SOLAR ELECTRICITY IN SWEDISH DISTRICT HEATING AREAS

– EFFECTIVE ENERGY MEASURES IN APARTMENT BUILDINGS TO INCREASE THE SHARE OF RENEWABLE ENERGY IN EUROPE

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ABSTRACT

To overcome the climate challenge is one of the greatest tasks of our time. In EU, renovating the existing building stock has been found an effective measure. In Swedish buildings with district heating, lowering heat demand could be questioned, because the energy used is mainly renewable bio energy or waste heat from industries. In addition many district heating systems cogenerate electricity, which could reduce the overall European greenhouse gas emissions.

The aim of this article is to find effective measures for Swedish apartment buildings, in order to increase the share of renewable energy in European energy consumption. As a basis we use a previous study of energy saving potentials in apartment buildings. Added to this we study the impact of heat savings in 30 of Sweden's largest district heating systems.

The results show that on average heat reductions will lead to a decreased share of renewable energy, while electricity reductions will lead to an increased share of renewables. Of the investigated measures, using photovoltaics for local solar electricity generation has the largest potential.

Our conclusion is that using the potential of solar electricity production should be considered in national energy policy and future building requirements. Heat reduction, on the other hand, could have lower priority in district heating areas, at least for existing buildings.

INTRODUCTION

A. THE CLIMATE CHALLENGE

The latest report from the International Panel on Climate Change (IPCC) shows that emissions of greenhouse gases must be reduced very dramatically in order to reach the 2 degree target of the 2010 UN Cancun Agreements [1], [2]. Ultimately the climate challenge is an act of will. The humanity has to ignore the possibility to use fossil fuels and leave them preserved – at least to a very large extent. The starting point of this article is a long term goal of a global energy system with 100% renewable energy (all sectors included), as described in the Ecofys Energy Scenario [3].

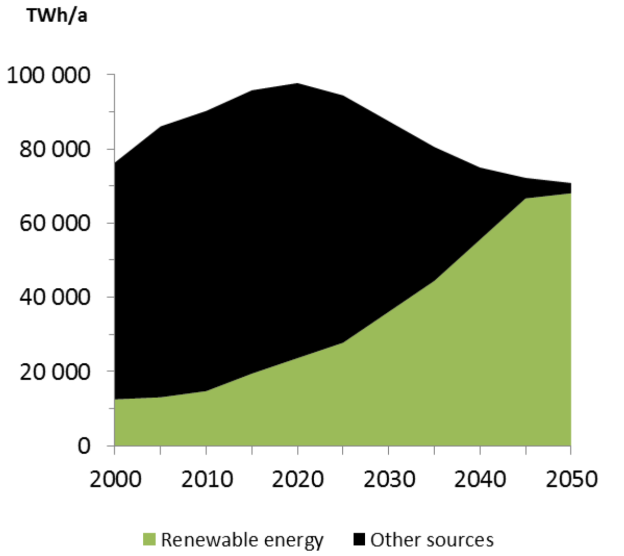

Fig. 1 Ecofys Energy Scenario, aggregated to renewable energy and other sources [3].

B. THE ENERGY SITUATION IN EUROPE

The situation in the European Union is about the same as on the global level, with a renewable energy share of about 14%. Buildings account for 40% of the total energy use, if the sectors Residential and Services are included, and 65% if also Industry is included [4].

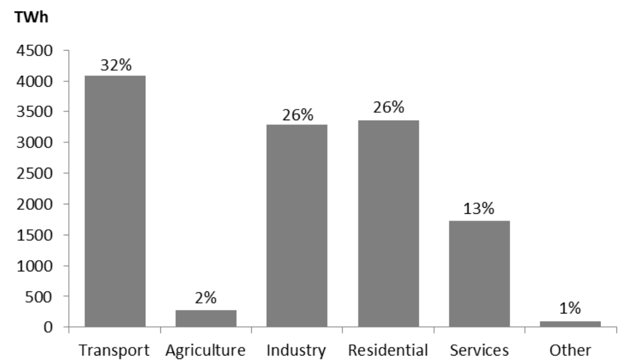

Fig. 2 Energy use in EU 2012 [4].

The share of renewable energy is lower in Transport and Agriculture, but the total use of non-renewable energy is larger in the built environment (including industry).

