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THE ROLE OF DISTRICT HEATING AND COOLING TECHNOLOGIES IN ENERGY PROVISIONS FOR BUILDING SECTOR: CHALLENGES AND PERSPECTIVES

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Abstract. District heating and cooling technology finally is recognized at European level as promising tool for implementing energy and environment policy goals. At the same time new approach towards traditional concept of DH systems should be elaborated based on recently adopted European energy policy targets in the field of energy efficiency, renewable energy and environment. New challenges for district heating and cooling (DHC) sector are related to the possibilities of large-scale integration of renewable and local energy resources, creating an energy infrastructure capable to integrate different distributed heat producers, together with ability to be competitive against emerging distributed heat generating technologies.

The paper addresses evaluation of main DH sector characteristics and management practice and suggests necessary changes for the sector development policies. DHC perspectives were analyzed with regard to identification and existing shortages and barriers in energy policy in European context with particular focus on Lithuanian DH sector. The methodology principles of DH sustainability and viability is provided taking into account energy efficiency and green labeling approach. The background of further DH development strategy is provided based on comparison of the DH characteristics in European context and devoted sector role in implementation national energy strategy and policy targets.

Keywords: District heating and cooling, ecolabelling, primary energy resources, CO_2 emissions.

1. Introduction

District heating and cooling (DHC) is a technology and infrastructure during decades used for heat and cooling delivery to industrial and residential consumers.

The fundamental idea of district heating and cooling is to use local fuel or heat resources that would otherwise be wasted, in order to satisfy local customer heating and cooling demands by using a distribution network of pipes as a local market place. This idea contains the three obligatory elements of a competitive district heating system: the suitable cheap heat source, the demands from the heat market and the pipes as a connection between demands and sources. These three elements must all be local in order to obtain short pipes for minimizing the capital investment and heat losses in the distribution network.

The building energy provision using heat supply networks is well-known in Central and East European and Scandinavian countries where half of building area is heated via DH networks. Nevertheless the technology is not widely applied and has big expansion potential in a number of West and South European countries and Norway. DH market share in EU countries is nearly 10% in average, however there are big differences among countries – from more than half in Nordic countries, Baltic States to nearly zero in some Southern European countries, Ireland and UK (Fig 1).

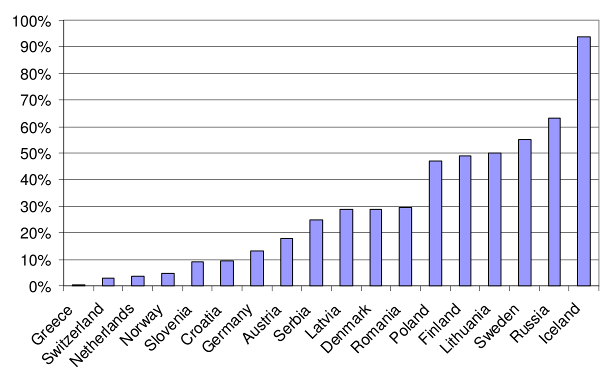

Fig 1. Percentage of DH used to satisfy heat demand in the residential, services and other sectors

In cities like Copenhagen, Helsinki, Warsaw, Vilnius, Riga as much as 90% of residential heat demands are satisfied by district heat. Commercial and public buildings show high connection rates in district heated cities.

District cooling (DC) is not so widely used today but rapidly growing technology. The first known DC system began operations at Denver's Colorado Automatic Refrigerator Company in late 1889. In the 1930's, large DC systems were created for Rockefeller Centre in New York City and for the U.S. Capital Buildings in Washington, D.C. In May 1995 Stockholm Energi started supplying buildings in central Stockholm with cooling from its new district cooling system. Installed DC capacity in European cities was nearly 1300 MW in 2006 (Euroheat 2007). According to a study from (EECCAC, 2003) the annual cooling installations in EU-15 increased four times between 1980 and 2000. District cooling, due to its use of surplus heat from the district heating network and natural cooling sources, has a resource efficiency rate 5 to 10 times higher than electrically driven air conditioners. This leads to significant primary energy savings and a reduction in electricity demand of up to 80% over typical conventional cooling systems.

