depicts the installed power in the Spanish peninsula, per technology. Regarding coverage of demand, Spain is well placed, with surplus power, as cogeneration contributes with 10.4% to the electrical demand in peninsular Spain. However, the specific aforementioned circumstances of the system and electrical market hinder the development of urban heating networks associated with cogeneration systems.

3. Characterization of the consumption of heating and sanitary hot water in Spain

Given the significance of the energy consumption of the residential sector and the necessity of better knowledge on this specific sector, the Institute for Energy Diversification and Savings/Ministry of Technology and Science of Spain presented the proposal "SPAHOUSEC project" (Analysis of the Energy Consumption in the Spanish Households) to Eurostat within the framework of the SECH project [22].

Energy consumption in Spanish homes has the main objective of covering heating and sanitary hot water (SHW) demands, which across the country adds up to 404,817 TJ (total energy consumed: 614,453 TJ). The SPAHOUSEC project divided the Spanish territory in three climatic zones: Atlantic, Mediterranean, and Continental; the latter presents higher climatic severity and therefore highest energy demands. The energy sources generally utilized for heating are electricity (46%) and natural gas (32%), according to the study carried out by SPAHOUSEC [22]. The report also affirms that in the Mediterranean zone, electricity is predominantly utilized for heating purposes, while in the Continental zone gasoil predominates with 57,732 TJ for heating and 4,176 for SHW, followed by natural gas, responsible for 36,123 TJ in heating and 31,541 in SHW [22].

Obviously the consumption of natural gas is only available for those municipalities that present natural gas grids (generally those with larger populations). The consumption of gasoil occurs mainly in rural environments where natural gas networks remain unavailable, with populations under 10,000 inhabitants (NGF10k). In many occasions these rural environments are located at higher altitudes, close to the mountains where forest biomass is available. Regarding the heating systems utilized, most are individual boilers (50%) and electric systems (46%) [22]. Figure 2 depicts the heating systems available in Spain, by climatic zone.

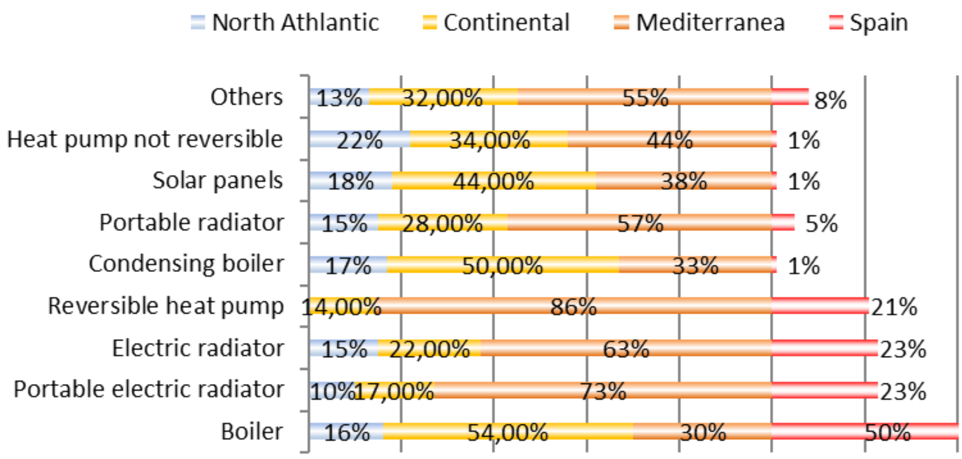

Fig. 2. Heating systems in Spain, by climatic zone [22].

4. Methodology for the evaluation of biomass heating networks

The evaluation of the feasibility of a heat network project must be carried out considering social, environmental and economic sustainability criteria.

Spain presents a strong dependence on energy (73.3%), which greatly exceeds the European average (53.3%) [23]. This implies in high costs and variability in heating costs for users, which purchase the fuel individually in municipalities without gas supply networks and population under 10,000 inhabitants (NGF10k). Following the Euro zone economic crisis, the situation has been aggravated to the point that a new concept, "energy poverty", has been coined [24]. Projects that offer a more stable, lower price for heating and SHW services, besides providing security and convenience, are guaranteed to have a wide social buy-in.