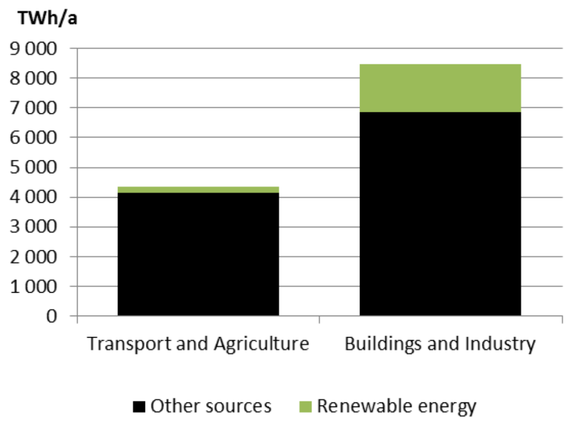

Fig. 3 Energy use in EU 2012. Processed statistics from Eurostat [4]. The share of renewable energy in agriculture is assumed to be zero.

To reach the goal of 100% renewables, the use of other sources has to be reduced as well as the overall energy consumption. According to the Energy Roadmap 2050 from the European Commission all sectors need to invest in energy efficiency [5].

In this work we will analyze the environmental benefits from energy reductions in buildings and to do this thorough we have to distinguish between the reduction of heat and electricity. From Eurostat statistics we have therefore calculated the shares of renewable energy used for producing heat and electricity, according to figure 4 [4].

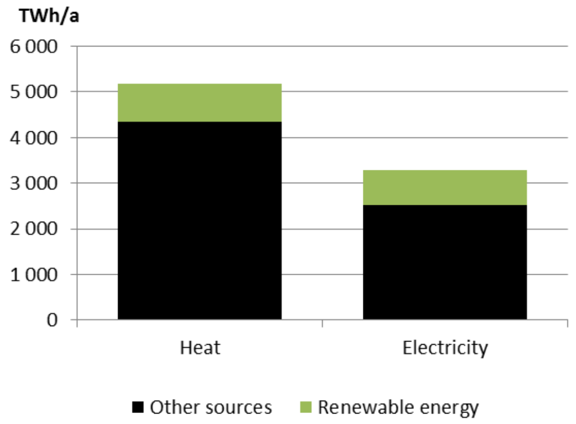

Fig. 4 Energy used in EU buildings and industry 2012. Processed statistics from Eurostat [4]. It is assumed that all energy used in these sectors can be characterized as either heat or electricity. In the calculations electricity used for transport and agriculture has been assumed to be zero.

It is also instructive to show the differences between countries, which make it obvious, that the most effective strategy might not be the same for all. Figure 5 is showing the renewable energy shares of energy used as heating and electricity in buildings and industry. Electricity used for transport and agriculture is assumed to be zero in the calculations.

Norway and Sweden stands out, with a very large use of electricity, which in turn has a large share of renewables (mainly hydro power). One can also see that the renewable energy share for heating is large in several countries, with Sweden outstanding.

C. ENVIRONMENTAL ASPECTS OF HEAT AND ELECTRICITY REDUCTIONS

Heat is always used locally or distributed in local areas, whereas electricity can be transited cross-borders. This makes the complexity of environmental issues regarding heat and electricity reductions very different.

The simplest case is heat produced with a boiler in the building. Reduction of heat in this building will of course correspond directly with reduced need of fuel to the boiler.

In a district heating system, the production of heat is usually done with a mix of fuels. Reduced heat demand will in this case generally correspond to a reduced need of the most expensive fuel, which can vary from time to time. In addition the district heating demand is in many cases used for cogeneration of electricity. This means that reduced heat demand could lead to reduced electricity production.

In the same way production of electricity is done with a mix of fuels. And since countries are interconnected, reduced electricity demand in one country may lead to reduced fuel need in another.