Until recent years the District Heating and Cooling technology was not an important player on the agenda of European energy policy. The major changes appeared with introducing new energy policy goals by adoption the RES Directive (Directive 2009/28/EC), where DHC is recognized as promising technique for reaching overall strategic energy goals: safety of energy supply by increasing independence from imported energy resources, wider use of waste energy from industries and integration of renewable energy sources into energy supply infrastructures. DHC is also included among priorities in the latest communication of European Commission to Parliament – "substantially increase the uptake of high efficiency cogeneration, district heating and cooling" (COM (2010) 639 final).

An ambitious goal is set in technology platform "DH+" vision: to double DH market share by 2020. The goal is based on recent "Ecoheatcool" study supported by Intelligent Energy for Europe program (Ecoheatcool, 2005). Thus, the heating market share covered by DHC technology would be 18-20% against present ~10%. By the same time district cooling growth potential is to satisfy 25% of cooling demands. The expansion of modern systems combined with further improvements of existing infrastructure would bring a multiplication of the benefits district heating and district cooling are already providing today.

At present around 82% of district heat in the European Union comes from surplus heat sources. The largest share (>75%) of this heat is from combined heat and power production. The result is a reduction in European primary energy demand of at least 0.9 EJ (250 TWh) per year (Ecoheatcool, 2005).

There are more than 5.000 district heating systems in Europe, currently supplying more than 9% of total European heat demands with an annual turnover of €19.5 billion and 2 EJ (556 TWh) heat sales. Market penetration of district heating is unevenly distributed, being close to zero in some countries while reaching as high as 70% of the heat market in others. In cities like Copenhagen, Helsinki, Warsaw, Vilnius, Riga as much as 90% of residential heat demands are satisfied by district heat. In average the share of renewable energies in district heating is 25%.

Buildings are the most heat consuming sector of the DHC infrastructure in EU countries.

Here, a potential contradiction comes to the light between the achievement of net energy savings per individual building (e.g. through its insulation) and low primary energy input into an entire built district (e.g. by means of a low resource energy solution). Under the given market conditions these goals might enter into competition, both from the points of view of energy efficiency as well as cost-effectiveness.

2.Challenges for DH expansion

Recognizing DHC technology as energy supply solution able to help implementing European energy policy goals, the appropriate practical steps are necessary to remove existing barriers and create favorable environment for the technology expansion. For identification of such non-technical barriers and support measures the Ecoheat4EU project was launched in 2009 under Intelligent Energy for Europe program. The project analyses legal frameworks and support measures in 13 EU countries and Norway. With respect to different DH market situations, the countries were divided into 4 groups according to its targets (Table 1).

Table 1. Countries investigated in Ecoheat 4 EU project

Country group	Countries
Consolidation	Denmark, Finland, and Sweden
Refurbishment	Croatia, The Czech Republic, Lithuania, and Romania
Expansion	France, Germany, Italy, and Norway
New development	Ireland, Spain, and United Kingdom

In Consolidation countries, district heating systems have reached a very mature, almost saturated market share of 50-60%. The market share denotes the share of buildings area heated by district heat. Some countries include only residential buildings in the market share, while other countries also include the service sector buildings.

In Refurbishment countries, district heat has also high market shares (10-50%), but the systems need some refurbishment in order to increase customer confidence, energy efficiency, and profitability. The common denominator for the district heating systems in these 4 countries is that they were introduced and developed within planned economies.

In Expansion countries, district heating systems appear in some cities, but the total market share is rather low (3-15%). By expanding existing systems and establishing new systems in other cities, the market shares can grow significantly.

In New development countries, very few ordinary district heating systems exist, giving typical market shares below 1%. However, genuine interest for district heating and cooling is growing in these countries.

Though the project ends in mid 2011, main findings based on stakeholders answers and interviews are already developed (Table 2).

