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Industrial Energy Use and Interventions in Urban Form: Heavy Manufacturing versus New Service and Creative Industries

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A B S T R A C T

Now that it becomes obvious that disregarding the seriousness of climate change and the exhaustibility of fossil fuels would have severe and unpredictable impacts, improvement of the efficiency of urban energy consumption is of utmost importance. Hence, a rather diverse spectrum of policies to encourage this improvement has been put into practice. This paper focuses on the interrelations between interventions in urban form and improvements in energy efficiency of industries. These interventions, particularly spatial planning and urban design, are rare compared to other types of policies, in spite of their potentialities. This observation is illustrated by the case studies of two medium-size cities. Moreover, insofar as spatial planning aims to improve industrial energy efficiency, its implementation is limited to traditional and large-scale heavy industries at peripheral urban locations. Regarding new service and creative industries that tend to cluster in central city locations, both empirical evidence and policy practices are still missing.

1. INTRODUCTION

Households, transport and industry are the three largest energy consumers in European cities. For the EU as a whole, industry is the third largest user after the residential and transportation sectors: in 2012 their proportional shares of consumption were respectively 32, 27 and 25 percent [1].

From a historic perspective, energy use by the industrial sector has fluctuated probably more than the use by the other two major consumers. The 'classic' Fordist large-scale and mass-production manufacturing industry was a large energy user approximately until 1970. At that time, a process of de-industrialisation started to accelerate across the western world, which went together with the decrease in industrial energy use. The following stage of post-industrial urban development was characterised by a rapid growth of advanced producer services based on ICTs, employing a new middle class. Since the late 1990s, a process of urban reindustrialisation can be observed [2]. Rather than a return of the Fordist manufacturing economy, a substantially broader diversity of new types of industry has developed in cities. Scott (2012) distinguishes three main categories of leading industries in the current 'cognitive-cultural economy': advanced business and financial services, technology-intensive industrial ensembles, and cultural and creative industries [3]. Nevertheless, it is highly likely that a trend sometimes labelled reindustrialisation is being accompanied by increasing industrial energy use.

In 2010, the EU decreed the EU 2020 long-term development strategy with the objective to transform Europe into a competitive, social and green market economy. Part of the strategy is the 20/20/20 objectives to decrease the emission of greenhouse gases by 20%, to generate 20% of total energy production in a sustainable way, and to increase energy efficiency by 20%, all taking 2020 levels compared to 1990. On a city level, three dimensions that impact on industrial energy consumption can be distinguished: implementation of (new) technologies, changes in behaviour, and urban form or spatial structure [4], [5], [6]. This paper focuses on the last of these dimensions, in particular on how policy makers can intervene in urban form by spatial planning and design to reduce energy use. Its objective is twofold: (1) to investigate the relations between urban form and industrial energy use and efficiency, and (2) to explore if and how urban spatial planning and design can play a role in the reduction of that use, i.e. by means of interventions in various features of the built urban environment, including location, density and compactness, mix and clustering of urban land-uses. The second question is examined by a brief review of literature on energy efficiency policies and by two cases of medium-sized cities in the EU, carried out in the EU-FP7 project PLEEC [42] (see section 5 for details on methods).

