A reflection on the consequences of multifunctionality on long term sustainability with district heating as a case study

A. L. Vernay[1], K.F. Mulder[1] and K. Hemmes[1],

[1]Technology Policy and Management, section Technology Dynamics and Sustainable Development, Delft University of Technology, Delft, Netherlands

Abstract:
More and more initiatives at the local, national and international level are taken to tackle the problem of climate change. In that context Mr. Tanaka, executive director of the International Energy Agency mentioned, in a recent speech in Poznan, strategies that government should follow to “lock in sustainable technologies and reduce CO2 emissions”. Even though it is undeniable that large scale implementation of sustainable technlogies should be promoted, facilitated, and even locked-in, we should however remain cautious. Indeed, there might be a risk that technological systems with clear short term environmental benefit create a lock-in for longer term transition to sustainability. This is especially relevant when, in order to optimize their (environmental) performance, two systems with previously separate functions are integrated. The resulting multifunctionality could have positive as well as negative consequences on long term sustainable innovation potential. Using district heating as a case study, this paper intends to raise awareness in relation to this issue.

Introduction:

In the last decades, we have started to recognize that human activities are damaging to the environment and that they have consequences not only locally but also globally. Similarly, we have begun to realize that our current systems of production and consumption must evolve and meet challenges brought forward by sustainable development. The energy system is no exception. For instance if we look at the electricity system only, while about 25% of the world’s population does not have access to electricity [1], electricity generation is responsible for large emission of carbon dioxide, one of the greenhouse gases responsible for climate change. Public awareness in that respect has increased together with political commitment. Moreover, private companies slowly begin to view climate change policies not only as a threat but also as business opportunities. As such, more and more initiatives at the local, national and international level are taken to tackle the problem of climate change. In that context during the COP 14 in Poznan, Mr. Tanaka executive director of the International Energy Agency stated that "by adopting new energy efficiency measures, constructing green energy infrastructure and taking steps to integrate cleaner energy into the power grids, governments can lock in sustainable technologies and reduce CO_2 emissions" [2].

Even though it is undeniable that large scale implementation of sustainable technologies should be promoted, facilitated, and even locked-in, we should however remain cautious. Indeed, there might be a risk that technologies or technological systems with clear short term environmental benefit create a lock-in for longer term transition to sustainability. We are basing that remark on two main observations. First some technologies that are promoted as sustainable are mere optimization of existing systems. And second, in a number of cases, this optimization involves or results in new interactions between systems that were initially separated. Combined heat and power is a good illustration of these two facts. It is promoted as one of the technologies to implement in order to fight climate change. However, in itself it only is an optimization of incumbent technologies for electricity generation. Moreover, cogeneration creates a physical link between the electricity and the heat system which were initially separated.

Using district heating as a case study, the goal of this paper is to highlight that system integration and resulting increasing multifunctionality may have unforeseen consequences. Moreover, we also want to reflect upon these consequences by questioning whether implementing such technologies will facilitate or create additional barriers in a long term transition to sustainability.

District heating, an introduction:

District heating is a system where heat is produced centrally and distributed to a number of commercial or residential end users via a double pipe heat network [3]. High investments are required in the pipeline network leading to a long return on investment. The size of district heating systems may range from a single neighborhood to an entire city. When the district heating network covers a large area, there are usually multiple heat sources. This has the advantage that when there is a low heat demand, some installations can be completely shut down in order to ensure that those running do so at full load. No efficiency is then lost because of part load operation (international Energy Agency (IEA) 1999). On the contrary heating systems build on-site are designed to be able to meet peak load demand. This means that most of the time they would be working at part load and at a lower efficiency[4].

Moreover, heat losses usually between 5 and 10 % occur during transport. District heating systems are thus an interesting solution both in term of efficiency and from an economic perspective mainly in dense urban areas where heat demand is high (international Energy Agency (IEA) 1999).
The efficiency of the system also depends on the temperature of the source. It differs depending on country standards and may vary from 140°C to 68°C in low temperature district heating system. Moreover, the difference in temperature between the supply and the return flow influences overall system's efficiency as well, the higher the difference the higher efficiency. This is especially the case when the heat comes from cogeneration and the return flow is used as cooling water for the power plant (international Energy Agency (IEA) 1999).