Table 2. Ranked identified support measures for DHC

Rank	Top 12 support measures	Short description of the support measure
1	Planning – Heat planning and/or zoning	Strategic energy planning at municipality level. May include encouraging or even enforcing particular energy solutions (zoning).
2	Support – Investment grant, DH distribution	Financial support for district heating pipes through provision of grant from government and other sources.
3	Planning – National energy policy	The framework, within which relevant legislation, possibly including measures on this list, is framed.
4	Support – Operation support, CHP including feed-in tariff	Supporting CHP through regulatory means, one prominent example being by means of a Feed In Tariff or a CHP bonus.
5	Support – Investment grant, DH connection	Financial support for connecting customers to existing network through provision of grant.
6	Burden – Carbon tax	Implementing a tax penalty on fossil fuels proportional to its fossil carbon emissions. Applicable to all energy systems.
7	Support – Favourable loans	Providing low interest loans to finance the capital cost of establishing, extending or refurbishing district heating.
8	Support – Investment grant, CHP	Financial support for CHP through provision of grant from government, or other sources.
9	Support – Tax reduction	Implementing a tax benefit for district heating consumers .
10	Planning – Building regulations	Using existing regulatory framework to encourage deployment, and removing unnecessary barriers.
11	Support – Investment grant, renewables	Financial support for renewables through provision of grant from government or other sources.
12	Planning – Waste planning & landfill bans	Promoting in a strategic way disposal of waste, so that the energy can be recovered and put to use in district heating schemes.

Despite evident technological and environmental advantages of DHC technology and competitive price in most cases, expansion of existing systems and constructing of new ones often is complicated task. First of all it is related with raising significant investment into heat or cold transport and distribution infrastructure – underground or on ground pipelines to be laid in urban territories connecting heat sources and consumers. Therefore infrastructure planning is ranked as very important component when setting such big infrastructure as DHC network. Other priority measures differs from country to country and selection of country groups was relevant, since many different outcomes were identified by country groups.

Specific recommendations for countries investigated would be prepared and discussed with stakeholders in each particular country. For Lithuania the following measures are recommended:

- Waste planning and landfill bans. Though all municipal waste at present is buried in landfills, and the second priority is energy recovery, Ministry of Environment tends to more complicated (and more expensive) mechanical-biological treatment (MBT) with less amounts of combustible fraction being used for energy recovery. This creates uncertainty about amount of waste for incineration plants.
- Building regulations. Requirements for efficient energy use in buildings, including renewable energy share (eco-labeling) are not adopted yet. The possibilities of DHC to supply heat and cool with less CO_2 emissions should be regarded as alternative to renewable energy use in individual building heating and cooling systems.
- Investment grants for renewable CHP. Need for such grant is based on considerable investment needed for the installations and fluctuating capital market cost. Long term investment pay-back is not attractive for potential investors. Reduction of capital costs would positively affect both: production costs and CO_2 reduction from power generation.
- Carbon tax for non-ETS heating installations. Further developments of Emission trading system (ETS) foresee including fuel combusting installations with lower capacities and gradual reduction of free allowances. This would negatively affect DHC economic and competitiveness if not counterweighted by relevant taxation of fossil fuels used for individual heating.
- Investment grants for DH connection. Clear and transparent support scheme for connecting DHC consumers would be valuable for planners and customers when considering building heating options for newly constructed buildings.

Different from individual heating solutions, best economy of district heating is achieved when heat load density is sufficiently high. Therefore it is very important connecting all heat consumers in the area to DH network making relative capital costs of an infrastructure as low as possible.

3. Competitiveness of DHC at diminished heat demand

Highest concern among technical issues is reducing heat demand and network relative heat load with lessening heating demand in renovated buildings. Newly constructed (and better insulated) buildings also use less heat. Both factors affect heat load and competitiveness of DHC technology at the same time.

DHC competitiveness against alternative heat supply in large extent is determined by capital cost of distribution networks. The capital distribution cost (CDC), as part of heat price to consumer, depend upon heat amount delivered through network and can be expressed by relative network load - amount of heat passing one meter of route (MWh/m) during one year. Capital costs of distribution network also depend on consumer's characteristics: at the same relative network load heat delivery to big consumer needs higher investments and higher capital costs comparing to a number of small consumers (Kveselis and Strazdas, 2007). Calculated CDC are shown in Fig 2

