Industrial Symbiosis for more sustainable, localised industrial systems

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Abstract:

As opposed to their centralized large-scale counterparts, regionally distributed, small-scale production units prioritizing the use of local resources and markets are likely to have a more solid contribution to regional sustainability. It is argued that industrial symbiosis (IS) concept, through a renewed focus, can support the development of such systems. To be useful at this end, better integration of production activities with regional resource base and local consumption systems should be given increased consideration in IS developments. The potential IS holds to contribute to the emergence of more sustainable production and consumption systems at the regional level is demonstrated by a hypothetical example where integration of localized paper recycling, waste management, and energy production systems is considered. Organisational and political difficulties facing such developments are also discussed and suggestions are provided that may help address these.

Keywords: regional sustainability, industrial symbiosis, distributed economies, localization, small scale production systems, pulp and paper industry, recycling.

1. Introduction

Both *incremental improvements in existing industrial systems* and the *development of radically new production and consumption systems* are needed for bringing the industrial system to a more sustainable state. The recently proposed Distributed Economies idea (Johansson et. al 2005) is one alternative approach to increased sustainability that address both of these two needs. The idea departs from unsustainable characteristics of most large-scale centralized production units, and calls for increased (re)distribution of a selected proportion of the production systems to the regions in the form of smaller-scale, flexible production units and establishing a renewed balance between large-scale central production and distributed smaller-scale production. Various dimensions of this idea is discussed by Johansson, Kisch, et. al. (2005) Mirata, Nilsson, et. al. (2005). The production systems promoted in this thinking, among others, are argued to prioritise:

- the needs and wills of local communities;
- the sustainable use of local resources, and;
- increased local ownership and retention of added values.

In this paper we further the discussion by focusing on the Industrial Symbiosis (IS) concept and the important role it can play in fostering the development of systems aligned with the principles of DE. IS is regarded as a subsection of the emerging Industrial Ecology (IE) (Chertow, Ashton et al. 2004), a discipline exclusively concerned with issues pertaining the long-term sustainability. IS aims to contribute to sustainability through an alternative organization of economic activities within geographically coded areas. One of the prominent scholars of the field defines IS as a collection of activities that "engage traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products." (Chertow 2000)

To this date, IS applications dominantly focus on realizing incremental eco-efficiency gains through retrofitting the existing and/or conventional production systems with necessary elements enabling the revalorization of waste and by-product streams of production. Developments driven by such focus are subject to criticism as they not only have a limited contribution for the realization of systemic changes necessary for sustainability, but also may be hindering such changes. However, as we will argue, this is more due to the intentions in the use of the concept rather than being an inherent weakness. In fact, if applied to serve a renewed intention, such as the catalysation of distributed economies, the concept holds a key potential. Here, the major contribution of IS occurs in the form of enhancing the technical and economic viability of small-scale production units, which may be disadvantaged against their large-scale, centralized counterparts. Through this focus, IS can facilitate the development of innovative production systems and become an enabler of systemic changes, possibly making a more solid contribution to sustainability.

In the next section we first review some characteristics of the dominant large-scale, centralized production systems that counteract sustainability needs. Then we provide an overview of regionally distributed, small-scale production units and elaborate on their desirable characteristics in terms of making a contribution to sustainability. We also highlight some of the difficulties facing their development. In section three we review the IS concept and its common applications in the context of regional sustainability. Here we also provide an alternative orientation for IS's role in industrial development. In section four we first review how such role influences the viable evolution of the so-called "biomass heat entrepreneurship" in Finland that are good examples of energy solutions with high sustainability profiles. Then building on the findings of Metso Corporation's research in the last decade we introduce a hypothetical example to demonstrate how the development of a small-scale paper mill can be influenced if symbiotic connections with other local activities, in our case a power plant and municipal waste management services, are considered. In the final section, we elaborate on the difficulties anticipated to face such developments, and share our suggestions that can help address these.

2. Sustainability and small-scale, diverse, locally focused production systems.

The term sustainable development has emerged as a response to the recognition of a multitude of social and ecological crises around the globe and aims to guide economic development so that the conservation of natural resources, preservation of the environment and meeting the social objectives are properly taken into consideration. The agreement is such that, while economic development remains to be an important engine for sustainability, this process can no longer be solely driven by economic motives. If a more sustainable state is to be reached, there are at least three challenges the economic development needs to address. First, as Goodland and Daly (1996) state, development should be decoupled from increasing resource throughput (Goodland and Daly 1996). This will not only help to conserve the limited resources, whose availability is likely to influence how well the future generations can meet their needs, but also reduce the waste generation and pollutant emissions, contributing to the efforts to meet the second challenge. That is, the flows from human techno-sphere to natural eco-sphere should not cause irreversible damages to the latter. Thirdly, and perhaps most importantly, the economic development should find a renewed balance between the profit maximisation and improvement of quality of life for the broader community, preservation of cultural identify and diversity, social inclusion, and ability to exercise power by the communities on actions that effect their livelihoods.

In sustainability discussions, it is increasingly recognized that creation of sustainable communities at the local and regional[1] levels is a prerequisite for a more sustainable global system. This recognition compounded by the understanding that regions constitute well suited entities within which coherent and meaningful sustainability policies, tools, and strategies can be developed and implemented (Wallner, Naradoslawsky et al. 1996; Ekins and Newby 1998; Renn, Goble et al. 1998; Bridger and Luloff 1999; Chatterton 2002) increases the importance of regional focus for the efforts towards sustainability.