Biomass is considered a renewable fuel and therefore guarantees a significant reduction in CO_2 emissions. The fact that heating networks are situated in NGF10k municipalities, very close to forest or agrarian environments, contributes to achieving real emissions of approximately 0%, already accounting for the transportation of biomass. However, controlled combustion and emission treatment accomplished in DH systems eliminate the discussion on local contamination problems, which are the greatest issue with small domestic biomass boilers. Another aspect to be considered is that the continuous and systematic use of forest biomass acts as a catalyst for the compliance to mountain organization plans (instrument that establishes the rules regarding biological requirements and indirect benefits provided by tree-covered mountains). Without doubts, for NGF10k municipalities, the use of biomass in heating networks is the best alternative possible from an environmental perspective.

The economic aspect of sustainability must also be considered: the project must generate sufficient revenue to recover the invested capital plus realize reasonable economic benefits. The three variables that will allow for the evaluation of the project are: CAPEX (Capital Expenditures), OPEX (Operational Expenditures), and the revenues from the project. These are the economic terms, but there is a clear direct relationship with the energy variables that characterize each heat network.

This study will assess the economic sustainability of biomass heating systems in Spain, following the guidelines established by Annex IX of Directive 27/2012 [19] where the principles and methodology are determined for the Cost and Benefit Analysis (CBA) of these systems.

4.1 Thermal power and CAPEX

The size/power of the heating network will be equal to the sum of the calculated demand for each building that constitutes the network, weighted by a simultaneity coefficient. For each network, this power will be utilized in the selection of thermal generators, and for the definition of the remaining elements of the thermal power plant. The established power and the thermal difference selected for the distribution network allows for the preliminary design of the thermal network (diameters and load losses). Once the thermal plant and network are dimensioned, CAPEX can be evaluated by adding the remaining engineering and development costs.

The instantaneous heating demand is obtained from (Eq. 1):

$$(1) \qquad (P(kW) = \left(\sum_{i=1}^{i=n} A_i U_i + V_{ainf}\rho \cdot C_p\right)(t_{c\_indoor} - t_{out})$$

Where P is the power demanded (kW), A_i is the surface (m^2) of the exterior wall (i), U_i is the global coefficient of transmission (air/air) of this wall ($W/m^2{\cdot}K$), V_{ainf} is the flow of infiltration air (m^3/s), ρ is the density of the exterior air (kg/m^3), c_p is the average specific heat of the exterior air (W·s/kg ·K), t_{c_indoor} is the comfort temperature selected for the indoor space (base temperature, 20ºC), and t_{out} is the temperature of the exterior air in a specific moment. When t_{out} is the same as the design temperature, it is taken from a meteorological data source.

The following expression is the thermal constant of the building ($K_{building}$):

$$(2) \qquad K_{building} = \left(\sum_{i=1}^{i=n} A_i U_i + V_{ainf}\rho \cdot C_p\right)$$

This expression, in kW/K, is a constant (if infiltration is considered constant or if its maximum value is employed), which is characteristic of the building. Eq. 2 presents some imprecision as it does not consider the thermal inertia of the building, that infiltration depends on the geographic orientation and predominant wind direction, the permeability degree for the building, the extra power required for fast startup until comfort levels are reached and finally, distribution losses. Traditionally, heating installations were designed based on Eq. 1, until methods for the calculation of transitory regimes were developed. In the case presented herein, the available calculation methods for transitory regimes present the inconvenience of analyzing thousands of buildings and grouping the final result. Given this impossibility, the calculation of the required power for an existing urban set is not carried out utilizing Eq. 1 since the geometric and constructive characteristics of the building envelope are unknown. In these cases, indices for P (kW)/ surface (m^2) or P (kW)/ volume (m^3) are utilized.

