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THE (UP)SCALING OF RENEWABLE ENERGY TECHNOLOGIES: EXPERIENCES FROM THE AUSTRIAN BIOMASS DISTRICT HEATING NICHE

Markus SEIWALD

Abstract

The successful diffusion of sustainable technologies is termed "upscaling" in the transition studies literature. This paper maintains that upscaling is an ambiguous notion that suggests that technology diffusion processes follow a linear trend from small-scale pilot plants to industrial-scale facilities. On the ground, however, socio-technical configurations are implemented at a variety of scales, simultaneously. These issues are demonstrated in this paper by analysing the historical development of the Austrian biomass district heating niche. Drawing on secondary statistical data and primary qualitative semi-structured interviews, it is possible to identify four generic socio-technical configurations or dominant designs that, in conjunction, shape the diffusion dynamics of this technology in Austria.

Shrnutí

(Up)scaling technologií obnovitelné energie: zkušenosti z rozvoje dálkového vytápění biomasou v Rakousku

Úspěšná difúze udržitelných technologií je v literatuře zabývající se studiem přechodů označována termínem "upscaling". Tento článek dokládá, že upscaling představuje nejednoznačný pojem, sugerující, že procesy šíření technologií sledují lineární trend od malých pilotních elektráren k velkým průmyslovým zařízením. Nicméně ve skutečnosti jsou socio-technické konfigurace implementovány simultánně na různých úrovních. Tato problematika je demonstrována analýzou historického vývoje trhu dálkového vytápění biomasou v Rakousku. S využitím sekundárních statistických dat a kvalitativních semi-strukturovaných rozhovorů byly identifikovány čtyři generické socio-technické konfigurace neboli dominantní vzorce, které ovlivňují dynamiku šíření této technologie v Rakousku.

Key words: *energy transitions, scale, biomass, district heating, Austria*

1. Introduction

Research on sustainability and energy transitions is an expanding scientific field, as a growing number of publications and special issues in journals show (Markard et al., 2012). Recently, economic geographers have proposed a series of conceptual points of departure to elaborate the spatial aspects of sustainability and energy transitions (Coenen et al., 2012; Bridge et al., 2013), and one of the most prominent concepts is scale. In the sustainability transitions literature, the establishment and especially expansion of novel socio-technical configurations[1] is termed the Upscaling of Technological Niches: "Upscaling is defined as increasing the scale, scope and intensity of niches experiments by building a constituency behind a new (sustainable) technology, (...)" (Coenen et al., 2010, p. 296, emphasis added). Actors that participate in a local project share their experiences with other projects. They compare and aggregate lessons and thereby contribute to the creation of an emerging technological trajectory (Schot, and Geels, 2008). The approach of Strategic Niche Management thus uses the notion of upscaling as a shorthand symbol for deliberate technology diffusion. The underlying picture is one of a rather linear development trajectory, pushed by a homogenous community and resulting in a continuous increase in artifact size for the realization of economies of scale. In this article, I suggest that this notion of upscaling represents an overly simplistic view of technology diffusion. I maintain that a technology can be divided into several generic socio-technical configurations or dominant designs. Each dominant design consists of a particular combination of technical (hardware) and institutional (software) components and follows its own life cycle. The successful diffusion of the wider technology results from the aggregated implementation rates of the individual dominant designs, and cannot be reduced to the realization of large-scale industrial facilities that intensify energy production.

To illustrate this contention I analyse the development of the Austrian biomass district heating (BMDH) niche which experienced high diffusion rates throughout the 2000s. The number of installed plants increased four-fold to over 2,000 from 1999 to 2010 (Rakos, 2001; Mayerhofer and Burger, 2011), while the amount of fed-in heat increased five-fold to approximately 37 PJ, thereby covering around 45% of the overall district heating output (Statistik Austria, 2012). The spatial distribution of these plants is shown in Figure 1. Although no technology-specific goals exist for a further expansion of capacities, diverse supply- and demand-side policies at the national and the provincial scale support

[1] A socio-technical configuration is understood as a certain combination of technological artifacts, actors that use and maintain those artifacts, and institutions that govern the relations between actors and between actors and artifacts (Markard et al., 2012).

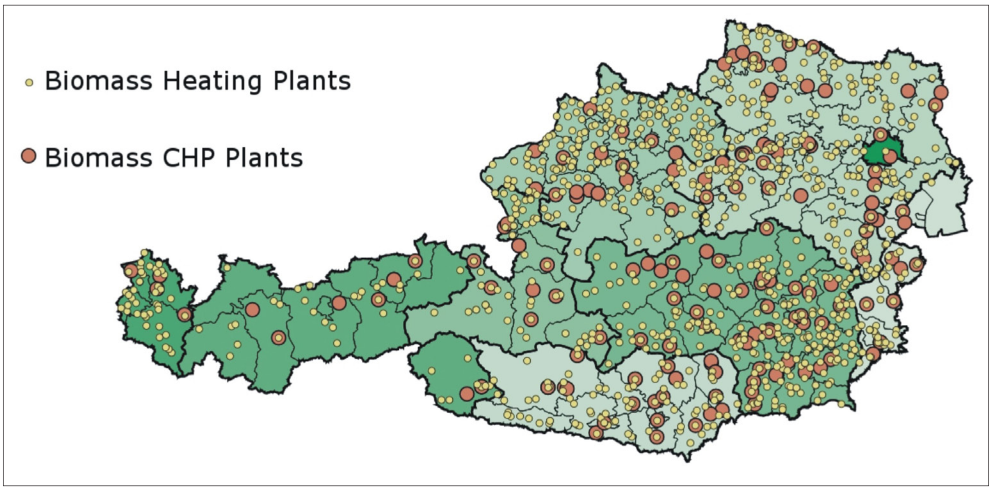

Fig. 1: Biomass Heating and Combined Heat and Power Plants in Austria 2010[2]
Source: Austrian Biomass Association, 2013

the ongoing diffusion. These policies are listed in the Austrian Renewable Energy Action Plan submitted to the European Commission as key contributions to increase the amount of renewable heating and cooling to roughly 175 PJ by 2020 (Karner et al., 2010). This currently rather successful example of technology diffusion serves as a case study to answer the following questions: Which actors and institutions shaped the dynamics of technology diffusion? What were the consequences of these dynamics for the physical size of technology implementation and the interrelated organizational patterns of plant operation? What conclusions can be drawn for the concept of niche "upscaling"?

