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Energy systems, socio-spatial relations, and power: the contested adoption of district heating with combined heat and power in Sweden, 1945-2011

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Abstract

District heating (DH) and combined heat and power (CHP) are often considered complementary green technologies (DH-CHP) that can reduce greenhouse gas emissions. They are, however, complex given their operation at the intersection of shifting socio-spatial relations and political power struggles. We investigate the political processes behind the diffusion (and blocked diffusion) of DH and CHP in Sweden from 1945 until 2011, considered through the lens of Jessop, Brenner and Jones' (2008) Territory, Place, Scale and Networks (TPSN) framework. Foregrounding the socio-spatial constitution of policy decisions, we examine Sweden's changing patterns of DH and CHP adoption. First, we present the TPSN framework that considers space as simultaneously a structuring principle, enabling and constraining action, as well as a field of operation in which agency is exercised. Second, we examine the socio-spatial structuration of energy systems. Third, we analyse how the changing socio-spatial constitution of each socio-technical system affects key actors' interests and actions, including the spatial strategies they develop to advance their interests. District heating rapidly diffused across Swedish municipalities in large part because it was considered to be urban infrastructure aligned with the mission of municipalities and was not in direct competition with other actors supplying heat. CHP electricity generation, on the other hand, was initially seen as a benefit to municipal utilities, but was later considered a threat to the interests of large-scale utilities and blocked, only to gain favour again when changing socio-spatial conditions made CHP an asset to large-scale utilities. Our analysis suggests that technological diffusion and blockage is far from a straightforward matter. It requires examination of the dynamics of multi-level governance and overlapping socio-technical systems. Socio-technical regimes are in constant evolution and actors struggle to adapt to new circumstances. Socio-technical systems are not merely material systems, but an expression of dynamic power relations and adaptation strategies.

Zusammenfassung

Fernwärme und Kraft-Wärme-Koppelung werden oft als komplementäre grüne Technologien betrachtet, die einen Beitrag zur Reduzierung von Treibhausgasen in der Atmosphäre leisten können. Sie sind jedoch komplex, da ihr Betrieb mit einem Wandel sozio-räumlicher Beziehungen und mit Machtkämpfen der politischen Aushandlung verbunden ist. Im vorliegenden Beitrag untersuchen wir die politischen Prozesse, die mit der räumlichen Ausbreitung (und mit der Verhinderung) beider Technologien in Schweden zwischen 1945 und 2011 einhergingen, aus dem Blickwinkel des von *Jessop*, *Brenner* and *Jones* (2008) formulierten *Territory, Place, Scale and*

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Network-Ansatzes (TPSN). Im Vordergrund unserer Untersuchung der sich wandelnden Muster der Umstellung auf Kraft-Wärme-Koppelung und Fernwärme in Schweden steht die sozio-räumliche Konstitution politischer Entscheidungen. Dabei stellen wir, erstens, den TPSN-Ansatz vor, in dem Raum gleichermaßen als ein Strukturprinzip angesehen wird, das Handlungen ermöglicht und verhindert, wie auch als ein Feld für Betätigungen und Aushandlungen. Zweitens analysieren wir die sozio-räumliche Strukturierung von Energiesystemen. Drittens untersuchen wir, wie sich die Veränderungen der sozio-räumlichen Konstituierung der einzelnen sozio-technischen Systeme auf die Interessen und Handlungen von Schlüsselakteuren sowie auf die von ihnen entwickelten raumbezogenen Strategien zum Verfolgen ihrer Interessen auswirkt. Denn Fernwärme hat sich in vielen schwedischen Gemeinden und Städten vor allem deshalb rasch ausgebreitet, weil sie als eine städtische Infrastruktur angesehen wurde, die den Zielen der Kommunen entsprach und nicht in einem direkten Konkurrenzverhältnis zu anderen Wärmeanbietern stand. Andererseits wurde Kraft-Wärme-Koppelung zwar anfangs als die für Gemeinden vorteilhaftere Technologie angesehen, deren räumliche Ausbreitung jedoch im Laufe der Zeit als Bedrohung für die Interessen der Betreiber größerer Anlagen erachtet und blockiert wurde. Erst als die sich wandelnden sozio-räumlichen Bedingungen dazu geführt hatten, dass Kraft-Wärme-Koppelung für die Betreiber größerer Anlagen als geeignet erschien, wurde diese Technologie wieder begrüßt und unterstützt. Unsere Untersuchungsergebnisse deuten darauf hin, dass die räumliche Ausbreitung von Technologien und ebenso deren Verhinderung keineswegs geradlinig erfolgt. Deshalb ist es erforderlich, die Dynamik von multiskalaren Governance-Konstellationen und sozio-technischen Systemen zu untersuchen. Sozio-technische Regime befinden sich in ständiger Veränderung und die beteiligten Akteure sind bemüht, sich an die sich wandelnden neuen Bedingungen anzupassen. Dabei verstehen wir sozio-technische Systeme nicht nur als materiell, sondern auch als einen Ausdruck von dynamischen Machtbeziehungen und Adaptionsstrategien.

Keywords energy transitions, socio-spatial relations, district heating, combined heat and power

1. Introduction

District heating (DH) and combined heat and power (CHP) are often touted as viable complementary technologies (DH-CHP) to be employed in transition strategies toward lower carbon energy systems. There is growing worldwide interest in these technologies as a significant part of the means of building sustainable cities. They are, however, complex given their operation at the intersection of shifting socio-spatial relations and political power struggles. Not surprisingly, their adoption requires the coordination of a range of actors with different and sometimes conflicting interests.

This paper argues that politics and power relations are central to technological diffusion. It investigates the political processes behind the diffusion (and blocked diffusion) of DH and CHP in Sweden from post-WWII until the 2000s, considered through the lens of *Jessop*, *Brenner* and *Jones'* (2008) Territory, Place, Scale and Networks (TPSN) socio-spatial framework.

District heating is the dominant form of heating in Sweden, especially in urban areas. By contrast, CHP only accounts for 10 per cent of the country's electricity generation, below the European average. Immediately after WWII, district heating systems and combined-heat and power developed hand-in-hand, with CHP facilities supplying heat to district heating systems, while producing electricity for the electricity grid. In the 1970s, however, the two technologies dissociated: while district heating systems were still being built in urban areas, heat generated from CHP dropped in the heating mix of district heating systems. In the early 2000s, construction of district heating systems dramatically slowed, but heat generated through CHP rose again.

