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SRUNs
Sustainable Resource Utilisation Networks for Regions

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"*The tiny amount you and I can do is hardly likely to bring the huge worldwide moloch of plundering industry down? Well, if you and I don't do it, it will not be done, and the Age of Plunder will terminate in the Age of Chaos. We have to do it - just the two of us - just you and me. There is no "them" - there is nobody else. Just you and me. On our infirm shoulders we must take up this heavy burden now - the task of restoring the health, the wholeness, the beauty and the integrity of our planet. We must start the Age of Healing now! Tomorrow will be too late.*"

John Seymour, The Age of Healing

Zusammenfassung

Heutzutage ist es unumstritten, dass das globale Fördermaximum fossiler Ressourcen in diesem Jahrhundert erreicht oder überschritten werden wird. Neben dieser, sich deutlich abzeichnenden, Ressourcenbeschränkung, werden die Auswirkungen des Klimawandels immer deutlicher. Um dem entgegenzuwirken ist eine drastische Reduktion der (fossilen) CO_2-Emissionen unausweichlich. Aus diesen beiden genannten Entwicklungen geht klar hervor, dass im 21. Jahrhundert ein massiver Wandel erforderlich ist, weg von fossilen hin zu erneuerbaren Ressourcen.

Dieser Wandel bedeutet aber gleichzeitig auch eine Veränderung der Lieferketten: während fossile Ressourcen typischerweise von punktuellen Quellen bezogen werden, hängen fast alle erneuerbaren Ressourcen direkt oder indirekt von der solaren Einstrahlung ab und benötigen Fläche, um produziert zu werden. Dies stellt politische, wirtschaftliche und gesellschaftliche AkteurInnen zukünftig vor große Herausforderungen.

In der vorliegenden Arbeit wird der konzeptionelle Rahmen einer nachhaltigen Ressourcennutzung im regionalen Kontext innerhalb von Netzwerken (SRUNs) abgesteckt. Dabei wird die Verantwortung von Regionen, Waren und Dienstleistung für die Gesellschaft bereit zu stellen, beleuchtet. Regionen bringen die räumliche Dimension in die Betrachtung mit ein. Es wird gezeigt, wie nachhaltige Netzwerke erstellt werden und welche Elemente und Eigenschaften für sie kennzeichnend sind, welche Anreize und Hürden es für SRUNs gibt und wie Raumplanung und Stakeholder-Prozesse mit in die Betrachtung einfließen. Mit der Prozessnetzwerk-synthese (PNS) kann das wirtschaftlichste Netzwerk gefunden und können unterschiedliche Szenarien miteinander verglichen werden. Der Sustainable Process Index (SPI) ermöglicht die Berechnung des ökologischen Druckes. Beide Computer-Tools werden in dieser Arbeit beschrieben und deren vielfältige Anwendung in Fallstudien präsentiert. Online-Tools für die Entscheidungsunterstützung in Planungsprozessen helfen regionalen AkteurInnen ihre eigene Region zu analysieren und eine Idee von SRUNs und deren Umsetzungspotentiale zu erhalten. Die in dieser Arbeit beschriebenen Programme zeigen die notwendigen Veränderungen, um unser Handel nachhaltig zu gestalten.

Abstract

Nowadays it cannot be denied that fossil resources will approach or over-run their maximum global production rate within the 21st century. In addition to this resource constraints climate change has to be considered in parallel, requiring a drastic reduction in carbon emissions. These two trends clearly show that a fundamental shift is needed within the next decades, from fossil towards renewable resources.

This transition gives rise to a change in the supply chains: while fossil fuels are typically exploited from point sources, nearly all renewable resources depend, either directly or indirectly, on solar radiation and area is required for their provision. This poses a new challenge for political, economic and social actors who can decide about land use.

Within this thesis a conceptual framework of so called SRUNs – sustainable resource utilisation networks for regions - is developed. Regions have a responsibility in providing goods and services for the society within sustainable networks and bring the spatial dimension into consideration as well. The way how these networks are constructed is described in detail covering spatial planning, the stakeholder process, drivers and barriers as well as elements and features for SRUNs. Using the Process Network Synthesis (PNS) as an optimisation tool, the economic optimum of a network can be found and different scenarios compared. To show the ecological pressure of an established network an evaluation with the Sustainable Process Index (SPI) is carried out. Both computer tools are described and their application is shown in several case studies which are the versatility of the methods in practical implementation and application. Decision support tools offer the possibility for regional actors to analyse their region and to get a feeling about SRUNs. These tools provide an insight into the necessary changes which are needed to manage the shift towards a low carbon and sustainable society.

