D7.7 – Project Booklet

Fifth generation, low temperature, high exergy district heating and cooling networks

FLEXYNETS

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1 Foreword

How heating and cooling is supplied varies from country to country and from city to city. Reasons for this variation are climatic conditions, locally available energy resources and strategic energy decisions in the past. **With the global trend to urbanization, an urban approach to supply heating and cooling is increasingly relevant, limiting the import of energy**.

72% of the European population (EU28) lives in urban areas - defined as cities, towns and suburbs: 41% lives in cities and 31% in towns and suburbs[1].

It is in urban areas that the demand for heating and cooling assumes highest density. At the same time a huge amount of diffused renewable and low-grade waste heat is available within the urban texture, the largest amount being rejected by air-conditioners, cooling systems in industrial processes and tertiary buildings (i.e. dry coolers and wet cooling towers), chillers of refrigeration systems and service facilities, e.g. sewer pipes. Datacentres' chillers and supermarkets' refrigeration cabinets release a massive quantity of thermal energy: the refrigeration process in an average-size supermarket represents 50% of its energy uses and can cover the heating needs of 200 apartments.

Conventional, 3rd generation District Heating networks distributing energy at 80-90°C from a centralised generation plant to a number of remote customers are nowadays suitable solutions and consolidated praxis in many EU Member States. However, these systems suffer from

- significant heat losses
- highly unexplored integration potential of different available energy sources (e.g. renewables and waste heat) into the network
- high installation costs.

4th generation networks started to move in the direction of solving these issues by reducing supply temperature to customers down to 55-60°C, which strongly reduces distribution losses on the one hand, and unlocks the integration of a range of low-temperature, urban available waste heat sources on the other hand.

FLEXYNETS studied a 5th generation of district heating and cooling (DHC) networks that further reduce energy transportation losses, being operated at temperatures between 10 and 30°C, while reversible heat pumps exchange heat with the network itself. In this way, the same network can provide contemporary heating and cooling on the same pipeline.

Moreover, FLEXYNETS solutions can integrate effectively multiple generation sources, including low-temperature renewable and waste heat, where they are available along the DHC network. **5th generation DHC networks move forward from the state of the art, as they allow each customer not only drawing but also providing energy to the network, by rejecting waste heat from space cooling and refrigeration**.

