Cooling needs for a warming world? Economics and governance of district cooling

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Abstract

Energy use outlook in developed countries shows a particularly fast growing component: the demand for cooling. This demand of energy for indoor air conditioning represents a challenge for environmental policies, a potential enemy of energy efficiency and energy saving and, definitely, an issue at stake for global climate policies. The trend of energy demand for cooling purposes also brings many problems for the generation capacity and the management of peak loads. The technologies for centralized trigeneration (electricity, heating, cooling) seem promising but do not always enter the market with convincing commercial strategies. Nevertheless, the presence of district heating from cogeneration plants in large metropolitan areas (like in Turin, Italy) represent the possibility of developing district conditioning. The preliminary conclusions of the research are as follows: 1) given the assumed technology and the trend for indoor air-conditioning demand, district cooling brings net social benefits from both sides of industrial figures (global investments, maintenance and running costs) and environmental externalities; 2) some cautionary remarks are due in relation to the assumptions, sometimes questionable, about emissions rate per kWh, energy efficiency in electricity production, discount rate, market prices of alternative technologies, plumbing and networking costs. The analysis does not encompass the distribution of costs and benefits among stakeholders (among the others: electricity producers, network owners, end users), a question that is more relevant in the political local arena.
Keywords: district heating, district cooling, energy efficiency, environmental cost-benefit analysis, energy externalities.

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1 Introduction

In the domain of environmental policies energy planning at local level can get interesting results in terms of energy efficiency and, consequently, reduced emissions and use of natural resources.

In particular, combined heat and power (CHP) reaches high levels of efficiency in energy conversion: using waste heat from power generation plants to supply thermal energy for domestic or industrial purposes, reduces the energy (and environmental) content per unit of product/service.

The growing demand of energy for indoor air conditioning represents a further challenge for environmental policies, in the context of troubled Kyoto implementation. The trend brings strong implications for the generation capacity and the management of peak loads; furthermore it is deemed to produce negative environmental externalities such as air emissions from plants that produce electricity, ozone depleting gases (for the old installations, to be banned in few years), end-of-life equipment disposal, indoor noise, water use for cooling purpose in electric plants, and aesthetic impacts.

In spite of the relative large diffusion of CHP for electricity and heat production, the possibility of trigeneration, which adds cold production for air conditioning to traditional CHP, is less known. Technologies for trigeneration, presented in the following paragraph, seem promising but not yet able to enter the market with convincing commercial strategies.

The presence of networks for district heating from cogeneration plants in large metropolitan areas (like the south part of Turin, Italy) or commercial-industrial district, represents a possibility of developing district conditioning (DiCon): given some assumptions about the technical options for electricity production, heat is practically free and the existing network represents an irreversible (sunk) cost that can serve also for district conditioning purposes.

DiCon enhances the energy efficiency of buildings and contribute to significant environmental results in terms of CO_2, PM_{10}, NO_x, noise, water use for cooling purposes in the CHP plant.

In a recent study [1] supported by Provincia di Torino and AEM Torino Spa, the main technological, economic and environmental constraints surrounding a virtual district conditioning project in different scenarios have been outlined.

Starting from a definition of a possible catchment area, composed of communities instead of single independent homes, the simulation sets the average energy demand for cooling purposes and the consequent running condition for the polygeneration system in the different scenarios. Consequently, an economic and environmental assessment has been conducted, from the perspective of the society as a whole: commercial and financial implications for a possible real project are not considered.

After a survey of the state of the art technologies for trigeneration, the paper summarizes the economic and environmental parts of the study and its interesting conclusions about potential benefits not only from the environmental side but also from an industrial perspective.

2 Material and methods

2.1 The market for cool

In Europe 40% of the total demand of energy comes from buildings mainly for heating and cooling purposes: 70% of this share is related to civil buildings with fossil fuels as main energy vectors.

In a typical commercial building, cooling need can account for 20% of energy consumptions, with a foreseeable increasing trend in the near future. For example, domestic chillers where 5 million in 1990 in EU countries but market estimates say that the number will be 25 million in 2020 [1,3].

2.2 Technologies for polygeneration: state of the art

District conditioning consists in a centralized production of cold water (about 5-8 °C) and the supply of this fluid to the users through a pipe network. The room conditioning is operated with specific devices (panels or fan coils) located in each single room, which are fed with cold water.