The European Union sees district heating, especially when based on combined heat and power, as one of the strategies necessary to decrease CO_2 emissions and make the transition to a sustainable energy system [5]. Indeed, first efficiency of centralized heat production is usually higher than that of decentralized heat production. Second, it can valorize energy sources that would otherwise be discarded such as industrial waste heat. Third, as mentioned previously it can be generated by combined heat and power, increasing overall system efficiency. Finally, it can make use of renewable energy sources such as biomass, geothermal heat and solar energy.
However, some scholars are adopting a more cautious position and suggest that the presence of a district heating system can, as it has been experienced in Germany and Sweden, slow down the implementation of low energy houses. Indeed, in such a system, the costs of the infrastructure are high and in areas where linkage to a local district heating network is compulsory, developers may not have an incentive to invest both in the district heating and in technologies to decrease the energy demand of houses and buildings [6, 7]. Moreover, when industrial waste heat is used as an input, the heat produced during industrial processes changes from being considered as waste to being considered as a by-product of economic value. As such, industries may not be willing to invest in innovations that could increase their efficiency. As a result, district heating can cause a lock-in both in the input and in the output side resulting from economic, technical and institutional barriers.

Nevertheless, when analyzing both the opportunities brought forward by district heating and the possible causes of lock-in, the inherent and potential multifunctional character of district heating has not fully been considered.

In the following section we will analyze district heating as a multifunctional system and reflect on the consequences of this multifunctionality.

District heating as a multifunctional system

Which multifunctionality?

Before describing the multifunctional character of district heating, it is first important to explain the meaning of the term in the context of this paper.

The term multifunctionality has various meanings and can be used in different contexts. Materials, products, networks, processes, actors or complete systems can be described as multifunctional. Besides, can be multifunctional something that has more than one application (multi-purpose), and/or can perform multiple functions in a given production process, organization, network, system, etc., Furthermore, in literature the notion of multifunctionality is also sometimes used to refer to externalities or in other term functions or impacts that a given technology or system has on society but that do not have a market value either positive or negative [8].

In this paper we chose to focus on technologies that are or have the potential to perform multiple functions with market value. Indeed even though externalities are important to keep in mind especially when considering sustainable development, when included in our definition everything becomes inherently multifunctional. Keeping that in mind we are interested in the consequences of this multifunctionality on the way socio-technical systems operate.

Multifunctionality of district heating:

A variety functions are and could be associated with district heating energy system. First district heating is usually used to provide heat both for space heating and domestic hot water. Second, it is very often linked to a cogeneration unit, integrating the district heating system with the electricity system. Third, in summer, when heat demands are low, the district heating network can for instance also be used to deliver heat to absorption chillers that can in turn produce chilled water for cooling purposes. Fourth, cogeneration can also be considered as one of the options for demand side management if proper heat storage is developed. Last but not least, district heating can to a certain extend influence building design. This is what we can also refer to as a conditional function.

In the section that follows, each of these (potential) functions will be analysed in more details.

Space heating and domestic hot water: two separate functions

District heating was initially used for meeting both space heating and domestic hot water demand. We can say that historically district heating fulfilled multiple functions. It is still very often the case but a new trend also emerges. When low temperature district heating are developed, the DH system is only used to meet space heating demands, domestic hot water application being met using an on-site boiler for instance [4]. One of the reasons for this trend is that the quality of the heat required for both applications is different. Indeed while domestic hot water requires temperatures of at least 65°C in order to prevent Legionella growth, low temperature heating system can function with 45°C heat input [9]. As a result a decoupling of functions is slowly taking place.

Combined heat and power: integration of heat and electricity system

As mentioned previously, district heating is in many cases based on combined heat and power generation (CHP). As a result, CHP creates a bridge between the heat system and the electricity system leading to a partial technical integration of functions. We use the term partial because neither all the electricity nor all the heat is produced by cogeneration.