[1] PBL Netherlands Environmental

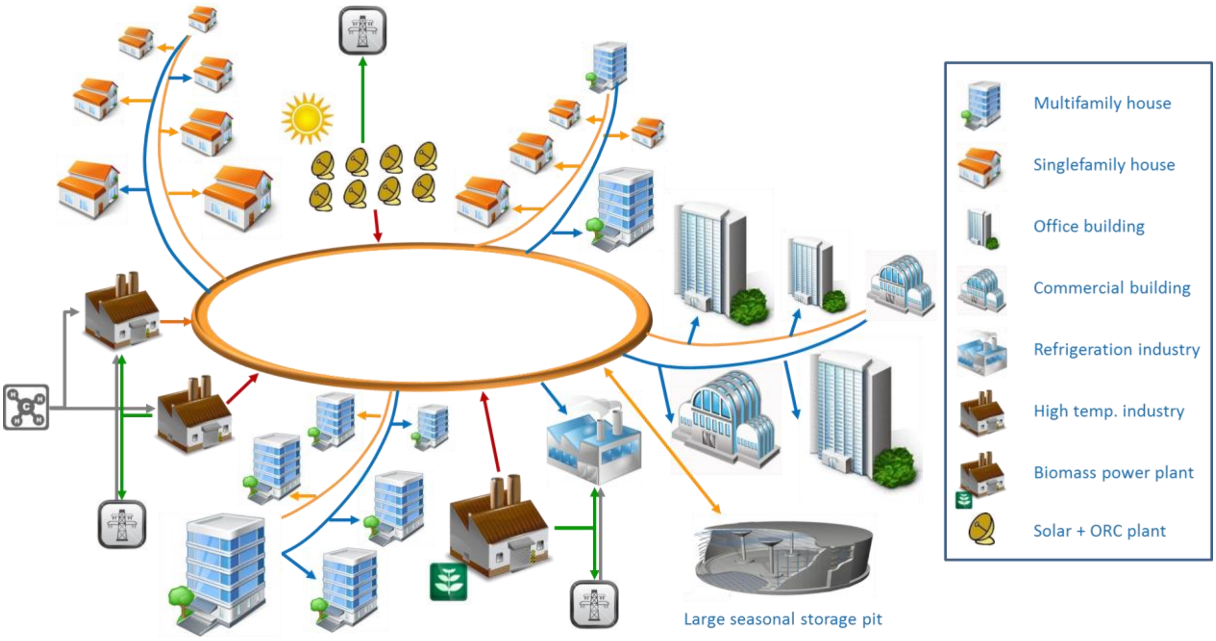

Figure 1 - Hypothesis of DHC network based on the water-loop concept

Together with thermal energy storages, control strategies that optimise the harvest of renewable energy sources are key from the technical and economic points of view. On the one hand, strategies are needed that ensure a thermal balance among diffused heat generation, storage and utilisation. On the other, approaches need to be agreed to select when energy is to be gathered locally or from the electricity grid.

This clearly complicates the management of the DHC network with respect to conventional solutions, since **it requires a high degree of digitalisation**. However, this also opens the doors to a number of new possibility:

- **heating and cooling can be not only sold as a commodity, but also as a comfort service**. Utility companies can profit of the digitalisation introduced by actively managing the energy exchanged with the single buildings, therefore enabling Demand Response practices.
- **since compression driven heat pumps are widely used, an effective coupling of the heating and electricity sectors is further enabled**, allowing to implement peak shaving and grid balancing services.

The optimal management of such new generation networks will lead to a synergic effect on primary energy savings (hence on the reduction of the CO_2 emissions), assuring at the same time investment and operation profitability.

This document is not deemed to provide detailed information on the above questions, rather to be a source of inspiration to utility companies, urban planners and local communities' decision makers when they need to start the planning process of a new DHC network. As such, here we offer a bird-eye view on the solutions analysed, while detailed information is reported in the technical deliverables published on the FLEXYNETS website: www.flexynets.eu.

2 5th generation network layouts in selected urban contexts

What would be a suitable path for a network through a town? FLEXYNETS has tried identifying the optimum layout of a DHC network in a real built environment: a range of settlements has been analysed together with different network options, in order to provide recommendations for their layout.

Figure 2 - Network layout example by using the GIS based tool for the case of Aarhus for the FLEXYNETS concept, small ring structure scenario.

Local conditions have a significant influence on the optimum solution. The analysis of DHC network layouts shows how a ring structure can be a suitable solution for urban environments: while a ring structure makes it possible to reach various heat sources along the ring, reaching the same sources with a branch structure would require a connection from the source(s) to the ‘starting point’ of the network. Hence, **the benefits of a ring structure become clear in case of waste or renewable heat that is:**

- **Available in significant quantities**
- **Scattered across the town/city**
- **Limited in each supply point**

On the contrary, if large size renewable energy sources feed the network, a branch structure is more economic feasible.

For connecting several smaller grids, the distance between two rings is in general be shorter than connecting two main branch centre points. Hence, the ring structure could have a benefit in terms of scalability and connections a neighbouring network.

In addition to this, a ring structure seems to be most feasible in dense urban areas.

However, the ring structure in some cases results in an additional investment costs as well as increased pumping costs, so care should be taken to identify (and quantify) the benefits of a ring structure in the specific case in question and compare with the drawbacks before deciding the final network layout.

The benefit of the decreased network losses in the FLEXYNETS concept becomes clear when comparing with conventional DH networks. **In the elaborated cases, the FLEXYNETS network heat losses are reduced with about 75% compared to conventional solutions**.

However, this benefit is partially compensated by the additional electricity use for network distribution pumps and heat pumps. Future energy system scenarios with large amounts of fluctuating wind and solar electricity production will require smart electricity use, facilitating the balance of demand and supply.

3 5th generation network operation scenarios

Along the project life, simulations have been run on selected scenarios, to assess interactions among buildings, energy sources and the network itself. The goal has been to provide an approximated description of the main effects at work and to identify energy performance and investment costs of the FLEXYNETS concept.