The required power for SHW is calculated from its demands, and assuming that two hours are required for water to reach the target temperature. SHW peak power does not coincide with the heating peak power. Actually, the design peak for SHW occurs at minimum temperature, at dawn. The maximum power at each home is required when heating is started, generally at noon or 1pm. When this occurs, the exterior temperature is not minimum and therefore the installation has a specific excess margin. The installation of SHW with individual heat storage can and must utilize the nocturnal hours when heating is disconnected or partially operational. The SHW power does not add up to the heating power. Determination of the simultaneity coefficients that could be applicable to the power sum requires the identification of the typology of buildings, according to the use (dwellings, buildings occupied permanently: homes or hospitals, buildings occupied during working hours, etc). With this classification plus knowledge on the heating pattern use in the homes, eventually a simultaneity coefficient different from one could be applied.

4.2 Thermal demand, revenue and OPEX

The thermal demand of the heat network will determine the revenues of the project, and must be calculated for heating and SHW. The operation costs of the heat network include: i) fuel costs (directly related to the demand, through the application of the efficiency values of the equipment plus the thermal losses of the network, and could represent between 60 and 65% of OPEX); ii) energy costs for pumping hot water through the network; iii) mandatory and preventive operation and maintenance costs; and iv) administration and management costs. It is therefore paramount to determine correctly the thermal demands, as the economic viability of the project (revenues and OPEX) is very affected by these values.

4.2.1. Heating and SHW demand

It is not possible to simulate individual lead curves for the entire building park. An expression will be applied to establish the demands of a building. The starting point is the required power, which is integrated over the operational interval of the facility:

(3)
$$D(kWh) = \int_{\theta_1}^{\theta_2} P(kW)\,d\theta(h)$$

The thermal power required by a specific space is:

(4)
$$(P(kW) = \left(\sum_{i=1}^{i=n} A_i U_i + V_{ainf}\rho \cdot C_p\right)\left(t_{c\_indoor} - t_{out}\right)$$

The thermal constant of the building is:

(5)
$$K_{building} = \left(\sum_{i=1}^{i=n} A_i U_i + V_{ainf}\rho \cdot C_p\right)$$

The energy demand, throughout a year, will be therefore assessed through:

$$(6)\quad D(kWh) = \int_{\theta_1}^{\theta_2} K_{building}\left(t_{c\_indoor} - t_{out}(\theta)\right)d\theta = K_{building}\int_{\theta_1}^{\theta_2}\left(t_{c\_indoor} - t_{out}(\theta)\right)d\theta$$

The constant of the building can also be calculated by:

$$(7)\quad K_{building} = \frac{P_{max}}{t_{c\_indoor} - t_{out\_design}}$$

Eq. (8) expresses the degree-days on the basis of the local temperature, and depends only on the climatology of the location. The integration interval is the entire annual heating period, which occurs at any instant when the exterior temperature is below the local temperature.

$$(8)\quad {Degree\cdot Days}/{year} = \int_{\theta_1}^{\theta_2}\left(t_{c\_indoor} - t_{out}\right)d\theta$$

The demand is therefore:

$$(9)\quad D\left({kWh}/{building\cdot year}\right) = 24\left({h}/{days}\right)\frac{P\left({kW}/{building}\right)}{t_{c_{indoor}} - t_{out_{design}}}Degree\cdot Days\left(K\cdot {days}/{year}\right)$$

The influence of internal gains due to occupation and domestic electrical equipment, and external gains due to solar radiation yields:

$$(10)\quad D(kWh) = \int_{\theta_1}^{\theta_2} K_{building}\left(t_{c\_indoor} - t_{out}(\theta)\right)d\theta - internal\ gains - external\ gains$$

Eq. (10) integrated across all homes of the municipality, should be corrected by an intermittence coefficient that adjusts demand, in the case that the operation hours do not correspond to the total available hours. Hourly data on dry temperature for a meteorological-type year is necessary for a correct adjustment. It is also necessary to obtain knowledge on the occupation of the buildings (permanent, temporary) and operation hours.

Calculation of the SHW demand requires data on the temperature of the network pipe water, number of inhabitants of the zone, and the liters/person ratio. A SHW temperature of 60º was considered, and its demands represent 5-10% of the heating demand.