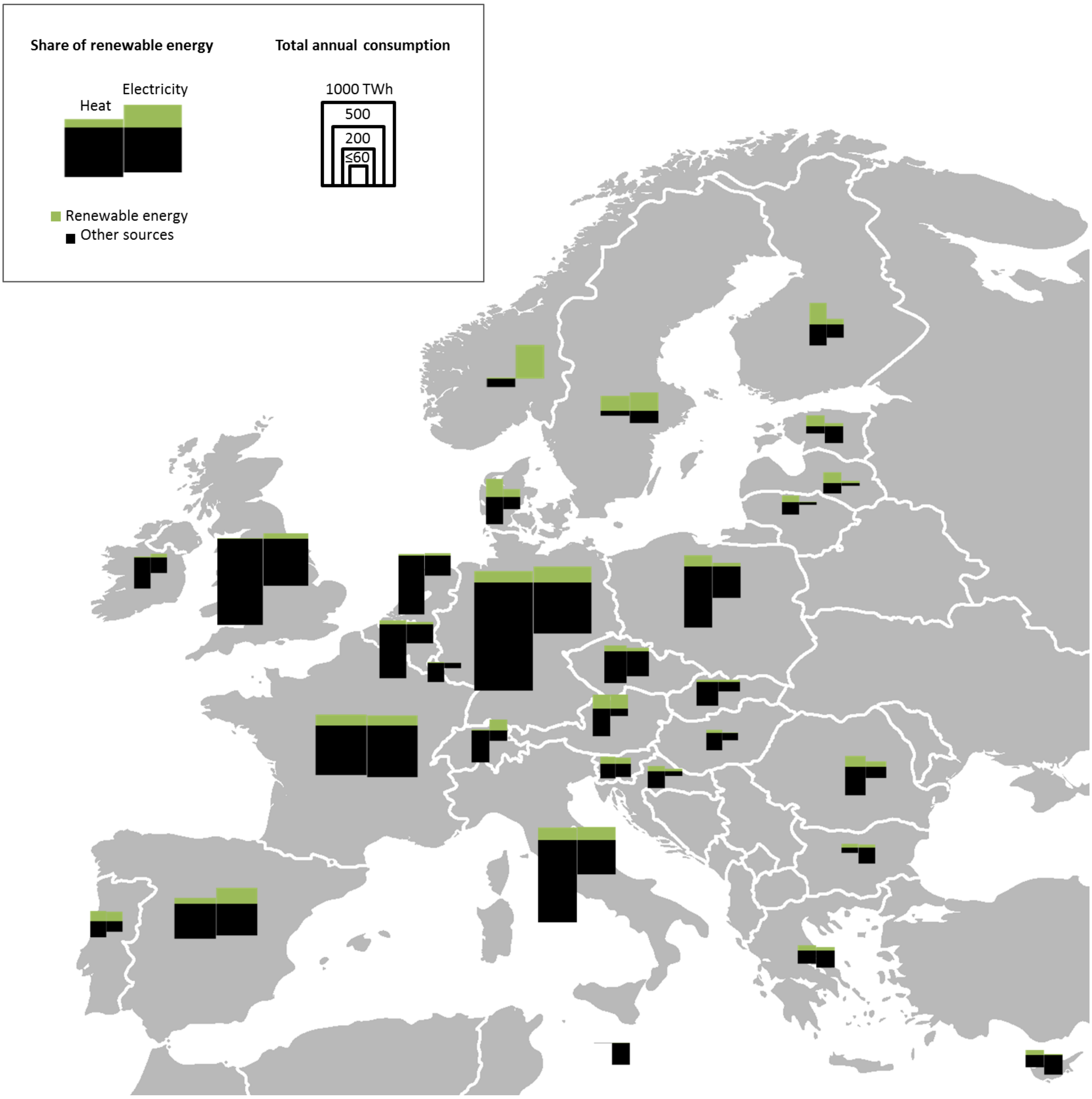

Fig. 5 Annual heat and electricity use in EU countries, Norway and Switzerland. Processed data [4],[6],[7].
All energy, which is not accounted for as electricity, is assumed to be used as heat. (Electricity used for transport and agriculture has been assumed to be zero in the processing. Renewable energy share in agriculture is assumed to be zero.)

D. ENERGY SAVING POTENTIALS

In our work we have focused on Swedish multi-dwelling residential buildings, which accommodate 55% of the total dwellings in Sweden and are usually connected to district heating [8], [9].

In a study from 2012, the energy savings potentials in 11 apartment buildings in mid Sweden were analysed [10]. Table 1 show average figures from this study.

Table 1 Avarage energy saving potentials for different energy measures in Swedish apartment buildings, processed figures [10]. Percentage of total energy used for space heating, tap water and ventialtion, and energy used per square meter heated area.

Measure	**Energy savings**	
	% of total	**kWh/m^2**
Insulation on walls	17%	25
Insulation on attic	5%	10
New windows	10%	15
Heat recovery ventilation	10%	13
Solar collectors	9%	12
Photovoltaics	9%	13
Lighting	1%	1

Most of the measures are focusing on heat reduction; only photovoltaics and lighting will give reduced electricity use. Heat recovery ventilation will even give a slight increase in electricity use, which is not accounted for in the presented figures.