So, what elements enhance the sustainability of a community? A partial answer to this question can be derived from relevant definitions. With a dominantly socio-economic approach, Bryden (1994) defines a sustainable community as one that “has a long-term capacity to regenerate itself socially and economically and that has the capacity to reproduce itself and evolve economically, socially, culturally and ecologically.” (cited in (Scott, Park et al. 2000) Kline (1995), on the other hand, states that to be considered sustainable a community

[1] The relevant question of “how a locality or region is defined?” arises. Through a synthesis of proposals given in Scott and Storper (2003) and Bridger and Luloff (1999) we define regions as “territories of subnational extent that is functionally organised around some internal central pole and that capture the majority of place related social interactions among people”.

should possess and maintain the ability "to utilize its natural, human, and technological resources to ensure that all members of present and future generations can attain a high degree of health and well-being, economic security, and a say in shaping their future while maintaining the integrity of the ecological systems on which all life and production depends (Kline, 1995 cited in (Bridger and Luloff 1999). Adopting a long term vision and focusing on the resource use and technology dimensions of sustainability for urban areas Van der Ryn and Calthrope argue that: "sustainability implies that the use of energy and materials in an urban area be in balance with what the region can supply continuously through natural processes such as photosynthesis, biological composition, and the biochemical processes that support life. New urban technologies will become less dependent on fossil fuels and rely more on information and a careful integration with biological processes." (Van Der Ryn and Calthorpe, 1986 cited in (Bridger and Luloff 1999). Rees and Wackernagel (1994) take a similar stand and state that global sustainability would be achieved "if all human populations were able to live within their own regional carrying capacities (i.e. on the continuous flows generated by local natural capita)". Acknowledging the non-uniform distribution of resources rendering interregional resource exchanges inevitable the authors add the condition of "import dependent regions are drawing on true ecological surpluses in the exporting regions" (Rees and Waskernagel 1994) as the next condition for global sustainability. Given that generally local authorities have more influence on the resources possessed in their jurisdictions, we will suggest that this condition will have more meaning if formulated as "regions should limit their exports to such resources that can be drawn from their ecological surpluses".

Implicit in these definitions is the necessity for local communities to:

- maintain access to a diverse range of resources, including materials, energy carriers, knowledge, human and financial capital, cultural identity, and the services provided by natural eco-system, and;
- possess the power and ability to control, self-organise and utilize such resources for the enhancement of their livelihood.

Nonetheless, local communities are increasingly being stripped off from such sustainability prerequisites. This is strongly linked to the fact that, supported by the dominant economic and political motives, production functions have been increasingly organised in the form of large-scale units and decision powers are concentrated in distant corporate board-rooms. In Table 1 we provide examples of how the domination of local economies by large scale production units bring about outcomes that undermine sustainability at the local level.

Table 1: Factors counteracting local sustainability brought by the domination of economies by large-scale operations owned by external power centres and their potential outcomes.

Factor	Potential Outcome
Loss of economic diversity	• Reduced robustness of local economy; • Increased vulnerability to external factors.
Decision powers shifted to centres outside localities	• People's ability to influence their institutional and ecological environment is eroded (Hines 2000).
Local activities are targeting the needs of distant stakeholders	• Local activities are not geared to build capacity useful for the local needs[2]
Larger volumes of resource throughput	• Higher potential for local depletion of resources; • Higher potential for local eco-system damage;
Distancing production and consumption	• Impacts from production phase are hidden from consumption phase, and vice-versa, thereby rendering crucial feedback feeble (Sundkvist, Jansson et al. 2001)
Imposition of a singular (western) culture	• Loss of cultural diversity and identity

We, however, acknowledge that large-scale production units have numerous beneficial aspects as well. In line with the DE thinking, our idea is not to get rid of such units once and for good, but to reemphasise the importance of realising a profound transformation at the local level, so as to create the conditions for local communities to become more sustainable. As we will elaborate in coming sections, the development of alternative production systems and establishing a renewed balance between these and large-scale units (more on this can be found in Johansson, Kisch et. al., 2005 and in Mirata, Nilsson et.al., 2005) is what we are calling for.

As argued under the DE discussions, many of such concerns can be addressed by first distributing a selective share of production to regions where a diverse range of activities will be organised in the form of small-scale, flexible units that are synergistically connected with each other and prioritise quality in their production. Next a renewed balance between large- and small-scale and between resource flows that take place within and across regional boundaries will be aimed (Johansson, Kisch et al. 2005; Mirata, Nilsson et al. 2005). Diversification dimension of such a shift will not only enable the satisfaction of a wide spectrum of local needs by local capacities but also help build robustness in the region. The businesses, and the production units, that drive the regional economies will primarily focus on local markets and be of scales better adopted to these markets and to local resource base. This can bring production closer to consumers and make the impacts of consumption decisions more visible thereby increasing the chances to shift to more sustainable consumption patterns. The smaller size can allow more room for local ownership, thus improving communities' influence on decisions with local impact. Local ownership can also increase the chances to retain a higher share of the value added benefits in the regions. With

[2] Klein notes that during her visit to a factory in Manilla she interviewed a seventeen year old worker who was assembling CD-ROM drives for IBM computers. She stated "we make computers, but we don't know how to operate computers" (Klein, 2001 p. XVII)

such dynamics the production units can be expected to aim for the best use of local resources and have a more genuine stake in such resources' maintenance and enhancement.

Also emphasised by Wallner and Naradoslwasky (1994), such transformation can also help at establishing a renewed balance in the exchanges of matter, energy, information, culture, capital, and persons that are taking place intra- and inter-regionally (Wallner and Narodoslawsky 1994). While maintaining regions still connected to the global economy, it will increase their self-reliance and change the nature of their interdependence. Here our understanding of self-reliance is in line with Chatterton's, which states:

> *In western economies the productive economy is largely geared towards meeting the demands of high consumption lifestyles and producing goods for external rather than local markets. However self-reliance in basic need such as food and energy are primary objectives of stronger sustainable development. Although self-reliance is protectionist in that production in the first instance is geared towards local demand, it is not isolationist nor does it entail reducing trade with the outside world. Rather, self-reliance is about promoting trade out of choice rather than necessity, setting mutually agreed trade barriers where applicable and reducing long distance transport of goods. (Chatterton 2002)*

There are, however, difficulties facing such a shift. One of the chief ones of these is linked to the fact that small-scale, locally oriented production units may find themselves in a disadvantaged position against the large-scale units regarding the costs of production. Nevertheless, such disadvantages can be offset by turning certain strengths brought by their small-size and closeness to factor and consumer markets into innovative management solutions. More specifically, they can:

a) differentiate by offering unique qualities, such as products customized for specific needs and tastes, with better environmental profile, and an enhanced service component;

b) increase resource use efficiencies through a web of diverse synergistic connections and interactions among various regional activities that conventionally maintain little or no connection. This can either be linked to transactions only feasible within geographic proximity or, as argued in Johansson et. al., to realizing economies of scale through networking (Johansson, Kisch, et.al, 2005).