Drawing on government and industry documents as well as the broad literature on energy systems, we analyse the socio-spatial and political processes that produced the coupling, decoupling, and recoupling of district heating systems and combined heat power in Sweden from 1945 to 2010. We identify distinct periods of transformation in the electricity and heating systems and the successive principles of socio-spatial structuration and associated power relations that enabled (or blocked) the combination of DH and CHP. First, we begin by presenting the TPSN framework that considers space as simultaneously a structuring principle, both constraining and enabling social relations, as well as a field of operation in which individual or collective actors deploy spatial strategies. Second, we examine the socio-spatial structures of the socio-technical systems in which DH-CHP is embedded, e.g. electricity systems, heating systems, the scaling of state powers and responsibilities, and the interests of electric utilities. Third, we examine how the spatial structure of each socio-technical system influences actors' interests and strategies toward these two technologies and how, in the context of different capacities for action and access to resources of key actors, different spatial strategies were developed for different contexts.

2. Transition studies, power relations, and the spatial diffusion of technology

There is now a well-developed and coherent literature on socio-technical transitions (*Chappin* and *Ligtvoet* 2014; *Markard* et al. 2012). One of its common touchstones is the Multi-Level Perspective (MLP) (*Geels* 2010, 2011), a heuristic model describing the process of innovation diffusion and the transformation of socio-technical systems through the interplay of dynamics at three 'levels' – niche, regime, and landscape.

Transition studies have been criticized for being overly technocratic and overlooking the role of power relations, as well as for neglecting space in its conceptualisation of technological diffusion, which is problematic since an "energy transition is fundamentally a geographical process that involves reconfiguring current spatial patterns of economic and social activity" (*Bridge* et al. 2013: 331). Recent contributions from transition studies scholars have attempted to re-conceptualise power relations in transition studies (*Avelino* and *Rotmans* 2009; *Avelino* and *Wittmayer* 2015; *Geels* 2014; *Lawhon* and *Murphy* 2011; *Smith* et al. 2014). An enhanced focus on power relations has shifted the analysis from seeking the conditions of technological diffusion through good policy, to understanding the conditions that make some actors more powerful and influential than others. Recent work by geographers has contributed to a more nuanced understanding of the spatial constitution of transitions, analysing the role of local context (*Bridge* et al. 2013; *Coenen* et al. 2012; *Coenen* and *Truffer* 2012; *Raven* et al. 2012), including cities (*Geels* 2013; *Hodson* and *Marvin* 2010), and the significance of uneven diffusion (*Affolderbach* and *Schulz* 2016).

Nonetheless, power relations and socio-spatial relations have rarely been considered hand in hand. We argue that our understanding of socio-technical transitions would benefit considerably from attention to the spatial constitution of power relations. Such an approach positions actors in the power relations of specific socio-spatial contexts and socio-technical systems, facilitating an understanding of their differentiated capacity to act to transform or reproduce socio-technical systems, i.e., to enable or block change. It casts light on the fact that socio-technical systems are, themselves, always embedded in broader socio-spatial relations.

The study of any transition implies the study of socio-spatial relations. In the *Lefebvrian* tradition (*Harvey* 2006; *Lefebvre* 1974; *Soja* 1989) space is not merely a Euclidean geometrical container passively supporting social relations. Rather, spatial relations are directly implicated in the shaping and constraining of social relations and, in turn, actively shaped and transformed by them. Spatial relations are a projection of past, present and future social relations.

Conceptualising space as simultaneously a socio-historical product and an ongoing social process affords the possibility of analysing socio-technical transitions as the result of both actors' agency and constraining structures:

- Space actively shapes social relations: it structures actors' agency by enabling or limiting their access to resources and scope for action.
- Space is malleable and can be shaped by actors to change or reproduce socio-spatial relations – it serves strategic objectives in the exercise of power (*Miller* 2013).

Jessop et al. (2008) conceptualise space as being simultaneously a 'structuring principle' of social relations (or principle of socio-spatial structuration) and a 'field of operation' in which actors employ socio-spatial strategies as they engage in social action. This 'duality of space' can be analysed through a framework emphasizing four simultaneous socio-spatial dimensions: territories, places, scales, and networks (TPSN). In this 'polymorphous space' each dimension is interdependent with the others.

Jessop et al.'s framework can be extended considering spatialities as technologies of power (*Miller* 2013) that can shape the capacity of actors (both proponents and opponents) to act. This addition allows us to see the exercise of agency in the context of relations of domination and marginalisation, acknowledging that actors do not operate on a level playing field. Capacity to act is largely a function of the ability of actors to mobilise to allocative and authoritative resources[1], which are themselves spatially constituted. Socio-spatial strategies, in essence, go hand in hand with the exercise of power. In any socio-spatial field, actors have differentiated capacities to advance their interests. An implication of this conceptualisation of power is that action, and associated socio-spatial strategies, are relational. First, because increasing the capacity of some actors may entail decreasing the capacity of others. Second, because actors can pursue strategies in anticipation of, or in reaction, to others. For instance, a coalition of actors (such as electric utilities) can pursue strategies to advance their particular interests or, similarly, block other actors if their agenda constitutes a threat. And third, the capacity to act can change in response to changing principles of socio-spatial structuration.

The TPSN framework, as developed by *Jessop* et al. (2008) and modified by *Miller* (2013), guides our analysis of the socio-spatial structuration of district heating (DH) and combined heat and power (CHP) in Sweden (*Table 1*). We consider four types of actors – municipalities, municipal energy utilities, large (public and private) electricity utilities, and the central state – to explain the diffusion (or blocked diffusion) of DH and CHP between 1945 and 2011. The capacity of these actors to advance their interests has changed over time as they have struggled to reshape territorial, place-based, scalar, and networked relations. In parallel, these actors have had to adapt to the socio-spatial changes that have occurred. Actors' uneven capacity to affect socio-spatial change has been critical to the diffusion, blockage, and then resurgence of CHP in combination with DH.