4.4 Cost and benefit analyses for the system. Sensitivities

The cost and benefit analyses, as proposed by Directive 27/2012, can be constituted by an evaluation of an individual installation project or a group of projects in wider local, regional or national environments. The objective is to establish the most profitable and advantageous option for heating or cooling, for a specific geographic zone, and plan the heating system according to social and environmental factors. The proposed steps are shown in Figure 3.

Firstly, the system and geographic limits must be established. The scope of the analysis includes an appropriate geographic zone, well-defined (*e.g.*, a specific region or metropolitan area) to avoid the selection of suboptimal solutions in function of the projects.

Secondly, integrated planning must be carried out for the options of demand and offer. All supply resources that are available within the geographic and system limits must be considered, including the residual heat from electricity generation facilities, from industrial facilities and from renewable energy. Characteristics and trends of heating and cooling demands must also be considered.

A baseline is then established. The goal of a baseline is to serve as a reference point, against which the alternative hypothesis can be evaluated. In the case herein presented, the baseline corresponds to the current supply conditions and energy prices for heating and SHW. In NGF10k municipalities, the baseline (L_{base}) corresponds fundamentally to the price of the useful heat supplied by individual gasoil boilers plus maintenance (C_{mto}^{boiler}) and amortization (C_{a}^{boiler}) costs of the individual generator.

$$(11) \qquad L_{base} = \frac{Annual\ cost_{gasoil}}{\eta_{individual\,boiler}} + C_a^{boiler} + C_{mto}^{boiler}$$

where C_a^{boiler} is given by the relationship between the capital cost (C_i^{boiler}) of the boiler and its lifetime.

$$(12) \qquad C_a^{boiler} = \frac{C_i^{boiler}}{Lifetime}$$

Alternative hypothesis are then defined. Although the directive proposes high efficiency cogeneration, efficient urban heating or cooling systems, and even individual efficient supply of heating and cooling, DH was selected as alternative hypothesis to the baseline.

Calculation of the benefits considers: i) evaluation and comparison of total costs and benefits at the long-term; ii) the Net Present Value (NPV) as evaluation criterion; and iii) the temporal horizon including all costs and benefits for the hypothesis (for DH systems, 30 years). Price factors and discount rates are used for calculation and prediction of prices, along with other hypothesis for economic analyses.

