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Urban Energy Generation and the Role of Cities

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A B S T R A C T

Although a major part of energy consumption happens in cities, contemporary energy generation is less obviously connected to the urban structure. Energy based on fossil fuels and consumed in transportation is produced at global scale; energy for electricity is usually distributed through a national or continental grid; energy for heating, if related to district heating systems or the use of local/regional resources for its generation (e.g. biomass, waste), has a more local or at least regional character. In the latter case, electricity might be a by-product of combined-heat-power plants, but still feeding into the grid. Furthermore, through the ongoing liberalisation of energy markets and a subsequent change in the organisation structure of energy providers towards larger co-operations as well as the development of new technologies as 'smart grid'-solutions, local authorities seem to lose further influence on energy generation and distribution. However, contemporary focus on sustainable and efficient use of resources and energy at local level, mainstreaming of renewable energy production and ideas of urban energy harvesting put energy generation again on the local agenda. The role of cities can be twofold: (1) cities as producers and (2) cities as enablers or promoters. Furthermore, energy production (renewable or not) has to happen somewhere, potentially also in the city where consumption takes place, and is related to specific spatial conditions. We review the contemporary options of urban energy generation, building on literature and findings from six European medium-sized cities who participated in the EU-FP7 project PLEEC.

1. INTRODUCTION

This paper discusses the role of cities in energy generation and distribution, based on findings from six European medium-sized cities that participated in the EU-FP7 project PLEEC.

A major share of energy is consumed in cities; however, energy generation is not explicitly connected to the urban structure. Depending on the resource and the type of produced energy, generation takes place at very different scales: fossil fuel based energy for transportation is produced at global scale; electricity generation and distribution is usually carried out through a national or continental grid; heat energy, however, is primarily generated and distributed at a regional or even local scale, for instance through district heating systems, and allows the use of local/regional resources (e.g. biomass, waste). Heat generation in combined-heat-power (CHP) plants produces electricity as by-product, which is, however, still fed into the national grid.

In general, local authorities seem to lose further influence on energy generation and distribution, which is directed by changes in the organisation structure of energy providers towards bigger co-operations due to an ongoing liberalisation of the energy market, as well as the development of new technologies such as 'smart grid'-solutions.

On the other hand, the increasing importance of renewable energy production and sustainable and efficient use of resources, put energy generation again on the local agenda through the use of local resources or urban energy harvesting. In this agenda, cities act not only as producers but also as enablers, promoters and mediators towards the general public. Moreover, the recent Paris agreement (COP21, 2015) of the UNFCCC on holding global temperature rise below 2°C above pre-industrial levels, put strong focus on renewable energy production, also in cities.

In this paper we first review the changing role of cities in energy production (section 2), especially focusing on changes in the past century, moving from local supply production to a liberal energy market and the current climate agenda. Related to the latter, a number of ideas and concepts have been developed, ranging from the zero-carbon city to the productive city. We further go into detail with our findings on different forms of urban energy production and distribution in European medium-sized cities (section 3).

We draw on work done in the EU-FP7 project PLEEC [1], [2]. PLEEC used an integrative approach, bringing together researchers and practitioners to increase energy efficiency in six cities and disseminating good practice across Europe. This study is based on material from the six partner cities, Eskilstuna (Sweden), Turku and Jyväskylä (Finland), Tartu (Estonia), Stoke-on-Trent (UK) and Santiago de Compostela (Spain), as well as selected experiences from Danish cities.

2. BACKGROUND AND ANALYTICAL APPROACH

2.1. Energy generation and the city

Urban energy generation is not new. Available resources as water, biomass and building material are decisive for a city's survival. Historically, their depletion *"may have become a constraint on the growth of cities"* [3]. However, since the industrial revolution and the exploitation of fossil fuels, cities gradually *"became spatially disconnected from the sources that allow an urban life style"* [4]. Today it is questionable if there is anything specifically 'urban' about energy, as energy systems mainly function on national and international levels [5], though with district energy systems as an exception.

Our starting point is thereby the energy that is consumed in the city, rather than where the energy actually comes from. The consumed energy is usually the driving force for the local authority to engage in energy generation and/or its distribution or, more general, in initiatives enabling certain energy generation. Consumption patterns are strongly related to settlement characteristics. For example, in suburban and rural areas, the consumption of fossil fuels mainly for transportation is usually the most prominent, whereas in urban areas (at least in Northern Europe) district heating might play a bigger role in the overall energy consumption. Also, the frame conditions for local energy production are changing, by energy policies, technologies and markets. Therefore, what belongs to the city-level of energy production should not be taken for granted.

Facing the complex energy systems, we need to clarify how local energy production and the local energy producer can be singled out in the myriad of relations. Local energy plants might produce for the national grid, e.g. electricity as by-product of CHP; however, local decision makers might not be independent actors, but rather members of large non-local systems. Local house owners, private housing estates, cooperative housing societies, local energy companies and energy processing industries, as independent actors, make their decision on energy investments based on individual priorities, economic profitability and climate responsibility. However, local decision makers, as members of large non-local energy systems, are subject to optimisation of regional or national systems for energy storage or timely production of energy during periods of changing supply-demand.

A look back in time illustrates the evolution of these complex relations. Four phases in the development of the current energy system (with focus on heating and electricity) highlight the development from independency towards interdependency.