Table 1 Territory, Place, Scale, and Networks in the Socio-spatial Structuration of Energy Systems. Source: Adapted from Jessop et al. (2008) and Miller (2013)

Dimension of socio-spatial relations	Principle of socio-spatial structuration/technologies of power	Associated patterning of socio-spatial relations	Socio-spatial structuration in energy systems
Territory	Bordering, bounding, parcelisation, enclosure	Construction of inside/outside divides, constitutive role of the 'outside'	Territorial integration/reach of energy system; organisation and control of energy markets and infrastructure
Place	Proximity, spatial embedding, areal differentiation of social and economic relations	Construction of spatial divisions of labor and production; horizontal differentiation among 'core' versus 'peripheral' places	Creation of sites of production and consumption; positioning in the electricity grid
Scale	Hierarchisation, vertical differentiation	Construction of scalar divisions of labor, vertical differentiation of social relations among 'dominant', 'nodal', and 'marginal' scales	Vertical organisation of the management of energy network; scalar division of state responsibilities; large-scale vs. distributed generation
Networks	Interconnectivity, interdependence, transversal or 'rhizomatic' differentiation	Building networks of nodal connectivity, differentiation of social relations among nodal points within topological networks	Creation of municipal and electric utility actor networks; structure of transmission and distribution networks

3. District heating and combined heat-and-power in Sweden

3.1 Spatial characteristics of DH and CHP

District heating systems provide heat to many buildings from a centralised thermal plant utilizing an underground network of pipes. A heating plant heats water, or generates steam, which flows into a closed-loop of undergrounds pipes. As the hot water, or steam, reaches heat exchangers installed in each connected building, heat passes into a secondary network of pipes internal to each building; cool water, or steam condensate, flows back to the thermal plant to be reheated. Depending on the size and heat demand of the system, there can be one or several thermal plants connected to a system.

District heating can use various sources of energy including biomass, fossils fuels, and geothermal energy. District heating can also recycle waste heat from industrial processes, such as municipal heat incineration or power generation. Recycling waste heat from an electrical power plant is called combined heat and power (CHP), or cogeneration. This technology increases the efficiency of the system from 33-60 per cent to 90 per cent. The flexibility of energy sources and the possibility of combination with CHP makes district heating a widely applicable tool for reducing greenhouse gas emissions in cities.

District heating systems are spatial systems:

- They have different *scales*, ranging from a district connecting only a few buildings, to an entire city, such as Stockholm's or Paris' district heating systems.
- District heating systems are capital-intensive infrastructure and rely on economies of scale to operate efficiently. Their economic viability depends on the *energy density* of an area, e.g. the heat consumed per kilometre of pipe network (KWh/meter of linear network). The higher the building density, the more secure the heat load, and the easier to secure a reasonable return on investment. For this reason, district heating is well-suited for urban areas, and is often developed hands in hands with urban development projects.
- District heating systems are *local* and *fragmented* energy infrastructures. Since hot water (or steam) circulating in an underground network of pipes is used to carry heat to buildings, there is a need to minimize heat losses. Insulated pipes are expensive which means that the sites of heat generation and consumption should be in close proximity.
- The quantity of electricity generated through CHP is limited by the magnitude of heating need, therefore CHP systems associated with district heating cannot generate large amounts of power.

These spatial characteristics highlight the fact that DH associated with CHP lies at the intersection of three socio-technical systems: the electricity system, the heating system and the political-economic system. But these systems involve different kinds of actors with different forms of socio-spatial organisation. The joint diffusion of CHP and district heating depends on how these three systems and their actors articulate with one another.

3.2 A brief history of the diffusion of DH and CHP in Sweden: coupling, decoupling, recoupling

Today, district heating is the dominant form of heating in Sweden: in 2010 it accounted for 93per cent of the heating in apartment buildings and 83 per cent of commercial heating (*Swedish Energy Agency* 2012). Around 440 district heating systems supplied a total of 55.4 TWh of heat (*Euroheat and Power*, 2011) in 290 municipalities, supplying heat to 48 per cent of the Swedish population (*Euroheat and Power* 2011). In 2011, district heating provided for 56 per cent of the total energy use in residential buildings and non-residential premises. Half of all district heating was used in multi-dwelling buildings, 36 per cent in non-residential premises and the remainder, 14 per cent, in single-family and two-family detached dwellings (*Swedish Energy Agency* 2013).

The first district heating system was built in 1948 in the municipality of Karlstad and was associated with a CHP facility (*Werner* 2010). In the following thirty years, the development of DH systems dramatically increased (*Werner* 2010) from less than 10,000 GWh of heat in the mid-1960s to almost 50,000 GWh in the mid-1990s (*Ericsson* 2009) (*Fig. 1*). Growth from the late 1970s through the mid 1990s, however, proceeded more slowly as most urban areas became connected to DH networks and heating loads stabilised (*Magnusson* 2012).

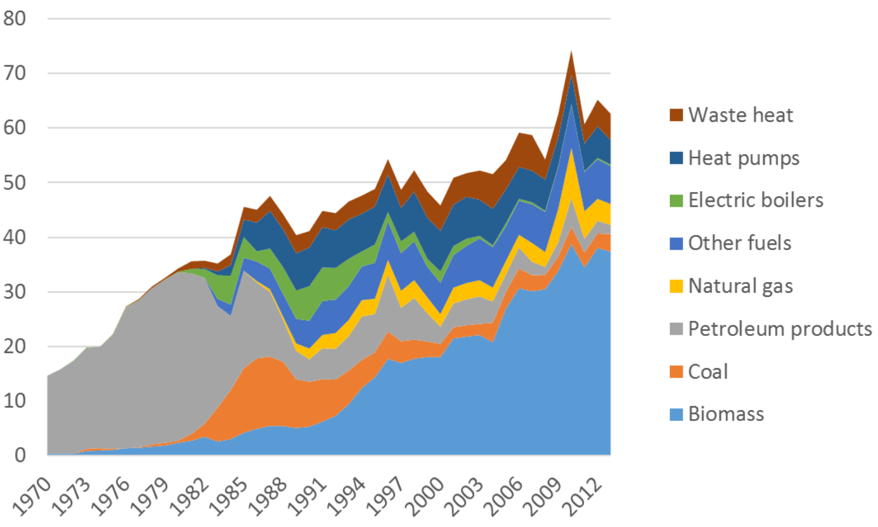

Fig. 1 Input energy used in the production of district heating (TWh) (without climatic correction) Source: Swedish Energy Agency (2012: 53)

The energy provided by district heating systems has been among the cheapest in Sweden *(Swedish Energy Agency* 2012) despite the dramatic transformation of its heating mix. In the early decades of DH diffusion, CHP was virtually always incorporated in the heating mix of DH systems (*Werner* 2010). The first ten municipal DH systems in the country were associated with oil-fired CHP plants. The rationale for coupling DH and CHP was financial as electricity generation provided additional revenue to municipalities that could be used to lower heating costs. *Werner* explains that in the 1940s and 1950s, district heating systems and CHP were considered two sides of the same coin. According to *Ericsson*, CHP plants were even "the main motive for [municipalities] to build DH systems" (*Ericsson* 2009: 10). *Figure 2* shows the continuous increase in CHP generation associated with DH between 1970 and 1979. However, in the late 1970s/early 1980s, CHP generation (associated with both DH and industry) dramatically dropped and became a marginal source of power in the country's electricity mix, largely due to the introduction of nuclear power and the slowed diffusion of district heating (*Ericsson* 2009; *Högselius* 2009; *Werner* 2010). It was only after the early 1990s that CHP generation associated with DH and industry began to increase again at a relatively steady rate. Today, almost 10 per cent of the electricity mix in Sweden is generated by CHP from industry and district heating. CHP associated with district heating represents 6 per cent of the electricity mix. In 2006 and in 2011, CHP accounted, respectively, for 34 per cent and 45 per cent of the district heat supplied (*Swedish Energy Agency* 2012).