Such a transformation is likely to be a gradual process. Moreover, the end state that is targeted through such transformation may seldom be defined in detail. However, it is important that such transition is guided by certain principles to assist its chances to contribute to local sustainability. From our earlier discussions, we can distil the following that needs to be among such guiding principles:

- Increasing the diversity of economic activities;

- Securing local parties' power to influence relevant decisions;
- Increasing the sustainable use of local and preferably renewable resources;
- Decreasing the amount of pollutant emissions and waste generation;
- Increasing the value addition to local resources and improving the quality of products;
- Increasing the share of value added benefits retained in the regions;
- Increasing the share of information and knowledge based, and higher added value products in the cross boundary flows;
- Increasing the diversity and intensity of communication and collaboration among regional activities;

Further elaboration on these ideas is provided, among others, under the Distributed Economies concept (Johansson, Kisch, et.al, 2005 and Mirata, Nilsson, et. al. 2005).

3. Industrial symbiosis in the context of regional sustainability

Industrial Symbiosis is regarded as a sub-section of the Industrial Ecology (IE) research field, the latter being explicitly concerned with sustainability. One central objective of IE is to identify and facilitate changes in industrial systems so as to reduce the resource use and waste generation associated with production and consumption systems. Transformation of the dominantly linear[3] patterns of resource flows into more cyclical ones, a practice inspired by the resource flow dynamics in natural eco-systems, receives particular attention as one of the necessary approaches to realize this objective (Allenby and Cooper 1994; Ayres, Ayres et al. 1998; Connelley and Koshland 2001), along with others such as dematerialization and efficiency improvements in production. A further reaching objective of IE, on the other hand, aims at facilitating a fundamental change in the industrial systems guided by a paradigm shift concerning industry-ecology relations (O'Rourke, Connelly et al. 1996). Here we emphasise that a paradigm shift, at least as important, is also needed in industry-society relations.

Achieving these objectives requires contemporary pursuit of two strategies: 1) the identification of necessary changes in existing industrial systems and facilitating their transformation into a more desirable states, and; 2) the design of new, innovative industrial systems and enabling their emergence and diffusion.

Industrial symbiosis (IS) networks[4] pursue the IE objectives by placing the main focus on economic activities within regions. In essence, such networks aim to harvest improvement

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[3] Linearity in resource flows stems from the fact that human economic activities heavily rely on extracting high quality resources from natural sources, degrading them through a series of consumptive processes, and returning its wastes back to the natural systems.

[4] There are other concepts, such as eco-industrial parks, and industrial ecosystems, that are regarded to manifest IE's regional application. Due to extensive similarities among IS and such other concepts in terms of their objectives and operational characteristics, in this work the concept of IS is regarded to represent all the other concepts as well.

potentials present at the inter-organisational interfaces via collaborative interactions among anthropogenic activities, mostly located within physical proximity to each other. A web of synergistic linkages emerging within an IS network allows improvements in the efficiency and effectiveness by which different resources and capacities are utilised, going beyond that which can be achieved by fragmented pursuit of improvements in individual units (Mirata 2004).

IS thinking is mostly applied or considered for existing production units (Boons and Baas 1997; Côté and Smolenaars 1997; Schwarz and Steininger 1997; Côté and Cohen-Rosenthal 1998; Mirata 2004), but it is also promoted as a design tool to guide the development of new industrial systems (Hawken 1993). In either case, however, the overriding emphasis remains on retrofitting conventional production systems, developed in accordance with the mainstream economic considerations, with necessary elements to enable waste and by-product revalorisation. To our knowledge, operational exceptions to this are rare and the increasing numbers of bio-mass based localised energy systems in Finland and Sweden employing innovative technological and managerial arrangements[5] (Korhonen 2001; Mirata, Nilsson et al. 2005) constitute the main examples. Thus, IS work appears dominantly bounded to production related waste and by-product cascades or cycles of large scale production units. This focus has reasonable techno-economic foundations as such production units are likely to be less dispersed, generate higher quantities of relatively uniform streams of wastes or by-products, and consequently offer better potential for economically viable inter-connections. Work with such focus, however, deals with a rather peripheral issue of waste streams and leaves the core of the production systems intact. Despite offering an improvement to status-quo in resource use, this way of employing IS is prone to slowing down or even counteracting the efforts to improve the sustainability of industrial systems. This risk is linked to the fact that the synergistic connections could be bringing business benefits to industrial units that can be part of an unsustainable production systems, thereby contributing to their economic viability and prolonging their life time. In situations where this could be the case, IS' contribution to sustainability efforts cannot be considered more than marginal, and is limited to incremental eco-efficiency gains.

In short, it can be stated that in its dominant form of application IS almost exclusively focuses on large scale production units and is inadequately developed in terms of integrating the production systems with *regional resource base* or *local consumption systems*. Thus, IS remains to concentrate on working with the existing systems for the realisation of incremental eco-efficiency gains. Its application as a strategy to foster the development and new and alternative systems and thereby catalysing necessary systemic changes remains weak. However, these shortcomings are more of an outcome of the commending intensions in the

[5] Development of synergistically connected facilities in a recycling park around urban areas to recover sections of MSW streams and turning them into commercial products have been suggested. But not only their number is very limited, but also to our knowledge, none such initiative has so far became operational.

use of the concept bound by "what the businesses are ready to take up", rather than being an inherent weakness. In fact, the fundamental principle of "bringing conventionally separate industries together for increased competitiveness through resource exchanges" is a novel one and can qualify IS as a key tool to enable the emergence of more sustainable production systems, if it is set to increase the viabilities of carefully selected "industries". Furthermore, as illuminated earlier, a regional economy organised in the form of a comprehensive IS network where diverse range of collaborative interconnections enabling the sharing and exchange of various resources among diverse range of regional activities, including consumptive ones, will have a much higher sustainability profile. However, it needs to be acknowledged that such developments are not much likely to happen and succeed as an outcome of a planned approach. Instead their emergence should be the outcome of a self-organisation process. Such self-organisation, however, could be inspired through various means. Provision of relevant information on the business potential linked to alternative forms of, more sustainable production units whose viability can be enhanced through IS is one of such means. Another one is to provide policy incentives for the development of such systems. In the coming section, we first attempt to do the former and show IS's role in assisting the development of more sustainable production systems. In doing this we first reviewing some characteristics of already operational "biomass heat entrepreneurship" initiatives from Finland. We then consider a hypothetical case where an innovative, small scale paper mill would be synergistically integrated with a power plant and waste management activities around an urban area attempt to its potential outcomes. In later sections, we also provide hints of what kind of policy incentives can be thought of.