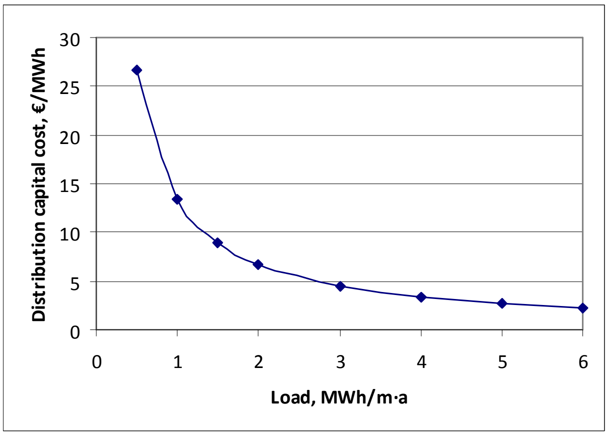

Fig 2. Average capital distribution costs versus relative heat load in networks

Average CDC of Lithuanian DH companies, depending on relative heat load vary from 3 to 10 €/MWh with weighted average of 4.4 €/MWh (shaded area in Fig 3).

Urban Persson and Sven Verner (Urban Persson and Sven Verner, 2011) provide extensive analysis of 1703 city districts and 83 cities in Belgium, Germany, France and Netherlands, demonstrating that 20% reduction of heat demand will have moderate impact to competitiveness, however 50% reduction considerably decreases competitiveness of DHC (Fig 3). Thus, assuming the marginal CDC of 8 €/MWh, present potential competitive market share of almost 70% would be reduced by 10% when heat demand decreases by 20% and becomes equal to just 15% if heat load is lessened by 50%.

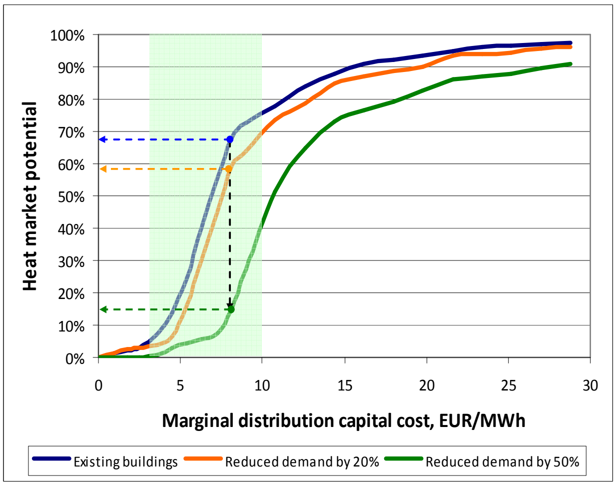

Fig 3. Influence of energy efficiency improvements of buildings to marginal capital distribution cost and market potential

Lower influence reduced demand have at higher marginal CDC. The marginal CDC here is that ensuring competitive heat price against alternative solutions (e.g. individual gas installations) for final consumers. It can be calculated as difference of DHC production and transporting costs (excluding capital distribution costs) and total heat supply cost of alternative. Marginal CDC much depends on fossil fuel taxation and fuel price difference for DHC and individual consumers.

Higher relative heat losses in existing networks at lessen demand can be compensated by lower supply temperature, however capital costs remains the same. Only replacement of steel pipes with plastic ones can somewhat reduce investment costs. However such replacement is expedient only when worn-out pipelines are replaced.

4. DHC operating characteristics

Among main barriers for wider exploration of DH there is lack of information about benefits and performance indicators clearly and simply demonstrating it to local authorities, city planners and customers. A common approach based on energy and ecolabelling principles could make comparison easier with other heat supply alternatives, such as individual biofuel installations, heat pumps etc. The task of elaboration DHC labeling scheme is set in the project Ecoheat4cities under Intelligent Energy for Europe program partially financed by European Commission.

Motivating heat consumers to connect the DHC network is a task needed addressing with serious care. Even in countries where DH is widely spread the customers and often also policy makers and city planners lacks of knowledge and clear and simple methodology for comparing DHC system with alternative building heating solutions: individual renewable solutions, heat pumps, etc.