A first advantage with respect to small air coolers is that the centralized production can be obtained using medium and large power chillers, characterized by higher efficiency.

Moreover, a positive effect on the environment can be obtained using absorption or adsorption chillers instead of the more usual vapour compression chillers. Those machines allow replacement of the most part of the electricity with thermal energy, provided through hot water, usually at a temperature between 85 °C and 120 °C. When thermal energy is available as waste energy or as by-product of a power plant, it is possible to increase the overall efficiency of the system, which means that the global emissions and resource depletions are reduced without reducing the users' demand. Economic benefits can be also achieved.

District conditioning is economically sustainable in temperate climate zones, when a district heating network already exists. In this case it is possible to use the network at high temperature, which can also be reduced with respect to the winter values, to feed thermal chillers located in users' buildings. In those cases where the request for air cooling is large, it could be advantageous to provide the service through a specific district network, operating at low temperature.

On this basis, numerous district networks are operating in Germany (for instance in Dresden, Kassel, Mannheim), U.S.A. (for instance Boston, Baltimore and Philadelphia where networks operate on areas constituted by 200 to 400 buildings, feeding commercial users, industries and universities) and Japan.

From both energy and economic point of view, it is also necessary to consider that the performance (COP) of vapour compression chillers varies between about 2.9 and 4.4, depending on the scale. These indicators are defined as the ratio between the thermal energy subtracted to the indoor environment and the electricity required. It is also necessary to consider that electricity is produced in power plants, with an average efficiency of 38%.

The alternatives represented by thermal chillers are characterized by lower efficiencies (COP). In particular the COP of the absorption chillers is about 0.8, while this value is about 0.65 for the adsorption chillers. Nevertheless, it is necessary to consider that thermal energy can result as a by-product or a waste of a productive process, such as in power plants. On this basis the following considerations are formulated.

2.3 Economic and environmental aspects, actors involved

The economic assessment of complex projects from the social point of view aims to reduce the information asymmetry which hinders appropriate public choices in complex markets with relevant failures (externalities, public goods).

The analysis here presented has been conducted from the social point of view, beyond the private interest of the actors involved in the project (technology producers, buildings designers, energy producers and distributors, big final users such as hospitals, communities and malls).

As known, firm's and consumer's choices and investments are addressed to profit, personal utility, market shares and other private goals; externalities and public goods, strongly relevant for the society as a whole, can not play a big role.

Furthermore, it can happen that projects which present a positive global balance and are consistent with profit or utility goals cannot find a path to implementation because of inertia. Inertia appears when institutions, firms or individuals resist to changes in economic decisions: uncertainties about cost-benefit structure and costs-sharing, sunk costs, information shortage, time cost-opportunity and psychologic costs are the main responsible of inertia. As the economic analysis will demonstrate later, it is not sufficient for a project to show positive savings in respect to "doing nothing scenario" if the distribution of costs between actors and through the time is not clear.

2.4 District cooling in a case study: introduction

The virtual project here considered can be summarized as follows:

a) in the absence of the project the business as usual (B.A.U. scenario) foresees air conditioning through electrical appliances and associated electricity demand (80% of domestic chillers and 20% of centralized chillers), for a catchment area that grows up to 2.2 million cubic meters, in 20 years (see Figure 1).

b) the district cooling project (the project) requires initial investments, running costs and dismission costs that are compared with the corresponding costs of business as usual.

c) for simplicity, cost analysis contains elements that in more sophisticated CBA are normally broken up (taxes and welfare contributions).

d) main environmental externalities (CO_2, NO_x, PM_{10}) are taken into account in the scenarios (project and business as usual); data about other negative externalities such as noise, water use, aesthetic impacts are not available.

e) the analysis does not consider the distribution of relevant costs among different subjects (plant managers, final users, network owners and so on), with consequences that will be shortly discussed in the final part of the paper.