2.2. Evolution of the urban energy system

Local generation. Historically, local energy generation covered the energy demand of cities. Since the industrial revolution fuels were increasingly imported (wood, coal) and transformed into heat and electricity in local plants. While oil production became a global business (though with increasing focus on providing energy for transportation), nation-wide electricity grids were evolving since the 1920s and 1930s, at the beginning still facing many different local and regional configurations. Gas got first more widely used in the 1960s and 1970s. Therefore power production was still a local or regional business for a long period after WW II. In Scandinavia and the Baltic countries, local energy production was reinforced by the installation of district heating plants in the 1950s and 1960s. In these countries, the construction of local plants was closely connected with post-war housing programmes. District heating was characterised by simple relations between local consumers and local producers connected by local heat grids. Thus, the energy companies owned all elements of the energy value chain, from production to the distribution of energy to the final consumers. Electric power and district heating was 'broadcasted' from central units to the individual customers.

Cogeneration. The oil crisis in the 1970s called for energy savings to reduce the vulnerability that was created by the dependency on fossil fuels. One of the policy implications was the decision to encourage the development of a more efficient use of energy, notably combined heat and power generation. The combination of heat and power generation was a first step into the new complexity of interdependencies between different kinds of energy production as well as multilevel connections of energy companies, since the CHPs were connected, on one hand, with the local heat grid and, on the other hand, with a local electricity grid, which was further connected with the national grid.

Liberalisation. In 1996, the EU launched the electricity market directive aiming at the liberalisation of electricity production [6]. Two years later, the electricity directive was followed by a corresponding directive on the liberalisation of the gas market. The principle used for the liberalisation of the electricity and gas supply industries was that generation and supply are subject to competition, whereas the grid activities – transmission and distribution – remain monopolies that are subject to regulation. The cogeneration of district heat (DH) and electricity requested a homogenisation of two principles of price calculation: the price of heat from DH plants, based upon the principle of cost-recovery of each single DH plant, and the price of electricity based on the market. Homogenisation of the two price principles was needed in order to avoid cross subsidies between heat and electricity sales – and the market principle was chosen as the common principle [7]. As a consequence, neither consumers nor distributors were any longer tied to their own power plants, thus, liberalisation implied that power plants no longer need be anchored in the local community, and nor should municipalities hold monopolies within certain geographical areas. From then on, they should compete for the customers and about the prices – not only at the local and national levels, but also up to the European level [8]. To be a player in the liberalised market is more demanding than holding a monopoly in the local market. Liberalisation was thus followed by several mergers of local energy companies, mergers of municipal plants with those of larger municipalities as well as takeovers by large private companies. As a result, energy companies tended to become fewer and larger and with ownerships that tended to loosen the ties with the local.

Climate policy and smart grid. The introduction of climate policies in energy production called for further cooperation in this sector. According to Frías et al. (2009), the public goal of a sustainable electricity system is strived for by a number of national technology-specific support schemes in the member states *"for renewable-based electricity generation (RES-E) and co-generation of electricity and heat (CHP). This objective is a main driver of the growth of distributed generation – generators connected to the distribution network – to significant levels."* [9, p. 445]. In the climate-based energy policy, substitution of fossil fuels by renewable resources (RES) became a key issue. Since RES (e.g. wind and sun) are not steadily available, a focus on the availability of resource supply became urgent, in order for one non-available resource to be timely substituted by another available resource. Further, storage of energy produced by available resources in periods of low demands became urgent. These challenges called for cooperation between different kinds of energy production and storage capacities and led to the development of the so-called 'smart-grid', i.e. systemic monitoring of several production units to find optimum capacities in a world of fluctuation of prices, energy resources and energy demand. Smart grid solutions have pronounced impact on the energy system. It is not just a system for optimisation of existing production, but also about the development of systems best suited for optimisation [10].

"Smart Grid may be characterised as an upgrade of 20th century power grids, which generally "broadcast" power from a few central generation nodes to a large number of users. Smart Grid will instead be capable of routing power in more optimal ways to respond to a wide range of conditions and to charge a premium to those that use energy during peak hours" [11, p. 9].

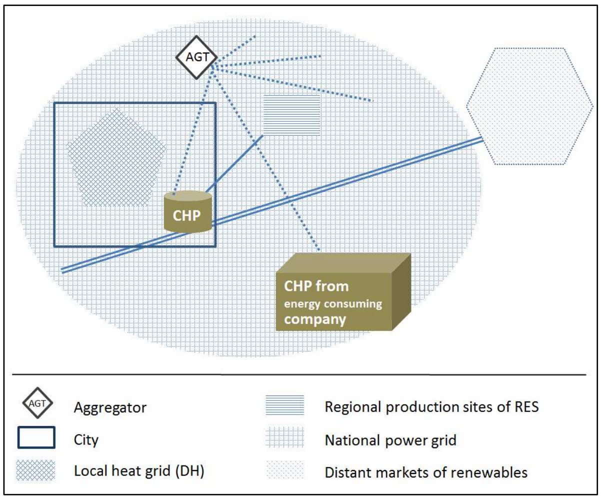

Fig. 1. Relations of a local CHP plant, located in the city, supplying the local heat grid. Energy production includes the use of RES available in the region and/or from international suppliers. The CHP plant is connected with an aggregator and so is an energy consuming plant in the region delivering surplus energy to district heating in the region.

In the smart grid, competent operators are needed. This is the background for the formation of so-called 'aggregators' that act on the electricity market in the interest of small producers or consumers. Such an example is the Danish NESA Energy, representing about 200 power producers, many of which are CHP companies. Each of the partners is equipped with remote control units facilitating a central coordination and optimisation of the partners' 500 generating units by NEAS. *"The CHP plants plan their day-ahead* *production considering both the electricity market and the district heating system. Over the course of the day they deliver different balancing services. They remove capacity, when there is a surplus. They offer NESA storage in hot water accumulation tanks and the district heating system. This storage facility has been further encouraged in district heating systems, allowing the district heating plant to maintain high levels of efficiency while decoupling their electricity and heat generation over certain time periods"* [12].