4. Biomass Heat Entrepreneurs for sustainable heating and Urban mills for paper recycling

<u>Biomass Heat Entrepreneurship</u>

Biomass Heat Entrepreneurs are small, rural enterprises that typically operate locally and provide heat to the local customers with wood based fuels. The operation works in such a way that the heat entrepreneur is contracted to provide heating to district heating systems or to large scale buildings, public as well as private. He then takes the responsibility for a larger segment of the supply chain activities. That is, he processes the locally available wood waste from forests and industrial activities to produce biofuel, carries out all necessary logistics, and is responsible for the operation and maintenance of the actual heating system. Various technical factors support the feasibility of such practice. For example, fuel processing and logistics activities are possible to carry out using conventional equipment necessary for farming activities (tractors, trailers, drying rooms, and so on). A chipper is usually the additional necessity, which can be owned by the heat entrepreneur, or can be shared among regional parties. Highly automated heat conversion plants, on the other hand, enable controls to be made remotely using common gadgets such as a mobile phone and thus allow minimum labor input. The heat entrepreneur may have full, partial, or no responsibility to make the investment for the conversion plant. The price of the heat provided is usually bound to the price of heat produced by light oil.

Alakangas (2003) reports that more than 140 heat entrepreneur plants were operational in Finland by the end of 2002, utilizing 160 to 200 GWh of woodfuel, and providing more than 140 employment. From the point of view of local economy the heat entrepreneurship provides the following benefits:

- Increase the use of local labor and create new business opportunities;
- Supply of local raw material for energy production and reduction of CO_2 emissions;
- Increased energy security and supply in localities;
- Reliability of heating in public and private buildings;
- Savings in energy production and environmental protection costs (Alakangas 2003).

An additional benefit with Heat Entrepreneurship is that the money that used to be spent on exported fuel now circulates locally promoting local livelihoods and increasing local taxable income. Alakangas reports that 45-55% of the production and transportation costs are estimated to circulate back to local municipalities (Alakangas 2003). Last but not least, heat entrepreneurship provides private benefits to forest owners and farmers. These include:

- Timber, that would have been wasted otherwise, becomes a revenue stream;
- Utilization rates of farming and timber harvesting machinery are increased;
- Farmers' experiences with "heating with wood" is better utilized;
- Economic viability of farmers are improved who otherwise have limited job opportunities.

Brofta Oy is one of many biomass heat entrepreneurships in Finland founded by Tapani Brofeldt. Currently, the company runs six biomass fuelled plants providing 3000 MWh/y of heating. About 80% of the fuel that is used by these plants are sourced from forests located within a 20 km radius. All necessary logistical and operation and maintenance jobs are carried out by 2 personnel who are already employed in Mr. Brofeldt's farm. Brofta Oy has the plans to increase its heating business to up to 7000 MWh/y. Brofat Oy makes 10 to 15 year contracts with its clients, which increases their business security. Heat entrepreneurship is seen as an activity where large scale industries may not become competitive. This is mostly due to the fact that local entrepreneurs utilize their existing machinery and workforce, and are willing except longer pay back times (as long as 7 years).

Urban Mills for paper recycling

Despite various policy interventions and increasing recycling rates, waste generation is still on the rise in Europe and poses a significant challenge particularly around urban areas. Waste paper generation in Europe, for example, has increased from 41 Mtons/y in 1983 to 79

Mtons/y in 2002. Although the recycling rate for waste paper has also arisen from 41% in 1990 to 56% in 2002 the waste paper going to incineration and landfills has remained more or less constant at 35 Mt/year. (Jacobsen, Brodersen et al. 2004). From a different perspective, today's urban areas are regarded to resemble a new form of modern mines where various material resources have been accumulating (Ayres 1997), and continue to do so, forming a resource base in addition to the naturally occurring ones they may possess. This has lead to the idea of employing certain production techniques at an appropriate scale so that their resource requirements to produce the urban areas with various products can be sourced from the same areas.

Urban Mills[6] (UM) are one of such units that rely on 100% recycled paper for the production of paperboard products. Rather than aiming to maximize economies of scale, UMs are designed to fit the resource base and consumer market of a specific location. UMs suffer from conventional economic drawbacks that are symptoms of being small (higher specific investment and operational costs, and so on). They have, however, certain attributes that strengthen their economic viability. Their smaller size translates into lower absolute investment costs. They have lower energy requirements and generate less wastes and effluents, again in absolute terms. Such smaller quantities offer the opportunity to purchase the energy needs from factor markets and the effluents can be taken care of by an existing wastewater treatment plant, such as a municipal one. This lowers the capital and operational costs for necessary energy production and waste management. Moreover, their main input, mostly surplus waste paper generated within the region, is competitively priced and their proximity to the raw material and product markets allow reductions in logistics costs. In addition to such direct factors, UMs hold the potential for realizing further benefits due to their possibility for better integration with downstream operations and developing closer connections with their markets (Ristola 2002).

UMs provide the environmental and economic benefits generally associated with paper recycling, including: a) up to 30-50 % reduction in energy use as compared to using virgin wood pulp; b) revalorizing a significant fraction of waste streams that would have to be managed otherwise (Johansson and Holappa 2004). However, they offer potential for further environmental and economic gains if their operations can be integrated with other systems, such as local energy provision and waste management operations. The importance of such integration multiplies in light of the EU's waste regulations. These impose tougher restrictions on the landfilling of waste calling for significant increases in both material recycling and waste-to-energy units in many EU countries. Thus integrated development of urban-mills, waste-to-energy units, and waste management practices provides a window for meeting this

[6] Popular term of "mini-mill" has earlier been used by the P&P industry to describe 100% recycled fibre based small production unit. Metso has in its research work enhanced the "mini-mill" concept by important elements of integration to local waste-to-energy solutions and has been refering such units as "Urban Mill". Thus in this article term Urban Mill comprises of both traditional mini-mill features and the additional features introduced by recent Metso research.

challenge in an economically feasible manner. In the following we review three scenarios demonstrating the impacts of different levels of integration between an urban mill and other local activities.