2. GENERAL TRENDS IN INDUSTRIAL ENERGY USE IN THE EU

The project ODYSSEE MURE explores trends in industrial energy use between 2000 and 2012 in the EU-member states plus Norway [7]. Ten heavy industries were included in the project, consisting of very large-scale firms that process raw materials or produce semi-finished and capital goods: chemicals, paper, steel, machinery, food, non-metallic, non-ferrous, transport vehicles, textile and wood. Between 2000 and 2010, the final energy use by these industries decreased by 12% as a share of total national consumption in these 29 countries together. In absolute figures, this implies a net saving of 38 Mtoe (Million tonnes of oil equivalent). Primarily accountable for this overall trend are structural changes in production, for instance a shift from bulk consumer chemicals towards less energy-intensive light chemicals (like cosmetics and pharmaceuticals) and cyclical impacts of the economic downturn at the end of the past decade. In 2012, the minimum and maximum values of industrial energy use as a proportion of national total were 10% in Cyprus and 47% in Finland. Industry in Finland's neighbouring Nordic country Sweden is also a major energy user (37%). This reflects the importance of the energy intensive forest industry, especially paper and pulp, and steel production in both countries [8], [9]. Due to the decrease of proportional energy use by the ten basic industries, but particularly chemicals and metals, the overall energy efficiency in the 29 countries improved rather rapidly, by about 1.5%/year between 2000 and 2012. Since 2009 however, efficiency improvements slowed down due to the economic downturn, which resulted in industrial plants operating at less than full capacity.

Statistical data on energy use by the office- and workshop-based new types of cognitive-cultural industries are not available for several reasons. In the case of cultural and creative industries, the groups that are named in the various working definitions of these industries - there is still no generally accepted definition and classification - are barely distinguished separately in energy statistics. Furthermore, these new industries have received a lot of attention by academics, urban planners and policy makers over the past twenty years. These have focused on many issues, such as economic performance, innovativeness, geographical clustering, unequal labour conditions, but still have a blind spot for their energy use. Nevertheless, the reindustrialisation of urban economies is obviously accompanied with increasing energy use, mainly electricity. Many of these new industries are ICT-based in their working processes: upper-tier occupations in the cognitive-cultural economy labelled by Scott (2012) are highly 'digitized' [3]. The title of a publication by Mills (2013) - 'The Cloud Begins With Coal' -, illustrates that ICT is a major energy user [10]. Each activity in the realm of the internet costs energy, and new industries contribute significantly to the rapid growth of the global amount of these activities. As Mills comments, "*the world's ICT-ecosystem uses an amount of electricity annually equal to all the electric generation of Japan and Germany combined*" [10, p. 4], and "*if the Cloud were a country, it would have the fifth largest electricity demand*": after the US, China, Russia and Japan but before all the EU countries [10, p. 15].

In conclusion therefore, recent trends of energy use by the ten heavy basic industries in the EU move towards the objective of EU 2020, due to both structural and cyclical processes. Against this trend, however, the recent growth of new types of industries in cities is being accompanied by increasing energy use. However, for a detailed picture of the contribution of the industrial sector as a whole to the EU 2020 objectives, data is still missing.

3. RELATION BETWEEN URBAN FORM, URBAN PLANNING AND INDUSTRIAL ENERGY EFFICIENCY

In a study on the impacts of urban density on energy consumption of the service sector, Morikawa (2012) comments: *"Many studies suggest that energy consumption and CO_2 emissions are lower in denser cities. However, previous studies have been confined to the gasoline consumption of vehicles or the energy usage of households. Studies on the commercial sector, including retail and service industries, are scarce"* [11,

p. 1619]. This scarcity also holds for studies of the relationships between industrial energy use and the urban form, with density as one of its features. Nevertheless, it can be reasoned that this relationship is a function of type of industry, scale of industrial establishment and location of industrial firms, both vis-à-vis one another and within the urban fabric as a whole.

The location of industries in central as opposed to peripheral areas of the city is accompanied with obvious differences in types and scales of industrial establishments. The usually very large-scale establishments of basic heavy industries are, in general, no longer found in inner city areas. Instead, these are the areas of the city where the most part of the offices and workshops of the post-industrial economy and the recent process of reindustrialisation tend to cluster. Whereas technology-intensive industrial ensembles are situated at inner city fringes or in greenfield areas, in knowledge locations like campuses and science parks, the shiny offices of advanced producer services and workshops of cultural and creative industries tend to cluster first and foremost in the cores of cities, in particular larger ones, although in different districts [3], [12], [13].