The work of the aggregator illustrates the key issue of smart grid, remote monitoring of energy generation in the interest of the total system. As a consequence, the individual producer, including the local energy producer, sacrifices his autonomy for the benefits of being part of the 'common good'. If sustainability is a goal, the aggregator thereby also has the key role of managing the 'common good' by favouring renewable energy in the system.

Figure 1 shows how the local CHP is connected with a regional and international supplier of RES via the national and regional infrastructure. Within the borders of the municipality the CHP is connected with the local heat grid. Due to the production of electricity the CHP has chosen to be a member of an aggregator, made responsible for the optimal production of power. Also, the industrial CHPs are connected to the aggregator. While the heat is produced for the local heat grid, the electricity is distributed by the aggregator to the national (international) power grid. It is likely that local energy policy will turn into fulfilling obligations as defined by the larger system, rather than develop independently. This does however not imply that municipalities, cities or regions cannot advocate for their say in the system, by defining their rules.

Also, the development of new systems and technologies has crucial implications for the overall system. For example, future low-energy buildings could completely remove the need for heating. This is opposing the approach that excess heat from industries, waste incineration and power stations may also be used, together with geothermal energy, large scale solar thermal energy and large-scale heat pumps to utilise excess wind energy for heating. In the first case, a district heating network may not be needed, while, in the latter case, a district heating network becomes essential [13].

2.3. Local visions for self-sufficiency in the network reality

Many cities today have energy production somehow included in their local strategies – directly or indirectly. A couple of ideas and brands around that have emerged, including 'a productive city', 'a self-sufficient, independent, resilient city', 'a regenerative city, producing energy, recycling and reusing', 'a CO_2-neutral city (zero-city)' or even cities with a circular (inclusive) metabolism. Many cities strive for such visions, also due to an expected positive impact on their economic development and a more efficient and sustainable use of resources or an increasing autonomy and economic resilience against negative effects of global economic crisis [14].

All concepts are related to the general idea of sustainable development. It is however doubtful if a city really can be sustainable in the meaning of self-sufficient, i.e. only dependent on its own resources. Barbosa et al. (2014) pointed this out by stating that "[s]*ome studies advocate that to consider a city sustainable, it must be self-sufficient in terms of energy, materials, food and water [...] Despite this, among some authors there is some criticism about the concept of self-sufficient cities [...] They assert that sustainability is a desirable and attainable goal at the global scale, but do not agree that is achievable locally*" [14]. Self-sufficiency (especially after a transition towards renewable energy sources) might be a more realistic vision at regional level. The point is, that cities (again) are not only consuming resources but also producing them by harvesting available local renewable resources and waste [4] as made explicit by the idea of 'urban mining'. Besides the ambition of a renewable energy supply, the aim of being independent from imported energy is fuelling the idea of self-sufficiency. For example in Estonia, the independency from foreign energy supply plays an important role for policy making and it is also one of the reasons for the extensive use of oil shales for electricity production, covering almost entirely the domestic demand [15]. Although this contributes to Estonia's self-sufficiency, it is a very environmentally-harming way of energy generation. In that sense, the aim for self-sufficiency is in opposition to climate goals.

The six PLEEC-cities also show that the ambition of providing sustainable energy in their case does not necessarily mean to invest in renewable energy generation within the municipality [16]. For example, the local energy supply company in Eskilstuna (EEM) has invested in solar cells and wind turbines in other areas in Sweden to increase the share of renewable energy in their portfolio [17]. However, the precondition for that is a reliable grid and distribution system, something which cities can hardly influence by themselves.

3. RESULTS

3.1. Local production in European medium - sized cities

As emphasised in the previous sections, the trend towards building large complex energy systems is not about replacing local with central energy production. It is rather about combining local and central production and monitoring of energy systems, in which local production has importance. In the following we will review different energy supply technologies with special reference to their application in the studied case cities. Table 1 gives an overview of different kinds of collective/municipal production and its application in the six cities. The six cities resemble medium-sized cities in various geographical and regional contexts. However, they are also typical for the European urban landscape, where more than half of the urban population lives in urban regions with less than 500,000 inhabitants [18].

Table 1. Collective/municipal energy generation in the PLEEC cities.

Energy supply technologies	Eskilstuna (SE)	Tartu (EE)	Jyväskylä (FI)	Turku (FI)	Stoke-on-Trent (UK)	Santiago (ES)
District heating and CHP	×	×	×	×	×[1]	
District cooling	×[3]	×[1]	×[4]	×		
Ground source heat pumps		×	×			
Deep geothermal					×[1]	
Solar (solar farms)	×	×	×	×	×	×
Wind	×		×[5]			
Biogas from waste	×		×	×		
Waste incineration				×[2]		
Micro CHP			×[6]			
'Surface energy' e.g. bicycle lanes						

[1] Implementation decided.
[2] Closed down in 2010.
[3] Smaller district cooling grids for industries.
[4] Planned in Kangas area.
[5] Wind power park is planned to be built in the city area by 2016.
[6] Biogas micro-CHP using landfill gas (in operation as of spring 2015).