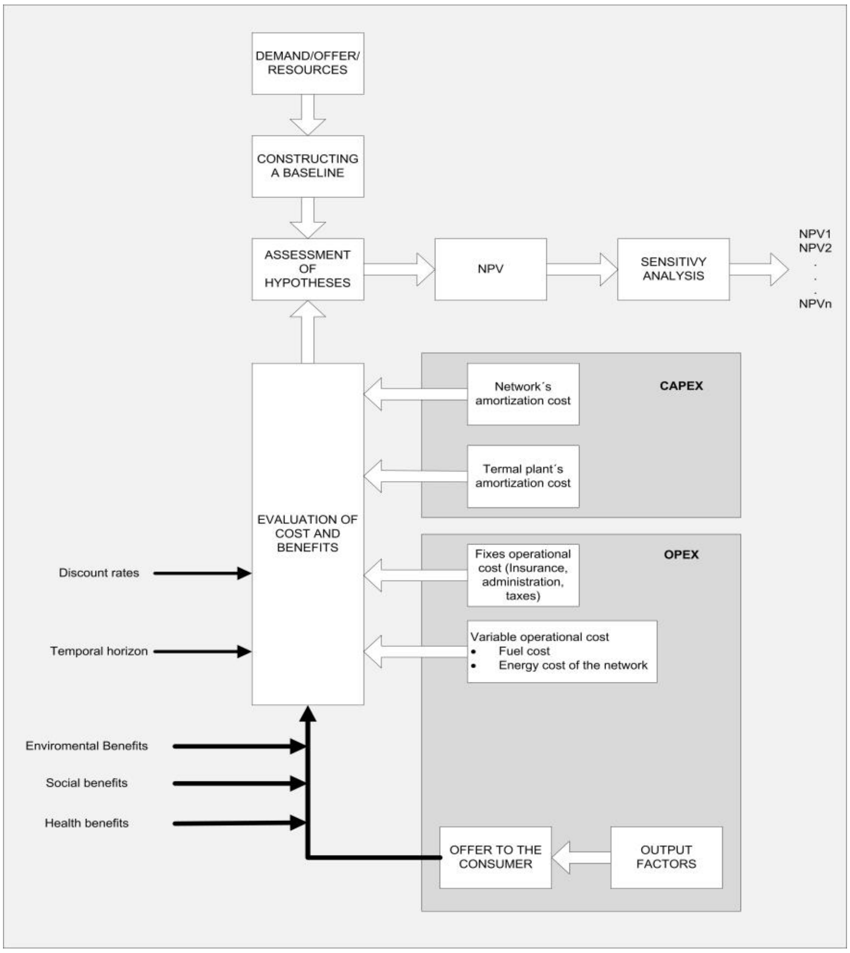

Fig. 3. Cost/benefit analyses and technical-economic characteristics of the DH network.

Within the economic analysis, at least in an annual evaluation, the following will be considered: i) benefits: value of the offer to the consumer (heating and SHW) and external benefits, such as environmental, social and health benefits; ii) costs: annual amortization costs of installations and equipment, annual amortization costs of the associated energy networks, operation (fixed and variable) costs, energy costs, and environmental, social and health costs. Sensitivity analysis will be carried out for the factors that affect significant the results.

Regarding the present model for evaluation of costs and benefits in a 10-20 MW biomass DH system, in a time horizon of 30 years, 55% of the costs are associated with the consumption of fuel, 15% of the costs relate to the amortization of the thermal plant, 12% relate to fixed operational costs (administration, insurance, taxes), 11% relate to the amortization of the network, and 7% correspond to the energy costs for the network. This allocation of annual costs, when compared with the economic revenues that can be currently quantified, allows for the determination of an equilibrium point (starting from which the benefits exceed the costs, as shown in Figure 4). The following equation must be fulfilled:

$$(13) \qquad Benefits_{Sale\ of\ heat} = \sum_{i=1}^{n} CostsDH_i$$

$$(14) \qquad E_{sold} \cdot Price_{kWh} = C_{fixed} + C_a^{central} + C_a^{network} + C_E^{network} + C_{fuel}$$

This equilibrium point can be expressed as the equivalent number of operation hours:

$$(15) \qquad P_{DH} \cdot h_{eq}^{*} \cdot Price_{kWh} = C_{fixed} + C_a^{central} + C_a^{network} + C_E^{network} + C_{fuel}$$

As the equivalent operation hours of the system is a parameter that depends on the calculated demand, if the value is over h_{eq}^{*} it indicates that the benefit and cost analyses are viable. Systems with average values above 1200 hours present guaranteed viability.

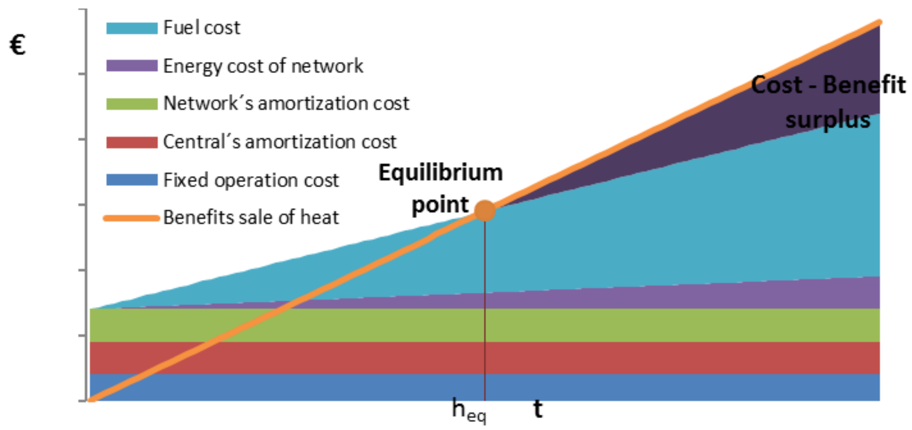

Fig. 4. Revenues and costs in a DH network, per equivalent hour of operation.