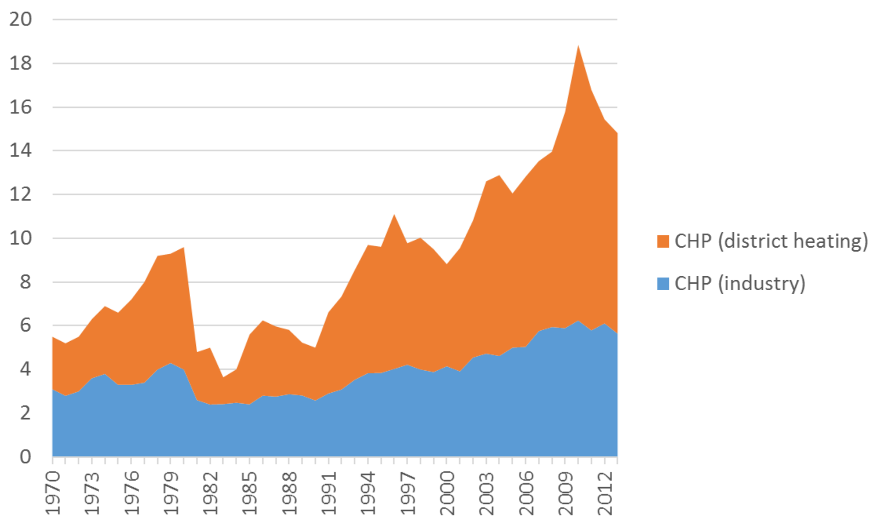

Fig. 2 CHP generation in Sweden from 1970 to 2012 (TWh) Source: Swedish Energy Agency 2015, no page given

4. The coupling and decoupling of DH and CHP during the state-regulated era (1945-1996): serving the economic interests of the 'power club'

4.1 The structuration of heating systems at the municipal scale: municipally owned utilities and state support

The Swedish heating system has always been territorially fragmented and has not historically been guided by strong national policy, given the absence of a major domestic energy industry, e.g., oil and gas. The absence of nationally integrated oil and gas infrastructure – and national policy to promote an oil and gas industry – helps explain why municipalities have played an important role in the structuration of heating systems in Sweden. As in many other European countries, urban heating systems transitioned from (often imported) coal to oil, as the latter became a cheaper heating fuel after WWII (*Kander* 2002). The first DH systems were developed in the late 1940s and were strongly associated with CHP, in a context of rapid urbanisation and scarce energy resources (*Nilsson* 2007). These systems supplied heat at an affordable cost and, even today, heat delivered by DH systems is typically price-competitive.

The provision of heat has been viewed as a municipal responsibility and virtually all district heating systems in Sweden were built by municipally owned utilities (*Magnusson* 2012; *Werner* 2017). Municipal ownership must be seen in the context of the structuration of Swedish urban governance more broadly. Municipalities have historically had strong urban planning powers, significant responsibilities in public service provision, including housing, and the possibility of creating municipally owned utilities (*Collier* and *Liifstedt* 1997; *Ericsson* 2009). The 1947 Building and Planning Act gave Swedish municipalities extensive and integrative urban planning powers (*COMMIN Project 2007)*, especially in land-use planning, to the point of "effectively eliminating private land use decisions within the plan area" and allowing municipalities "to expropriate land for dense development" (*Goldfield* 1982: 27). As a result, municipalities could ensure a sufficient heating load to make DH systems viable and had the capacity to make the long-term investments necessary for supplying affordable heat (*Werner* 2017). According to *Åberg* et al. (2016), a significant majority of municipally owned DH systems (62 per cent) applied a cost-based pricing strategy, rather than market-demand pricing. In 2011, DH systems are even more attractive when combined with CHP, due to the additional revenue stream.

Another important structuring principle has been the synergistic scalar relationship with the central state. The central state is responsible for providing municipalities with the financial resources needed to carry out their functions through equalizing grants or direct subsidies. While the national level is in charge of defining the main lines of public policy, it grants a high degree of autonomy to municipalities (*Goldfield* 1982; *Heinelt* and *Hlepas* 2006). This was the case during the national One Million Homes Program, implemented between 1965 and 1974 to fight cramped housing conditions and housing shortages. The national government subsidised the construction of one million dwellings in urban areas, mostly multi-family units built by municipally owned housing companies (*Lind* 2014). In the context of fear over energy shortages, the national government encouraged the connection of new residences to district heating systems, and most multi-family dwellings were actually connected to a DH system (*Ericsson* 2009; *Werner* 2010). *Werner* (2017) argues that the concentration of authoritative power at the municipal scale with regard to housing (through municipally-owned housing), heating (through municipally-owned utilities), and urban planning, significantly contributed to the successful implementation of DH systems in municipalities across Sweden.

The Swedish District Heating Association, created in 1949, also played an instrumental role in the diffusion of district heating. The organisation built a strong national network of municipalities and encouraged knowledge dissemination and best practices through report publication and conferences. From a technical perspective, the association worked on the harmonization of technical standards to streamline industrial processes and construction. It also played a crucial role fostering research on pipe insulation (*Ericsson* 2009). All of these activities resulted in cost reductions in development, construction and operation. By recruiting new members and making technical knowledge public, the association managed to build momentum around district heating and to present it as an efficient, cheap, and replicable heating system – an argument that was widely accepted by Swedish municipalities, during an era when municipalities wielded significant power and there were few countervailing policies emanating from the central state (*Table 2*).