3.1. Central locations

The explanations why cultural and creative production, consumption and spectacle cluster, and particularly why they do so in centrally located locations, are various and interact with one another. Among them, it is worth mentioning: the typical small or micro-size enterprises with high level of specialization and crucial social networks; the high density and diversity of people engaged in production and consumption; the presence of ancillary services and urban amenities; and last but not least a preference for old, often obsolete industrial buildings for their activities [13], [37], [38], [41]. Both their typically small size, the significance they attach to face-to-face contact, and their financial inability to rent an office or workshop for themselves makes many of these firms co-locate in multi-tenant buildings. This co-location allows for sharing of heating, cooling, lighting and energy uses like refrigeration, hence leading to less energy use per capita than working in separate buildings because the volume in cubic meters per capita that has to be heated or cooled is smaller. For the comparable situation of multi-family dwellings, Ewing & Rong (2008) observe that "*an otherwise identical household consumes 54% less heating energy and 26% less cooling energy*" than in single-family dwellings [1, p. 16].

Much more, the multi-tenant buildings where cultural and creative industries tend to cluster are usually located within the dense and fine-grained urban fabric of inner-cities, i.e. at short mutual distances. Furthermore, the specific urban form of the area limits their use of motorised transport, and hence of fuel, for interactions within their social and business-related networks. Using cars is even time- and cost-inefficient because of the short distances and parking problems to visit each other in workspaces, or meet each other at the inner city's 'third places' - cafes, clubs, parks – which acts as anchors of the community of creatives. Moreover, the 'creatives' in these industries consider cycling cooler than driving – if the distance is too long to walk.

Short distances between buildings (working spaces) is a dimension of the compactness of the urban form of the areas where cultural and creative industries tend to cluster. Two other dimensions of compactness – street lane widths and building height - also matter with regard to energy efficiency (Fig. 1).

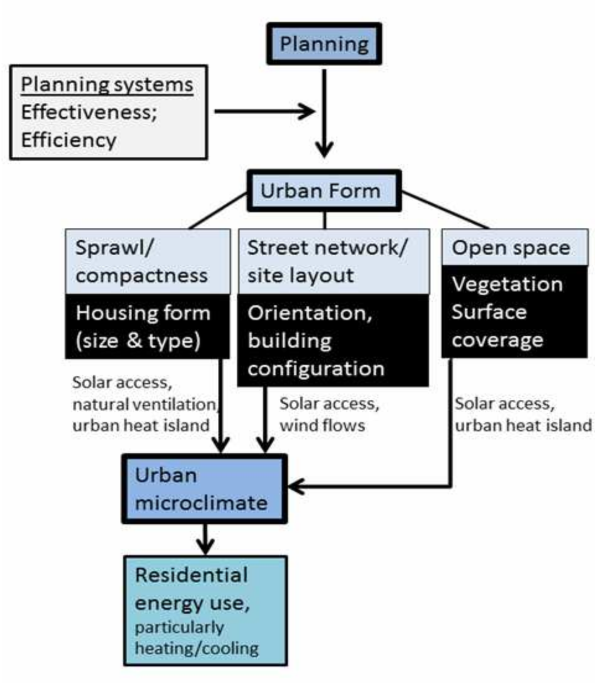

Fig. 1. Urban form and energy use in buildings *([1, p. 10] adapted from [36]).*

Their impacts are not universal however, but depend on the climate in the area. Besides, some impacts cause rebound effects. In hot and dry climates, narrow streets and high buildings increase the level of shading of buildings across the street from each other, hence diminishing urban heat island effects and demand for cooling. This may offset, however, the benefit of natural ventilation by wind that increases with the width of the street. In cold climates on the other hand, increasing solar access to buildings by means of wide streets and low buildings is essential, especially in winter, to decrease energy use for heating. But this may be offset by more exposure to cold winds in wider streets [1].

Furthermore, the orientation of buildings towards the cardinal directions also influences the demand for energy, in terms of solar access and ventilation. Randolph and Masters (2008) observe that demand for heating diminishes by some 20% in case the houses are oriented to the south – with an east-west roof peak - compared to orientation to the west or the east [1]. Urban form features related to building orientation are in the lay-out of both individual plots and street networks, i.e. themes of urban design. Finally, covering the open space between buildings with trees influences the need for heating and cooling due to their effects on modifying wind flow for ventilation, blocking of cold winds and shading of buildings. In addition to their situation and density, specific features of trees, e.g. height, crown shape and deciduousness, also matter [1].