The paper is structured as follows: Section 2 briefly introduces the concept of scale with respect to transitions in the energy system and connects it to the hardware/software scheme proposed by Walker and Cass (2007), as well as the Technology Life Cycle approach (Taylor and Taylor, 2012). The following section describes the methodology for empirical data collection and analysis. Drawing on the approach by Walker and Cass (2007), the dominant designs for BMDH in Austria are classified according to typical combinations of hardware and software components. In a second step, the current phase of the Technology Life Cycle (TLC) is identified for each dominant design. Section 4 delineates the system of interest and briefly discusses the particularities of the BMDH value chain. The next section focuses on the historical trajectory of BMDH in Austria and identifies the relevant actors and institutions that had a strong influence on the (up)scaling of the niche. Section 6 combines the theoretical perspective with the historical case study data and quantitative material to develop a classification of dominant designs in the Austrian BMDH population. The final section concludes the paper and proposes lines of inquiry for future research.

2. Theoretical departures

2.1 Energy transitions and the concept of scale

In a recent contribution, Bridge et al. (2013) review a set of geographical concepts that might help to better understand the transition from fossil to renewable fuels. They argue that this alleged transition might have similar social and geographical implications as the shift to coal as the primary energy source in the 19th century. Currently, however, the sustainability transitions literature is mainly concerned with temporal processes, though its proponents stress geographical metaphors like local and global niche or upscaling. Bridge et. al. (2013) intend to move space to the centre of the discussion. They discuss a number of geographical components of transitions with scale as one of them. From a geographical perspective, scale can be conceptualized in at least two different ways (ibid., p. 337f): (i) as levels of governance with a specific geographical reach that are interrelated to each other; and (ii) as the physical aspects of a phenomenon in combination with its organizational structures. The first concept in particular is widely discussed in the geographical literature (Brenner, 2001; Marston et al., 2005). A thorough account of this rich discussion does not fit within the scope of this paper, especially as I intend to focus on the second of the mentioned conceptualizations.

On the other hand, some insights of the discussion about scale as the relation between governance levels might be helpful for the purpose of this paper. As Swyngedouw (2004) emphasizes, scalar levels of governance – such as local, regional or national – must not be taken as predetermined, nor as organized in a fixed hierarchy where the higher levels rule the lower ones. Scalar levels are instead actively produced by powerful actors who may adapt the level they are operating in to fit it to their interests. Similarly, the "right" capacity of energy production facilities is not predetermined but depends on a number of external structural circumstances as well as the needs and interests of stakeholders. In the case of Biomass District Heating (BMDH), the preferred scale of heat production may for instance vary according to the views of a local farmer cooperative which wants to sell a certain amount of wood from its forest, the municipality which wants the facility to supply all households within its territory, or an energy utility that operates the plant and strives to optimize heat sales to large customers. Thus it seems appropriate to refer to scaling as a deliberate activity in its verb form and not to scale as a given characteristic. In the context of this article, I will refer to scaling as a strategy that actors deliberately apply to match the physical size and the mode of governance of a socio-technical configuration to their needs and interests.

[2] AUSTRIAN BIOMASS ASSOCIATION (2013): Bioenergie. Basisdaten 2013. Österreichischer Biomasse-Verband. [cit. 30.10.2013]. Available at: http://www.biomasseverband.at/publikationen/broschueren/?eID=dam_frontend_push&docID=2019

To properly characterize the latter two dimensions, Walker and Cass (2007) develop a scheme for the categorization of socio-technical systems in the energy sector. They directly link the physical aspects of the energy system – like plant capacity or geographical extent of the infrastructure – to questions of operation and governance. They distinguish between the hardware and the software of a socio-technical configuration, the hardware being the engineered artifacts of the infrastructure in question, while software comprises its social organization. Considering the hardware, Walker and Cass (ibid., p. 460) stress the "hypersizeability" of renewable energy technologies, i.e. the possibility to realize plants from a macro- (e.g. the Three Gorges Dam, offshore wind farms) to a micro-scale (e.g. a micro- turbine inside a drinking water pipe, roof-top wind turbines). Each implementation size is characterized by different relational qualities of physical presence, connection to other infrastructure, degrees of mobility and the potential for environmental impact that comes with a certain size. The software side comprises the specific arrangements between actors and institutions. Walker and Cass propose to characterize the software component by its function and service (What is the energy used for and who uses it?), ownership and return (Who owns the technology and what benefits are returned as a consequence?), management and operation (Who manages the hardware and to what extent and through what mechanisms is management regulated?), and infrastructure and networking (What is the scale of the network the energy is fed into and how is it managed?). Hardware and software as two aspects of a socio-technical configuration have to be seen as co-dependent and co-evolving. This means that one might expect to observe a certain path dependency in the development of a new technological niche. A range of possibilities for viable configurations exists for every technology, but not every combination of hardware and software matches specific needs at a given point in time and space.