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List of Abbreviations

a	year
ARL	Academy for Spatial Research and Planning
BAU	Business as Usual
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
EC	European Commission
ELAS	Energetic Long term Analysis of residential Settlement structures
ETS	Emission Trading System
EU	European Union
GHG	Green House Gases
ISCED 4	International Standard Classification of Education level 4 programmes
kg	Kilogram
kW_{el}	Kilowatt electric
kWh	Kilowatt hour
m^2	Square meter
m^3	Cubic meter
MJ	Megajoule
Mtoe	Million Tons of Oil Equivalent
MWh	Megawatt hour
NRP	National Reform Programme
OECD	Organization for Economic Cooperation and Development
ORC	Organic Rankine Cycle
PNS	Process Network Synthesis
RES	Renewable Energy System
S	Summer
SNG	Synthetic Natural Gas
SPI	Sustainable Process Index
SRUN	Sustainable Resource Utilisation Network
SRUNs	Sustainable Resource Utilisation Networks
TJ	Terajoule
W	Winter

1 Introduction

There is a worldwide hope that the concept of sustainability might give answers to solve the crises of the 21st century; no matter what crisis it is. Any solution can only count as sustainable when in every single step the concept of sustainability is applied. There is one widely-accepted representation of sustainability which was proposed at the Earth Summit in Rio de Janeiro in the year 1992, the so called "Munasinghe triangle" or "sustainable development triangle" (Munasinghe M, 2004), shown in Figure 1. It implies that sustainability in any process can just be achieved, if the solution found is a balance of importance and impacts of three categories - social, environmental and economic - and hence has to cover all aspects of human activities. Especially in case of resource utilisation these three categories are often imbalanced with a bias to economic arguments as soon as it comes to decision making. The low-cost solution easily attracts decision makers, but means to keep existing technology pathways and to use the low priced resource, which is mainly the fossil one. This implies that renewables have strong importance, but still low impact.