Table 2 Socio-spatial structuration of the heating system in Sweden during the state-regulated period (1945-1996). Source: Own elaboration

Dimension of socio-spatial relations	Principle of socio-spatial structuration/technologies of power	Associated patterning of socio-spatial relations
Territory	National bordering of policy and networks Municipal responsibility for heating	Diffusion of DH across the national territory Territorially fragmented systems Municipal ownership and control of DH systems
Place	Areal differentiation urban/rural Place-specific heating systems	Material collocation of sites of energy production and consumption Place-specific heating rates (cost-based recovery) Convergence of housing and DH programs
Scale	Strong municipal powers: high degree of municipal autonomy from central state	Municipal control of urban planning powers, housing, heating provision, and heat distribution grid system Scalar synergies between the central and local states: national programs promoting municipal DH (One Million Homes Program, equalisation grants)
Networks	Heating distribution network National knowledge network	Diffusion of DH systems and expansion of DH distribution infrastructure National network for DH knowledge and research creating municipal expertise

4.2 Structuration of the electricity sector: from scarcity to over-capacity of large-scale generation

As in many Western countries (*Hughes* 1993), by the middle of the 20th century Sweden's electricity system was transformed from a locally fragmented grid powered with small- and medium-size power plants to a nationally integrated grid powered by large-scale power plants. This electricity system was transformed again in the second half of the 1990s through the liberalisation of the electricity sector, characterised by a shift from a publicly-owned and planned system (state-regulated system), to a market-driven system[2].

In 1909, the Swedish government created Vattenfall, a publicly-owned 'commercial government agency' ('affärsverk') to accelerate the electrification of the country, meet the growing needs of energy intensive industry, and prevent the formation of a private electricity monopoly which could have imposed high electricity prices and jeopardized the country's economic development (*Högselius* 2009; *Högselius* and *Kaijser* 2010). The status of commercial government agency meant that all major investment decisions had to be formally approved by the Parliament (*Högselius* and *Kaijser* 2010: 2247). Vattenfall's mission was to develop large-scale hydro-power plants to keep the electricity price down. By the end of the 1950s, virtually all water resources had been exploited. By the 1980s, the state company generated around 50 per cent of the country's electricity.

At that time, forecasts predicted increasing electricity demand creating fear of electricity supply shortage (*Kåberger* 2002). The national government decided to launch a nuclear power program to keep up with the expected increase in electricity demand. The first nuclear reactors were commissioned in the mid-1970s to complement hydropower (*Kåberger* 2002). Today, hydropower and nuclear power[3] remain the two main sources of electricity generation. Until the end of the 1980s, electricity generation grew rapidly before reaching a plateau in the mid-1980s, when the last two nuclear plants were commissioned (*Högselius* 2009) (*Fig. 3*).

Soon after the commission of the first nuclear power plants, electricity demand began to plateau, contradicting forecasts of growing demand. The overestimation of the country's electricity needs created a structural situation of overcapacity in electricity generation (*Högselius* 2009; *Kåberger* 2002).

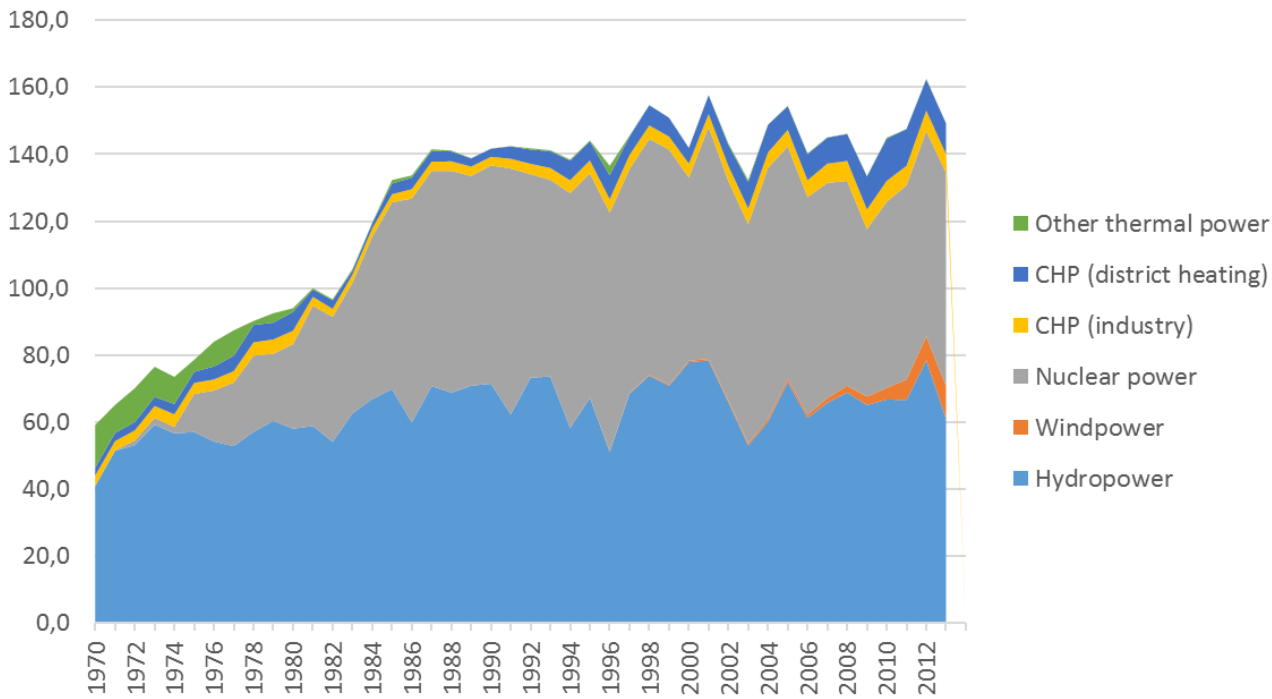

Fig. 3 Net electricity production by fuel type in Sweden (TWh). Source: Swedish Energy Agency (2012: 47)

On the transmission side, the national government nationalised the electricity grid in the early 20th century and built extensive interconnections to accommodate increasingly large-scale generation. In 1947, the national government charged Vattenfall with operating the national transmission grid and it in turn negotiated grid access conditions with large private electricity producers. Special contracts were signed between Vattenfall and the largest utilities of the country, strengthening the regional monopolies that were created at the beginning of the century. The twelve utilities, including Vattenfall, formed the Swedish State Power Board. Municipalities, which owned the local distribution grids, in turn had to sign contracts with one of the twelve regional monopolies to obtain electricity as well as to establish regulations governing the feed-in of distributed electricity, largely from CHP, to the grid. *Högselius* and *Kaijser* (2010: 2247) summarise the implications of this monopoly system on grid management:

> Key components of the regulatory structure were 'area concessions' and 'line concessions'. These gave electricity companies a monopoly, for a certain period of time, on building and operating electricity networks within a certain geographical area or along a certain corridor, respectively. The law stated that electricity consumers within a defined area could only buy electricity from the concession holder. Conversely, the concession holder was obliged to provide electricity to anyone in the area who wished to be connected to the grid. […] The Electricity Law paved the way for the creation of regional monopolies. […] In the beginning of the 20th century a bipolar structure emerged within Swedish electricity supply, with Vattenfall and the large regional companies generating and transmitting power and with mostly municipally owned companies distributing electricity to the end users. (*Högselius* and *Kaijser* 2010: 2247)