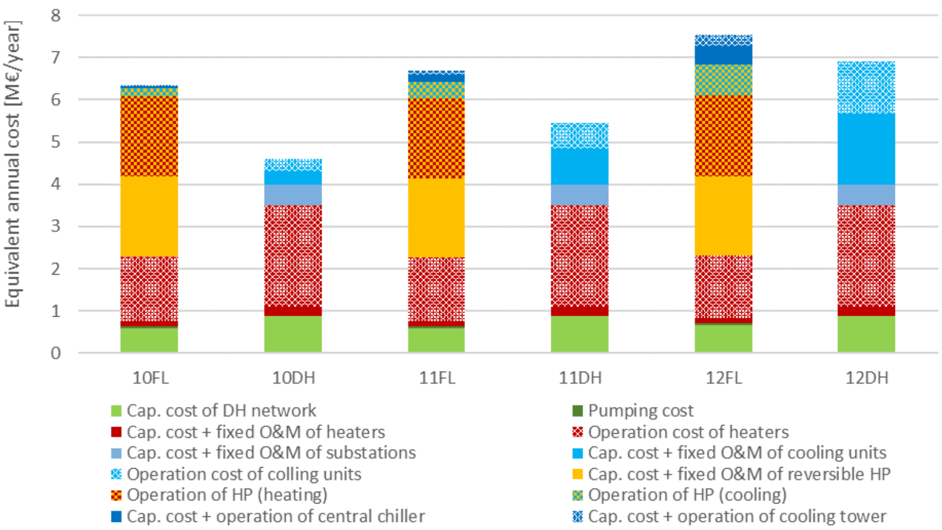

Figure 3 - Composition of the equivalent annual cost for FLEXYNETS systems (FL) and for conventional DH in different scenarios (London-10, Stuttgart-11 and Rome-12)

The scenarios in Figure 3, are calculated with a central gas boiler used as the main heat source of the network (natural gas cost equal to 30 €/MWh) and electricity costs relative to substations' heat pumps consumption born by the single customers (200 €/MWh typical of an average household tariff).

In general, it has been found that under these conditions and if only heating uses are accounted for, the FLEXYNETS approach is about 50% more expensive than conventional DH networks. While lower operation costs of central heaters are clearly encountered, these are more than topped by electricity costs at customers' substations. Moreover, distribution pipeline costs are slightly lower due to cheaper materials, but the investment needed to install the same substations is much larger than in case of conventional solutions.

This shows how building and managing 5th generation networks as "low-temperature conventional networks" is not a suitable solution.

Reducing operation costs through inexpensive waste heat and renewable energy sources is key. Economic analysis has shown that heat costs down to 15 €/MWh can be obtained through recovering waste heat from supermarkets and datacentres, and to harvesting renewable energy from geothermal energy (especially from water wells).

Reducing electricity costs to the final customer is also needed: if the electricity is fed to the substations by the utility company managing the network, better tariffs can be indeed negotiated ("industrial" electricity costs down to 100 €/MWh have been considered in our studies). Once more, the use of locally generated PV electricity improves significantly the economic performance.

Under these new operation conditions, the FLEXYNETS approach is around 20% more expensive than the conventional one. However, if space cooling is also offered as a service to tertiary and residential customers, similar (in northern climates) or better performance (in southern applications) is obtained, since space cooling through 5th generation network is inexpensive with respect to market available split units.

Although space cooling is not strictly needed in northern climates, this could be offered as a free-service, in order to gather cheap waste heat partially balancing DHW uses. In southern countries, on the contrary, space cooling could be offered as a service to customers, who therefore pay a tariff to the network manager: 90 to 100 €/MWh of cooling delivered to the substations have been assessed as suitable tariffs. **In this case, not only the operation of the 5th generation network is less expensive than the combination of conventional DH and space cooling delivered through split units, but the network manager can experience additional incomes**.

As a final consideration, investment costs relative to the installation of the customers' substations have been calculated based on equipment (heat pumps, pumps, valves, thermal storage tanks, etc.) price lists and the setup has been imagined as a custom solution mounted on site by professional. This gives no margin to economies of scale that can be obtained through industrialisation and prefabrication: **a prefabricated substation that is standardised and manufactured in a factory to be plug-and-play mounted on site, can reduce the initial investment by up to 50%. With this further cost reduction, the FLEXYNETS approach would be cheaper than conventional DH networks, also considering heating services only.**

This is therefore considered as an essential future step forward unlashing the full potential of the 5th generation of DHC networks.