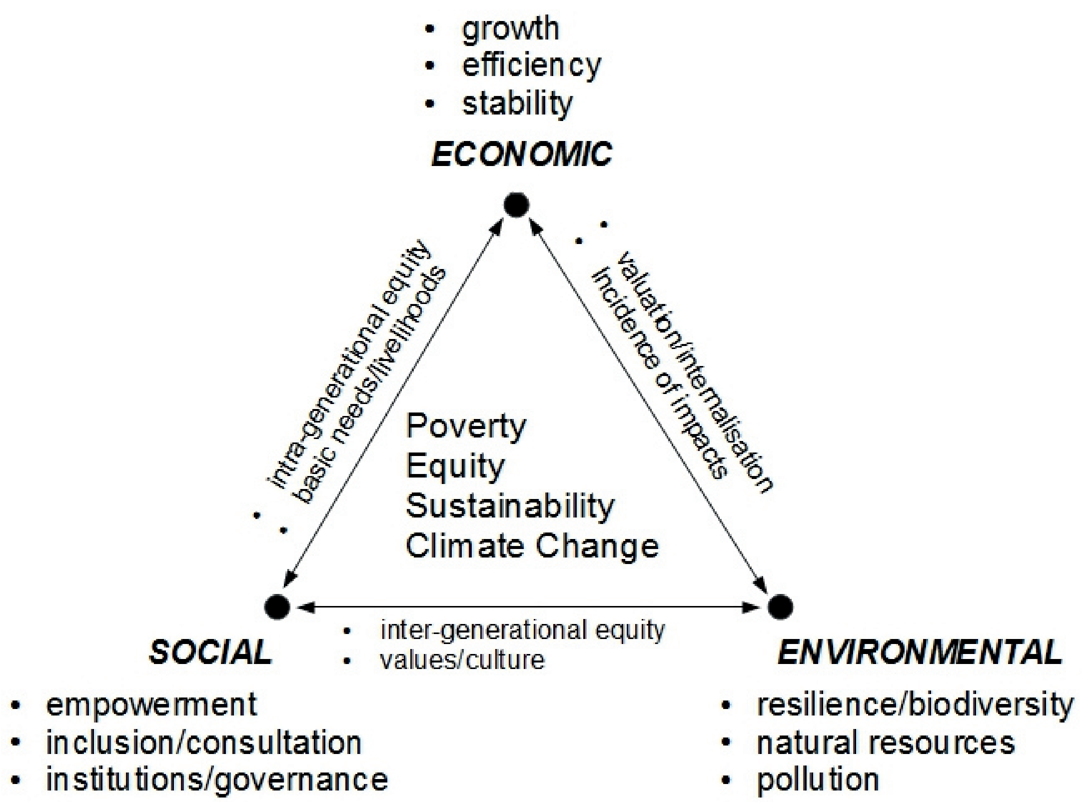

Figure 1: Elements of sustainable development; Munasinghe Triangle (1992)

Since the Rio Conference in 1992, regions have become dynamic political actors. As a counterbalance to globalisation regional and local entities became driving forces of political change in Europe mostly due to the fact that they are the administrators of natural income.

The responsibility, however, lies not only in comprehensive planning goals which deal solely with the technical side of resource use, but must bring ecological and social aspects in line with economic considerations, while spatial planning and energy provision as well as use have to be included. In this context regions play a key role.

There is an EU-wide focus on regions (Lafferty, 2002) which is reflected amongst others by several funding programs. On a regional scale a high level of community involvement can be maintained in planning and decision making (Terlouw, 2012). The political framework is part of chapter 3. Through regional collaborations and region partnerships, issues can be addressed on an even wider scale.

In the last decade renewable resources became more and more important for energy production and are nowadays overtaking the production from European fossil fuels. Figure 2 shows the primary energy production of the EU-28 in 1000 TJ and Mtoe from 1990–2012 with a total amount of 788 Mtoe in 2012. Between 2002 and 2012 the trend in primary energy production was negative for most energy sources except for renewables, where it increased by 81% (eurostat, 2014). 15.6% of the EU's heat consumption is provided by renewables while 88.9% of this renewable heat is provided by biomass (Aebiom, 2014).