From a scalar perspective, the socio-spatial structuration of the state-regulated electricity system in Sweden was characterised by a hierarchisation of electricity generation and electricity distribution. The Swedish electricity system was centralised at the national scale, with decision-making powers regarding generation and grid management falling to Vattenfall. Vattenfall came to own the majority of the country's electricity generation capacity and operate the national grid. The 'bipolar structure', created by concession contract, produced a scalar hierarchy of the transmission and distribution systems with Vattenfall and the regional monopolies establishing domination over the municipal distribution grids. At the municipal level, this scalar relationship meant that municipalities could control the management of the distribution grid, but neither the electricity generation nor price (except for that electricity produced through CHP). This scalar structuration also impacted the territory of Swedish electricity systems. The nationalization of the electricity grid resulted in national borders for the electricity generation system. The transmission network produced a territorially defined electrical grid for Swedish electricity producers, allowing them to dispatch electricity across the entire national territory. By contrast, the management of consumption by grid by 'concession areas' or 'concession lines' fragmented the national territory into twelve regional distribution monopolies. The creation of regionally defined distribution systems trapped customers within a territory controlled by one of the twelve large-scale utilities. This organisational structure, moreover, created functionally segregated sites of production from sites of consumption. The co-location of both, through distributed generation, was an exception. The embedding of municipalities and small-scale generators within territorially defined regional monopolies meant they had to comply with conditions dictated by large-scale utilities regarding access to electricity and the feed-in of electricity to the grid.

As a result of the territorial and scalar re-structuring of the electricity system, the network of electricity sector actors changed: in the mid-1960s, the Swedish State Power Board controlled 90 per cent of the power generation in the country and members "cooperated closely with each other, forming a 'power club'" (*Högselius* and *Kaijser* 2010: 2246). This cooperation was facilitated by both the material network of transmission lines that accommodate large-scale hydropower and nuclear power and the new territorial structures of management and operation (*Table 3)*.

Table 3 Socio-spatial structuration of the electricity system in Sweden during the state-regulated period (1945-1996). Source: Own elaboration

Dimension of socio-spatial relations	**Principle of socio-spatial structuration/technologies of power**	**Associated patterning of socio-spatial relations**
Territory	National bordering of the electricity system Territorial fragmentation of electricity transmission and distribution	Territorially integrated grid: generation dispatching across the entire national territory Inclusive electrical grid for large-scale producers Regionally defined transmission and distribution systems controlled by large-scale utilities
Place	Areal differentiation (production/consumption) Embedded transmission-distribution system	Municipalities, embedded in regional monopolies
Scale	Hierarchisation of electricity generation and electricity distribution	Decision-making on generation and transmission centralised at the national scale Hierarchical 'bipolar structure' between production and consumption, transmission and distribution Scalar mismatch: municipal control of the distribution grid but no control of electricity rates
Networks	Material interconnection of electrical network Network of powerful utilities	National transmission network accommodating large-scale generation Network of regional monopoly utilities: shared-interests in the 'power club' (Swedish State Power Board)

4.3 Spatial strategies and capacities: from active promotion to active blockage of CHP by the 'power club' and municipal specialisation in heat-only DH systems

The structuration of the electricity sector in Sweden during the state-regulated period created a socio-spatial energy landscape dominated by Vattenfall and the eleven other large-scale electricity generators. The transition from a fear of electricity shortages in the context of the complete exploitation of all available sources of hydro-power (1950s-mid-1970s), to the creation of excess electricity generation capacity as the result of nuclear power plant construction (mid-1970s-early 1990s) led to a re-evaluation of relations between the dominant electricity generation utilities and municipally owned distribution utilities on one hand, and of the perception of distributed generation, including CHP, on the other.

Prior to the late 1970s, dominant actors in the electricity sector – i.e., the national government, Vattenfall, and the other large-scale utilities part of the 'power club' – actively promoted CHP generation combined with DH. Given the limited capacity of large-scale electricity producers to keep with growing demand, a territorial approach was developed around national energy security. The national government encouraged the collocation of CHP and DH systems in urban municipalities in order to increase electricity generation and to reduce the electrification of heating (*Werner* 2010). Given their ability to control access to the grid, large utilities encouraged the integration of distributed generation to complement large-scale generation. While interests of large-scale and small-scale generators aligned along a common objective, they remained different. On one hand, CHP associated with district heating systems alleviated heating costs of municipally-owned DH systems, thanks to the additional revenue from electricity sales. On the other hand, distributed generation from CHP associated with DH allowed Vattenfall and the other large-scale generators to keep up with electricity demand in a context of scarcity – all major waterfalls and hydropower sources had been exploited by the end of the 1950s. As a result, municipally-owned energy utilities employing CHP, and the 'power club' responsible for most electricity generation, formed an unstable coalition of actors with congruent interests around CHP generation combined with DH.

By the end of the 1970s, however, in a context of electricity over-production, CHP became a direct competitor to the large-scale electricity generators, threatening their market share (*Kåberger* 2002). The 'power club' actively blocked the diffusion of CHP and shrunk the share of distributed electricity in the national electricity mix. Members of the 'power club' colluded to phase out CHP generation. In this period their capacity to control the grid allowed them to practice discrimination in electricity pricing and to charge exorbitant electricity rates to municipalities operating CHP units (*Ericsson* 2009; *Kåberger* 2002; *Magnusson* 2012; *Werner* 2017). This differentiated pricing was a territorial strategy to exclude municipally owned utilities from the electricity grid and thereby from generation activities.

Until the end of the 1970s, the socio-spatial structuration of the Swedish electricity system was oriented toward increasing municipal capacity to build CHP in association with DH, supported through the mobilisation of central state resources (subsidies from the One Million Housing Program, access to the grid for distributed electricity, and attractive purchase agreements for CHP generation). By the end of the 1970s, however, municipal construction and operation of CHP plants decreased as large-scale electricity generators implemented policies to deter the feed-in of distributed electricity to the grid. By the end of the 1970s, as a result of this asymmetric power relationship between municipal utilities on the one hand and large-scale electrical utilities with spatial monopolies granted by the central state on the other, municipal utilities were forced to abandon electricity generation associated with district heating if they wanted to provide affordable electricity to their customers. With little capacity to generate electricity, municipal utilities depended on large-scale utilities for most of their electricity supply. By the early 1980s, CHP power generation was successfully blocked (*Fig. 2*) despite the increase in district heating systems (*Fig. 1*). The decoupling of electricity generation and heating production in urban municipalities represented a scalar specialisation of energy production: municipally owned utilities were in charge of heating generation and distribution, while big public and private utilities, backed by the central state, were in charge of electric power generation and transmission (*Table 4*).