In the first scenario, a conventional recycled paperboard mill with 150 000 ton/y capacity, using only pre-sorted waste paper streams and fossil fuel sources is considered. Such scenario is depicted in Figure 1. From the technical point of view, this scenario is quite close to a state-of-the-art solution, with the main exception being the scale of the operation that is only 40-50% of typical new installations. The resulting high specific investment and operating cost in this case is difficult to compensate by the logistical and customer service benefits of smaller size only. Moreover, while the production of RDF out of rejects is not very common today, it is likely to grow rapidly when the cost pressure from various EU waste legislation enhances the competitiveness of this practice.

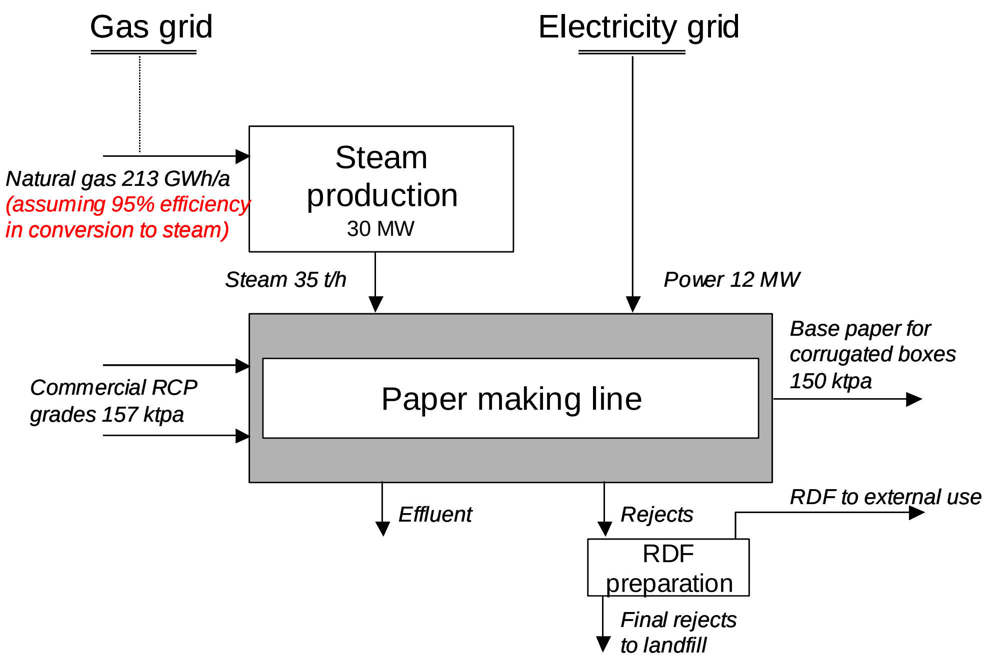

Figure 1: A 150 000 t/y urban mill utilising only pre-sorted recycled paper and natural gas.

Production of paperboard products can receive an important part of their raw material from an urban waste stream. This is considered in the next scenario where through the installation of right technologies fibre rich fraction of municipal solid waste (MSW)[7] is turned into a feedstock (Ristola 2002; Ristola 2004). Moreover, the refuse derived fuel (RDF) from the mill's rejects are used for production of process steam, substituting significant portion of the fossil fuels. In addition to the fibre recovery equipments, this setting will require a MSW stream that does not include household waste and the presence of a fibre recovery system and suitable

[7] This amount of waste is likely to be produced from an area with approximately 1 to 1.5 M inhabitants.

combustion equipment, such as a bubbling fluidized bed boiler, in the mill. This scenario is depicted in Figure 2.

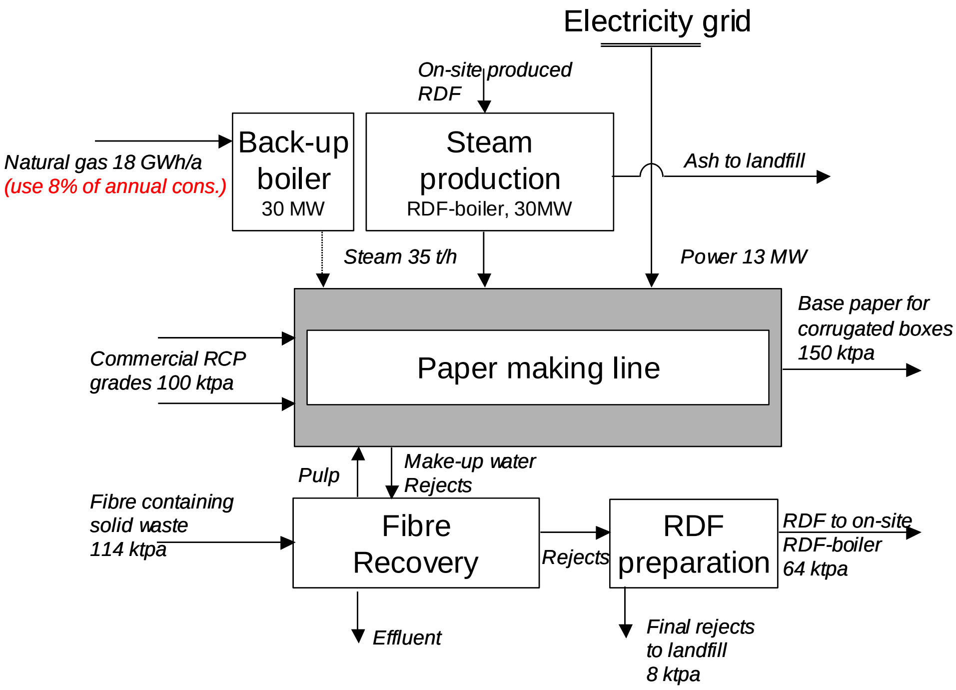

Figure 2: A 150 000 t/y urban mill utilizing fibre from MSW and substituting RDF for natural gas.