5. Application of the analysis methodology to different villages in Spain

The cost-benefit analysis of a DH system in different municipalities will be fundamentally sensitive to three factors: cost of fuel, cost of biomass, and amortization costs for the network, which depend on the building density of the geographic environment where the system is installed.

The relative humidity of the fuel will influence its heating power, which leads to the situation that, in many occasions, biomass transactions are made with fixed prices (€/MWh). The size of wood chips can be between P16 and P100 according to EN 14961-1 [26], and the most common size is P45.

Table 1. Total cost of biomass depending on the collection treatment and transport distance [25].

	Biomass total cost * [€/t]	%Transport cost *	%Transport cost 10 km	% Transport cost 40 km	% Transport cost 80 km
1st cleaning	66,02	15	8	21	32
2nd cleaning	46,51	21	12	29	43
1st clearing	41,57	24	14	33	47
Last cut	41,57	24	14	33	47

*Distance to the treatment and storage center: 30 km, access via 50 km/h roads.

Under the same conditions of humidity, the cost of forest biomass at the distribution gate can vary considerably, between 40 and 100 €/t, incrementing the slope of the total costs in the same proportion as its variation. This requires more operation hours to guarantee the viability of the system. This situation will be possible only in locations with severe climatic conditions. Unitary cost variations for different transportation are shown in Fig, 5.

Biomass costs will also depend on the pine, and on the type of forestry treatment used for obtainment. Depending on the origin, cost can vary by 50%. The total costs also include the weight and cost transportation, as expressed in Table 1.

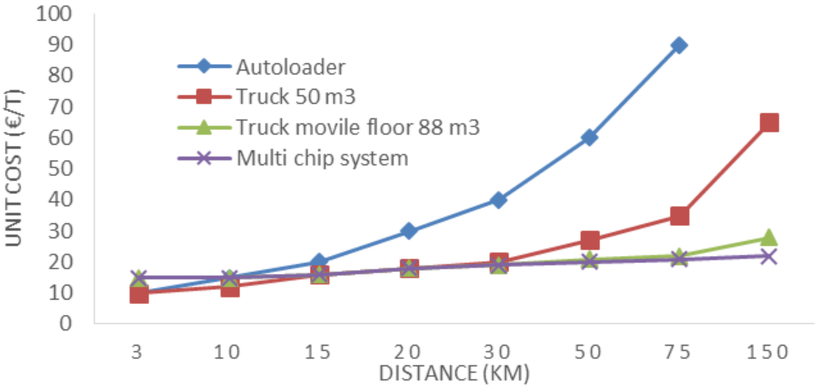

Fig. 5. Transportation costs for easily accessible biomass. [25]

Depending on the type of biomass and the distance traveled, costs can increase by 47% for distances up to 80 km. This limits the affordable resource to a 80 km-radius.

Given the importance of transportation in the cost-benefit analysis, when the capital originates from private investors and bank financings, they require stable fuel prices for at least the amortization time of the investment or financing. Except for the eventual influence of other biomass demands on its price, it is simple to set the biomass price at the medium-term when ownership of the resource is municipal and the DH service is within the same municipality.

The next factor that could affect the results is the building density within the DH geographic environment, even if the climatic conditions remain the same as well as fuel price and total installed power. Systems such as the one proposed for NGF10k municipalities would require a lower operation limit h^*_{eq}, which could be very different in function of the building density (0.3-1.2 m^2/m^2 of built surface in relation to the considered geographic area, for houses). The variation of the network investments does not follow the density variations lineally, given that besides the length of the network, the power to be transmitted is another determining factor for investing in this concept. Fig. 6 shows the variations in cost-benefit analyses for three municipalities, with building densities between 0.4 and 0.8 m^2/m^2. The remaining parameters that define the system follow the assumptions of: minimum design temperature, installed power, Degree Days, demand, intermittency coefficient, and fuel prices.