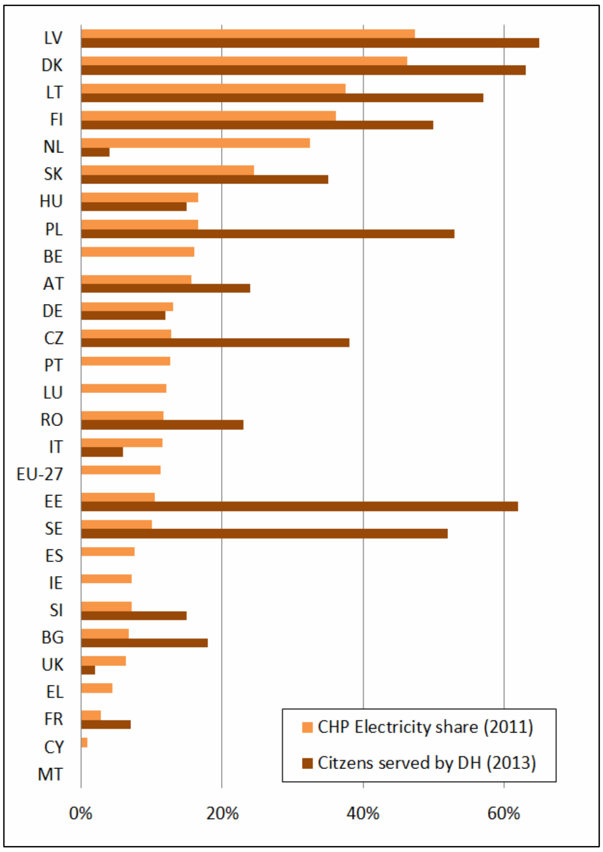

Fig. 2. The use of combined heat and power (CHP) and district heating (DH) in the EU member states.

District heating and CHP. District heating is a major contributor to local energy production, especially in the Nordic and Baltic Countries. In all the cities district heating is combined with electricity production in CHP plants, most of which are fuelled by biomass.

Figure 2 gives an overview of district heating in EU member states. Two statistics [19], [20] are combined, showing the share of CHP in the national electricity production on the one hand and the percentage of citizens serviced by DH on the other. The statistics reveal, that the use of DH varies substantially in the EU, and so does the contribution from CHP to national electricity production. Usually, CHP is driven by residential consumption of heat. But in the case of the Netherlands, with high consumption of heat in green houses and refineries, industrial heat processes have been the drivers for installing combined power production. Two different kinds of CHP seem to be at play, (1) the residential CHP driven by heat produced for residential purposes, and (2) the industrial CHP, that generates heat as surplus from industrial processes. Denmark and Latvia show high figures on DH and CHP as well, whereas Sweden and Estonia show high rates of DH but modest shares of CHP, indicating potentials for further transformation of DH into CHP. Connolly et al. (2014) revealed that excess heat from industry is available all over Europe [21]. Only about 3% is used for district heating. This could also be an important element to a more sustainable energy supply for DH in cities like Tartu. The city's CHP is fuelled by peat extracted from large inland areas with peat. Although peat is biological, it is not considered renewable.

In Santiago's recent Energy Efficiency Action Plan ('Plan director de eficiencia energética y sostenibilidad'), the implementation of CHP and the use of biofuels are recommended. However, the city owns only small plants and no district heating system.

In Turku, district heating is generated at the CHP plant in Naantali. Heat is generated from a variety of fuels: coal, refinery gas, waste, wood, biogas and oil. The combined heat and power production cuts fuel consumption by one-third [22, p. 136]. There will be changes in the energy generation solutions in the region when the Naantali power plant is replaced by a new multi-fuel power plant in 2017. The aim is to use domestic biofuel as much as possible.

However, the use of biofuels augments daily hauls with biomass to the CHP plant, many of which are still located close to the city centre. In Eskilstuna a relocation of the plant is being considered in order to respond to (1) the need for a technical renewal of the 14-year-old plant and (2) the need to reduce the heavy transport of wood chips into the city. Currently, the Eskilstuna CHP consumes 900,000 MWh biofuels (wood chips) per year, delivered by over 8,000 lorries per year. In the cold winters, about 80 lorries pass through the town each day. Former plans included a new CHP plant which would decrease the annual number of transports to the city to about 3,500 lorries, while 30-50% of the wood chips would be delivered by rail to the new plant, thus reducing the number of lorries by 2,800-4,600. However, the plans are currently (June 2015) halted.

District cooling has been introduced as an energy efficient alternative to the traditional power-based cooling systems. In Tartu, a district cooling system based on water from the Emajõgi River is going to start up in 2016. The major customers of the new system are situated in the city centre, characterised by high building density, business and shopping centres.

In Turku, a district cooling system was inaugurated in 2000 [23]. Further, in 2009, the extraction of heat energy from household waste water by a heat pump was put into operation. The heat recovery takes place after the treatment process and before the water is discharged back into the sea. Prior to discharging the cooled water into the sea, it is used a second time to cool the water for Turku's district cooling network. The heat pump plant replaces district heat for about 12,000 residents of Turku, without any local air emissions [24].

Geothermal energy and ground source heat pumps. Energy from the underground can be generated from deep or near surface geothermal energy or ground source heat pumps. 'Stoke-on-Trent has decided to start up England's first fossil fuel free district heating plant, fuelled by deep geothermal energy from natural resources 2 km below the city, using remedies of old mines. Due to the lack of central heating in the city, the project is only for businesses and new housing area.

The benefits of the project include the production up to 45GWh of heat energy annually, lowering heating costs for businesses by up to 10%, and saving approximately 10,000 tonnes of carbon dioxide annually. Consequently, new forms of urbanisation, e.g. densely built and located in proximity to the grid, as well as new forms of public-private partnerships are envisaged.