Choosing of appropriate performance indicators must allow direct comparison and therefore be adjusted with similar indicators used for eco-labeling of alternative solutions. Primary resource factor (PRF) is among them, allowing comparison of primary (non-renewable) energy resources. As one of methods laid down in prEN 14335 can be used for DH performance assessment. The basis for this method is fuel and energy balance within DHC system boundaries, as it is shown in Fig 4.

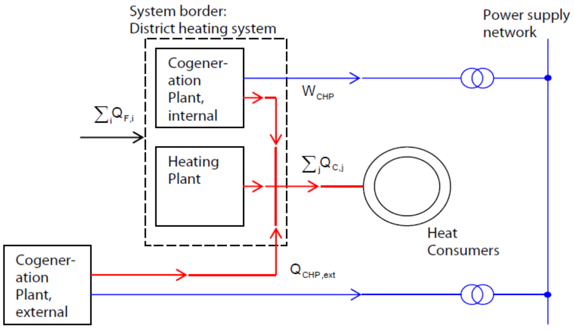

Fig 4. Method of the balance for an existing district heating system

In this balance electrical power is included as well using a primary energy factor according to that part of the fuel mix, which is replaced by heat and power cogeneration (power bonus method). According to definitions in prEN 14335, primary energy factor is primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy of the same type, taking account of the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used. Energy as input to the system is weighted by its specific primary energy factor (Table 3).

Table 3. Primary energy factor, dwelling substation performance

Fuel	Primary Energy Factor	Primary Resource Factor
Lignite Coal	1.30	1.30
Hard Coal	1.20	1.20
Oil	1.10	1.10
Natural Gas	1.10	1.10
Excess heat e.g. from industrial proc.	1.05	0.05
Regenerative Energies (e.g. Wood)	1.10	0.10
Waste as Fuel, Landfill Gas	1.00	0.00
Electrical Power, European Average	2.80	2.50

The inputs to the calculation are:

$Q_{F,i}$ -Fuel (final energy) input to the heating plants and to the cogeneration plants within the considered system within the considered period (usually one year). The amount of this energy is measured at the point of delivery.

$Q_{CHP,ext}$-heat delivered to the considered system from external cogeneration power plants.

$f_{P,F,i}$ Primary resource factor (PRF) of the fuel (final energy) inputs. The primary resource energy factor is resource energy divided by delivered energy, where the resource energy is that required to supply one unit of delivered energy. Any renewable energy component of the delivered energy is ignored.

W_{CHP} Electricity production of the cogeneration plants of the considered system.

$f_{P,elt}$ Primary resource factor of electrical power. This factor is given by the European average - in accordance to principles laid down in annex III of Directive 2004/08/EC.

$Q_{C,i}$ Heat energy consumption measured at the primary side of the substations of the supplied customers within the period of interest (usually one year).

The result of the calculation is the primary resource factor $f_{P,DH}$ of the district heating system considered. The calculation formula results from the above balance:

$$f_{P,DH} = \frac{\sum_{i} Q_{F,i} \cdot f_{P,F,i} - W_{CHP} \cdot f_{P,elt}}{\sum_{j} Q_{C,i}} \qquad (1)$$

Typical primary resource factors for DH technology and individual heating solutions are presented in Table 4. The factors were calculated using average DH performance values for fuel consumption, heat losses in networks and electricity consumption for heat distribution.

Table 4. Typical primary resource factors and relative CO_2 emissions for DH technologies and alternative individual heating solutions

District heating	$f_{P,nren}$	f_{CO2}, kg/MWh
Natural Gas (CHP)	0.18	0
Natural Gas (HOB)	1.78	265
Coal (CHP)	0.73	405
Heat pump (COP = 3.5)	1.03	186
Biomass (CHP)	0	0
Biomass (HOB)	0.40	15
Waste heat (CHP)	0	0
Waste incineration	0.16	118
Industrial waste heat	0.18	32
Building specific heating		
Natural gas (individual boiler)	1.67	224
Heat Pump (COP =3)	1.21	133
El (direct heating)	3.16	400
Biomass (Pellet burner)	0.2	14

District heating technologies with regard to primary resource usage have no advantage against individual heating if heat is produced from fossil fuel in heat-only boilers. However significant primary resource savings are obtained when waste heat from electricity production or industries is used.