Both systems are driven by one particular function: the delivery of either electricity or heat respectively. Nevertheless, they also have their own technological specificities and requirements. To name only a few, regarding the electricity system, [1]the supply and demand must constantly be in balance, as failure to do so may lead to system breakdown; [2]large scale electricity storage is uneconomical, [3]it is possible to transport electricity over long distances; [4]most of electricity networks are connected to each other allowing for exchanges at transnational level. In the heat system on the other hand, [1]networks rarely go beyond the municipal boarders; [2]long distance transport is uneconomical; [3]medium to large scale heat storage is possible; [4]heat delivered should also meet the demand (both in term of quality and quantity) but failure to do so does not have dramatic technical consequences for the system. Moreover, both system involve different actors and are governed by their own regime or sets of rules.

For CHP plants, this means that on the one hand to be successfully implemented they must be able to fit in both systems and on the other hand that if they are implemented at a large scale, they may change these systems and the way they operate.

If we look at cogeneration in the Netherlands for instance, its successful implementation resulted in changes at various levels. First a number of CHP plants are owned by energy distribution companies. Indeed, in 1998, these companies were given the right to generate electricity but at a small scale [11]. As a result, thanks to CHP, EDC gained influence and power both in the electricity and the heat system. This suggests that to a certain extend, CHP led to a change in power balance in these two systems. Moreover, implementation of CHP, especially in industries and horticulture, has been very successful in the Netherlands. This had technical consequences for the electricity system. Indeed, an increasing amount of electricity delivered to the grid was coming from decentralized and uncontrolled sources. Thus as more and more CHP plants were installed, the electricity grid had to accommodate for increasing amounts of electricity that may be generated even in periods of low demand. As a result, it became more challenging to maintain the system in balance and to overcome that, new regulations had to be developed [10]. We can thus conlude that what started as a physical integration also resulted in an integration at the level of actors and to a certan level governance.

District cooling:

Similarly to district heating, district cooling is a system where cold is produced centrally and distributed to end users via a double pipe cooling network. Cold water is usually supplied at around 6-7 C while the return temperature varies between 12 and 17 C. The difference between supply and return temperature is rather small which makes district cooling a viable option only in dense areas with high cooling demands [13].

District cooling systems can be designed independently, with their own cold source or they can be integrated with district heating system. In that case, two main possibilities exist. First, a heat pump can be used both for heat and cold generation, the evaporator generating cold and the condenser generating heat [13]. This is the case in Sörnäinen, a district of Helsinki where a heat pump has a capacity of 90 MW for district heating and 60 MW for district cooling [14].

The second possibility is to use surplus heat in an absorption chiller for cold generation. Generating cold from heat has a very low efficiency and it is only economically feasible if a low cost heat source is available. This is the case for instance in summer when CHP plants produce excess heat. Two options for cold generation are possible. First heat can be transported to individual building using the district heating network and absorption chillers can be installed in individual buildings [13]. This option has been implemented in Copenhagen for example. Second, it is also possible to use an absorption chiller of higher capacity to produce cold centrally and distribute it to the various customers [13].

Demand side management:

The notion of demand side management is not new. Many governments in Europe and North America introduced policies regarding demand side management in the 70's in response to the oil crisis and the insecure supply of fossil fuels. When prices of fossil fuel decreased, so did the political interest in this concept [15]. However, recently DSM is regaining in popularity. Indeed, in order to decrease CO2 emissions, renewable energy sources such as wind and solar are being implemented. However, these are fluctuating and rather unpredictable power sources and their large scale implementation requires strategies to maintain the system in balance. Demand side management is one of them and district heating can, if equipped with the proper technologies, be used for that purpose.

To increase reliability and decrease capacity required to meet peak demand, district heating system may be equipped with heat storage facilities (international Energy Agency (IEA) 1999). These can also be used for demand side management if the district heating system is (at least partly) based on CHP. In this case, in periods of high electricity but low heat demand, the CHP plant can generate electricity while storing excess heat. On the contrary, in periods of low electricity but high heat demand, heat could be pumped out of the storage system, avoiding the production of excess electricity and risks of grid congestion. Operating CHP/heat storage in such a way can add flexibility to the electricity system and may increase the economics of CHP plants as it could better adapt its electricity production to market prices [16].