2.2 The evolution of socio-technical configurations through the Technology Life Cycle

Sandén and Hillman (2011) use a value chain approach to delimitate technologies for alternative transport fuels and identify crucial interaction points between them. Using a very broad definition of technology, they identify physical objects, organizations, knowledge and regulation as elements of socio-technical systems that are organized in value chains (ibid., p. 404). In a similar way, Taylor and Taylor (2012) search for a viable methodology to delimitate the boundaries of a technology for the foundation of a better understanding of the Technology Life Cycle (TLC). They start by classifying the generic category of "technology" into four types: from a simple product without any separable components (like glass or cement) to complex open assembled systems that have no clear boundaries, are made up of distinct subsystems and artifacts that are linked through interface technologies, and are delivered through a network of multiple organizations. The authors state electricity supply as an example for such an open assembled system. Each of its subsystems or artifacts is subject to its own individual life cycle along which it evolves. To follow these individual cycles is virtually impossible. Thus, Taylor and Taylor (ibid., p. 545) propose to define such complex technologies at an aggregated level according to their application. The overarching application usually can be divided into different paradigms. Paradigms for their part follow their own life cycles which may be consecutive or may overlap in time. They can be divided further into different generations. Taylor and Taylor provide "technology for music playback" as an example of an application and divide it into the dominant paradigms: "analog-phonographic", "analog-magnetic" and "digital". They finally define different generations like "record", "compact cassette", "compact disc", or "MP3". How can we now apply this approach for a better understanding of the Austrian BMDH niche?

BMDH plants can be seen as an appropriate example of an open assembled system in the sense of Taylor and Taylor. The overarching application can be defined as "centralized heat generation for distribution via a pipe network". The paradigm of interest in this article is "biomass-based heat generation". This basic principle might be adapted and modified to meet the needs and interests of different actors. These modifications often have the character of a trial and error search process. Actors that engage along the value chain of BMDH search for a satisfying combination of hardware and software. If they succeed in establishing a socio-technical configuration that delivers performance (within the local circumstances), this configuration might be regarded as a best-practice example and become copied elsewhere. It has to be emphasized, though, that a mere imitation of a successful example without adaptation to the local conditions is condemned to failure.

Nevertheless, generic configurations might develop over the years that shape the path dependent evolution of a technology. Each of these generic configurations can be regarded as one dominant design[3]; a further sub-level of the paradigm that follows its own life cycle. The ideal type of the life cycle follows an S-shaped curve with time plotted on the x-axis and a performance or diffusion indicator (such as total sales) plotted on the y-axis. The life cycle can be divided into different phases. During the embryonic or formative phase, growth is slow due to uncertainties at the producer- and user-side and childhood diseases of the technology. In the growth phase, technology diffusion accelerates, a dominant design emerges and technological change tends to be incremental. In the maturity phase, diffusion slows down again as cumulative technology adoption reaches saturation (ibid., p. 550ff). Drawing on these theoretical concepts, I argue that the open assembled system BMDH, in the Austrian case, followed a complex innovation pathway that encompassed several dominant designs that overlapped in time. I reject the idea of a linear trend from small-scale to industrial-scale plants that is driven by a group of actors that share the goal of technology diffusion. The question then arises: how can these dominant designs be delimitated, and what is their effect on the diffusion of the broader technology application, in other words, the "upscaling" of the niche?

3. Methodology

The empirical quantitative data presented in the following sections were collected from different primary and secondary sources. The distinctions between the consecutive phases of the life cycle are based on quantitative data published by the Austrian Statistical Office (Statistik Austria, 2012), the Chamber of Agriculture (Furtner and Haneder, 2013), the

[3] Compared to the classification by Taylor and Taylor (2012), the notion of "generation" is not considered because it suggests a continuous progress from one generation to another, which is not necessarily the case for different socio-technical configurations. Thus, I use the term "dominant design" instead of "generation".

Ministry for Traffic, Innovation and Technology (Biermayr et al., 2013), and the Federal Government of Lower Austria. Section 5.1 briefly sketches the formative and early growth phase of the niche. It draws mainly on research that was conducted by the Institute for Technology Assessment Vienna, the Austrian Energy Agency and the University of Natural Resources and Life Sciences Vienna. Section 5.2 describes the developments during the growth phase of the TLC.

The qualitative data were collected in several ways:

- in a series of 17 semi-structured interviews with staff of the national and provincial subsidy departments, lobbying organizations, plant operators and research organizations (see Tab. 1);
- by an analysis of studies and reports by federal agencies, research and lobbying organizations; and
- attendance at five conferences (Tab. 2) on bioenergy with a strong focus on district heating.

The semi-structured interviews lasted 1 to 2 hours, were recorded, transcribed and added to a database. The guiding issues for the interviews were: (i) the general development of the niche during the last 15 years; (ii) the business model used in cases where the interviewee was a plant operator; (iii) normative and cognitive institutions that guide the actions of the interviewee (good practices, common problems and bottlenecks, future possibilities for the technology, etc.); and (iv) the strategies of other actors with respect to competitors that operate plants.

4. The value chain of biomass district heating – processes, actors and spatiality

The basic process steps along the value chain of BMDH plants are shown in Figure 2. One reason for actors to dedicate themselves to an emerging business field might be that they have a strong relation to at least one of the crucial activities along the value chain. An expansion to upstream or downstream activities might then seem obvious to increase value creation and capture. The core business of the agricultural and forestry sectors, for instance,

	Organization	Position	Date
1	Austrian Biomass Association	CEO	28.11.2012
2	Lobbying Organization for Natural Gas and District Heating	Referee	28.11.2012
3	Austrian Energy Agency	Scientific Staff	28.11.2012
4	Lobbying Organization of Electricity Producers	Referee	30.11.2012
5	Federal Forestry Agency	Executive Director of former Bioenergy Division	30.11.2012
6	ESCO	CEO	24.01.2013
7	Subsidy Administration	Referee	24.01.2013
8	Syndicate Small Scale Biomass District Heating	Referee	07.02.2013
9	Energy Utility	Executive Director Renewables	22.02.2013
10	Energy Utility / ESCO	Executive Director Heatcontracting	06.03.2013
11	Energy Utility	Executive Director Heat Executive Director CHP Executive Director Networks	12.03.2013
12	ESCO	CEO	07.05.2013
13	Small Scale District Heating Plant	Administration	14.05.2013
14	Medium Scale District Heating Plant	CEO	14.05.2013
15	Provincial Scale Lobbying Organization and Planning Office	CEO	29.05.2013
16	Medium Scale District Heating Plant	Chairman	06.06.2013
17	Provincial Subsidy Administration	Referee	11.06.2013