The PRF values for 29 Lithuanian DH companies were calculated using (1) formulae and Lithuanian district heating association data (LDHA, 2010) on fuel mix and waste heat from CHP and industries used in DH systems (Fig 5). Calculation results demonstrate high primary resource factor in the companies using mainly fossil fuels for heat production in heat-only boilers, while companies using waste CHP and industrial heat and biomass show low PRF values. A weighted average of PRF value of all analyzed companies is 0.975 which is by 42% lower comparing with individual gas boilers.

Lower PRF value is obtained for individual biomass pellet burner. However, use of this technology in densely urbanized zones is complicated because of fuel and ash handling and local air pollution problems.

Above data now available on company's level should be detailed for each separate DHC system for the purpose of eco-labeling. Further development of DHC eco-labeling scheme includes discussions and decisions on such crucial methodological issues as national baseline PRF and CO_2 values for heat and electricity production, resource and emissions allocation principles between heat and power production in CHP plants, waste incinerators, etc.

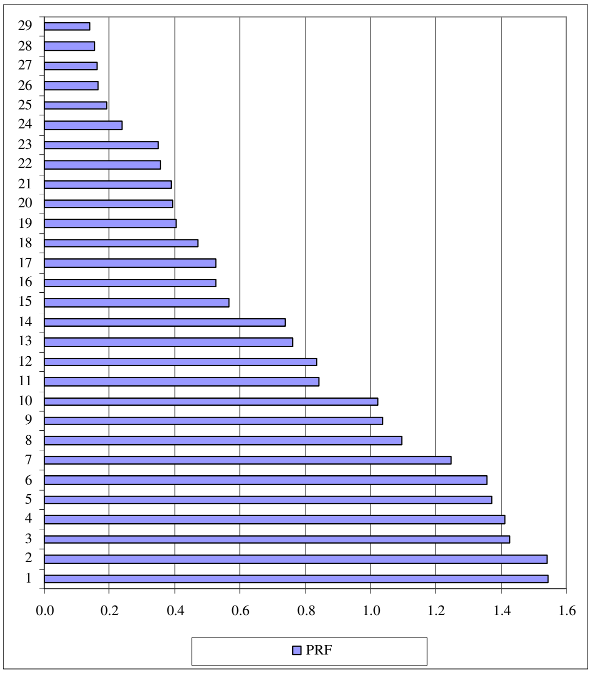

Fig 5. Primary resource factors of Lithuanian DH companies

5. Assessment of environmental efficiency

The environmental efficiency assessment of heating or cooling systems is based on the same principle as calculation of primary resource factor. CO2 emissions and air pollutants as well as the use of non-renewable primary energy resources are related to the heating or cooling energy transferred to the building. All savings and losses carried out along the whole energy chain are taken into account.

6. CO_2 emissions and CO_2 savings

CO_2 emissions are related to the use of fossil fuels and therefore CO_2 emissions are related to value of primary resource factor. Total CO_2 emissions of heating or cooling systems also depend on the specific emission factor of fossil fuel used. Using the following formulae:

$$CO_2 = \frac{\sum_i Q_{F,i} \cdot f_{CO2,i}}{\sum_j Q_{C,j}} \cdot f_{P,DH} \qquad (2)$$

it is possible to benchmark different heating and cooling technologies. Because of lower total use of fossil fuels, CO_2 emissions of district heating or district cooling systems are typically much lower than the emissions of alternative heating or cooling systems. Fig 6 presents the results of calculated renewable fuel (RES) share and CO_2 emission values for the 29 Lithuanian DH companies.

As shown in Fig 5 and 6 lower primary resource factor value means lower CO_2 emissions. CO_2 emissions are almost directly related the value of PRF. The weighted average of CO_2 emissions in DH companies is 198 kg/MWh, which is by 12% lower compared to individual gas boilers alternative. Relatively high CO_2 emission factor in some DH companies is observed. These uses mainly fossil fuels and produce heat in heat-only boilers. CO_2 emissions also depend on heat losses in networks.

Life-time CO_2 values of different fuels used in the calculations (Defra, 2010) reflect complete fuel chain starting with fuel extraction, pretreatment, transportation and effectiveness of final usage.