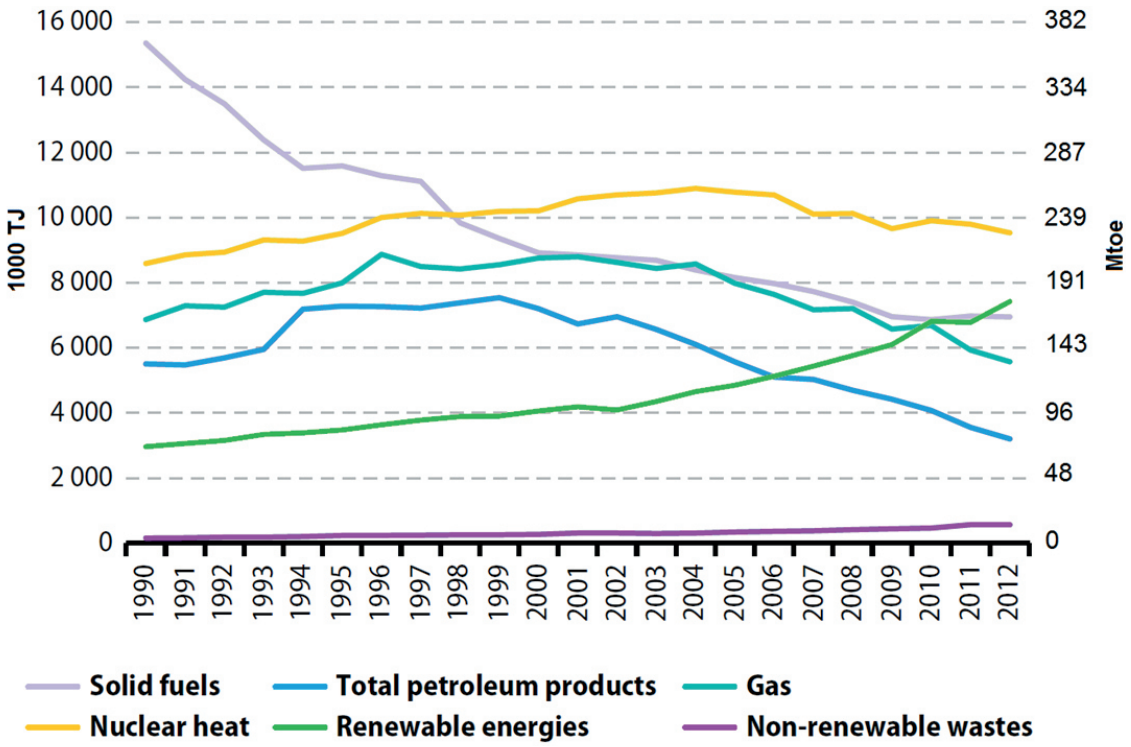

Figure 2: Primary energy production, EU-28, 1990–2012 (1 000 TJ, Mtoe), (eurostat, 2014), modified

The European Bioenergy Outlook (Aebiom, 2014) predicts an upward trend in the final energy consumption of bioenergy from 2012 to 2020 of 35.4%. Figure 3 depicts this increase and the distribution of the different end-use.

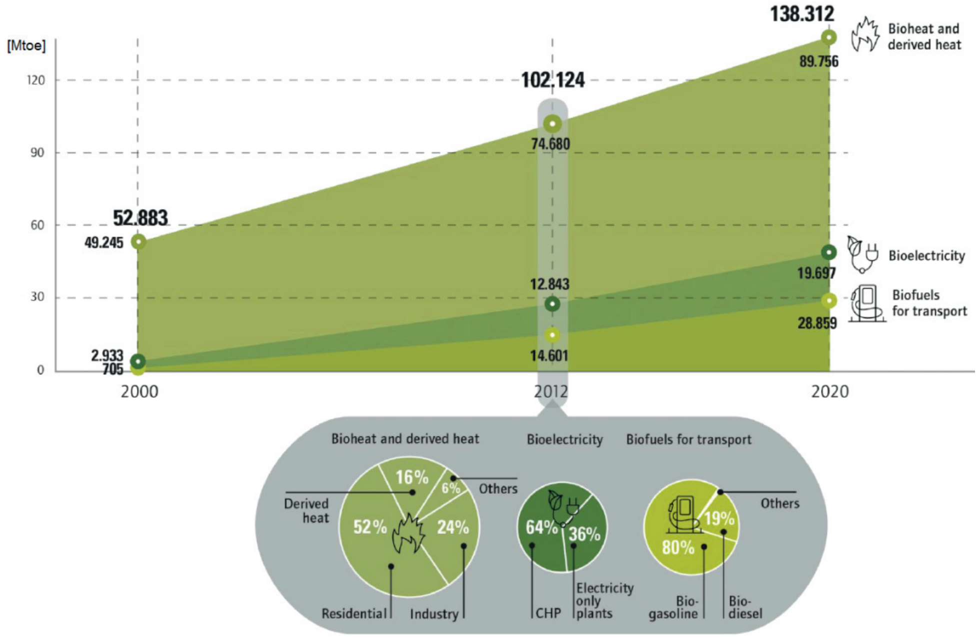

Figure 3: Final energy consumption for bioenergy 2000-2020, (Aebiom, 2014)

European's final energy consumption amounted to 1104.5 Mtoe in 2012 (eurostat, 2014). Despite the contribution of renewables in the production, Europe still remains highly energy dependent on oil (85%), natural gas (66%), coal (62%) and Uranium with an average energy dependence in the EU-28 of 53.4% in 2012 (Aebiom, 2014; eurostat, 2014).

The substitution of fossil fuels to reduce carbon dioxide emissions is one of the drivers for change and seems to be a huge challenge all over the world (Schindler & Zittel, 2000; IEA, 2013). Most sources for renewable energy can be deduced from solar radiation as the main natural income of society. Geothermal energy is the only exception generating thermal energy which is stored in the Earth. The conversion from bio-resources[1] to utilisable material requires inter alia productive area, which is limited as our planet has a limited surface with a certain production rate. However, bio-resources are extremely versatile with regard to their use and can meet every demand currently covered by non-renewables (ESEIA, 2014).