4 Large storage systems for 5th generation network

FLEXYNETS has analysed the potential role of large-scale thermal energy storages in a low-temperature district heating network. Four thermal storage types have been taken into consideration:

- Tanks (TTES)
- Pits (PTES)
- Aquifers (ATES)
- borehole storages (BTES)

The storage time scales, temperatures, volume, storage medium and investment costs have been described and quantified. The required volume and investment costs are highly dependent on the temperature difference in the storage itself. As the FLEXYNETS concept works with very low temperature differences between forward and return temperatures (approx. 5-15 K difference), this would require any thermal energy storages to be larger than at conventional district heating networks.

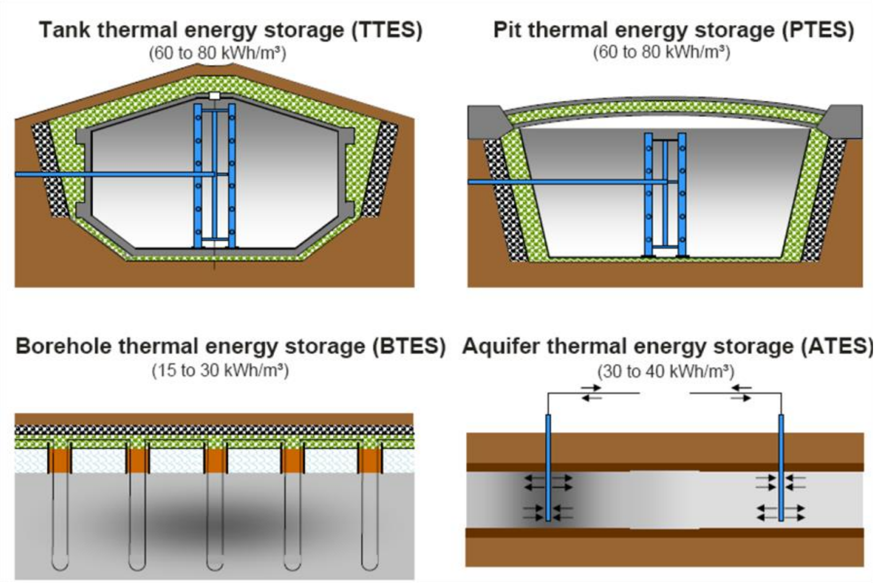

Figure 4 - Concepts of four different thermal energy storages. Figure from Mangold, 2007[2]

However, scenarios can be identified where waste or renewable heat is available at temperatures higher than the network temperature, and this heat is directly transferred to the large thermal storage. The storage can in that case take advantage of the larger temperature difference between the surplus heat temperature and the FLEXYNETS cold pipe temperature, which lowers the required storage volume and investment.

The results of the simulations have shown that especially ATES, but also PTES and BTES, can be very relevant as seasonal storage in the FLEXYNETS concept in case excess heat is available to the system. Investing in such thermal energy storages can significantly lower the system's annual CO_2 emissions associated with heating and cooling (by up to 95% in the investigated scenarios) and the heat costs (up to 50% in the investigated scenarios). These benefits can play an important role during the decision-making phase of a specific project.

5 5th generation network management and interaction with the electricity grid

Historically, Demand Response programs in the electric sector have existed to ensure grids reliability, frequency balancing and to prevent blackouts and brownouts.

In recent years, Demand Response has become a more dynamic resource that can also provide price mitigation and participate in providing ancillary services to utilities and grid operators. Until now, Europe has mainly seen commercial and industrial Demand Response projects. Little has yet been done in the residential sectors.

FLEXYNETS networks offer a massive opportunity for Demand Response services as buildings thermal loads are covered through heat pumps -therefore thermal and electric sectors are coupled- and several thermal energy prosumers can be aggregated through the network manager. Moreover, the FLEXYNETS concept is largely based on the availability and management of distributed thermal

2 Dirk Mangold, Seasonal Heat Storage – Pilot projects and experiences in Germany. Presentation at Intersolar 2007

energy storages, which can be effectively used to shift thermal -therefore electric- loads through the day.