However, it is not only paper products that can receive a significant portion of their inputs from urban waste streams, but also energy production. Although there are alternative developments in recent years, in the 20th century the energy needs are typically met through large-scale, centralized, capital intensive units which rely upon the importation of energy from fossil fuels having unstable prices, limited supplies, and high pollution costs. Thus, small-scale, decentralized energy systems that rely on locally available fuel sources, including RDF, represent another development aligned with regional sustainability objectives. From the point of view of waste management, waste-to-energy is usually seen as a reasonable option for handling large volumes of mixed waste. However traditional incineration of mixed waste has low energy efficiency and very high investment costs. Therefore, a lot of emphasis is recently being put on researching alternative solutions rather incineration technology. Current possibilities include co-combustion of source separated dry waste and gasification of the suitable fraction of the waste prior to combustion. A prominent example of such solutions is fuel production from source separated waste that can be co-combusted with fossil fuels (Nieminen 1999).

Considering the high energy consumption of paper production and the potentially large reject flows from processing of poor quality waste paper points at the synergies associated with the integration with combined heat and power production. Taking these into consideration, in the next scenario, the integration of the mill with a neighbouring combined heat and power (CHP) plant that uses RDF is considered. In addition, a 50% increase in the use of feedstock recovered from MSW streams is assumed. Besides its presence in sufficient geographic proximity, the integration with the power plant will demand that suitable technologies, such as a fluidized bed boiler equipped with proper gas cleaning systems or a gasifier, are in place so that RDF can be used as a fuel. The increase in the use of recovered fibre, on the other hand, will result in a 25% increase in the additives used in the process to ensure sufficient quality. This scenario is depicted in Figure 3.

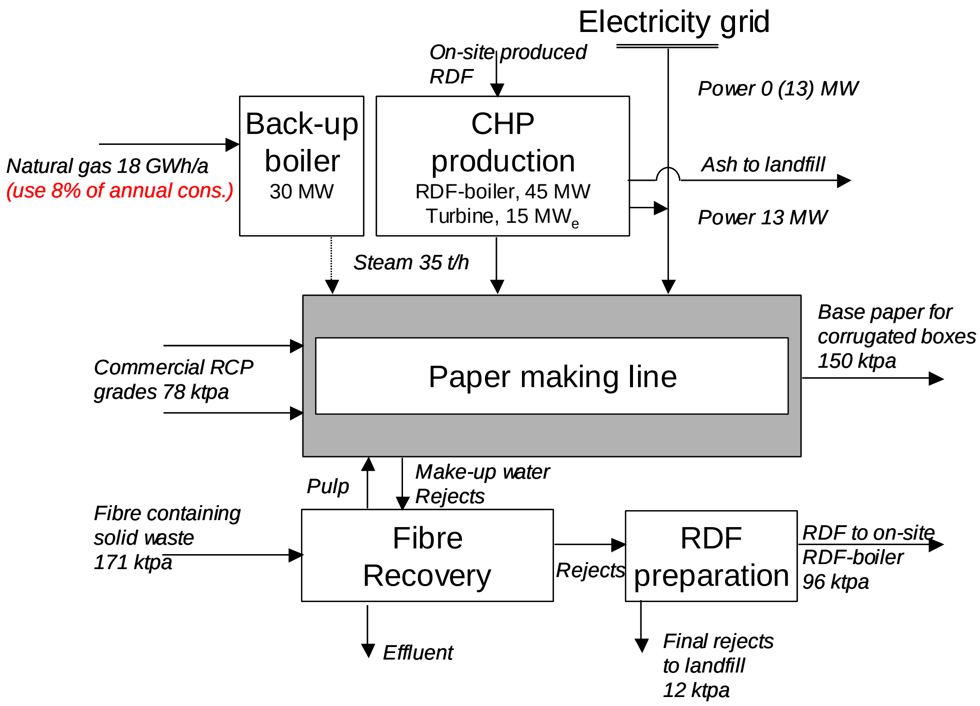

Figure 3: A 150 000 t/y urban mill utilising an increased fraction of fibre recovered from MSW and supplying its heat and power needs from a neighbouring CHP plant.

There are various environmental benefits associated with these developments. Some of them are summarized in Table 2.

Table 2: Environmental gains associated with integrating an UM with local power production and waste management activities.

Factor enabling the environmental gains	Environmental gains		
	Scenario I	Scenario II	Scenario III
Use of recycling grade waste paper locally*	Linked to reduced transportation	Linked to reduced transportation	Linked to reduced transportation
Use of fibre rich fraction of MSW	-	Reduced waste to landfill (106 kt/y)	Reduced waste to landfill (159 kt/y)
Use of UM rejects in the process steam production.	-	Reduced natural gas usage (~ 20 M m^3/y) Reduced CO2 emissions (35 kt/y)	Reduced natural gas usage (~ 42 M m^3/y) ⌘ Reduced CO2 emissions (73 kt/y) ⌘
Use of rejects in CHP production			Reduced natural gas usage; Reduced CO_2 emissions per kWh output (max 60%)

*: Other environmental benefits associated with the use of recycling grade paper in the production of paper products are not considered as it is assumed that if not in the UM the collected quantities will be utilized in another paper mill.

⌘: Based on the assumption that electricity from grid is produced in a modern natural gas fired power plant.

More importantly, however, developments in line with IS thinking as described in scenarios two and three provide financial gains strengthening the economic viability of UMs. These are summarized in Table 3.

Table 3: Summary of financial parameters under different scenarios.

Parameter	150 kt/y			300 kt/y
	Scenario I	Scenario II	Scenario III	
EBIT* (as % of Gross sales)	16	27	39	17
ROCE¤ (%)	8	11	14	10

*: Earnings before interest and tax.