By definition, solar collectors and photovoltaics will supply energy to the building and not reduce the demand. However, with a traditional view of the energy system where buildings are consumers of energy, solar energy supplied to a building will have the same effect as energy reductions. In our work we therefor consider all presented measures to be energy saving measures.

E. PURPOSE OF THIS WORK

We want to investigate how owners of Swedish apartment buildings can contribute to reaching the goal of 100% renewable energy, which leads us to the following research questions:

- What is the difference between district heating and electricity savings, in terms of the impact on overall renewable energy shares?
- Which building related measures are the most effective to in the pursuit of reaching 100% renewables?

STATE OF THE ART

Climate benefits are generally quantified as reduced CO_2 emissions. This requires complex calculations in combination with trying to answer a series of questions about how to allocate emissions and how regulatory framework and market functions interact with your measures [11].

In order to reduce the complexity we only focus on the share of renewable energy. This will make the results less exact, but still indicative to formulate an appropriate strategy.

METHODS

A. DISTRICT HEATING SAVINGS

We have picked 30 of the largest Swedish district heating systems with a total heat delivery of 33 TWh in 2012, which is 60% of all heat deliveries in the statistics from the Swedish District Heating Association [12]. The energy mixes of these systems have been divided into four compounds; renewable energy, waste heat, electricity and other energy sources.

We have then estimated the effect of reduced heat demand, taking into account any cogeneration of electricity or use of heat pumps. The assumed ratio between cogenerated electricity and heat is 1:3 and the assumed ratio between input electricity and output heat in heat pumps is also 1:3.

The renewable energy content of waste fuels varies between district heating systems and is for instance 55% in Stockholm and 85% in Gothenburg [17], [18]. In our work waste fuels are considered to be 75% renewable and 25% fossil. Peat is considered as a non-renewable fuel.

In some cases heat is exchanged between district heating systems. This heat is considered to have been produced with 70% renewable energy and 30% energy from other sources.

The data used is annual figures, which is a limitation for the accuracy of the results. This will be further commented in the discussion.

B. ELECTRICITY SAVINGS

The effect of electricity savings has been investigated by many parties, among them Swedish Electrical Utilities' R & D Company (Elforsk). In their report it is stated that there are a number of approaches that can form the basis for environmental evaluations but that the concept of marginal electricity was concluded to be of central interest [13]. By marginal electricity they refer to the last used unit of electricity at any given point of time, which generally is supplied with the most costly means of generation in the generation merit order.

The nature of the marginal electricity thus can shift from time to time, but for reduced electricity use in Sweden the effect will most likely be reduced use of fossil fuels in condensing power plants, either in Sweden or in some of our neighbor countries, as shown in figure 6. Even though the power balancing is usually made with hydro power, the hydroelectric energy will be saved in the reservoir to be used later.

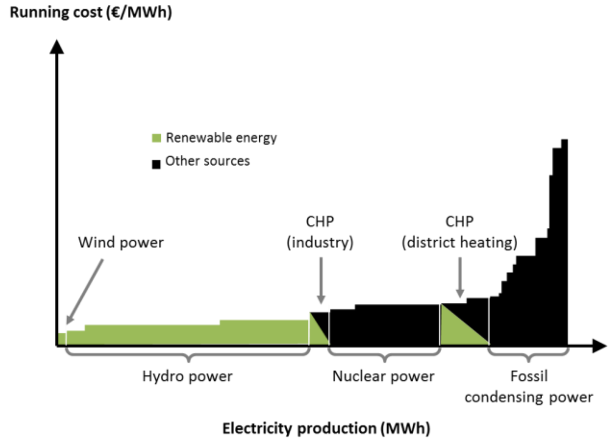

Fig. 6 Principle diagram of running costs for producing electricity, which is used in Sweden [14].

According to EIA the average efficiency of coal-fired plants was 32.5% in 2012 [15]. In our work the ratio between electricity produced and fuel energy used is assumed to be 1:3.

RESULTS

Figure 7 gives an overall view of the studied district heating systems, with fuel mixes along with import of waste heat from industries and net import/export of electricity. Renewable energy sources are dominating, but other sources are not neglectable in many cases (coal, oil, natural gas, peat and the fossil part of waste). Many of the bigger systems have cogeneration of electricity (resulting in electricity export) and a few systems depend highly on waste heat from industries. 9% of the total heat delivered is produced with heat pumps.