However, heat sources just below the ground are more widely available for extraction with ground source heat pumps. Most of the case cities include them in their energy strategy. Heat pumps are also seen as sustainable alternative in sparsely built-up areas, where district heating is not feasible. If combined with other systems, such as solar cells, heat pumps are also relevant in new urban areas. An example is being developed in Skanssi, a new urban development area in Turku [23]. Due to high insulation and low temperature heat systems (floor heating), houses are suited for solar and geothermal energy and less attractive for traditional district heating, especially during the construction phase. A feasibility study from Denmark on a similar development ('Vinge') that compares a decentralised individual system, a semi-decentralised system and a centralised system (district heating), gives priority to a semi-decentralised system, based on heat pumps constructed for small clusters of houses, instead of individual heat pumps. If, in the future, a district heating system provides a better alternative, it would be feasible to connect to the clusters [25].

Solar energy includes power cells (PV) and heat panels. These devises are mushrooming on the roofs of individual households, and – like heat pumps – are seen as a complement to district heating. Like heat pumps, solar cells and panels are also relevant at larger scales. For example, one of the world's largest reservoirs of warm water heated by solar panels has been established in the Danish town of Vojens (Fig. 3 & 4). The reservoir has a capacity of 200 mil litres of water, heated by 4,166 solar panels with a joint surface of 52,500 m^2. The reservoir was established in a former gravel pit. The solar panels are added to 17,500 m^2 panels that are already established, extending the total surface up to 70,000 m^2. The system is going to supply energy for 2,000 households in the city [27]. The Danish Energy Agency projects that solar heat will cover 4% (6,000 TJ) of the energy supply in district heating in Denmark by 2020 [28].

Fig. 3. Visualisation of the Vojens Solar District Heating project when completed [26].

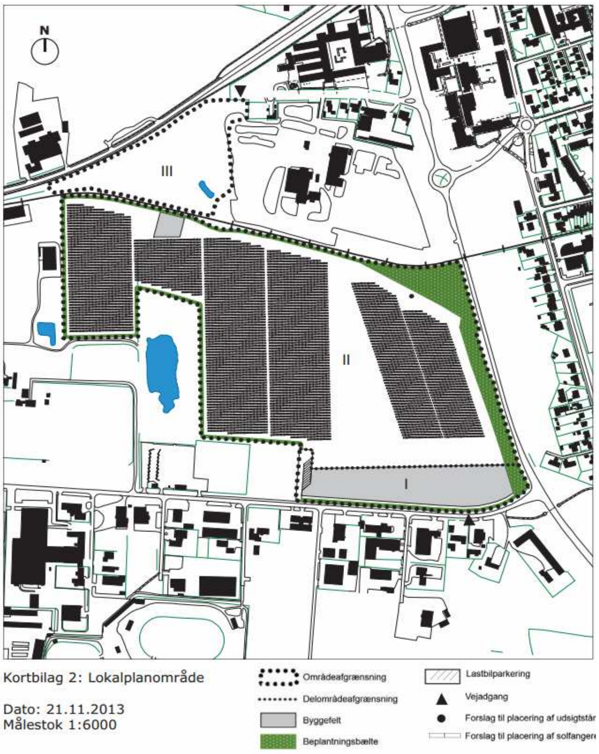

Fig. 4. Local plan for Vojens District Heating plant. Area I: DH-plant; Area II: Solar panels; Area III: Warm water reservoir. The total area of the district heating plant - signified by the dotted line – is 33.5 ha. The volume of the warm water reservoir – area III – is 225,000 m^3. The DHP is situated in the industrial zone of the town adjacent to industrial buildings south of the area and residential housing east to the area [26].

Wind and hydropower are tightly anchored to suitable sites. Also, they are costly. Municipalities usually enter into wind and hydro production only as shareholders or in cooperation with other municipalities. In 1998, the Hyötytuuli wind power production company was founded by several major Finnish energy companies, including Turku Energia. The share of wind power will increase to 10% in Turku in 2020. In 2003, Turku Energia and two other energy companies bought *"Eastern Norge Svartisen",* a Norwegian hydro power plant. Also, Eskilstuna Energy & Environment (EEM) has invested in solar cells, hydro and wind turbines, yet with only minor shares.

Energy from waste. A public service run by many cities is the handling of waste. Several cities use waste in incineration and biogas production. EEM has set up a production of biogas from waste. The production takes place at the central wastewater treatment plant. In the water treatment process, biogas has been a by-product since the 1960s. Formerly, biogas was used for electricity production. Today, it is used as fuel for busses and municipal vehicles and has also a branding value.

Waste incineration is one of the energy sources for CHP plants. Usually waste incineration is organised in huge CHP plants run by private companies or by a cooperation of municipalities. However, if not available locally, waste may be exported. This is what the city of Turku does. On average, 8 hauls per day are shipped to Estonia every day, to be incinerated at Eesti Energia's new incineration plant from 2013. In 2010 Turku's own incineration plant was laid down, and the city started to export the waste to Sweden and since 2013 to Estonia. According to the operations manager at the Turku region waste management company, Patrik Jalonen, emissions from the transport of waste are notably lower than emissions from its treatment. The top priority on the issue of municipal waste is to reduce the amount of waste produced and to encourage its re-use. Recycling is the third option and incineration only the fourth. A tender for waste treatment resulted, however, only in bids for the fourth prioritised category [29].