3.2. Peripheral locations

As mentioned, large-scale heavy basic industries are mostly found at the edge or outside the built-up areas of cities. The reasons why these are located in such peripheral parts of urban areas are mostly environmental and economic, ranging from nuisance and environmental regulations to lower land costs and better accessibility by car and lorry in comparison with inner city locations. The interrelated concepts of industrial ecology [9], industrial symbiosis [14], [15], [16] and eco-industrial park [17] explain why these industries are located in symbiotic clusters based on spatial proximity. Leaving aside the distinctions between these three concepts, their shared essence is to improve the efficiency of use of both energy and materials based on 'roundput' between firms. Thus, symbiotic firms form networks of suppliers and consumers that mutually exchange waste materials and waste (residual) energy, often by-products of production processes. A clear example is the graph of energy and material flows in the Kymi eco-industrial park of forestry industry, Finland, elaborated by Sokka et al (2011). The centre of the park's 'symbiosis boundary' consists of a pulp and paper plant. This plant includes a water purification plant and a wastewater treatment plant of its own, and is further surrounded by three chemical plants (chlorine dioxide, calcium carbonate and hydrogen peroxide), a wastewater treatment sewage plant, a power plant and a local energy plant [15]. The graph distinguishes a total of twenty-three flows of energy sources (heat, steam, and electricity) and materials (different types of waste, water, wastewater and outputs of the chemical plants) between the plants, but in a vast majority to and from the pulp and paper plant. Besides, three types of waste flows are dumped in landfills.

The benefits of these exchanges are both environmental and economic. Environmentally, they achieve reductions of consumption of 'virgin' raw materials and fuel, of waste production, and of greenhouse gas emissions. Instead of dumping waste materials and greenhouse gases into the environment, these are recycled within the networked system. Various authors present quantitative estimations of the efficiency gains of industrial symbiosis up to about 50% of virgin fuel use and emissions by comparing these with the hypothetical reality of non-existent symbiotic relationships [9], [15], [18]. Economically, spatial proximity in these systems saves expenses for road transport and for the construction of networks of pipes and cables, and limits energy loss over distance. Further, on a company level, gains include reduced costs for waste management, for investment in own energy supply installations, for environmental taxation and last but not least for purchase of material and energy - supplies of waste may be charged for but these are usually cheaper than virgin materials from elsewhere.

In addition to exchanges within the symbiotic system, these are often connected to external actors, such as local towns, by upstream and downstream effects. Upstream for instance, savings can be achieved on transport of virgin fuel from elsewhere and by incinerating these towns' municipal and household waste. Downstream, typical combined heat and power (CHP) plants based on exchange of different types of energy and material can supply towns' district heating (DH) systems and provide power to electricity grids. Korhonen (2001) estimates a fuel efficiency of CHP plants as high as 85 to 90% [9]. On the other hand, since heat can only be transferred over relatively short distances – Korhonen mentions a maximum distance of 10 to 20 km – industrial symbiosis that includes this type of downstream effect works best at the geographical scale of a city and its immediate hinterland or, at the most, of a dense urban region [9].

It can be concluded that the relationships between urban form and industrial energy use differ between the two types of location and highly different types and scales of industries discussed above. In general terms, urban form has an impact on industrial energy use by new industry clusters in central locations, whereas the reverse impact is more common in peripheral locations. The clustered symbiotic systems of heavy industry plants are large in size and typically established in non-urban open land, hence impacting on urban form rather than the other way around.