For each district heating system we calculate the average effect from heat reductions on fuel use and import/export of energy, according to (1).

$$\Delta E_F = \Delta E_H \left(\frac{E_R + E_W + \Delta E_E + E_O}{E_H} \right) \quad (1)$$

where ΔE_F is change in fuel use and import/export of energy,

ΔE_H is change in heat delivery,

E_R is total annual use of renewable fuels,

E_W is total annual use of waste heat,

ΔE_E is the total annual corresponding net use of electricity,

E_O is total annual use of other fuels

and E_H is total annual heat delivered.

The corresponding net use of electricity is in turn calculated according to (2).

$$\Delta E_E = \frac{E_{HP}}{3} + E_E - \frac{E_{PROD}}{3} \quad (2)$$

where E_{HP} is total annual electricity used in heat pumps,

E_E is total annual electricity used in electric boilers and other equipment

and E_{PROD} is total annual electricity production.

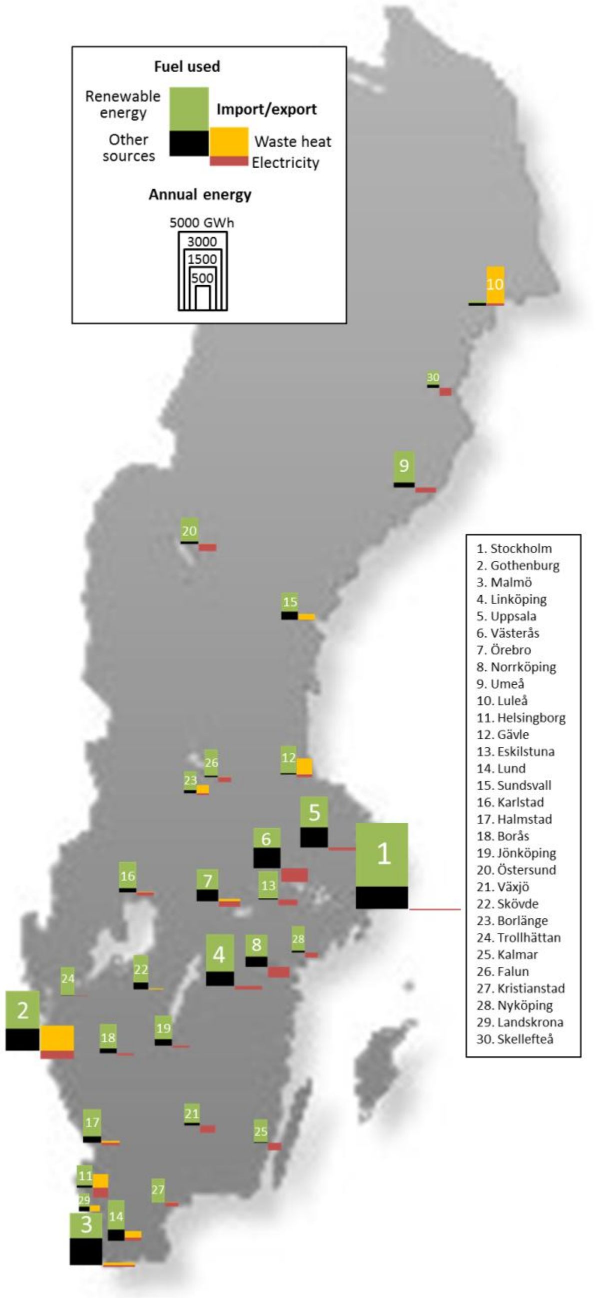

Fig. 7 Energy used for heat production in 30 Swedish district heating systems in 2012. Negative values show export of electricity due to production in combined heat and power plants [12].