Building design:

As mentioned previously, some scholars have pointed out that the presence of district heating system could, in certain circumstances, slow down the implementation of low energy houses [6, 7]. Späth explained that very well based on a case study in Freiburg. In brief, new residential areas were to be built and connection to a district heating network was made mandatory. Moreover, heat price was divided into two main components: the cost of the infrastructure representing fixed price, and the actual cost of heat or in other word variable price. Furthermore, all the buildings connected to the district heating network had to pay for the same fixed price, regardless of their energy demand. This implied that for low energy houses, fixed price represented a larger proportion of heat price than it was for standard houses. This also limited the economic gains that could be made by investing in energy saving technologies. As a result, even though designers initially showed interest in building low energy houses, none were actually completed. This could probably have been avoided if connection to the district heating network had not been mandatory or if fixed costs were charged as a function of the demand (Spät 2005).

This example also shows that in newly built residential areas, building design and district heating system are to a certain level inter-connected. This is what we could refer to as a conditional function. This also raises the question whether or to which degree district heating system and the design of existing building influence one another. Indeed, existing building blocks with their low or average energy performance require somewhat higher temperature input than those with a high energetic performance. It is true however that transmission and distribution networks can be separated, allowing for different temperature and pressure in different parts of the district heating network. As such both buildings with high and low energetic performance can be connected to the same network.

<u>Long term consequences of multifunctionality:</u>

In the previous paragraphs, we have shown that a number of functions can be associated with district heating. For example, DH can be used both for the provision of heat for DHW and space heating. Moreover, some of these functions create bridges or links between district heating and other systems. For instance, combined heat and power plants physically links DH system with the electricity system. Moreover, when DH is used for demand side management, an additional link with the electricity system is created through the provision of a service. Finally, we have also shown that there are interactions between district heating system and building design.

This multifunctionality and resulting systems' interactions may have long term consequences on the capacity of these systems to further innovate towards sustainability. A number of questions can thus be raised. First, as we have seen, district heating, especially in new system, may be developed only to meet space heating demand and not domestic hot water as well. This raises the following question: if a decoupling of functions leads to a higher efficiency, how easily can it be done in existing DH system built to meet both demands?

Regarding combined heat and power, developments in the Netherlands were analyzed. We have seen that what started as a technological integration developed into an organizational and institutional integration as well, in other words a more mature systems integration. However, district heating based on CHP also developed in other countries. Did technological integration lead to organizational and institutional integration as well? What led to organizational and institutional system integration? Can we find a common trend in the integration process or are there differences? Finally, systems integration in the Netherlands occurred rather recently and we can question whether it will facilitate or render more difficult further transition to sustainability.

Besides, we have also pointed that the some characteristics of district heating system and building design are somewhat related. Indeed, the heating system and to a certain extend the heat

demand of buildings links to a district heating network must fit with each other. However, is connection to district heating an end in itself or are improvements still possible? For instance if the temperature of a district heating system is to be lowered in order to improve environmental performance, the heating system in all residential areas connected to it have to be adapted in order to still function properly in the new conditions. This raises a number of additional questions: can the presence of a district heating system slow down the implementation of more radical energy efficient policy in existing buildings? And reversely, can existing residential areas slow down the switch to low temperature DH? More generally speaking can sustainable innovations in district heating or building design be prevented or slowed down because of their inter-dependency? Finally, if it is so, could these potential conflicts be avoided through system integration?
Last but not least, we have analyzed the functions and resulting systems integration separately. However, it is important to keep in mind that these functions may influence one another and changes in one may have consequences on others.