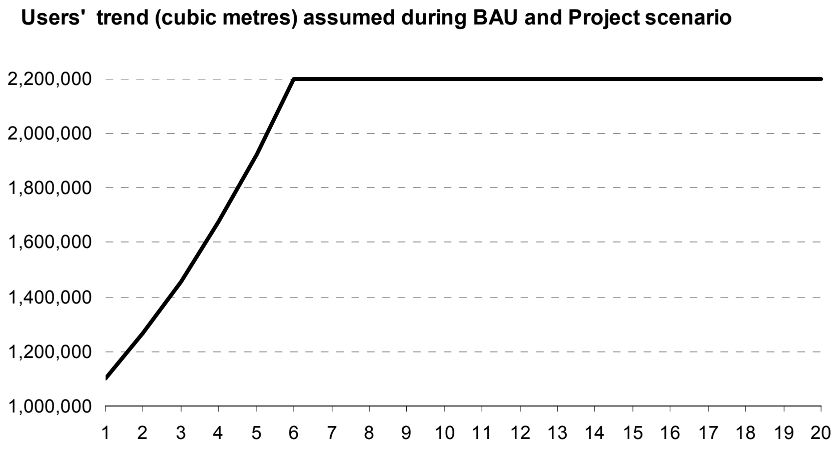

Figure 1: Trend hypothesis for the buildings volume served each year in the BAU and Project scenario.

2.5 District cooling in a case study: project description and energy analysis

The case-study considered in this project is based on the south area of Turin, where a district heating network provides heat to the buildings in this area for winter heating and in some cases for domestic water. The network is fed by a large power plant and some auxiliary boilers. The maximum heat flow is about 610 MW and the total volume of buildings is about 22,000,000 m^3

In this study district conditioning has been considered available for 10% of the total volume, quota to be reached in 20 years (see Figure 1). In the analysis, the operation of district conditioning has been considered for 800 hours at the nominal power, without any time shift between the users. The specific energy request of users has been assumed as 30 W/m^3

To comply the with the users' request, about 66 MW of cold water, through thermal chillers it is necessary that the network provides 83 MW in case that absorption chillers are used or 95 MW in case of absorption chillers are used. If vapour compression chillers were used, the electric energy need would be between 40 and 60 MW, depending on the equipment size. Energy, economic and environmental analysis must be performed considering that in case a cogenerative plant is used, it also produces electricity, that can be supplied to the grid.

The plants supplying heat to the district heating network are a steam turbine, a gas turbine and some auxiliary boilers. The main part of heat is provided by the steam turbine, through a steam extraction. Thus, when the plant operation moves from electric production to cogenerative mode, the electricity production decreases from 136 MW to 101 MW when also 162 MW of thermal energy are produced. In case these plants are used for district conditioning for 10% of the users, the overall electricity production would be 118 MW if absorption chillers are used and 115 MW if adsorption chillers are used. The primary energy requirement (fuel) is in both cases 348 MW.

As a comparison, if the same amount of electricity were produced by a power plant characterized by the average efficiency of the Italian plants and the air conditioning were operated through vapour compression chillers, the primary energy requirement would be between 380 and 420 MW, depending on the size of chillers. This means that additional fuel depletion and externalities are associated with this case, with respect to the use of district conditioning.

Both the economic and environmental impacts of this choice are discussed below.

2.6 District cooling in a case study: cost analysis

The BAU case and the project are economically specified by a list of costs that are attributed mainly to indirect methods (cost-coefficients from the literature).

The cost categories are the following.

Design costs: costs of dimension setting, safety equipment, the need for space for chillers and other machineries are estimated as € 26 per installed kW for the 66,000 kW installed [4].

Initial investments: domestic (80%) or centralized (20%) electric chillers for the B.A.U. scenario; adsorption equipment for the project case. In both cases equipment costs are estimated on the basis of coefficients (€/kW) [5]

Connection and plumbing costs: they include connection to the district heating network, internal piping and possible costs on the "last mile". In case of new connections to clients, the cost of the necessary segment of network should be, in theory, attributed to district cooling only for the extra-cost due to extra-diameter of pipes. Thus the assumption overestimates, precautiously, the cost of connections to new users.

Maintenance costs: estimated as a percentage of the initial investment costs.

Electricity consumptions quantified on the basis of the domestic market price per kWh in the B.A.U. case. For example, an average apartment (240 m^3) is characterized by a yearly cost of € 200 with a price of € 0.1172/kWh. In the B.A.U. case, effective consumption by chillers is estimated. In the project case the analysis accounts for negligible absorption consumption plus the electricity crowded-out at the power plant for the mentioned trade-off.

End of life: a cost of € 0.104/kg of equipment to be disposed of, assumed to occur at the 21st year of the timeline of the analysis.