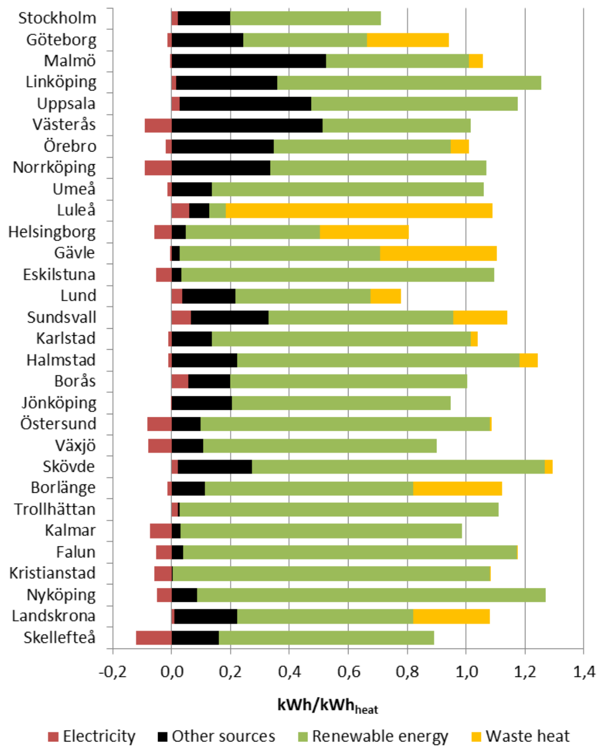

Fig. 8 Reduction of energy used for district heating production, when reducing heat demand. Negative values means that energy use increases. Calculated from annual figures for year 2012. [12]

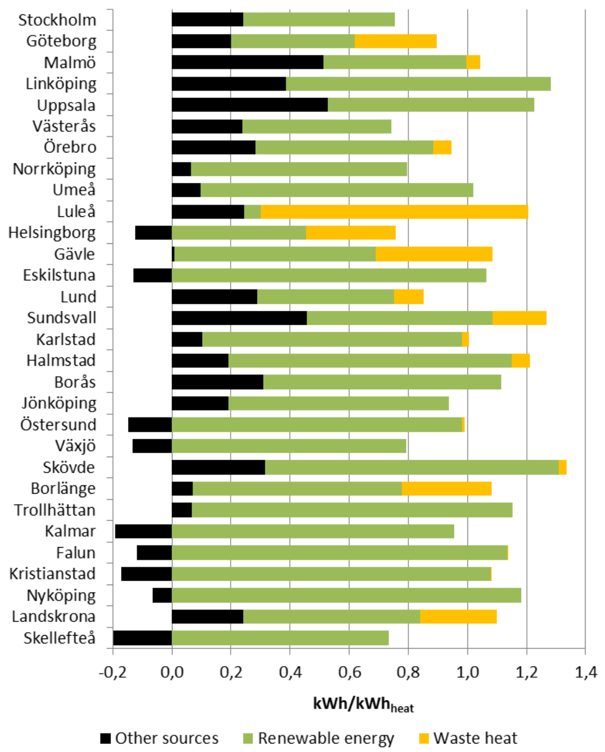

Fig. 9 Reduction of energy used for district heating production, when reducing heat demand. Assuming marginal electricity produced by fossil fuels. Negative values means that energy use increases. Calculated from annual figures for year 2012 [12].

Figure 8 shows the calculated changes in fuels used or waste heat and electricity imported, due to end user heat reduction. Positive values indicate reduced use of fuels or reduced import of waste heat and electricity. Negative values indicate reduced export of electricity from cogenerating plants.

The sum of changes might be >1 due to boiler losses or <1 due to use of heat pumps or to cogeneration of electricity.

In figure 9 values for electricity has been converted to fossil fuel, assuming marginal production in fossil-fired plants, according to (3).

$$\Delta E_{O,E} = 3 \cdot \Delta E_E \tag{3}$$

where $\Delta E_{O,E}$ is the total annual net use of non-renewable energy sources corresponding to change in electricity use.

In some cases the amount of non-renewable fuel energy is reduced by 50% of the heat reduction, but in general heat reduction corresponds to less than 30% reduction of non-renewable fuels. In 9 cases heat reduction will lead to increased use of fossil fuels, because of reduced electricity production in cogenerating plants.

When using the average values of the 30 district heating systems studied, and comparing them with reduction of electricity, the result is according to figure 10.