Tab. 1: Qualitative field interviews

1	Biomass Days 2011	Biomass Association	16.–18.11.2011
2	Biomass Days 2012	Biomass Association	22.–24.10.2012
3	Energy Symposium	Chamber of Agriculture	25.01.2013
4	INREN Wood Gasification Conference	AgrarPlus	21.02.2013
5	Renewable Heat – Key for the Energy Transition	Biomass Association	08.05.2013

Tab. 2: Conferences attended

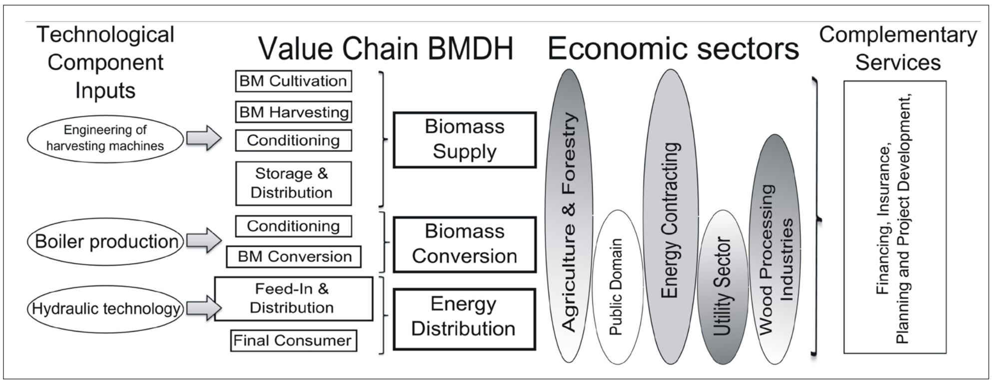

Fig. 2: The value chain of biomass district heating plants. Source: Author

lies in biomass cultivation, harvest, conditioning and distribution. In Figure 2 these core activities of an economic sector are depicted in dark grey shading. Newly-developed business segments are depicted in light grey to white. In the case of BMDH, actors from agriculture and forestry expanded their activities further downstream into biomass conversion and energy distribution. Likewise, the wood processing industries – especially the sawmill industry – expanded downstream from their core activities of biomass conditioning and distribution. Energy utilities have always been concerned with the feed-in and distribution of the final product (heat and/or electricity), but were somewhat hesitant with their commitment to biomass-to-energy conversion. They mainly stick to their core competencies and do not extend their activities further upstream.

The public domain is mainly represented through municipalities, which play a central role in most projects. On the one hand, they maintain buildings in the village or town centre that are important customers for most district heating networks, e.g. schools, retirement homes or public swimming pools. On the other hand, they act as a project initiator in many cases, and sometimes even as a plant owner and operator. As BMDH plants spread throughout Austria, energy supply contracting emerged as an independent business field consisting of heterogeneous actors. Energy contracting firms, also called energy service companies (ESCOs), are usually involved in a number of projects. ESCOs can be run by planning offices, mergers of freelancers, or subsidiaries of energy utility companies. Thus, the distinction between traditional economic sectors is fuzzy. Additional to the organizations that operate along the value chain, planning offices and project developers played and still play a key role for the development of the niche. They provide similar services to those of the ESCOs (pre-studies, site selection, application for subsidies, etc.), but do not finance or operate plants.

The specific spatiality of BMDH derives from the particularities of biomass cultivation at the upstream end of the value chain and district heating at the downstream end. Considering the scale of facilities for bioenergy production (the hardware component of the socio-technical configuration), Jack (2009) emphasizes the trade-off between economies of scale for the conversion of biomass to energy and the dis-economies of scale for biomass collection and transportation. Compared to fossil fuels, biomass has a lower energy density. Thus, transportation over long distances is not economically feasible. Nevertheless, biomass must be collected from extensive cultivation areas to provide feedstock for processing and conversion. Assuming simplifications like an equal distribution of feedstock and homogenous road tortuosity throughout a region, Jack demonstrates technology-specific economic optima. Even within the same class of technology – heat-only boilers – demands for feedstock characteristics vary according to boiler scale: smaller boiler classes require a higher feedstock moisture content to avoid excessive temperatures during combustion, and thus are not suited to burn dry wood waste. Large-scale facilities with a high feedstock demand, on the other hand, require more complex logistics that raise costs.

The regional characteristics of biomass distribution, transport routes and potential alternative value chains for material use thus have a very strong influence on the optimal scale of biomass-to-energy conversion. Regardless of these regional characteristics, Roos et al. (1999) detected dis-economies of scale for biomass combustion facilities in Austria. Their main reason was increasing specific investment costs per kW capacity of larger plants. Large-scale boilers are not standardized products but usually are custom solutions for specific projects that raise costs. Environmental legislation also has an influence; emission thresholds for large-scale facilities are lower, which requires the equipment of more efficient and expensive filters. The picture becomes even more complex when district heating is added to the socio-technical configuration as an important commercialization pathway for the produced energy. In contrast to mainly rural biomass cultivation, district heating systems usually can be found in urban areas, because of the need for a high customer density. Heat is distributed via networks of pipes filled with hot water. Losses in distribution rise very quickly with increasing length of the network, with decreasing heat density per pipe running meter.

Considering the scale of district heating, smaller networks are associated with lower costs for digging and pipe installation as well as for project planning (Rakos, 2001). Networks with a higher number of customers also require more frequent hydraulic maintenance measures, which touches the issue of organizational scaling, i.e. the software component of the socio-technical configuration. Many small- to medium-scale BMDH plants are operated as a sideline by farmer cooperatives (see Section 5.1). Such farmers often invest unpaid working hours into the operation of their plant. Large-scale plants connected to extensive networks, on the other hand, need a dedicated workforce for maintenance, feedstock acquisition, customer service, on-call duty and the like. This workforce has to be paid according to wage agreements, which results in significantly higher operational costs for commercially-owned large-scale plants.