Discussion and Conclusion:

The last decades, our attitude towards the environment has changed. It is not only seen as something from which we can harvest or extract resources, or against which we must gain control but also as something we must learn to live with and that we must preserve. In other words, we are starting to realize that we must make a switch towards a more sustainable mode of development. In the energy field, this translated into research, investments and implementation of renewable or energy saving technologies. Using district heating as an example, we have tried to show that long term consequences of a given technology or technological system on sustainable innovation potential are difficult to evaluate. It is even more so when the system is or can perform multiple functions. The consequences of this multifunctionality can take place at different levels: at the technological level itself as it might create new opportunities or results in new barriers. For instance in the case of district heating, the presence of heat storage makes demand side management possible. Consequences can also take place at the organizational level as the relationship between the actors as well as power balance may change. For example development of CHP was caused by and resulted in an increase in influence of energy distribution companies in the Netherlands. Finally, consequences can also take place at the institutional level as integrated governance may be required both to facilitate the implementation of the multifunctional technology and to ensure that conflicts that may develop can be overcome. Let us take the example of CHP development again. Their successful implementation in the Netherlands resulted in technical problems mainly in relation to the maintenance of power balance. To solve this problem, new regulations had to be developed to better integrate CHP and thus district heating in the electricity system.

What is also interesting with this example is that CHP has been and still is developed with the purpose to meet two separate functions. What would happen if a technology was initially developed for a single purpose but that other functions emerged over time? Similarly what would happen if a technology fulfilled more than one function but that only its primary function would be recognized? Would additional conflict emerge and what would be needed to solve them?

As a result, we would like to stress the fact that Technological multifunctionality should be identified, recognized, and its consequences on socio-technical systems investigated. Nevertheless, we must acknowledge the fact that by continuously questioning the long term consequences of technologies, we face the risk of not taking any constructive decisions. Besides given that the future can not be predicted with accuracy, we can question how much of these consequences can actually be foreseen. However, despite this uncertainty, it worthwhile to investigate necessary conditions and to develop strategies under which potential threats can be turned into opportunities.

References:

1. International Energy Agency (IEA), *World Energy Outlook 2002*, International Energy Agency, Editor. 2002: Paris.
2. International Energy Agency. *IEA calls for "Clean Energy New Deal" to stimulate global economy and combat climate change*. 2008 [cited; Available from: http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=278.
3. international Energy Agency (IEA), *District Heating and Cooling Connection Handbook*, International Energy Agency (IEA), Editor. 1999: Paris.
4. Harvey L.D., *A handbook on low-energy buildings and district-energy systems : fundamentals, techniques and examples*. 2006, London: Earthscan.
5. The European Parliament, *on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC*. 11 february 2004, The European Parliament and the council of the European Union.
6. Spät. *District heating and passive houses - interfering strategies towards sustainable energy systems*. in *ECEEE conference*. 2005. Paris.
7. Thyholt, M. and A.G. Hestnes, *Heat supply to low-energy buildings in district heating areas Analyses of CO2 emissions and electricity supply security.* Energy and Buildings, 2008. **40**(2): p. 131-139.
8. Bjorkhaug, H. and C.A. Richards, *Multifunctional agriculture in policy and practice? A comparative analysis of Norway and Australia.* Journal of Rural Studies, 2008. **24**(1): p. 98-111.
9. Dijk et al, *Voorstudie naar de effecten en het gedrag van Laag Temperatuur Systemen*, ,. 1998. Delft Netherlands.
10. Verbong, G. and F. Geels, *The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004).* Energy Policy, 2007. **35**(2): p. 1025-1037.
11. Raven, R. and G. Verbong, *Multi-regime interactions in the Dutch energy sector: The case of combined heat and power technologies in the Netherlands 1970-2000.* Technology Analysis & Strategic Management, 2007. **19**(4): p. 491-507.
12. Verbong, G., Van Selm, A., Knoppers, R, Raven, R.P.J.M.,, *Een Kwestie van Lange Adem. De Geschiedenis van Duurzame Energie in Nederland 1970–2000.* 2001: Aeneas, Boxtel.
13. Werner S, *district heating and cooling.* Encyclopedia of Energy, 2004. **1**.
14. Hokkanen. *Helsinki Energy's District Heating and Cooling with CHP*. in *Sustainable Develoment of Cities*. 2009. Zagreb, Croatia.
15. Eberhard et al, *Electricity Supply and Demand Side Management Options: the History of Demand Side Management in the Power Sector*. 2000: word commission on dams, Option Issues Series IV. 1.
16. Rolfsman, *Combined heat and power plants and district heating in a deregulated electricity market.* applied energy, 2003. **78**: p. 37-52.