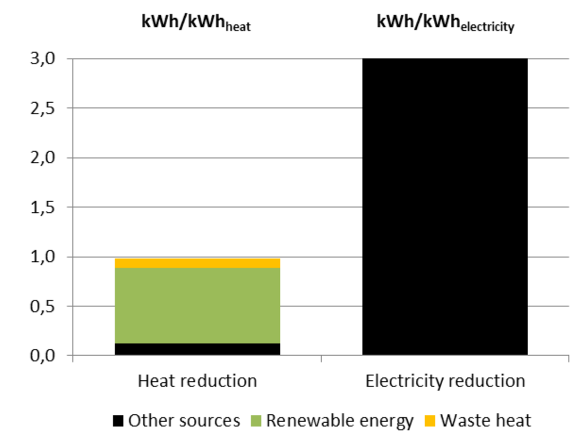

Fig. 10 Reduction of energy used for district heating production, when reducing heat demand (left) and reduction of energy used for electricity production, when reducing electricity demand (right). The left bar shows the average for the 30 district heating systems studied.

When we apply the results in figure 10 with the energy saving potentials in table 1, we get the resulting values in figure 11. For heat recovery ventilation an increased electricity use of 2 kWh per square meter heated area has been assumed.

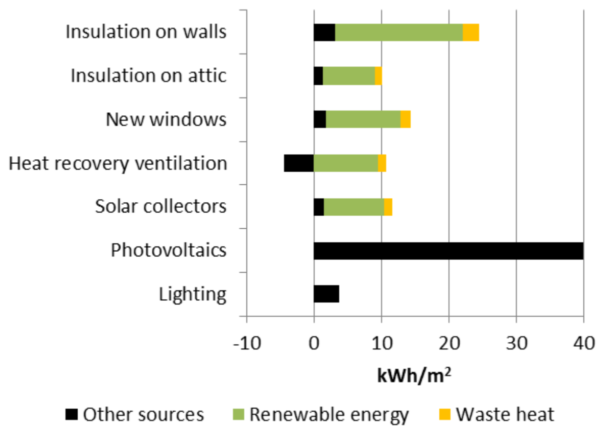

Fig. 11 Calculated effects on heat and electricity production from energy related measures in apartment buildings, per square meter heated area.

DISCUSSION

A. ACCURACY OF THE RESULTS

The analyzed effect on district heating from heat reductions was done with annual figures, which limits the accuracy of the results. Figure 12 show a principle duration curve for the delivered heat, where we assume that renewable energy or waste heat is used for base load and fossil fuels are used at peak load.

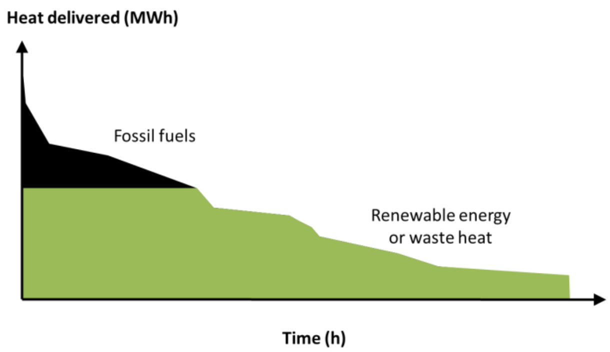

Fig. 12 Principle diagram of annual heat delivery duration and mix of fuels in a district heating system.

In this case any insulation measure in reality would give larger reductions of fossil fuels than calculated, since the heat reductions appear mainly in winter. On the contrary, solar collectors would lead to less reduction of fossil fuels than calculated, as the heat reductions in this case occur mainly in summer. Despite this, we believe our conclusions to be accurate.

More detailed analyses of particular Swedish district heating systems will be carried out within the Reesbe post-graduate school.

B. USING RESULTS IN FUTURE POLICY WORK

Many building owners put a lot of effort into reducing heat demand as a way to lower their environmental impact. This article shows that, within the studied Swedish district heating areas, reducing electricity demand is much more effective in order to increase the share of renewable energy. Installing photovoltaics has outstanding potential of the studied measures and a small measure like renewing the facility lighting may have the same reduction of non-renewable energy as insulating the walls.

In the longer perspective we most likely need near zero energy buildings to overcome the climate challenge and to be able to reach the goal of 100% renewable energy. This "near zero" on average can, however, at least in Sweden consist of new buildings which use very little energy and generate a lot of solar electricity – and of existing buildings which use more energy but also generate solar electricity. The new buildings will become "plus energy" buildings and the heat demand of the older ones will generate electricity through cogeneration in district heating plants.

To achieve this, one first step would be to strengthen the position of photovoltaics in Swedish building regulation code (BBR) by including household electricity as a basis for energy reductions and by calculating the net energy reductions from photo-voltaics on an annual basis [16].