Externalities: physical quantities (tonnes of CO_2, PM_{10}, NO_x) are estimated as follows: in the B.A.U. case, emissions per kWh are those typical of the Italian average thermal gross production. In the project scenario emissions are those specifically produced to satisfy extra-demand of thermal energy for cooling purposes, at the power generation plant which supplies energy to the district heating system in Turin. Indeed, as known, there is a partial trade-off between electricity and heat production. Monetary values come from a prudential survey of the literature on putting a value on externalities, in particular the ExternE project by the EU ad its recent updates [6].

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3 Results

Table 1 presents values (P.V.) of direct market costs and environmental externalities for the project and business as usual are presented. The P.V. result from discounting at 5% rate the yearly values in the time range of the analysis (20 years).

As shown in Table 1 the district cooling project implies market costs of around 33 million Euros, in present value, distributed in the 20 years. Compared with more than 55 million Euros in the B.A.U. scenario the potential savings are relevant. The cost variables that contribute mainly to the result are initial investments (much higher in the B.A.U. case for diseconomies of scale), connections (higher in the project for obvious reasons), electricity consumption (relevant savings in the project case, due to use of waste heat for cooling instead of electricity).

Furthermore, the project brings also environmental net benefits that amount to more than 5 million Euro saved, at present value, in negative externalities for 20 years: the net result comes from a direct comparison of the externalities flows in the competing cases. Figure 2 and Figure 3 show the yearly nominal values for costs and negative externalities.

Shortage of reliable data about water uses for cooling purposes and indoor noise suggests they should not be included in the analysis.

Table 1: Market costs and externalities (Euro) for the BAU and Project scenario.

	Business As Usual *present values (r=0.05)*	**Project** *present values (r=0.05)*	**Project vs B.A.U.** *present values (r=0.05)*
Market Costs (Euro)			
Design	302,105	3,233,048	2,930,944
Initial investments	28,890,733	9,699,145	- 19,191,588
Connections	2,805,650	12,450,695	9,645,045
Maintenance	1,162,919	1,459,745	296,826
Electricity consumptions	22,119,701	6,221,166	- 15,898,535
End of life	22,748	59,021	36,274
Total market costs	**55,303,856**	**33,122,821**	**- 22,181,035**
Externalities (Euro)			
CO_2	3,711,133	324,676	- 3,386,457
Nox	1,164,543	94,415	- 1,070,128
PM_{10}	795,985	64,534	- 731,450
Water use	n.a.	n.a.	n.a.
Noise	n.a.	n.a.	n.a.
Energy saving	n.a.	n.a.	n.a.
Total externalities	**5,671,660**	**483,625**	**- 5,188,035**

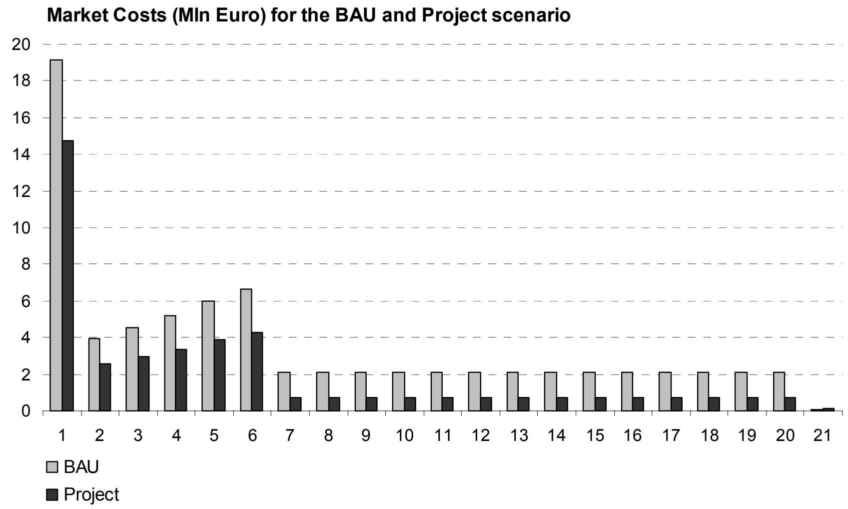

Figure 2: Total Market Costs: design, investments, connections, maintenance, electricity consumptions and end of life (Mln Euro) for the BAU and Project Scenario.