4. URBAN FORM AND URBAN PLANNING IN INDUSTRIAL ENERGY-EFFICIENCY POLICIES

Various authors comment that industrial energy use and efficiency policies serve environmental and economic objectives [11], [14], [19], [20], [21], [22]. Facing climate change with apprehension, these policies first and foremost aim to reduce the emission of greenhouse and pollutant gases that are primarily held responsible for climate change. Scientific evidence now makes it obvious that ignoring the causes and seriousness of climate change and continuing business as usual would have severe, and partly still unpredictable effects on natural systems and human ways of life. Secondly, improved energy efficiency also aims to contribute to energy security and lowering of costs for both energy imports and industrial production. Given growing scarcity and higher prices of fossil fuels, it becomes urgent to include the utilization of renewable energies, defined by Faller (2014) as *"energy generated out of resources that are not (necessarily) depleted, as long as the replacement rate is not exceeded by usage* [23, p. 890]. A third objective - cleaner air due to reduced emissions - is both environmental and economic in nature as it contributes to the quality of life as an amenity of the city, attracting highly skilled creatives and business professionals, and investors in their wake [24]. In a broader sense, these objectives all fit in the *"growing appetite for principles of fairness, human solidarity and ecological sustainability"* that are at the root of a new kind of economy [25, p. 7541].

To achieve such objectives, a diversity of planning and policy measures and instruments have been outlined and implemented, some national and others on regional, urban or community scales. Thollander *et al.* (2007) categorize these into three types: economic, administrative and informative policy instruments [26]. The economic type includes financial and fiscal instruments like pricing, taxation, duties and subsidies. The aims of this type are to discourage the use of polluting and non-renewable fossil fuels and promote a shift to bio energy and renewable energies. In addition, these economic instruments can aim to accelerate the introduction of new, energy-saving technologies. In particular, SMEs may require some financial support to introduce such technologies because they entail large investments and long payback periods. The second type, administrative instruments, includes rules, regulations and acts, for instance on emissions. Progressive taxation as part of these instruments makes them economic, as well. Finally, informative policy instruments are meant to enhance information and knowledge about opportunities to reduce energy consumption. Energy audits for instance, identify such opportunities. Audits are primarily organised for SMEs which have limited resources to employ full-time experts in these fields [27]. In this respect, it needs to be commented that most instruments serve a general societal interest but that company managers ultimately decide on efficiency measures, unless it concerns compulsory or inevitable instruments. In addition, some instruments may cause feedbacks that affect the effectiveness of others. For instance, the use of waste material from the forest industry for power plants in industrial symbiosis systems saves on costs but might increase CO_2 emissions.

The three types of policy instruments target technology and behaviour driven efficiency potentials [4]. In contrast, urban spatial planning and design do not play an evident role in policies to improve cities' energy efficiency. Two possible hypotheses can be drawn from this observation: urban form does not really matter, or actual policies leave a valuable policy issue to improve industrial energy efficiency unutilized. It can be argued that the first hypothesis does not hold. Section 3 makes obvious that there are opportunities for urban planning and in particular for urban design to increase the energy efficiency of new industry clusters. These opportunities are, nevertheless, limited for two reasons. First, urban design can only intervene in the location and orientation of buildings and buildings' immediate surroundings, not in the energy-consuming production processes of these new industries. Secondly, the people working in these industries, in particular in cultural and creative branches, tend to cluster in specific parts of inner cities, especially because of their preference for existing old buildings with their typical design and atmosphere of manufacturing industries, and for existing urban environments due to their historic nature, place qualities and amenities [37], [39], [40], [41].

Hence, directed interventions by means of urban design or spatial planning have to be very well-considered to avoid backfiring on the attractiveness of buildings and inner city environments for these industries. On the other hand, the development of clustered symbiotic systems of large-scale heavy industries that spring up in non-urban, former open land is usually based on top-down urban, regional or even national policies, with urban planning to take the lead with regard to their specific location features.