In the very long perspective – when we have achieved a 100% renewable energy system in Europe – there will be no need for Swedish heat consuming buildings, but until then at least there should be a clear distinguish between district heating and electricity in national energy policy and in the building regulation code.

Danish regulations have a ratio between electricity and district heating of 2.5:1, which will be changed to 2.5:0.8 in 2015. Finnish regulations have ratios of 1.7:1.0:0.7 between electricity, fossil fuel and district heating. We propose that Sweden should introduce similar factors, for instance 3:1 as the ratio between electricity and district heating.

OUTLOOK

We expect the trends in Swedish district heating to be even higher shares of renewable energy and even more cogeneration of electricity, which will even further strengthen our conclusions.

One draw-back would be if some waste heat industries had to shut down, which would affect some of the studied district heating systems, and potentially lead to increased shares of fossil fuels in these areas.

CONCLUSIONS

Our conclusion is that building related energy measures generally should focus on reducing use of electricity rather than heat, within Swedish district heating areas. We have also found that installing photovoltaics is a building related measure with a large potential to increase the share of renewable energy.

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REFERENCES

[1] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 28.

[2] United Nations Framework Convention on Climate Change, Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010, Part Two: Action taken by the Conference of the Parties at its sixteenth session, Decision 1/CP.16 The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, p.3.

[3] Y. Deng, S. Cornelissen, S. Claus, ”The Ecofys Energy Scenario”, Ecofys Netherlands BV (2010), p. 140.

[4] Eurostat, Data from 2012 retrieved from Statistics Database, tables “Share of renewable energy in gross final consumption (tsdcc110)”, “Electricity generated from renewable sources (tsdcc330)”, “Total gross electricity generation (ten00087)”, “Final energy consumption, by sector (tsdpc320)”, “Final energy consumption of electricity (ten00097)” and “Share of renewable energy in fuel consumption of transport (tsdcc340)”, epp.eurostat.ec.europa.eu/ (2014)

[5] European Commission. Energy Roadmap 2050, Publications Office of the European Union, Luxembourg (2012)

[6] OECD/IEA, “Energy Policies of IEA Countries – Norway, 2011 Review”, Paris (2011)

[7] OECD/IEA, “Energy Policies of IEA Countries – Switzerland, 2007 Review”, Paris (2007)

[8] Statistics Sweden, “Statistical Yearbook of Sweden 2013 – Housing and construction” (2013), p. 166

[9] Swedish Energy Markets inspectorate (Energi-marknadsinspektionen), www.energimarknadsinspektionen.se/sv/Fjarrvarme/ (2014)

[10] Gävleborg County Administrative Board (Läns-styrelsen i Gävleborg), ”Energy efficiency in apartment properties – Eleven local examples year 2012” (“Energieffektivisering av flerbostads-fastigheter – Elva lokala exempel år 2012”) (2012)

[11] Swedish Electrical Utilities’ R & D Company (Elforsk), ”Environmental evaluation of electricity – focusing CO_2 emissions” (“Miljövärdering av el – med fokus på utsläpp av koldioxid”) (2006), pp. 1-8.

[12] Swedish District Heating Association (Svensk Fjärrvärme), “Statistics of fuels in district heating” (“Bränslefil-fjärrvärme-2012.xlsx”) www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/ (2014)

[13] Swedish Electrical Utilities’ R & D Company (Elforsk), “Marginal electricity and environmental evaluation of electricity” (“Marginalel och miljövärdering av el”) (2006)

[14] Swedish Energy Markets inspectorate (Energi-marknadsinspektionen) http://www.energimarknadsinspektionen.se/sv/el/elmarknader-och-elhandel/elmarknader-prissattning/ (2014)

[15] EIA, “Average Operating Heat Rate for Selected Energy Sources”, www.eia.gov/electricity/annual/html/epa_08_01.html (2014)

[16] The Swedish National Board of Housing, Building and Planning (Boverket), “Building regulation code” (“BFS 2011:6 – BBR 18 Boverkets byggregler”) (2011), p. 94.

[17] Fortum Heat, “Key figures for Green Buildings 2013” (“Nyckeltal Miljöbyggnad 2013”), http://www.fortum.com/countries/se/foretag/fjarrvarme/miljo/miljocertifiering/Documents/Fortum_MILJOBYGGNAD_nyckeltal_2013.pdf (2014)

[18] Renova, ”From waste to clean energy” (”Från avfall till ren energi”) (2010), p. 5.