Table 4 Socio-spatial strategies and structuration leading to the coupling and decoupling of CHP and DH during the state-regulated period (1945-1996). Source: Own elaboration

Dimension of socio-spatial relations	**Socio-spatial strategies and structuration**	
	Fear of electricity shortage and active promotion of CHP (1950s-mid 1970s)	**Electricity generation over-capacity and active blockage of CHP (mid 1970s-early 1990s)**
Territory	*Reduced capacity* for large-scale producers to increase electricity production (scarcity, main water resources across the country already exploited) *Existing capacity* for large-scale utilities: control of the national transmission grid *State strategy*: national approach to energy security – promote CHP	*Existing capacity* for large-scale utilities to control electricity prices within their respective spatial monopolies *Large-scale utilities' strategy*: exclusion of municipally owned utilities from the electricity grid if they pursue generation
Place	*State strategy*: target collocation of CHP with DH in urban areas to increase electricity generation and reduce electrification of heating *Increased capacity* for municipally-owned utilities to combine CHP and DH	*Reduced capacity for resistance* from municipalities trapped within spatial monopolies *Large-scale utilities' strategy*: areal discrimination in pricing (high electricity rate for municipalities operating CHP plants) *Municipally owned utilities' strategy*: decoupling of generation and heating production to preserve benefits of DH
Scale	*Large-scale utilities' strategy*: integration of distributed generation to complement large-scale generation in the national grid	*Large-scale utilities' strategy*: scalar energy specialisation with municipally owned utilities in charge of heating, large-scale utilities in charge of electricity generation
Networks	*Shared strategy*: formation of an unstable coalition (municipally owned DH with CHP and large-scale generators) to advance aligned, but different interests	*Large-scale generator's strategies*: collusion among members of the 'power club' to pursue phase- out of CHP by municipal utilities to reduce excess capacity and support prices

5. The recoupling of CHP and DH during the era of market-liberalisation: market-oriented electric utilities looking for economic diversification (1996-2011)

Sweden's entry into the European Union led to the liberalisation of its energy market. Liberalisation policies were adopted in 1996 after several years of intense debate and lobbying (*Högselius* and *Kaijser* 2010). In preparation for the liberalisation process, Vattenfall adopted a limited liability corporate structure in 1991. This process was accompanied by an unbundling of generation and distribution: the national grid was removed from Vattenfall's portfolio and put under the management of a national regulator (*Högselius* 2009). The liberalisation of the country's electricity market ended the regional monopoly system and the associated 'power club', initiating a process of mergers and acquisitions in the Swedish electricity industry that had two implications for electric utilities: a market concentration of generation activities and growth of activities in other European countries through partnership, fusion, and vertical-integration (*Högselius* and *Kaijser* 2010). The three largest electricity generators in the country, Vattenfall, Fortum, and E.ON, controlled about 90% of power generation by the end of the 2000s (*Högselius* and *Kaijser* 2010). In parallel, large electric utilities also diversified their activities by investing in the district heating sector, including municipal DH systems (*Åberg* et al. 2016; *Högselius* and *Kaijser* 2010).

The liberalisation of the energy sector resulted in two significant shifts in the socio-spatial structuring principles of district heating systems. First, liberalisation moved ownership of DH systems from municipally owned utilities to the large-scale utilities of the former 'power club'. A majority of municipalities decided to privatize their municipally owned DH utilities and sell them entirely or partially to large utilities (*Högselius* and *Kaijser* 2010)[4]. Between 1990 and 2011, the share of space heat produced by municipally owned DH companies dropped from 98 per cent to 65 per cent. During the same time, the private ownership rate increased from almost 0 per cent to 35 per cent (*Åberg* et al. 2016). Municipal DH systems were caught in the merger and acquisition strategies of the former members of the 'power club' which were looking to position themselves to compete in the larger European market (*Högselius* and *Kaijser* 2010). In 2011, the three main leaders in the transformation of the district heating sector in Sweden were Vattenfall, Fortum (which operates only in the Stockholm area), and E.ON (which operates mainly in southern Sweden) (*Åberg* et al. 2016).

Second, liberalisation changed the dominant business-model from long-term cost-based recovery to market-based pricing and return on investment (*Åberg* et al. 2016). *Åberg* et al. estimate that 62 per cent of municipally owned utilities apply cost-based pricing while only 11 per cent of privately-owned utilities apply this pricing method. Privately-owned utilities prefer to use market-based pricing (68 per cent). In addition, the European directive on liberalising the energy market forbade cross-subsidisation as it was perceived as a distortion of competition. Public utilities were required to separately account for each activity, i.e. they were no longer allowed to fund a loss-making activity with profits generated by another activity (*Högselius* and *Kaijser* 2010). This may explain why an increasingly high share of municipally owned utilities (29 per cent) now use market-based pricing (*Åberg* et al. 2016).

A few years after the onset of liberalisation, in the early 2000s, district heating entered in a phase of stagnation due to a combination of factors: increased energy efficiency of dwellings, market saturation (over 85 per cent of multi-housing dwellings were already connected to district heating systems), and competition with electricity as a heating source in single and two-dwelling housing (including the use of heat pumps) (*Magnusson* 2012). According to *Magnusson*, the district heating sector managed to maintain a relatively constant level of heat sales by developing a strategy of territorial extension of pipe networks to reach non-traditional markets, thanks in part to national subsidies promoting conversion to non-electric sources of space heating.

Low electricity prices had been a barrier to CHP electricity generation through the early 1990s. By the mid-1990s, however, the situation started to change. First, the debate around nuclear phase-out, and the additional electricity generation it would have required to offset nuclear generation, encouraged large-scale energy utilities to consider CHP generation associated with DH (*Magnusson* 2012). Second, and more importantly, in a context of the fight against climate change, the national government adopted policies to lower greenhouse gas emissions and to encourage green energy production. Measures included the introduction of a carbon tax in 1991 that was substantially increased in the 2000s; introduction of a green electricity certificate in 2003 to promote renewable energy generation, including biomass-fired CHP generation (around 64 per cent of the green electricity certificates issued by 2012); subsidies for the construction of biomass-fired CHP plants in the 2000s; and exemption from the carbon tax for CHP generation (instituted in 2013 after a decade of lobbying). The outcome of these measures was to shift the district heating energy mix from coal to biomass and to increase the number of district heating systems associated with biomass-fired CHP plants. Between 2006 and 2011, the CHP heat contribution to DH systems increased from 34 per cent to 45 per cent (*Swedish Energy Agency* 2012).