In this case, h^*_{eq} decreases as the building density increases. Three types of municipalities were analyzed, corresponding to three villages in North Spain with different building densities. Municipalities A, B and C were considered, with respective building densities 0.4 m^2/m^2, 0.6 m2/m2 and 0.8 m^2/m^2. These municipalities were considered representative for the application of the methodology.

From Fig. 6 it yields that fuel supply must respect a 40 km-radius. For municipalities type A, the number of annual operation hours must be under 1,700h. Values above 1700h will limit the application of DH to very few locations in Spain. For municipalities type B, operation must be under 1,500 hours per year. This pattern of operation will be representative of an important number of municipalities. For municipalities type C, 1,350 annual hours of equivalent operation are required. For this case, important different benefit-cost results will be obtained if the supply distance is under 60 km.

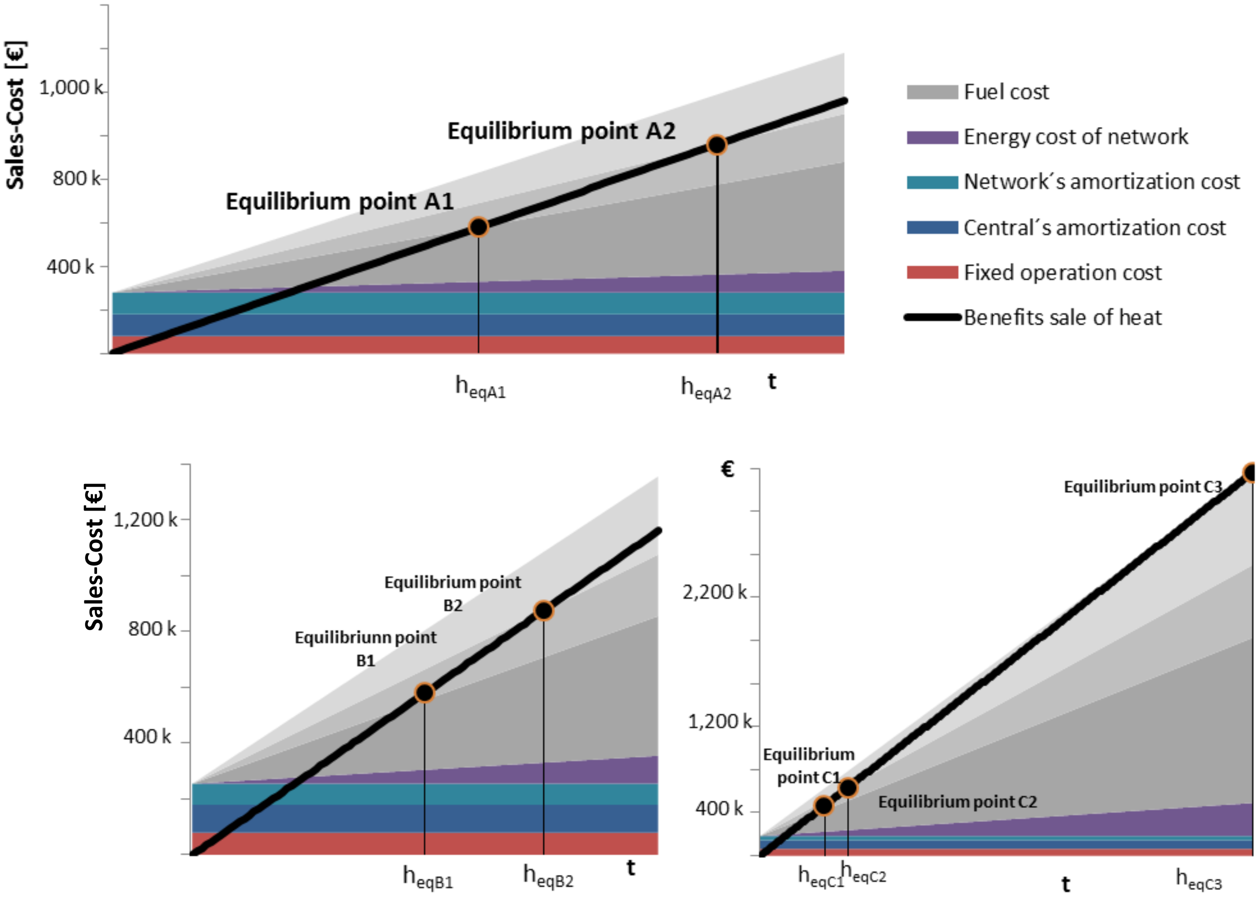

Fig. 6. Sensitivity of revenues and DH network costs to building density per operation heq

6. Conclusions and Final remarks

This manuscript presented a methodology for the evaluation of the viability of District Heating systems in Spain, based on location, climatology and availability of forest biomass. The methodology is based on the cost analysis requirements of EU Directive 27/2012.

The methodology presented herein is based on the analysis of the location, weather and biomass resource. The study showed the advantages of the application to municipalities with population under 10,000 inhabitants, where natural gas grid is not available. The methodology is applicable and extensible, to a global level, to locations with biomass resources and equivalent heat demands.

The methodology was applied to three different types of municipalities, identifying the economic impact associated with the different components. These municipalities were considered representative of Spanish municipalities with population under 10,000 inhabitants, and building densities between 0.4 and 0.8 m^2/m^2. These conditions correspond to many villages in Central and North Spain without natural gas grids.

For the representative locations analyzed, the number of equivalent hours required for the economic viability of the system were determined, for different biomass transportation scenarios. For a mean transport distance of 40 km, the number of equivalent hours for each case was 1.647, 1.500 and 1.352 hours, respectively. This trend was explained by the influence of the amortization cost of the DH network.