Contrary to conventional fossil and radioactive energy resources which are mined or pumped from point sources, solar radiation is a de-central resource which can be

[1] Bio-resources are non-fossil biogenic materials which can be utilised to a broad spectrum of products like food and feed, pulp and paper, timber, chemicals and other bio-based products and energy carriers.

converted into useful products and services (Narodoslawsky et al., 2014). Due to the fact that renewable resources are area dependent (for example biomass needs area to be grown and harvested), regions assume a new role as energy providers. Thus regions become key players within sustainable network solutions. In terms of renewable resource-based energy provision there cannot be one specific technology substituting the fossil-based ones. It is rather a combination of different technologies, linked in a mature network, utilising several resources, delivering variable kinds of products. The longer a resource is kept in use, the more functions it fulfils delivering different commodities within its life cycle. This resource efficiency, starting from the moment of harvesting, can lower with each utilisation step the overall ecological pressure exerted on the productive area as a primary resource. This kind of resource use requires different technologies that can utilise by-products and waste as well to fully exploit the potential of the resource (ESEIA, 2014).

Regions differ considerably in their structures, in the availability of resources and in their energy demand. Hence every single region needs a specifically designed technology network for its resource utilisation and energy provision (Narodoslawsky & Stoeglehner, 2010). The papers which are represented from page 52 on provide a framework for SRUNs and highlight the applications used for the network generation. They provide the basis for analysis in the thesis. Their focus is on the use of the regional resource potential in the most economic and ecological way. This can only be achieved, if the focus is not exclusively on energy, but rather includes other products and services as well. This turns an energy network into a sustainable resource utilisation network (SRUN) delivering both, energy and other commodities. These networks need to be economically feasible and ecologically justifiable at the same time. Within the planning process an economic optimum of a technology network has to be found.

A network can only count as sustainable, if there is a balance of the three corners in the sustainable development triangle (Munasinghe M, 2004). Therefore an ecological evaluation is required to analyse the ecological footprint of an economic optimised technology network. The balance between those two parameters has an influence on the social aspects which have to be considered by strong stakeholder involvement from the very beginning of the planning process.

The economic optimisation is achieved through Process Network Synthesis (PNS) (Friedler et al., 1995; Halász et al., 2005) a tool which will be closer described in chapter 5.2.1. In a second step the network, gained from Process Network Synthesis, is ecologically evaluated by the Sustainable Process Index (SPI) (Krotscheck & Narodoslawsky, 1995; Sandholzer, 2006). This methodology is described in more detail in chapter 5.2.2. Within this thesis these two applications have been used to solve research questions about ecological and economic feasibility of sustainable resource utilisation networks in a regional context. For decision makers this task requires a comprehensive set of planning tools. Two of them will be discussed and elucidated in the last chapter, firstly the ELAS-Calculator for the energetic long term analysis of settlement structures and secondly RegiOpt, a tool that combines the two methodologies PNS and SPI in a user-friendly way and delivers a SRUN which is optimised and ecologically evaluated including ethical statements. Both are open access tools, but are focused on the main target group of decision makers in communities and regions.

SRUNs provide an insight into the necessary changes which are needed to manage the shift towards a low carbon and sustainable society. With the help of two computer applications and interlinking their results a SRUN can be found based on the requirements and resource availability of a region balancing economic, ecological and social needs. Decision support tools draw the attention of regional actors to sustainable resource use and offer a path to a low carbon society.

2 Problem Definition and Research Questions

The aim of the thesis is to explain the role of sustainable resource utilisation networks, how they can be generated and evaluated to obtain a sustainable network solution for regions and society in general.

2.1 Problem Definition

In times of increasing demand for energy an optimisation of energy consumption in any aspect of society becomes even more important not only for regions and municipalities. The International Energy Outlook 2013 (EIA, 2013) predicts a growth of world's energy consumption by 56 percent between 2010 and 2040. The main increase (90%) is accounted for non-OECD countries, where demand is driven by strong, long-term economic growth. In OECD[2] countries the increase is 17 percent based on the demand in 2010 (EIA, 2013).

Some political goals and plans have already been communicated on a European level to pave the way forward for a transition to renewable energy within the 21st century (ARL, 2007). Europe 2020 (EC, 2007a) describes Europe's future energy policies to reach a 20% CO_2 reduction, a 20% increase in energy efficiency, and the utilisation of 20% renewable energy resources by 2020. The Energy Roadmap 2050 (EC, 2011) describes even more ambitious goals for an energy strategy for the year 2050 to reduce the overall emissions of greenhouse gases between 80 - 95 percent. Many international and European bodies focus on the challenges linked to the use of bio-resources and contribute to the discourse on European level (ESEIA, 2014).