In the broader context of a green policy agenda, liberalisation and the acquisition of district heating systems by large-scale electric utilities was central to the re-coupling of CHP and DH. By 2011, private utilities accounted for 45 per cent of the heat delivered by district heating systems (versus 2 per cent in 1990). Most of this heat came from the four leading power generators, including Vattenfall (*Åberg* et al. 2016; *Högselius* and *Kaijser* 2010). Control of these energy systems and the associated profit has shifted from municipal utilities to large-scale, for-profit electric utilities.

The changes have been complex. Recently deployed CHP generation associated with district heating is no longer in the sole hands of municipal utilities. The 'Power Club' has collapsed and electricity generation is concentrated in the hands of four European energy utilities (including Vattenfall, Sydkraft, the German E.ON and the Finnish Fortum). The resurgent diffusion of CHP was made possible by a shift of ownership from municipal utilities to large-scale utilities, liberalisation, expansion into the EU market, and a new regulatory environment at both the scale of the Swedish national state and the EU that subsidises the use of biomass energy. Now that CHP aids in expanding the market share of large-scale utilities, it is no longer seen as a competitor but as a motor for growth.

The relationship between DH and CHP is once again seen as synergistic. According to *Magnusson*, "district heating companies in Sweden are *broadening their scope of activity* into other sectors, especially electricity [...] For better economic results energy companies have made major investments in CHP production both in Sweden in general and in Stockholm in particular" (*Magnusson* 2012: 455 authors' emphasis). The liberalisation, privatisation, and re-territorialisation of energy markets is not an entirely good news story, however. DH systems have been transformed from a local public service to an economic asset for large-scale private utilities competing in the EU common market. Only 17 per cent of privately-owned Swedish utilities now consider energy supply as their main objective, as opposed to 38 per cent for municipally owned utilities (*Åberg* et al. 2016). This change in mission in part explains the significant increase in district heating rates for Swedish apartment buildings during the 2000s (*Åberg* et al. 2016; *Swedish Energy Agency* 2012), in Stockholm in particular (*Rutherford* 2008) (*Table 5*). The restructuring that has led to the recoupling of CHP and DH has promoted greater energy efficiency and biomass use, but may also pose a significant financial burden on those who struggle to meet basic needs.

Table 5 Convergence of the socio-spatial structuration of the heating and electricity systems during the market-liberalisation period, promoting the resurgence of CHP (1996-2011). Source: Own elaboration

<table>
<tr><th>Dimension of socio-spatial relations</th><th>Principle of socio-spatial structuration</th><th>Associated patterning of socio-spatial relations in the heating system</th><th>Associated patterning of socio-spatial relations in the electricity system</th></tr>
<tr><td rowspan="2">Territory</td><td rowspan="2">European bordering of market competition
National bordering of climate change policy</td><td>Stagnation of DH expansion
Territorially fragmented DH systems</td><td>Over-capacity lessened through entry into the EU market
Relatively unrestricted electricity grid access</td></tr>
<tr><td colspan="2">Construction of a more extensive energy system territory
Territorial integration of two superposed energy systems (heating and electricity) through EU market integration, competition, climate change policy and CHP incentives</td></tr>
<tr><td>Place</td><td>Place-specific heating systems</td><td>Local DH embedded in energy market and large-scale utilities' strategies
Shift in local management of DH
Placeless heating rate (market-based)</td><td>DH recoupling with CHP
Electricity generated in association with municipal DH systems feeds into more extensive grid</td></tr>
<tr><td>Scale</td><td>Control shifting from municipal to large-scale utilities</td><td>Scalar mismatch with loss of municipal control over locally embedded DH systems</td><td>Utility mergers concentrating control of large-scale and distributed generation</td></tr>
<tr><td rowspan="2">Networks</td><td rowspan="2">Interconnection of actors and systems</td><td>DH local asset for internationalised utilities</td><td>Collapse of power club</td></tr>
<tr><td colspan="2">Local-European-Global network of competing vertically-integrated energy large-scale utilities
Interconnection of heating and electricity systems through CHP nodes</td></tr>
</table>

6. Conclusion

In 2014, *Geels* invited scholars to “conceptualiz[e] existing regime actors as actively resisting fundamental change, rather than as locked-in and inert” (*Geels* 2014: 35). We have aimed to provide just such an account in our analysis of DH and CHP diffusion in postwar Sweden. We have done so by analysing power relations, the socio-spatial relations that both enable and constrain action, and the deployment of specific spatial strategies.

District heating managed to diffuse across Swedish municipalities because it was considered to be urban infrastructure aligned with municipalities’ mission and was not in direct competition with other actors supplying heat. CHP generation was not so much a niche innovation, but rather an actively ‘marginalised niche’: it was widely adopted until the end of the 1970s and then again in the early 2000s, but for much of the 1970s and 1980s it was seen as detrimental to the interests of large-scale utilities, which had considerably more influence on energy policy than municipalities.

Our analysis suggests that the study of technological diffusion and blockage is far from a straightforward matter. Rather, it may require examination of multilevel governance and overlapping socio-technical systems in a dynamic and spatial, rather than static and aspatial, way. Regimes are in constant evolution and actors struggle to adapt to new circumstances. This dynamic dimension is crucial. A regime is not merely the production of a material system and landscape, but an expression of dynamic socio-spatial power relations and adaptation strategies.

The diffusion of socio-technical systems is very much a political matter. As the coupling, decoupling, and recoupling of DH and CHP in Sweden illustrates, actors shape the socio-spatial structures of socio-technical systems which, in turn, differentially shape the capacity of actors to act. Asymmetric capacities to control legal and material resources and to build powerful coalitions enables dominant actors to actively block or promote certain technologies based on their interests. A dynamic socio-spatial framework allows us to analyse the who, where, and how of power relations and from there, illuminate possible avenues for transforming energy systems – by transforming power relations.

Notes

[1] The notion of transformative capacities and the distinction between allocative resources and authoritative powers is developed by *Giddens* (1984).

[2] In the context of liberalisation, we acknowledge that markets are a form of state-regulated system. For simplification, we make this binary distinction to contrast the role of state planning, and concentration of decision-making powers and allocative resources in the public realm, on one hand, and the role of market competition and allocation of resources from the private realm, on the other.

[3] Nuclear power has been contested and was supposed to be phased-out in the late 1980s following the Tchernobyl accident, but this decision was reversed in 1991.

[4] Those decisions were also driven by the economic crisis and the daunting financial situation of municipalities. Selling their utilities was a way to generate income and alleviate the financial burden they were facing following changes in urban governance (*Högselius* and *Kaijser* 2010).

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