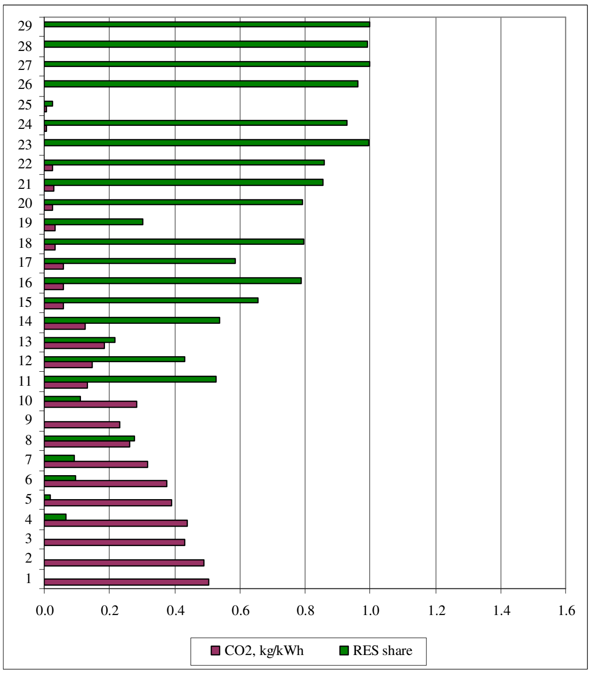

Fig 6. Renewable fuel share and CO_2 emission factors of Lithuanian DH companies

7. Discussion and conclusions

Bearing in mind general European energy policy strategy and targets it is evident, that DHC technology in Lithuania will remain as the main technology supplying energy to buildings in large cities and towns. At the same time we must conclude, that not all existing systems comply with the main district heating concept and should be changed to be in line with DHC vision – environment friendly and resource efficient way to meet heating and cooling needs. One third of companies have primary resource factors above 1, which means very small or no advantages comparing to individual heating solutions from this point of view.

Environmental performance indicator – CO_2 emission factor in this case – is also rather high in average as a result of prevailing fossil fuel used for heat production. Implementing the targets set in the National Renewable energy plan - increasing share of renewable resources from present 18% to 60-70% by the year 2020 should essentially improve this indicator. Foreseen expansion of biomass and combustible waste based CHP will positively affect both – primary resource and environmental performance indicators.

General characteristics of Lithuania DH sector – its high heat market share especially in big cities indicate strong position and therefore the important role in cities' energy supply. Developed in planned economy DH systems, however, not always were based economically and networks in many cases were shortened after disconnection of collapsed industries. Initially designed pipes appeared oversized and resulted high heat losses. Initial investments into distribution networks were made using government money and there was no significant burden of capital recovery in '90 ties and even in first decade of 21st century. However network aging problem becomes sharper when significant part of pipelines exceed 30 years in use.

Existing heat pricing regulations do not allow accumulation of means for pipe replacement, and depreciation rates based on bookkeeping value of networks are insufficient for pipe replacement. Therefore in general pipe replacement rates are below technical necessity and should be increased in the nearest future in order to avoid accidents and interruptions in heat supply especially at low weather temperatures.

The challenge of diminishing heat demand is not very important when this reduction is moderate (up to 20%), however, potential market share reduces significantly at 50% of present heat demand. The competitiveness of DHC technology also depends on energy and fuel taxation policy. In Scandinavian countries high taxes on fossil fuels increases marginal capital cost for distribution networks and as a result favorable conditions for biomass and waste based DHC technology expansion.

Increased energy use efficiency in buildings can be counterweighted by increasing build-up density, which is comparatively low in Lithuanian towns. Actually such processes are ongoing already in the main cities, but in smaller towns construction of new block houses on a large scale is unlikely. Compact cities always have better conditions for district heating (and cooling) than sparse cities.

New piping technologies and reduced supply temperatures can somewhat mitigate growth of capital distribution cost however introduction of such technologies requires also corresponding adjustments of all buildings in specific area.

The future competitiveness of district heating will always depend on the combination of distribution cost and the cost difference between district heat supply and alternative local heat supply.

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