The results of these physical and organizational preconditions along the value chain are tensions between the de-centralized character of biomass supply and the

Spatial aspects	Centralized biomass combustion for the distribution of heat via a pipe network	
Different geographies of supply and demand	Biomass → low energy density, extensive cultivation, long transport distances not cost-efficient	District Heating → high losses in long networks, high consumer density needed
Sectors that act at the respective end of the value chain	Forestry Sawmill industry Agriculture	Municipalities Public housing Industry Tourism (hotels, thermal baths)

Tab. 3: The spatiality of BMDH

centralized character of demand in district heating networks. Actors that combine the two technologies and operate BMDH plants have to cope somehow with these different spatial characteristics. This has major consequences for the geography of BMDH – for plant localization as well as for its physical and organizational scaling. Table 3 summarizes the spatial aspects and lists actors that typically engage at the respective ends of the value chain.

5. The historical development of the biomass district heating niche in Austria

5.1 The formative and early growth phase

Several scholars (Rakos, 1996, 2001; Weiss, 2004; Madlener, 2007) have analysed the formative phase of the BMDH niche in Austria. Their findings provide a valuable basis for further research. The history of the niche actually started with the imperfect material and energy flows in the sawmill industry. As Rakos (1996, 2001) explains, sawmills "discovered" the wood waste that accrued in the course of their production process as a source of cheap energy. They established biomass combustion to exploit this undeveloped potential for wood drying purposes. This trend was given further incentives by the effects of the 1970s and 1980s oil crises. By the beginning of the 1980s, the first innovative sawmill owners had the idea to commercialize their surplus heat by adding district heating systems to the technological configuration. This organizational innovation combined two existing technologies and altered their application. It transferred district heating technologies spatially from urban to rural areas where biomass was available. As sawmill operators are usually strongly locally embedded at their plant site, however, they were not suited to foster the further geographical diffusion of BMDH.

During the 1980s, the agricultural sector became aware of the possibilities that existed for farmers to commercialize logging debris from their forestry activities by establishing BMDH plants on their own. The farmers usually teamed up in cooperatives to cope with the high investment costs. The focus of these newly-emerging organizations was not so much on generating profits by selling heat to the final customer, but on creating demand for logging debris. Weiss (2004) detects a second organizational innovation here: namely the de-coupling of the BMDH system from sawmill locations where wood waste is readily available. The diffusion of the new socio-technical configuration, "agricultural cooperative for the operation of district heating networks in rural village centres", subsequently gained the interest of policy makers, who aimed to contribute to environmental protection by replacing fossil fuels and to regional development by providing incentives for the utilization of wood debris from forestry activities – at one stroke. Subsidy programs for the initial investments were first established at the provincial level and later became harmonized across Austria. Loans at reduced interest rates for operators from the agricultural sector and subsidies directed at the final consumers for the connection to the district heating network, complemented supportive measures (Rakos, 1996).

The agricultural sector became very active in promoting and lobbying for BMDH throughout the second half of the 1980s and the 1990s, for example through the chamber of agriculture or the newly-founded biomass associations. Additionally it created new networks that actively promoted knowledge diffusion and supported farmer cooperatives with planning activities. Weiss (2004) characterizes these developments as a strong transfer of key responsibilities from actors operating on the regional scale to entities operating on a sectoral base. It is also safe to say that the chamber of agriculture had a significant influence on policy development at the provincial level, especially in some of the pioneering provinces like Lower Austria, Upper Austria and Styria. In summary, the different activities carried out by the agricultural sector to support technology diffusion can be seen as quite successful. These efforts in the beginning, however, focused on one very specific socio-technical configuration: "village heating". Around the turn of the millennium this changed as a consequence of two developments: (i) the introduction of feed-in tariffs for electricity generated from biomass in 2002; and (ii) the entry of new actors into the business field and the interrelated development of new business models. These developments were the basis for an accelerated diffusion of BMDH and can be placed at the beginning of the growth phase of the Technology Life Cycle.

5.2 The growth phase

Spurred by international and national discourses, the Austrian government in 2002 issued the first Green Electricity Law. The law allowed for feed-in tariffs of electricity from solid biomass differentiated by plant size. These circumstances triggered an increased involvement of new, financially strong actors like the National Forestry Agency, or some of the incumbent integrated energy utilities. The latter were traditionally founded as public enterprises at the provincial level and became partly privatized during the 1990s. The introduction of feed-in tariffs for electricity from biomass provided an incentive for utilities to engage in biomass- based activities again, after some discouraging experiences with technically immature pilot plants during the 1980s and early 1990s. The first issue of the Green Electricity Law, however, did not impose a minimum threshold for overall energy efficiency. This led to a retrospectively politically undesired outcome. A series of large- (around 30 MW thermal capacity) and medium-sized (around 10 MW thermal capacity) CHP plants was installed all over the country where biomass was readily available. Many investment decisions were based on the historically low prices for wood fuel that prevailed from the early 1990s. With a guaranteed price for the produced electricity and in the absence of a minimum threshold for energy efficiency, operators had little incentive to develop plants with well-elaborated concepts for heat distribution and, in many cases, chose locations without any regard for the basic requirements of district heating networks, e.g. green field sites with missing or little demand for process heat or room heating.

The government finally introduced a threshold of 60% overall energy efficiency as a minimum criterion for a subsidy grant in 2006. At that time, however, many plants already were in operation and put enormous demand pressure on the wood fuel market. Due to the high investment costs for electricity production, CHP plants are bound to burn biomass all-year-round, regardless of the actual heat demand. For instance, in the province of Styria, 16 CHP plants burn nearly the same amount of biomass as 657 heating plants (Metschina, 2012, p. 124). The high demand for biomass by CHP plants led to a strong increase of prices from 2005 to 2011 (7% on average per year, according to Waldverband Niederösterreich, 2013). This turned many CHP plants into a loss-making business, as electricity feed-in tariffs were not indexed but remained constant over a time-frame of 13 years. Summarizing, many large- scale CHP plants that were constructed during the first hype about biomass electrification between 2002 and 2006, did not pay attention to a proper utilization of waste heat via district heating networks, and consequently must be assessed as both ecologically and economically unsustainable.