5. TWO CASE STUDY CITIES

The former section suggests that the second hypothesis - actual policies leave urban form unutilized as a valuable policy issue to improve cities' industrial energy efficiency - can be accepted. To present some more evidence for that conclusion, the hypothesis will be 'tested' by the case studies of two medium-sized cities in very different regional contexts: Stoke-on-Trent (249,000 people in 2015) in the west Midlands, UK, and Jyväskylä (136,000) in central Finland. Both have a history as major manufacturing centres, but Jyväskylä has been more successful in the imperative transformation towards a 'post-post industrial' economy, i.e. the development of new industries.

5.1. Methodology

The case-studies of Stoke-on-Trent and Jyväskylä are two out of a total of six that were addressed in the EU FP7 project PLEEC [4], [42]. The other four are of Santiago de Compostela (Spain), Eskilstuna (Sweden), Turku (Finland) and Tartu (Estonia). These case-studies are not exclusively about industrial energy use, but also about energy use by buildings, most in particular residential buildings, and transport, about urban and energy planning, and to a lesser extent also about energy production.

Stoke-on-Trent and Jyväskylä are selected to be presented in this paper first and foremost for a practical reason, i.e. that I came to know these two cities best throughout the project. Further, these two cities are relatively well comparable because they were both major manufacturing centres in the past and now face the necessity to transform towards a 'post-post industrial' economy, i.e. the development of new industries.

The realization of the six case-studies was equally divided between researchers of the Delft University of Technology (DUT) and the University of Copenhagen (UCPH), and was elaborated in a similar way according to a model that consisted of three tiers. First, a template on content was discussed between the researchers at the backdrop of the first data collected about the cities. Second, study visits to the cities were prepared with respect to key issues, beginning with discussions at a joint PLEEC meeting between researchers and stakeholders of the cities in March 2014. Third, the study visits were carried out by these researchers. The visits included in particular interviews, meetings and workshops with local hosting stakeholders and series of interviews with public policy makers, urban and regional, and representatives of private companies and civil society organisations. Finally, local stakeholders reviewed the draft versions of the case study reports written by the researchers Processing of their comments resulted in the final case study reports of Stoke-on-Trent [28] and Jyväskylä [33]

5.2. Stoke on Trent (UK)

Stoke-on-Trent in the county of Staffordshire, West Midlands, is located in the heartland of the first Industrial Revolution that dates back to the 18th century. Based on the presence of a unique combination of raw materials, such as coal, iron ore and clay, an industrial history of mining and ceramics developed far into the 20th century. Known as The Potteries, the Stoke-on-Trent area became the cradle of various internationally famous ceramics brands. Due to the gradual exhaustion of raw materials and increasing competition, mainly from the Far East, the ceramics industry declined towards the end of the 20th century [28], [29]. The size of the industrial workforce has decreased from about 70,000 in the heydays to one-tenth of this number today. But due to recent modernization of ceramics, including an educational branch to develop and implement new technologies and design, it has recovered as a significant industrial sector in the area – along with engineering. Nevertheless, despite a certain remaining significance of traditional manufacturing industries, transformation towards a post-industrial service economy is considered a major challenge for economic development in Stoke-on-Trent. This transformation faces some structural problems however. The main one is an overall low level of human capital inherited from the production structure of The Potteries, characterised by low skill levels, low industrial wages, and limited investments in human resource improvements. Valorisation of human capital by means of training and education is indeed regarded as a challenge. Attracting high quality human capital from elsewhere proves difficult due to the lack of diversity of high quality urban amenities in a dense city centre atmosphere. Instead, a typical feature of the city's urban form is its historically evolved polycentric structure composed of six towns with high levels of localism. It lacks a single focal point for investment in high-level services for a sizeable urban market area. There is an urban planning programme to transform the town centre of one of the six towns, Hanley, into the first level service centre for the conurbation as whole, but the status of the programme is as yet unclear.

Although incomparable with the heydays of The Potteries in 'Smoke-on-Trent', its current manufacturing industry is still a large-scale consumer of energy. This provides a strong argument for efficient use of energy sources, preferably low carbon. However, it also produces, in spite of limited clustering, excess heat in a quantity that made it possible for Stoke-on-Trent to become the first UK city to start a DH system. The innovativeness of the city in this respect (within the UK) is also indicated by the founding of a think tank for energy efficient heating systems and by the decision to invest in expansion of the DH network fuelled by local geothermal energy. However, relatively low land values and the lack of an attractive city centre for residential developments, accompanied by the polycentric configuration, do not help incentivise the densities that make investing in DH beneficial for private investors.