Small scale energy production: Micro CHP and 'Surface energy'. Hydro power cells that function as a Micro CHP provide a tool for storing power that is for example produced by wind turbines. In the village of Vestenskov, Denmark, 32 households were provided with micro heat and power units as part of an international research and development project, *KeePEMAlive,* testing low temperature fuel cells for stationary power generation and combined heat power production. The Danish pilot project was organised jointly between the Municipality of Lolland, the regional energy company, Seas-NVE, and IRD fuel cells A/S, in cooperation with the Danish parliament, the national power distributor Energi.net and the national program for development and demonstration of energy technology, EUDP. From the consumer point of view it was a success. The bottleneck and key challenge for a competitive production is to further develop the durability and the price of the power cells [30].

The extensive land needs of solar energy generation turned the attention for potential production sites towards 'secondary' locations, primarily focusing on building roofs. Another kind of surface currently tested are roads and bicycle lanes. In the Netherlands, a consortium of research institutions, industry and government is developing products feasible for integration in the public infrastructure. The consortium acronymed 'Solaroad' has started a full-scale pilot project, integrating solar cells in bicycle lanes providing power for road lightning (www.solaroad.nl).

All six PLEEC cities show commitments to local energy production. The variations in type of production show, that 'local' is not just about scale, but also about local uniqueness or deviations from other localities. The rationale of CHP has developed in the Nordic and Baltic countries; the use of industrial excess energy production has developed in countries characterised by energy consuming industries such as glass houses and refineries in the Netherlands; recent efforts in profiting from deep geothermal energy are related to countries that are endowed with suited geothermal energy resources, such as the UK; whereas in countries with relatively little heating demand (Spain), individual solutions dominate. These deviations show that there is no unique local energy solution. However, the PLEEC project also shows that the diversity of local solutions provides great opportunities to learn from each other. Just to mention a few: the extraction of energy from waste water in Turku and the construction of the world largest solar panels in Vojens, Denmark.

As the national energy policies are an important driver for local energy solutions, we shall thus turn to this aspect for a brief overview in the case-city countries.

3.2. National frameworks for local action

Local energy production is closely related with national regulatory frameworks. Investments in energy efficiency by house owners, private companies and municipalities are influenced by the national climate and energy agenda. However, local investments are not taking place until the market or economic incentives by the government make them profitable.

In this section we will elaborate on the following national policies and framework conditions that influence local action in the PLEEC cities:

- EU and National energy goals;
- voluntary agreements and commitments;
- economic incentives;
- green certification;
- knowledge diffusion and exchange;
- national policy supporting (or depending on) local action.

EU and national energy goals. National energy policy of EU member states is closely connected with the implementation of EU energy policies. This can be illustrated by the basic pillars in Spain's energy policy, which closely follows the EU's 20-20-20 objectives: promotion of renewable energy, diversification of energy sources and energy efficiency.

From these three policy strands, the development of renewable energy sources has high priority. Thus, in 2012 more than 27% of Spain's power supply came from renewable sources, excluding large hydroelectric generators, as compared to about 13% in 2007 — one of the highest shares in the EU. However, the highly subsidised renewable energy sector has been the most affected by a major restructuring of the energy sectors in 2013, designed to tackle the huge tariff deficit in Spain, representing the difference between the real cost of electricity generation and what was paid by consumers [31].

The national energy policy in Finland rests on three pillars: Energy, Environment and Economy. It thus requires the combination of different aspects such as energy safety or the reduction of fossil fuels within an economic framework. In practice, the Finnish energy policy includes investments in renewables along with nuclear power. Preparations for the next National Energy Efficiency Agreement Scheme 2017-2020 have started. They mainly address the cities' own activities and buildings. These are supplemented by strategies on how to encourage citizens and other actors in the city area to follow energy efficiency measures.

The framework for local energy production in Tartu is set by the Estonian national energy policy [32]. Besides a general concern about climate issues, the Estonian energy policy is aiming at pressing political issues such as reducing dependency on imported resources and ensuring security of energy supply. A more decentralised regional energy production is taken as a means of improving the overall energy security as well as a better exploitation of local energy resources (wind, solar, biomass, earth heat).

However, the interplay between national frameworks and municipal execution of climate measures is so closely connected that it is difficult to characterise the municipality as a simple executor of national policies. To a wide extent, initiatives are developed locally inspired by the generally increasing concern about the climate [17].

Voluntary agreements and commitments. In 1997, two years after joining the EU, the Finnish government introduced the so-called 'voluntary energy efficiency agreements' to integrate the most relevant partners to implement the EU regulations: municipalities, industry and commerce, the oil sector, hotels and restaurants, farms and the transport sector. The voluntary agreements include energy efficiency plans and audits; and the implementation is facilitated by subsidies and energy efficiency service provided by energy companies.

While the national energy policy focuses on the implementation of EU energy policies, the municipal energy policy takes the implementation of national energy policies as starting point. Thus, Jyväskylä has engaged in the National Energy Efficiency Agreement Scheme 2008-2016. By signing this policy scheme, Jyväskylä has entered a commitment of achieving 9% energy savings annually by 2016. The Climate programme, adopted by the City Council, includes 170 measures and the involvement of city decision makers, employees and citizens [33].

The Stoke-on-Trent City Council has empowered its capacity by joining a so-called Local Enterprise Partnership (LEP) with Staffordshire County Council. LEPs are supported by the government, but formed on a voluntary basis by local authorities and business representatives. They have been set up since 2011, partly to substitute tasks that were taken care of by the regional development agencies, which were dissolved in 2012. The Stoke-on-Trent & Staffordshire LEP has been a stepping stone for local energy policies in Stoke-on-Trent. In 2014, the network won a bid for energy efficiency funds from the central government for the first fossil fuel free district heating plant in England.