From a technological viewpoint, DH systems did not present higher risks than the connection of the new systems to those already operational. From an economic perspective, the results were highly sensitive to the building density and transport distance for fuel.

There will also be social benefits realized with DH systems: work positions will be made available for the extraction and treatment of biomass and users will enjoy a safer service, as no fuel is required to be stored at home. Also, security of supply is guaranteed (almost 100%), much superior to that of individual generators.

Regarding the environmental impacts, all the emissions associated with the consumption of gasoil would be eliminated along with the management costs of forests regarding the prevention of fires. Moreover, further reductions in CO_2 emissions could be possible as the consumption of biomass occurs in municipalities close to the source. An overall improvement (10-20%) in the DH system efficiency was observed in comparison with individual generators. When compared with the consumptions of gasoil and propane in the continental zone (70,000 TJ), these conclusions translate into energy savings of 14,000 TJ and reductions in 5.5 million tonnes of CO_2 emissions.

Nomenclature

DH District heating

DHC District heating and cooling

DES District energy system

CHP Combined heat and power

CAPEX Capital Expenditures

NGF10k Locations with population below 10000 inhabitants and without natural gas network

OPEX Operational expenditure

SHW Sanitary hot water

P power demanded (kW)

A_i surface of the exterior wall (m^2)

U_i global coefficient of transmission (air/air) of this wall ($W/m^2 \cdot K$)

V_{ainf} flow of infiltration air (m^3/s)

c_p average specific heat of the exterior air ($W \cdot s/kg \cdot K$)

t_{c_indoor} comfort temperature selected for the indoor space (base temperature, 20ºC)

t_{out} temperature of the exterior air in a specific moment

L_{base} the baseline

C_{mto}^{boiler} maintenance cost of the individual gasoil boiler

C_a^{boiler} amortization costs of the individual gasoil boiler

NPV Net present value

P_{DH} District heating energy power

h_{eq}^* Equivalent operation hours

$Price_{kWh}$ Price energy sold

C_{fixed} Operational fixed cost

$C_a^{central}$ Thermal Central Amortization cost

$C_a^{network}$ Network amortization cost

$C_E^{network}$ Network energy cost

C_{fuel} Biomass fuel cost

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