There is scope, then, for interventions in the polycentric urban conurbation of Stoke-on-Trent by spatial planning to improve industrial energy efficiency. These should focus on modifying the favoured mixed-use development policies that hamper the development of large-size areas of industrial zoning, and on the large investments and long-term effective political and societal commitments required to develop Hanley into its single first level service centre. But even if these immense objectives can be realised, the resulting 'engineered' city centre misses much of the vernacular qualities of place that define popular residential and new industry business locations.

The main statutory planning document for the future development of Stoke-on-Trent, the Core Spatial Strategy, and its 'vehicle' in the making, the Local Plan, aim to encourage economic, social and environmental sustainability. Energy efficiency is a top priority: a comprehensive policy framework based on several multi-actor governance arrangements, both public-public and public-private, on local and regional scales has initiated quite a few large-scale schemes. These schemes' objectives are primarily economic and social rather than environmental and focus on energy use and efficiency in behaviours and buildings for companies, organisations and households. In line with the above mentioned typology of Thollander *et al.* (2007) these schemes are based on economic, administrative and informative instruments rather than on spatial planning policy [26]. A rare exception is related to transport planning, namely the extension of the cycling infrastructure. With regard to industrial symbiosis, the Strategic Economic Plan of the Stoke-on-Trent and Staffordshire Local Enterprise Partnership – a partnership formed in 2011 to bring businesses and local authorities together to drive economic growth and create jobs [30] - seek to maximise clusters of manufacturing and engineering. Overall, however, commitment to use urban planning to improve industrial energy efficiency is not a big issue in Stoke-on-Trent.

5.3. Jyväskylä (Finland)

The local economy of Jyväskylä has gone through a process of structural transformation during the past three decades. It has witnessed a decrease of its traditional manufacturing industry (including the large-scale sectors of metal industry, forest industry, paper manufacturing and paper machinery production) and has evolved more and more towards a service economy. The main component of this restructuring is the development of an ICT cluster that was initiated already in the 1960s [31]. Linnamaa (2002) analyses how this cluster has evolved over the decades from some first seeds without any conscious strategic planning towards its current key-role in the explicit long-term policy to transform the city towards a growth centre of high-tech industries [31]. Hence, rather than a 'stand-alone' production cluster, it "*can be considered a leader of the [economic, author's addition] development of the Jyväskylä urban region in recent years*" [31, p. 8] through linkages with various other industrial branches.

This evolution of the ICT cluster over 50 years has been accompanied by gradual but concerted and dedicated development in knowledge institutions such as University of Jyväskylä and JAMK University of Applied Sciences (former Jyväskylä Polytechnic), and particularly in the foundation of new Faculties. Analogously, an institutional framework of intensifying co-operation between a diversity of triple helix partners in knowledge institutions, public policy and private business has been developed. In addition, a Nokia R&D Centre in the city was an important stimulus between its founding in 1998 and closing ten years later.

In spite of the general trend of decline, several traditional manufacturing industries, including the sizeable forest industry, have modernised and recovered economically. It is highly likely that this has been accompanied with a decrease in industrial energy use since the new knowledge-based industries that replace traditional manufacturing are typically less energy intensive. Moreover, energy efficiency technologies have been introduced in the production processes of the remaining traditional industries. These industries are located outside the built-up area of Jyväskylä, but companies within the city benefit from their presence by supplying services, technologies and equipment. A major example is Valmet: since its start as a manufacturer of paper industry machinery in the 1950s in a former artillery works in Jyväskylä, it has developed into a multinational company that develops and supplies technologies, automation and services to pulp, paper and energy industries [32].