Since 2009, at the European level, the EU's initiative for sustainable local energy policies, called 'Covenant of Mayors', has supported over 6,000 municipalities to prepare Sustainable Energy Action Plans. Three of six PLEEC cities are signatories.

Economic incentives and subsidies can play an important role for public and private investments. For instance, in 2000, EEM received about 25% of the costs from national subsidies for renewable electricity to transform the existing district heating plant into a CHP plant in Eskilstuna. The subsidies are not equally suitable for all kinds of renewables. Thus, EEM has invested in solar cells, hydro power and wind turbines, but only in minor shares. The Swedish subsidies are also available for private homeowners, encouraging them to invest in solar cells, which the state subsidises by up to 35% of the costs.

Green Certification. Certification schemes are another way to encourage energy efficiency and the use of renewable energy. For example, the Swedish green certification system was launched in 2003, conveying a flow of financial means from energy consumers to producers. Producers of renewable electricity are rewarded with certificates that consumers of electricity are compelled to purchase. The consumers are the daily consumers as represented by energy distributing companies, as well as large industrial, single electricity consumers and consumers buying electricity from the Nordic energy grid. Every year, these consumers are assigned an obligatory quota of certificates for purchasing electricity from the renewable energy producers. For EEM the green power certification system generates an income of 35–70 million SEK annually.

Knowledge dissemination and exchange. Besides economic incentives, the national climate and energy policies often include promotional activities on various levels and targeted towards different stakeholders. In the Swedish cooperation programme for sustainable municipalities *("Uthållig kommun")* about 35 municipalities take part, including Eskilstuna. The national energy authority conveys knowledge, resources for cooperation and assistance for setting up networks. Especially, they address ambitious municipalities in order to develop and inform about advanced pilot projects.

To enhance the efficiency of policy measures oriented towards the citizens and other decision-makers in the municipality, the city of Jyväskylä and the Finnish Innovation Fund Sitra launched a joint project, *"Towards Resource Wisdom"* in 2013. The purpose was to create duplicable models for ecologically resource-wise lifestyles in urban environments in cooperation with local residents, companies and organisations.

National legislation provides the framework for local action. Besides the previous initiatives as subsidies or certification systems, other policies also define the scope of action and can support municipalities' ambitions, but also hamper them.

The 1999 Master Plan of Tartu included an energy development plan (DH, electricity) and assigned DH areas. In this respect, Tartu was ahead the national legislation, which enabled municipalities to establish special zones that make connection to DH compulsory first in 2003 with the implementation of the District Heating Act.

The current Master Plan (2006) includes further areas in the DH system. In order to include these new areas, the city had to establish stricter regulations in DH zones, since the energy companies would otherwise refuse to expand their network due to its high costs. In other countries as Sweden such compulsory energy districts are not allowed. Spanish cities like Santiago face the limitation that energy planning is done by the provinces (i.e. Galicia), whereas local authorities are only implementing it.

However, such a national policy is no guarantee that municipalities also implement it. From that perspective, the UK policies on energy, environment and climate are similarly relying on local action. This was emphasised by the UK Government White Paper 2006: Strong and prosperous communities. Fudge et al. (2015) highlighted that the focus of policy making in the UK lies on the leading role of local authorities in energy conservation, generation and efficiency [34]. Thus, 'place based' – i.e. locally embedded – initiatives were given a prime position in the national Low Carbon Transition Plan, launched in 2009. The UK energy policy approaches the local household as well as local enterprises and local authorities.

As an example, the UK Green Deal programme sets up a framework for assessment of the energy performance in households followed by suggestions for technical and economic feasible improvements. The Green Deal can also be seen as an 'economic incentive' policy as described above, however, not being a direct subsidy but rather opening up for different financial support schemes, similar to those applied by ESCOs (Energy Service Companies). Repayments of the work done according to the Green Deal programme are added to the electricity bill. Thereby investments in energy efficiency are directly compensated by energy savings. Most initiatives are about energy savings in the households, but also initiatives about energy production, e.g. by solar cells and panels, are eligible [35]. Local authorities are asked to produce "positive strategies" to promote energy from renewable and low carbon sources. They should also identify opportunities for decentralised, renewable or low carbon energy supply systems and for co-locating potential heat customers and suppliers.

The UK energy policy presupposes that local authorities and households are capable of handling projects. It has, however, been observed that the Green Deal programme is almost impossible to fit in the numerous needs of deprived households, which account for a high number in Stoke-on-Trent and other UK cities. It is less attractive for low-income households in privately rented homes, since they are unwilling to contract long-term debts that have an impact on their monthly income. Also, fragile households (the elderly, the very poor and the illiterate) are much less inclined to seek the Green Deal, because it is a difficult programme to understand, and their housing arrangements might be uncertain or short-termed.

For all six PLEEC cities national energy policy is an important regulator of obligatory local actions but also a stimulator of local voluntary energy initiatives. In this national-local interplay, local institutional capacity, competencies and political commitment are crucial.

4. DISCUSSION

4.1. Consumption – production – transmission – distribution – regulation – calibration

The basic types of activities in energy production may be summarised by the activities mentioned in the above heading. In modern energy production, former simple relations between consumption and production are now connected by an independent transmission and distribution allowing for competition between consumer and producer. Important drivers are the EU and national regulations and frameworks for energy production, distribution and consumption. The growing number of interdependencies has caused the need for calibration of activities, for example by aggregators and smart grids.