FLEXYNETS has analysed strategies for the energy efficient integration of a DHC network with the electric grid. On the one hand, **the implementation of the control strategies shall be based on**:

- **smart meters installed at each connection to the network**. They are used to meter the energy supplied and used, and to communicate in real-time energy needs and thermal storage tanks' availabilities to the central management system.
- **datamining software capable of gathering large amounts of monitoring data** and converting it into pre-elaborated information for the control.

On the other hand, by acting in advance with respect to the foreseen thermal energy demand in each single building, an optimised balancing can be continuously guaranteed, together with low energy production and transportation costs. To this purpose, the elaboration of **management strategies based on Model Predictive Control** and adapting to the ever-changing operation conditions (through the day, seasons and year) have shown large potential.

Through this approach, the management of the network can cope with utility companies requesting to reduce/increase electricity consumption for peak loads shaving and grid voltage balancing. This will be extremely valuable in the near future to avoid negative electricity prices on the stock market during peak production hours.

Although computationally very efficient and technically effective from the load shifting perspective, the implementation of advanced predictive controls is quite complex due to the monitoring and communication infrastructure that must be set into place for their utilisation (which is far ahead the actual praxis in the DH sector). Thus, a thorough demonstration phase carried out in real networks is yet needed to move to the full-operation.

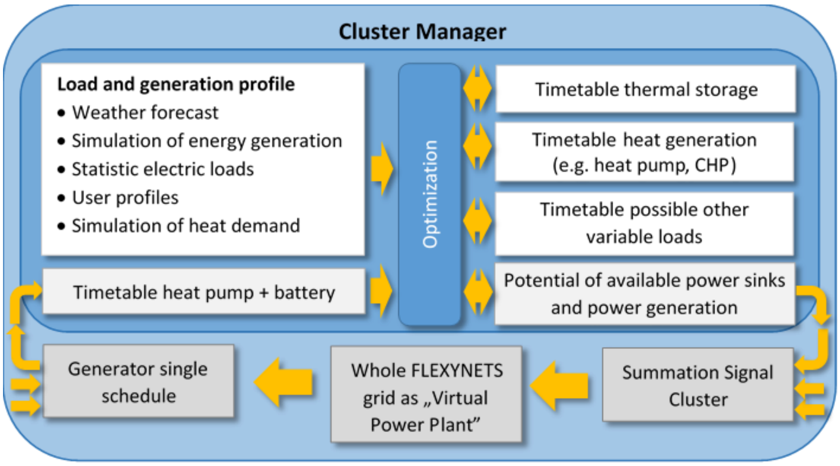

Figure 5 - Flow chart of a building cluster manager optimization routine

6 Business models for heat trading

The distributed energy generation approach elaborated within FLEXYNETS produces heat marketability and management issues: a change of paradigm is needed to move from the actual "monopolistic" generation, distribution and trading structure implemented in today's DHC networks, to a structure where multiple actors can play the role of the energy provider and where consumers can eventually profit economically from their waste heat provided to the network.

Trading strategies must stimulate on the one hand heat production from local RESs and waste heat. On the other hand, they must boost energy storage practices and off-peak drawing from the network. With respect to the first element, a number of sources can be considered as suitable for integration, starting from high temperature solar thermal fields moving to urban-available, low-grade waste heat provided by supermarkets, data centres and air-conditioning systems. With regard to the second, as the source of thermal energy cannot be switched on and off on demand, thermal capacity has to be wisely set up and managed at centralised and diffused levels (thermal storage tanks at producers and users side).

Installing thermal storage tanks at customer site (both final user and prosumer) produces contractual issues due to the additional volume needed in the technical room (compared to conventional solutions) and to the eventual demand side management.

Conversely, integrating diffused thermal energy producers in the network involves a certain risk to the energy utility company as the energy delivery through the years is not fully assured: what happens if the provider moves or goes bankrupted? Contracts assuring penalties against missing energy delivered, would reduce the risk for the utility company but probably also dishearten entrepreneurs from consider the eventual integration.