A system of industrial symbiosis based on the forest industry's by-products, along with a significant amount of wood fuel procured from forests, are major suppliers of non-fossil fuel for CHP and DH networks that have been developed since the 1980s. The fuel mix of these networks shows an increasing share of renewable sources (also biogas next to wood fuels) and a decreasing share of peat, coal and oil. The aim is to increase the share of renewable fuels up to 70% in 2020. It is Finland's current strategy to expand the area of managed forests in order to produce wood fuels but also to increase the country's net carbon sink capacity. For, the use of wood fuels is not carbon neutral.

Both local governments and the Finnish national government have already been committed to the compact city concept as a leitmotiv for land use (and transport) planning for some 25 years. Energy efficiency goals, including development of commercially profitable CHP and DH networks, are explicitly incorporated into Jyväskylä's planning policy to control its rather compact building stock, in particular in its inner city.

In addition, it is now an explicit policy objective to invest in a viable pedestrian and cycling network, again particularly for the city centre, to curb car-use. In spite of the compact city policy, suburban sprawl takes place as an unintended consequence of the attraction of skilled professionals for hi-tech industry with car-oriented, suburban residential demands.

The 2012 Master Plan aims to concentrate part of the volume of suburbanisation in new, concentrated residential developments where options of mobility and services are, or can be easily made, available at reasonable distances. Nevertheless, the present Structure Plan aims *"to maintain compactness as far as possible and to rationalise and concentrate land-use and transport within the existing pattern of centres, prioritising the main centre"* [33, p. 16].

This priority points at monocentricity next to compactness as a spatial planning objective. Although it is not a primary objective of the policy to maintain a compact and monocentric city, it fits well with the city's economic development policy to grow high-tech and service industries. Such a planning approach can create the dense, diversified and cycle friendly central city environment that appears favoured as a residential and business start-up location by students and graduates in urban population. There is no reason to suppose that the preferences of students and graduates in Jyväskylä are an exception.

Spatial planning has also enabled the development of innovative science park-like clusters of education and knowledge institutions and high-tech sector ICT firms. There are opportunities for exchange of waste energy and material in these clusters, although limited.

Overall, urban spatial planning and design has impacted upon improvement of industrial energy efficiency in Jyväskylä. However, these impacts are mostly indirect or unintentional: energy efficiency objectives are also found in policies other than those of spatial planning, and are often combined with or subordinated to economic objectives, social considerations (e.g. high-quality housing in concentrated new residential developments) and image building ('Jyväskylä as centre of knowledge and knowledge-based industries').

6. CONCLUSION

In a world-wide overview of energy efficiency and conservation policies, Tanaka (2011) takes as a basic assumption that *"[i]ndustry's large energy use and vast potential for energy savings make it an attractive target for improving energy security and climate mitigation through increased energy efficiency"* [21]. Indeed, although industrial energy consumption decreased during the process of deindustrialisation in the 1960s and 1970s in Western economies, it has increased again since the end of the 1990s with the emergence of new hi-tech, cultural and creative industries, and advanced producer and financial services.

This paper hypothesises that urban spatial planning and design policies can play a significant role in improving energy efficiency of industrial activities in both traditional and new industries. Overall however, despite industry is one of the three largest urban energy consumers, energy efficiency policies in practice appear to focus considerably and more explicitly on the other two main consumers in cities - the residential and, in particular, the transport sector. Moreover, relatively little importance is given in practice to spatial planning and design of urban form as policy fields to improve industrial energy efficiency. In the two presented case-studies, this observation is most obvious in Stoke-on-Trent but also holds to some extent in case of Jyväskylä.

The available studies of energy consumption and efficiency of industry deal almost exclusively with traditional manufacturing industries. In contrast, an internet search for literature on the energy use of new cultural industries has yielded only one journal paper, about greenhouse gas emissions by the music industry in the UK [34]. It is suggested by several authors that a transformation towards an urban economy with growing service and creative industries is accompanied by a reduction of energy use [11], [35]. However, evidence that supports this suggestion is still almost non-existent.

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