Besides the early efforts by the agricultural sector and the later activities in CHP production by financially strong actors like energy utilities, energy service companies (ESCOs) emerged as a third dominant organizational form to engage in BMDH. As already mentioned, the population of ESCOs is very heterogeneous. Some are made up of mergers by freelancers, while others are subsidiaries of bigger energy utilities. The first specialized ESCOs were founded around the turn of the millennium. Many of them originally focused on the realization of renewable energy projects for single facilities like hotels or public buildings. Some firms then decided to extend their activities and search for partners for the realization of larger district heating projects. Networks that provided services and knowledge to potential operators had existed for some time, but these organizations usually did not get involved as shareholders of the plants. This changed to some extent with the diffusion of the energy contracting model. Trans-locally active firms started to cooperate with local partners to establish and continually operate projects. Some especially successful enterprises are involved in up to 50 BMDH-networks today.

The ambitions and abilities of these professional operators differ from those of the locally- embedded actors like farmers or municipalities. The cooperation with ESCOs thus renders a series of advantages to the locally-embedded actors. ESCOs provide the necessary technological and managerial know-how for project realization. Compared to stand-alone planning offices, the involved ESCOs are liable with their investment in the project and have a strong interest in establishing an economically suitable plant design. Additionally, ESCOs can put into practice valuable experiences considering plant operation, which is absent from planning offices that never actually operated their designed plants. This renders advantages for the on-going optimization of the plant, which is critical for the economic and ecological sustainability of the project. During the last 10 years, ESCOs have played a critical role in the expansion of the Austrian BMDH niche. They often occupy an intermediary bridging position between feedstock providers, local plant operators and heat customers with respect to performing central tasks like customer service and billing. Most ESCOs focus on the realization of small- to medium-scale district heating systems, as well as on micronets for residential complexes or holiday resorts.

6. Identifying life cycles and corresponding dominant designs

The overall development of the Austrian BMDH capacity followed the typical life cycle S-shaped curve, roughly passing through the phase of introduction during the 1980s and 1990s, experiencing exponential growth during the 2000s, and showing abrupt signs of maturity and saturation from the beginning of the 2010s. This overall life cycle can be subdivided into several dominant designs or generic socio-technical configurations with their own sub-cycles. Drawing on statistical data (Statistik Austria, 2012), we can roughly match the advent of the growth phase to the turn of the millennium and distinguish it initially into two dominant designs that followed different life cycles – combined heat and power (CHP) and heating plants. Figures 3a and 3b show the amount of heat from biomass that was fed into district heating networks on a yearly basis. The figures for CHP plants (Fig. 3a) are rather unambiguous in their interpretation. Plant numbers and fed-in heat began to rise very rapidly after the introduction of the Green Electricity Law in 2002, which guaranteed fixed feed-in tariffs for electricity from renewables. The installed capacities for electricity production increased five-fold in the period from 2002 to 2006 and subsequently stagnated (see Fig. 4a below, green curve), while fed-in heat from CHP plants rose from 2 Petajoule (PJ) in 2003 to over 14 PJ in 2008 (Statistik Austria, 2012). The continuing increase in Fig. 3a after 2006, compared to CHP saturation in Fig. 4a, can be interpreted as the result of rising biomass prices that forced plant operators to maximize their heat sales to stay profitable. The graph in Fig. 3a is split into energy utilities and plants attached to private enterprises as operator classes, with fed-in heat by the latter recently being on the rise. This might indicate a slightly differentiated timing of technology diffusion for distinct socio-technical configurations within the CHP segment. The data for fed-in heat from heating plants (Fig. 3b) are more difficult to interpret than those for CHP plants. We can observe a relatively strong increase from 2000 to 2003, from 2003 to 2007 fed-in heat stagnated, but another strong rise followed from 2007. The stagnation probably mirrors the strong expansion of CHP capacities in that period. A better interpretation of these changes might be possible by drawing on the data shown in Figures 4a and 4b.

Figure 4a splits biomass heat only boilers into two different classes. Considering large-scale boilers, a slight slowdown in sales can be detected which indicates the advent of the maturity phase for this capacity class. Medium-

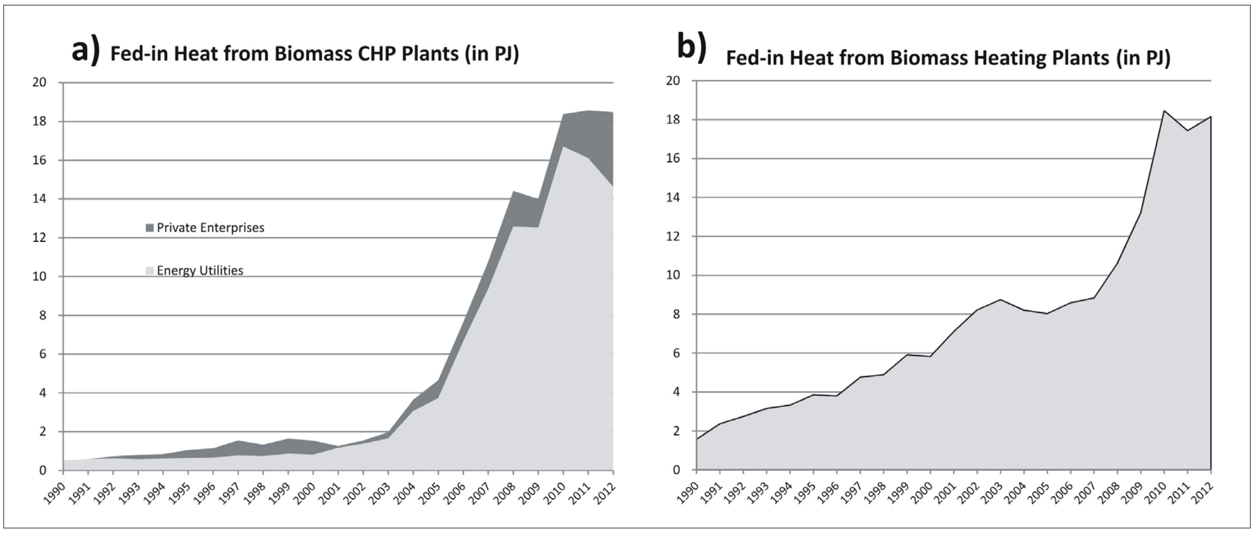

Fig. 3: Fed-in Biomass Heat 1990–2012 – a) CHP and b) Heating plants
Source: Statistik Austria 2012; Author's compilation/design