4.2. The local energy policy

Local policies have to respond to the needs of superordinate policies that demand cross-cutting calibration of supply and demand as represented by the smart grid. On the other hand, these also provide new possibilities for cities and regions, such as the case of Eskilstuna's investment in renewable energy outside their territory. Under these circumstances we consider the production of energy as local if produced locally (for local consumption) in private households (e.g. solar panels, solar cells, heat pumps) or in a local energy plant distributing energy via the local grid - no matter the ownership of the producer. Co-generation of electricity from local heat production, contributing to national consumption via a national power grid, is a by-product contributing to the efficiency of the heat production, but is not considered as local electricity production. Local energy production is developing from broadcasting energy from a few local or regional producers to a much more complex situation characterised at least by three trends:

a). Energy production techniques are mushrooming due to a diversification of techniques, resources and scales. However, diversification is also often developed within the specific local context, giving cities a key role.

b). Apart from energy production tied to resource availability (e.g. wind and hydro) most of the energy production is becoming decentralised, whereas regulatory frameworks and policies as well as the development of new techniques are becoming more centralised in the hands of national governments, international governmental co-operation and national research institutions and energy companies. These two trends, decentralisation of production and centralisation of regulation, are part of the same overall trend towards a 'networked energy production', crowned in a few years by smart grids, or by the 'energy internet'. Municipalities need to set their agendas within these systems and take active roles and responsibilities for their territories.

c). Generally, downsizing fossil fuels from energy production causes a drive towards electricity based systems. In this system, energy storage is the bottleneck. Two kinds of storage solutions are being developed: technical and relational. Technical solutions are usually on the site of the producer, whereas the relational storage is established by connecting energy producers.

4.3. Implications for urban planning

Different impacts on the city and urban planning are caused by these trends and techniques.

Site dimension and location. New techniques require sites tailored for the technique. The solar panel based district heating (DH) system in Vojens, Denmark, is a notable example (section 3.1). In several cases, old energy plants are moved from a central location in the city to more peripheral location in order to give room for extension (e.g. when DH is transformed into CHP).

Traffic generation and logistics. The relocation of Eskilstuna's CHP from the central part of the city to a logistic area 10 km east to the city was promoted by a wish for reducing the daily heavy lorry transport of wood chips in the centre of Eskilstuna as well as improving the logistics of regional fuel transport to the plant.

Resource availability. The availability of resources causes diverse restrictions on the location of grids and plants. In Tartu, the presence of peat quarries in the region is an asset for the Tartu CHP. Even closer connected are the local DH grids and industries delivering excess heat from the production.

Local DH grid tissues. Since the very beginning of DH, it has been common that investments in the DH plant and grid were decisively depending on dense grid facilitating dense housing areas developing stepwise in the so-called energy districts. Density is still preferable to the effectiveness of the DH system. However, the liberalisation of the energy market and the priorities given to individually established sustainable energy solutions have outpaced the criteria of density. This is the case of both Eskilstuna and Turku cities.

Grid districts and clusters. A special challenge to common energy systems is energy saving. For instance, DH is only feasible if a minimum amount of heat is needed. The development of zero energy houses has caused a re-evaluation of DH. In the case of Vinge, Denmark, houses were not planned as zero-energy houses, but rather as low energy consumers. As an alternative to DH small clusters of water based heat-pumps were chosen for the urban development.

Public works. The idea of reusing waste has caused a turnaround for the municipal public works. Some kinds of reuse are bound to the site of the public works. This is the situation, when heat is extracted from wastewater by heat pumps as in city Turku. Solid waste, on the other hand, is usually transported to huge incinerators in the region or even abroad.

Urban surfaces – road and roof. Urban environments are characterised by artificial surfaces suitable for multi-purpose use. Roofs and even facades on buildings are used for solar panels. Other optional surfaces are roads and bicycle lanes, as revealed by the Solaroad initiative in the Netherlands.

City and village – questions on scale. The fact that we live in scattered as well as dense built up areas, calls for energy solutions suited for both. Connolly et al. (2014) recommend a combination of DH plants (CHP) in the cities and heat pumps in the scattered built-up rural areas and villages [21]. Along with heat pumps an alternative may develop, if the micro heat and power units get mainstreamed. These micro units are especially suited for small settlements rather than large cities.

5. CONCLUSION

The raison d'être of local energy production is space and proximity. Space is needed for solar panels, solar cells and heat pumps and proximity is needed for efficient transportation of heat. Other kinds of energy production, such as the production of electricity, are relatively independent of distance when produced in central power plants and transported in high voltages transmission grids. Electricity production by wind and water turbines is of course determined by the suitability for wind and hydropower. Besides the technical requirements, strategic and political requirements are greatly influencing how central and local energy production is combined.

Thus, the strategic turn towards combined production of heat and electricity and vice versa, is decisive for producing electricity where heat is produced, for instance at district heating plants. Also, it is decisive for the production of heat in energy-intensive industries. Finally, local production may be chosen to enhance security of energy production, to develop energy technology as a local competence and job generator, or to enable local political steering.

The interrelations between urban form and energy production are developing along with new technology. New forms of heating systems (related to electricity), decentralised and small scale energy production and efforts in energy efficiency widen their suitability for urban development. On the other hand, new requirements for energy saving will limit at the same time suitable locations. We set up a number of parameters to consider: the site, the traffic generation, logistics and availability of resources, the grid and heat pump clusters, public work dependencies, urban roofs and roads and the scale of village and city. All these parameters are relevant and need to be considered jointly with the urban parameters of energy consumption.

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