¤: Return on capital employed

As can be read in Table 3, the financial outlook of the UM significantly improves due to its integration with other local activities, to the extent that it becomes significantly more economically viable even as compared to larger scale alternatives that rely solely on recycled grade waste paper. It should also be noted that, although they are not quantified at this stage, additional economic and technical benefits can be obtained if for example the UM in question is integrated with a local CHP plant. Moreover, these units are not only economically competitive, but also they are associated with relatively low capital investments increasing the opportunities for local ownership.

It is also worth noting that these synergies may be developed with certain organisational arrangements that provide further benefits. One of these would relate to joint investments by the UM, the power plant and the local waste management organization, into necessary infrastructure elements. This may both provide economic gains in absolute terms (e.g. due to shared auxiliary functions such as boiler water preparation or maintenance crew) and can significantly reduce the investment and operations related risks.

5. Discussion

As can be seen from the previous section, smaller scale, locally embedded economically viable systems that adds value to locally available resources has various benefits. Such benefits, as well as the technical and economic viabilities of such units, on the other hand, can be enhanced through their integration with other local activities in line with IS thinking. As illuminated by the heat entrepreneurs, such developments are dependent on various factors. In that case, for example, developments are enabled by the existence of already present but underutilized resources that include forest wastes, farming equipment and personnel. The viability of such developments are further catalysed by technological advancements such as highly automatised heating systems using fluidized bed boiler systems. Perhaps most importantly, however, such developments receive strong support from policy elements. In the case of Finland the Action Plan for Renewable Energy Sources that sets ambitious targets for bioenergy utilization, the carbon taxation applied to fossil fuels, and subsidies granted for new installations under the National Energy and Climate Change strategy are among such important policy elements. Last, but not least, organizational dynamics such as long-term contracts and willingness to accept longer than usual pay-back times are important elements enabling the successful development and operation of such systems. Likewise, the development and proper operation of a system as described in our scenarios above will depend on various factors. In the following we review some of these suggest alternative approaches to assist such developments.

First of all, the operational efficiencies of both the UM and the power plant will highly depend on the quantitative and qualitative characteristics of the waste streams that will arise from the local communities. Surely, advanced separation activities, the closer to the source of generation the better, will have a considerable impact on this. It is, therefore, essential for the waste management function, and perhaps more importantly for the local community, to have an awareness regarding the importance of proper waste separation. Efforts of the local community will be particularly important for the assurance of the availability of good quality waste streams at a reduced cost. This can be catalysed via educational programmes and various sorts of incentive schemes.

In the case example we have assumed the paper mill to extract significant part of its fibre raw material from paper rich MSW flows. The safest assumption is that dry waste from commerce and industry is separately collected and pre-treated. Although it is technically possible to source a portion of the feedstock needed for the UM from the mixed MSW streams, including those originating from households, today this is not allowed due to regulations restricting the contents of packaging material that comes into contact with foodstuff. There is also a fine line in the regulation if separately collected, multi-component fraction from commerce and industry could be used in food contact materials. We acknowledge that such rules are based on solid and valid concerns. However, we would like to emphasise that it is technically possible by thermal processes to provide a proper disinfection of the product. In addition, preliminary test results indicate that the heavy metals and organic chlorine compounds contents in source separated paper and paper fraction of more mixed waste streams are also not likely to show high variations. In other words, there can be cases where such concerns are unfounded leading to the sub-optimisation of systems (i.e. not allowing a value adding use of paper in more mixed waste streams). This problem can be addressed through case specific investigations in the application of regulations, but exercise can escalate the transaction costs of control and enforcement. The case however remains that certain regulatory obstacles are more based on the political difficulties than factual realities.

Meeting the technical requirements is a necessary prerequisite but is not enough for such a system to function. The parties will have to assure sufficient economic returns from the partnerships. This depends: a) on the extent of cost reduction and revenue generation attributable to their synergistic connections, and; b) the longevity of inter-organisational connections enabling them to recover their “relation specific investments” and collect sufficient economic returns. Two main and somehow interconnected groups of factors influence these. First group is related to the dynamics of markets and political environments. More specifically, the economic viability of the above mentioned integrative connections is supported by the increasing prices of fossil fuels as well as the escalating costs of landfilling paper based waste materials. Additionally, different fiscal incentives are available (in the form of subsidies or tax reductions or exemptions) today (at least in certain countries such as Sweden and Finland) for the production of power from biomass based fuels. It is, however, uncertain whether such market trends and policy elements will continue to provide such support. In addition, strong support instruments may disturb material use of biomass - at the extreme the recycling of paper - and thus recycling should be granted by at least equal amount of support than biomass' energy use.

The other group of factors is related to the governance mechanisms the parties employ to safeguard their transactions against intentional (e.g. opportunistic behaviors, changes in the operational attributes) and unintentional (e.g. bankruptcy) disruptive developments. Such governance mechanisms can be (listed in an order of decreasing cost of monitoring and control and decreasing room for legal enforcement) formal (e.g. legal contracts), semi-formal (e.g. joint investments) or informal (e.g. based on trust and good will of parties). Among these alternatives joint ownership schemes should be given priority for the case in hand. This will not only help avoid opportunistic behavior but also will optimize different parties efforts to make the overall system work effectively and spread the financial risk associated with capital investments.

Satisfaction of technical and economic considerations is a vital prerequisite for such a system to function. Here the transaction costs are likely to constitute an important factor affecting the economic outlook. Such costs, among others, are linked to the way transactions are governed. A review of the relevant literature reveals that formal, semi-formal and informal arrangements can be utilized for such governance. While the former ones will include specific legal contracts, these tend to be more costly than other means. Transactions founded by informal means founded by trust are regarded to be effective and less costly, but need longer time spans to develop. Although it can be speculated that if such elements are developed by local owners, being part of same community can provide a head start with having the desired level of trust. But this may not be taken for guaranteed. An attractive solution, on the other hand, lies with joint investment schemes, which raise the financial stakes of parties in the successful functioning of transactions. As the integrations we reviewed require the involved parties to make "relation specific" investments, they would like to assure the longevity of inter-organisational connections. Thus, joint investment will help avoid opportunistic behaviour and thereby reducing the transaction costs.