FLEXYNETS has analysed a number of operation scenarios accounting for the integration of large and small size producers and prosumers, demonstrating the economic viability potential of the FLEXYNETS solutions both from the energy providers' and consumers' perspectives. In particular, the questions addressed have been:

- What energy sources are worth to be integrated from the economic perspective?
- What price shall be granted to each energy source?
- What business models are reasonable from the energy utility and the customer perspectives (based on the entity bearing the investment cost)?

Figure 6 reports on the variants of business models accounted. We have considered two main segments: the first accounts for Energy Producers providing thermal energy to the network either from waste or renewables heat. The investment cost for the integration of the energy source into the network can be on the Producer itself or on a third part company.

In the first case, the Producer has strong interest in the implementation of the measure since it experiences direct benefits, e.g. electricity savings for a datacentre air-conditioning. In the second case, the third party can be the energy utility managing the network, an ESCO or an Aggregator acting as intermediary between the energy source and the network manager. For both combinations it is possible in principle that the thermal energy harvested is remunerated or not, and that the electricity needed to drive the Production substation is paid by the Producer or by the third part company.

A meaningful case is represented for example by the above datacentre, which integration to the network is implemented by the utility company that also pays for the electricity running the substation. In this case, the datacentre owner encounters a reduced energy consumption without any initial investment and minimal disruption during construction; therefore, it might well be that the owner is inclined to render its thermal energy free available.

On the opposite, if the datacentre owner bears the initial investment costs and pays for the substation's electricity, indeed some sort of remuneration must be set in place.

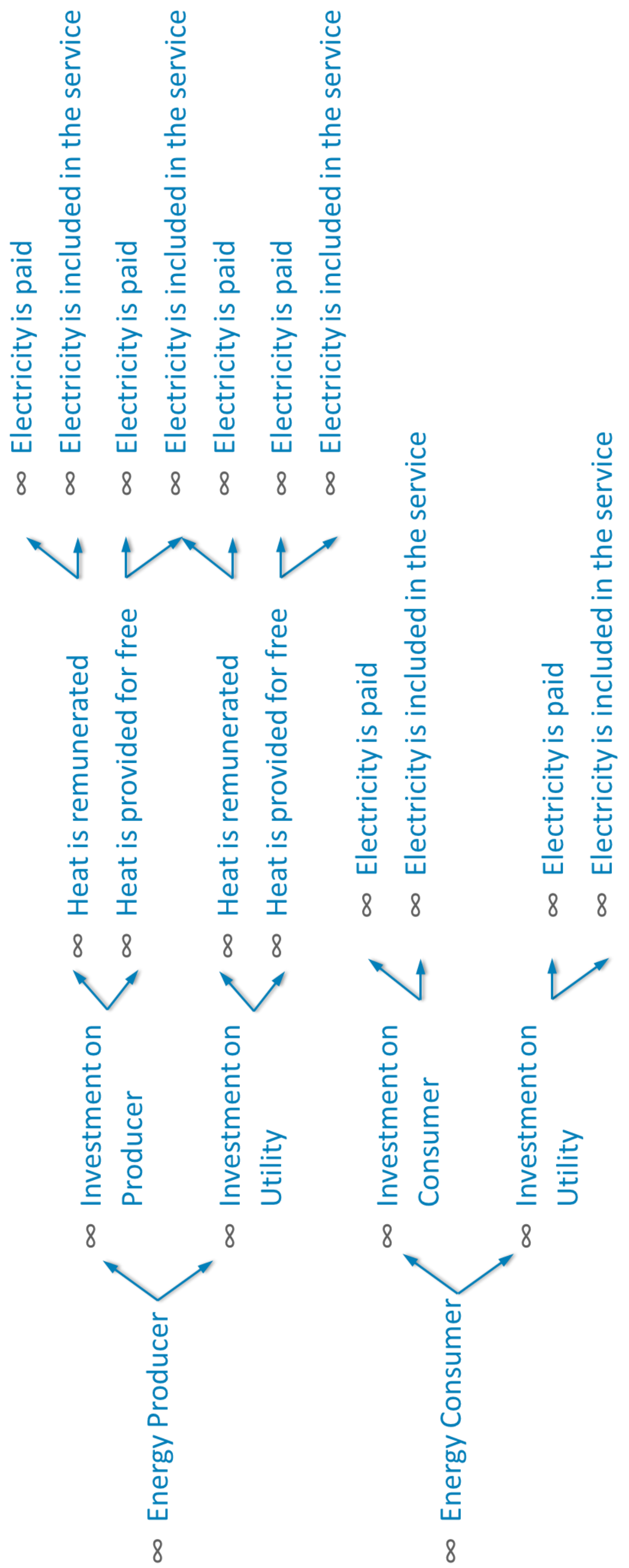

Figure 6 – Variants of business models dedicated to thermal energy Producers and Consumers