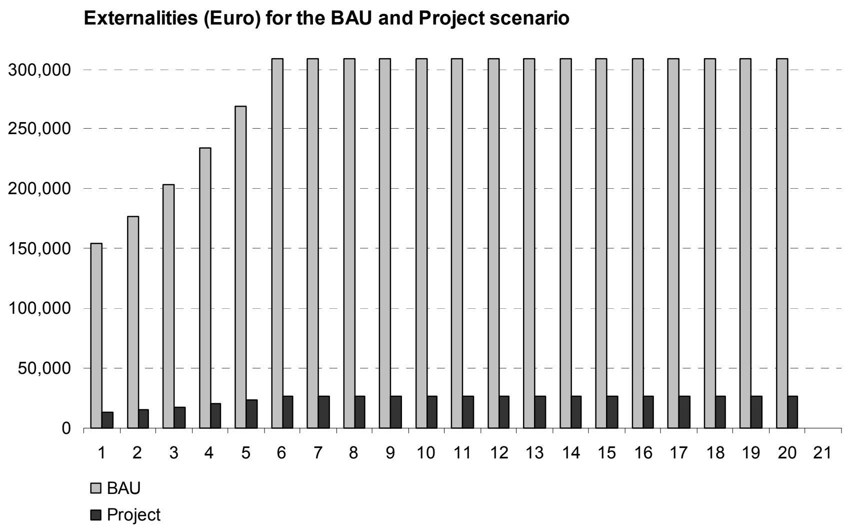

Figure 3: Negative externalities CO_2, NO_x, PM_{10} (Euro) calculated with damage factors per ton of pollutant emitted in EU-15 [7].

4 Discussion

The results of the analysis are based, as always, on a set of hypotheses and simplifications. The authors have made handicraft sensitivity tests, with encouraging results (changes in the values of some crucial variables does not overturn the balance in favour of the project of district cooling). Yet, for complete information, the main critical aspects of the analysis are listed in the following points, some work in favour of the project, some against it;

- the share of 80% attributed to domestic chillers in the BAU scenario could be overestimated. Centralized chillers may be interested by price falling due to economies of scale;
- the presence, in the cost list, of elements that in more sophisticated CBA are normally broken up (taxes and welfare contributions) should not encompass significant biases because the simplification is assumed in costs of both scenario, leaving the balance as it is;
- externalities are crucial to represent the overall social costs and benefits of a project, nevertheless their existence is practically irrelevant for market choices of firms and consumers. Policies for externalities internalization (taxes, tradable rights, subsidies, etc) are recommended;
- district cooling could also be assessed as a complementary system for air conditioning: in this case DiCon would supply a basic quantity of thermal energy, leaving the satisfaction of peak loads to traditional vapour compression equipment;
- The positive global performance of the project versus BAU scenario should be taken with care: apart from total cost figures it is important to know more about cost sharing among different actors: the power plant owner, the network runner, large end users (hospital, commercial building, civil buildings), small end users. As an example, the willingness to pay for connections and plumbing could make a big difference for the practical feasibility of the project.

5 Conclusions

Technologies for trigeneration seem to be in a particular phase of their product life-cycle: they are promising but not yet able to enter the market with convincing commercial strategies. Obstacles at work are the large fixed costs for the networks and indoor plumbing, the high (in absolute terms) average cost of machinery (mainly absorption-adsorption equipment) due to narrow markets and their relative low, though improving, energy efficiency: furthermore, electricity producers and distributors have no interest, in the short-middle term, to develop technologies that erode the business of electric utilities.

Nevertheless, the presence of district heating from cogeneration plants in large metropolitan areas represents a possibility of developing district conditioning: given some assumptions about the technical options for electricity production, heat is practically free and the existing network represents an irreversible (sunk) cost that can serve also for district conditioning (DiCon) purposes.

In spite of doubts about the economics of DiCon from a business perspective, environmental externalities and social benefits should be highlighted in order to assess it. In particular, the following benefits are at stake: CO_2, NO_x and PM_{10} reduction, primary energy savings, water use reduction, noise abatement and aesthetic improvements.

The preliminary conclusions are as follows:

1) given the assumed technology and the trend for indoor air-conditioning demand, district cooling brings net social benefits from both side of industrial figures (global investments, maintenance and running costs) and environmental externalities.

2) some cautionary remarks are due in relation to the assumptions about energy efficiency in electricity production (which influence the emission rate per kwh), discount rate, market prices of alternative technologies, plumbing and networking costs. Furthermore, the analysis does not encompass the distribution of costs and benefits among stakeholders (electricity producers, network owners, final users and so on).

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