One advantage of small-scale systems is that they require lower absolute investments, thereby increasing the chances for local ownership. Besides supporting the retention of added value benefits in the locality, local ownership can also result in more consideration to be given to the environmental and social interactions of such facilities. It can also be speculated that being part of the same community can provide higher levels of trust. This, in turn can be effective reducing the contracting and control costs of transactions, and therefore can help the economic viability of developed systems.

In addition to the benefits that will be realized by the facility owners, there will be others that will be realized by the wider community. On the employment side, such a scheme will create new jobs. Financially, such activities will likely to increase the tax revenues in the region, which can then be used for public goods.

We are supportive of the argument that developments such as the one defined above are difficult to be realised as an outcome of a planning exercise. Their development and sustained operation hold much higher chances if they can emerge as successful businesses within existing market conditions (Desrochers 2000; Desrochers 2002). We believe, however, demonstrating the business case for IS applications, as we tried to do in this paper, has a promising potential to facilitate such organic development. Such importance multiplies in cases where there is no or inadequate policy elements at the regional level to support a transition to more sustainable systems and thus such transition will have a heavier reliance on business initiatives.

Moreover, the roles policy elements have played, and still do play, in stimulating more efficient production systems and in acquiring more cyclical patterns in resource use cannot be overlooked. The interplay between the creation of almost closed metabolisms with certain materials (e.g. lead) in the U.S. and European economies and regulations that govern the flows of such materials, between the substantial increases in recycling rates in most west European countries and their gradually increasing fees for streams destined for landfills and other regulations that extend the producers' responsibilities on their products, and between the increasing number of CHP plants and the climate change levy of the UK are just a few of such examples. The way such policies are implemented, however, are not necessarily supportive of carrying out such activities at the local scale and in cases can even be argued to be counteractive. Due to space limitations, we leave the elaboration of this issue to another article. Instead, here we shortly highlight the possibility that through setting regional targets for meeting recycling objectives, and restructuring the fiscal systems that attached to recycling activities in favour of local initiatives, the development of localized, small-scale operations that help close material loops can be enhanced.

Presence of large quantities of waste streams, that are mostly associated with large scale production units is commonly regarded as a prerequisite for the evolution of IS networks (Ayres 1996; Ehrenfeld and Gertler 1997; Lowe 1997). We support the importance of having sufficiently large stream containing resources, however, reject the assumption that this needs to be sourced from or processed by large scale production facilities. In the earlier sections we have shown that IS can be operationalised by extending its boundaries to include local consumption both as a source of resources and as a market for products, thus making the presence of a single large waste producer unnecessary. We would also argue that smaller scale operations may have attributes strengthening their success potential, including integration with other activities. First, following Johansson and Holappa's (2004) work on the strengths of small scale steel mills mainly using scrap we would argue that facilities at small scale can take advantage of innovative technologies (Johansson and Holappa 2004). Besides holding the potential for being more efficient, such technologies also provide a unique flexibility, albeit within a limited scope, that cannot be matched by large scale units. This is most distinct in their ability to swiftly adapt their operations to respond to changing conditions in factor and product markets and to take advantage of productivity gains. In the case of UMs, for example, the chances of finding a compatible existing / neighbouring / local partner for integration would be higher than a mega plant, due to the scale of operation. More specifically, the odds of finding 35 MW of low pressure process steam are much higher than that of 140 MW. Although the small scale of synergistic exchange would be a disadvantage if "relation specific investments" are to be made. However, such comparisons can only be made, if there is a compatible partner for the large scale operations. Moreover, the losses on the scale of operation can possibly be, at least partially, offset by the enlarged scope of scope of cooperation, if flexibility allows more exchanges to be made. If establishment of a new plant is in question, then a similar logic applies for land availability. In cases where the possibility exists for integration, let's say, with an existing municipal CHP/Waste-to energy, it is much easier to look for five hectares in close proximity to your partner than 25-50 hectares. At least at paper mills, the need for lot size increases proportionally with the warehouse space which in turn increases faster than the production volume (at least in theory 'cause your shipping distances increase by the volume, so for the same effect you need more buffer). I think the physical restrictions at sites neighbouring industrial operations are typically nonfavorable for mega-operations to find attractive partners/matches. On a different account, in certain cases smaller quantities would be much less likely to cause a disruption in operations (this is particularly valid for power production, although it is dependent on the contents of the small stream) increasing the chances for integration.

Innovative new technologies and innovative ways of organizing already existing technologies is an important prerequisite for moving towards a more sustainable future. At this point we support Vollenbroek's argument that such innovative ways of organizing economic activities should be an outcome of society's pull, rather than that of a policy push. Such pull can be facilitated through the development of shared perspectives for the future, which are inspiring for public and private policy makers and investors. This way of directing innovation towards sustainability is termed "transition management", and it's most distinctive feature is that, under such framework "innovation is no longer driven by past, but attracted by the future."(Vollenbroek 2002)

6. Conclusions

In this paper, it is argued that small-scale, localised production units that are better integrated with local consumption activities and are more attentive to local resource base offer a more profound contribution for sustainability at the local level, as opposed to centralized, large-scale production units that are developed in sole pursuit of scale economies. Both the emergence and the functioning of such smaller-scale systems, on the other hand, can be enhanced if they are synergistically integrated with other similar systems. In other words, systems having more desirable environmental and social profiles and that are still economically viable could be developed through increased complexity at the local level.

Establishment of synergistic connections among regional activities enabling exchange of resources and thereby providing environmental and business benefits constitutes the main focus of industrial symbiosis concept. However, IS applications to this date are too pre-occupied with conventional systems and are mainly enablers of incremental eco-efficiency gains only. IS's potential to support the development of alternative systems with more desirable sustainability profiles is underutilized. To make better use of this potential the scope in IS application need to go beyond solely looking into revalorizing production related waste and by-product streams and should aim to increase the integration of production activities with local resource base and local consumption systems. As shown in this paper, the technical and economic feasibilities of localized, small scale systems can be enhanced through IS. There are, however, IS, numerous organizational and political difficulties facing the development of such systems. While the organizational ones can be addressed through innovative ownership and management arrangements, policy shifts that favour local initiatives and provide regulatory flexibilities may not only help overcoming difficulties but also can give the right incentives.

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