The second segment of business cases in Figure 6 mainly looks at residential and office prosumers gathering thermal energy from the network for space heating and DHW preparation and providing thermal energy to the network during space cooling operation. Once more, the investment and the substation's electricity costs can be considered on the property owner or on the utility company (ESCO, Aggregator respectively). The business cases one can imagine are largely the same as previously explained, however here we can also imagine that harvesting waste heat from space cooling is sold to the customer as a service. Therefore, the utility company gets a revenue both from selling energy for heating purposes and gathering energy from summer cooling.

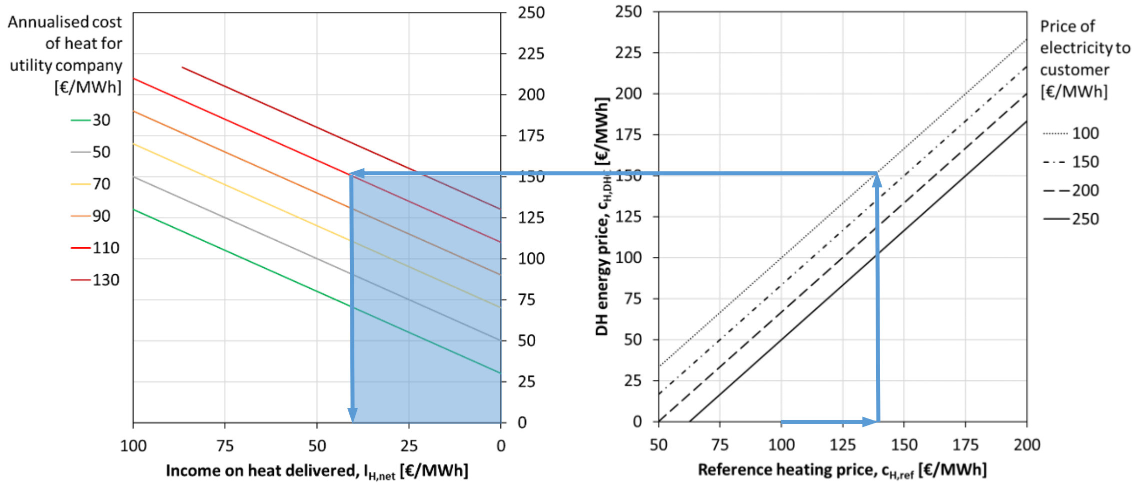

Figure 7 - Revenues (on the x-axis) based on the annualised costs of energy harvesting and distribution (heat pump SCOP at building = 4, electricity specific cost = 100 €/MWh)

The analysis of the heat trading models has shown that, depending on the temperature levels of energy source and network, the cost of energy made available can vary largely (factor 2). Moreover, better performance is obtained if the utility company managing the network also provides electricity to the single substations: in this case, customers handle only one contract covering their heating and cooling uses, while the specific electricity price is lower than what the single customer can negotiate.

As limited investments are involved in connecting substations to the network, business cases can be defined where private producers/prosumers invest. In principle, the utility company can be owner of the main network, while substations are all private owned.

Heat costs in the range of 15 to 40 €/MWh have been calculated in the most suitable cases of waste heat recovery. The same values are met with respect to renewable heating through geothermal/ground water and direct solar thermal energy integration.

The largest portion of heat cost to the final customer is related to the installation of the substations connecting the network to the single buildings: overall final costs of energy between 100 and 150 €/MWh have been computed (including heat harvesting costs). The first value is competitive with traditional gas heating and conventional district heating networks.

Space cooling offered as a commodity or allowing to gather rejected heat for free during summertime is suitable both in northern and southern countries. Waste heat from single households is a viable solution to partially balance DHW loads.