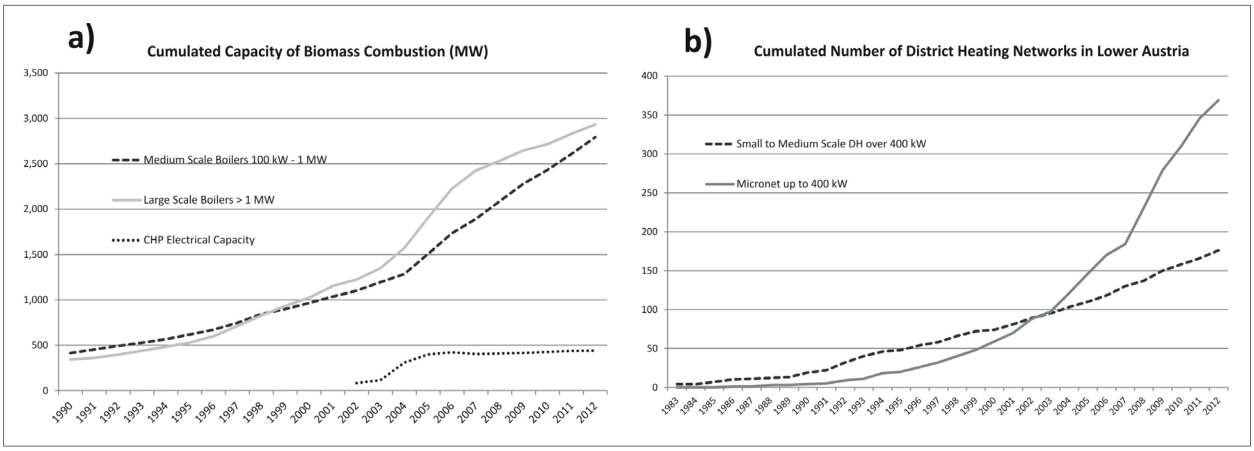

Fig. 4: a) Capacity of Biomass Combustion in Austria; b) District Heating Projects in Different Size Classes in Lower Austria. Source: Biermayr et al., 2013; Furtner and Haneder 2013; Federal Government of Lower Austria; Author's compilation/design

scale boilers, on the contrary, still experienced increasing sales and remained in the growth phase of the life cycle. Unfortunately, the data for Figure 4a is only available at an aggregated level with pre-determined size classes. Figure 4b, however, is based on data from the Federal Government of Lower Austria that allowed a manual classification[4]. It shows the comparatively late introduction of micronets in relation to traditional small- to medium-scale "village heatings". We may assume that the accelerated increase of fed-in heat after 2007 in Figure 3b (above) was carried at least partly by the more frequent implementation of micronet projects.

Some caution should be exercised, however, in that the amount of fed-in heat can only be estimated due to difficulties and vagueness in data collection for biomass compared to fossil fuels (Statistik Austria, 2011: 29f). Thus the initial analysis of the quantitative data was complemented by the qualitative expert interviews. Each dominant design is characterized by a series of attributes and arrangements along the value chain for the production and distribution of energy from biomass. These characteristics were identified by analysing the qualitative interview material. Table 4 summarizes the different dominant designs following the hardware-software scheme by Walker and Cass (2007). On this basis, it is possible to distinguish at least four distinctive dominant designs.

Put into chronological order, the first dominant design that spread throughout the country was the idea of "village heatings" – small- to medium-scale heating plants for the provision of heat to buildings in rural centres. These plants are often operated by agricultural cooperatives that aim to generate profits for their members through biomass sales. The underlying discourses that support the establishment of this kind of plant are the goals to increase regional value creation and to contribute to climate change mitigation. With over 2,000 district heating networks installed in 2,354 Austrian municipalities (Mayerhofer Burger, 2011), small- to medium-scale networks are close to saturation. The co-production of heat and power in large- and medium-scale plants as the second and third dominant designs was spurred by the introduction of the Green Electricity Law in 2002 and reached saturation within only four years. These two dominant designs share many characteristics. They focus on the production and feed-in of electricity for the generation

[4] District heating networks up to 400 kW capacity are termed "micronets" by Austrian administrative bodies. They typically supply only a limited number of facilities and have different criteria with respect to operating licenses and subsidy programs.

	Generic Plant Type/ Paradigm	Micronet	Small to medium scale district Heating	Medium scale CHP with ORC process	Large scale CHP with steam turbine
Hardware	Capacity/plant size	Up to 400 kW	Up to several MW, usually around 1 MW	Up to 10 MW thermal and 2 MW electrical	Up to 65 MW thermal and 15 MW electrical
	Feedstock	Pellets Forest wood chips	Forest wood chips	Forest wood chips Industrial wood waste	Industrial wood waste Black liquor
Software	Management and operation	Agricultural cooperative (AC), ESCO, Energy utility	Agricultural cooperative (AC) ESCO Small sawmills	ESCO Energy utility Sawmills	Energy utility, Paper and pulp industry Sawmill industry
	Customers/ function and service	Heat for: • Public buildings • Housing associations • Hotels and baths	Heat for: • rural centre (public buildings, private households)	Focus on electricity production for the grid. Heat for: • Internal industrial processes • Semi-urban district heating	
	Ownership and return	• AC: revenues from wood supply • ESCO, energy utility: heat sales	• AC: revenues from wood supply • ESCO, sawmill: heat sales	• Private heat demand for industry • Electricity (and heat) sales	
	Motivation/discourse	• Green image • Legal provision (public housing) • Local monopoly (utility sector) • Outsourcing to experts	• Supply with heat from regional origin • Green image	• Corporate social responsibility/green image • Optimization of internal material and energy flows • Flagship projects	
	Life cycle phases	• Formative phase late 1990s and early 2000s • Growth phase from around 2004	• Formative phase late 1980s and early 1990s • Growth phase from late 1990s • Saturation reached around 2010	• Quick growth phase from 2002 to 2006 • Some remaining potential in private enterprises	• Quick growth phase from 2002 to 2006 •Saturation reached
	Typical location	• Peri-urban areas • Dense residential zones	Rural areas	• Business parks • Small towns	• Industrial sites • Medium towns

Tab. 4: Dominant designs in the Austrian BMDH system
Source: Author, after Walker and Cass (2007)

of private profits. Heat is used all-year-round for industrial processes or primarily during winter for district heating in small- to medium-sized towns. CHP plants passed through the whole TLC very quickly. They reached saturation around 2006 – most locations that guarantee all-year-round heat demand and high efficiency were equipped by that time. There is still some remaining potential for medium- scale CHP plants attached to private enterprises however (Lang and Tretter, 2011). The main rationale for the realization of CHP plants is the optimization of material and energy flows within wood processing enterprises. Further motives can be the realization of flagship projects as a showcase, and the demonstration of corporate social responsibility.

According to interview participants, the fourth dominant design – micronets – shows the highest potential for future development. The development of this market segment is supported by the reissue of the EU Directive on the Energy Performance of Buildings (2010/31/EU) that foresees a high share of renewables for newly-constructed buildings. Micronets are the traditional business area for ESCOs. In response, however, actors from the agricultural sector reacted to the trend with a series of strategies, one of which was the creation of a centralized contact point for housing associations as new key customers. Energy utilities that previously concentrated on the implementation of large-scale projects, also became aware of the trend towards micronets and increasingly have focused on this market segment. They have also increasingly switched the feedstock for the boilers: wood pellets are a standardized product and thus are easier to handle compared to wood debris from forestry, and they do not require complicated arrangements with local suppliers. The main rationale for integrated utilities to engage in micronets is to keep their long-standing customer relations that often resemble a local monopoly, considering that these utilities also provide electricity and telecommunication services, besides serving the heat market via natural gas and BMDH. The primary growth areas for micronets are the rather densely populated peri-urban zones around large cities, especially Vienna, and to a lesser extent regions with high levels of tourism that are not yet provided by "village heatings".

7. Conclusions

The Austrian BMDH case suggests that diffusion processes for socio-technical configurations in the renewable energy sector are not necessarily driven by a homogenous group of niche actors. Rather, technology "upscaling" was carried by a diverse range of actors that did not follow the same set of cognitive and normative beliefs and visions. At best, an alignment of visions regarding the development of the technology happened between a limited number of actors as a consequence of the lobbying activities initiated by regional chambers of agriculture and biomass associations.

Furthermore, "upscaling" processes do not imply an increase of capacities or plant size, i.e. they do not necessarily rely on economies of scale and an intensification of production. On the contrary, many mistakes that led to economically unsustainable outcomes during operation were related to the 'over-dimensioning' of different components. According to interview participants, two particularly frequent mistakes were: (i) a wish to connect all village households to the district heating network to guarantee the inclusiveness of the socio-technical configuration, regardless of the regionally available feedstock and heat losses in long-distance networks; and (ii) the installation of CHP plants with a focus on electricity production combined with a neglect of the district heating component, which led to high amounts of unutilized waste heat in the first place, and subsequently to economic problems when feedstock prices started to rise. Another critical issue in relation to scale was the organizational establishment of operator companies. Micronets and small-scale plants are relatively easy to maintain and, in many cases, can be serviced as a sideline by locally present individuals – be they farmers, caretakers or municipal employees – while larger facilities require costly professional supervision.

The central task for BMDH plant operators from a techno-economic standpoint is to fit the scale of production, i.e. the boiler and network capacity, to bridge the gap between the locally available biomass potential and the local heat demand. By adapting the scale of renewable energy plants to local circumstances, the scope of technology diffusion can be increased. In retrospect, however, it becomes clear that every switch in the scale of district heating (and thereby an expansion to previously unsupplied areas and customer groups) was not only a question of technological issues, but was linked to changes in the organizational arrangements along the value chain – a switch of scales on the hardware side can only work if it is accompanied by corresponding modifications in the software. "Upscaling" thus should not be conceptualized as a linear trend from small-scale pilot and demonstration plants to large-scale industrial facilities, but rather should be seen as a much more nuanced process. Successful scaling activities result in a number of generic socio-technical configurations or dominant designs that, in conjunction, shape the diffusion patterns of technologies.

Consequently, the recently published FTI Roadmap for BioHeating and Cooling by the Ministry for Traffic, Innovation and Technology calls for the development of innovative business models that integrate new feed-in and storage technologies for heat, and broker between consumers, providers and producers (Wörgetter et al., 2012). For the establishment of these new arrangements, intermediary organizations that translate and mediate between feedstock providers, plant owners and customers will probably play a central role. Rohracher and Späth (2008) have already emphasized the role of this type of organization for the BMDH niche in Austria, and Hargreaves et al. (2013) further stress their importance for the expansion of niches in the community energy sector generally. From a policy perspective, then, future research should focus on identifying already successful intermediary actors in the field, and on analysing their organizational arrangements and future possibilities to develop new innovative approaches for the distribution of heat via networks.

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Author´s address:

Markus SEIWALD MSc.
Economic Geography Research Group, Department of Geography and Geology, University of Salzburg
Hellbrunnerstrasse 34, 5020 Salzburg, Austria
e-mail: *markus.seiwald2@sbg.ac.at*

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