Depending on the spatial conditions, aspects like number and relevance of stakeholders or the resource availability differ. Several parameters define the system boundaries for utilising renewable resources. Although if the spatial aspect has a small physical dimension, for example in an energy network of an industrial enterprise like it is described in Paper 1 (Niemetz et al., 2010), on closer examination the evaluation does never stop on the doorstep. Nevertheless the cobweb of the network will not be enmeshed in the surrounding that intensive, compared to a network which includes many different stakeholders or covers several needs.

[2] OECD member countries as of September 1, 2012, are the United States, Canada, Mexico, Austria, Belgium, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, Japan, South Korea, Australia, and New Zealand. For statistical reporting purposes, Israel is included in OECD Europe.

As regions become ever more relevant for energy provision effective utilisation of resources is becoming even more acute. Primary bio-resources like wood and energy crops have a high versatility of utilisation possibilities and compete with other sectors like the food industry for productive area (Körner, 2015). One way out of this dilemma is simply straight forward, but also challenging: to use preferably biogenous feedstock for biogas production which is not in competition with food or feed production like it is described in Paper 2 and 3 (Szerencsits et al., 2010; Niemetz et al., 2012b). Secondary bio-resources such as forestry and agricultural residues or grass face less competition and together with tertiary bio-resources like bio-waste from industry and society they have the highest potential for more intensive use in the future (Körner, 2015).

In the optimum case a network combines different technologies in a way that resource use can be minimized and “zero waste production” and full resource utilisation can be achieved. A good example is presented in Paper 4 (Narodoslawsky et al., 2014). Looking on the energy demand of regions it turns out that households are important energy consumers, covering 27% of the European energy demand within the settlement infrastructure plus a considerable part of one third of transport energy (eurostat, 2011). Paper 5 (Stoeglehner et al., 2014) introduces the concepts, methods and the implementation of a calculator for the energetic long term analysis of residential settlement structures (ELAS) and offers a planning tool which empowers decision makers to recognize the long-term consequences of their actions regarding the environmental and socioeconomic impacts of buildings and settlements along their life cycle. The link between spatial planning and energy systems is deepen in Paper 6 (Stoeglehner et al., 2011b) which describes the spatial dimensions of sustainable energy systems and builds new visions for integrated spatial and energy planning.

Networks are always characterized by complexity. Nor should be forgotten that the quality of an evaluation can only be as good as its data and the assumptions made. Therefore the data analysis is important, but in the end a not really visible part of the work although it is somehow the “heart” of a good evaluation. During the years a huge database could be set up which helped a lot in developing new computer tools like RegiOpt which is described in Paper 7 (Niemetz et al., 2012a), starting at page 123.

2.2 Research Questions

There are several questions coming up, if one is dealing with the utilisation of renewable resources with a focus on a regional level. With respect to SRUNs four main research questions emerge:

1) How can regions benefit from sustainable energy networks compared to a single technology pathway?
2) Why should sustainable energy systems be more than the simple application of isolated energy provision technologies and should therefore become “sustainable resource utilisation networks” (SRUNs)?
3) What are the predominant elements of SRUNs?
4) What are the methodology requirements for tools which are used by multi-stakeholder developing processes of SRUNs?

For this thesis seven papers have been chosen which help to find an answer to those questions. They are included from page 52 on. The case studies which are described in the papers have some aspects in common like the methodologies which have been used, but differ in several points like in their framework, scale, stakeholder commitment or resource availability and therefore allow a generalised analysis of SRUNs.

To find an answer to the research questions a clear concept of SRUNs is needed. This will be analysed in the upcoming chapter 3. Building on this framework the networks are described in more detail focusing on elements and features in chapter 4 starting at page 18. In chapter 5 the methodical base for SRUN generation is presented. All of that leads to model-based decision support tools which help interested stakeholders to generate SRUNs. Chapter 6 focuses on two support tools, the ELAS-Calculator and RegiOpt, both are online available.

The listed papers illustrate elements and features of SRUNs and help to analyse the research questions. It can be clearly shown that SRUNs have to include more than one technology or resource and to find a balance between economic, ecological and social aspects which is required by Munasinghe’s sustainable development triangle.

3 Sustainable Resource Utilisation Networks (SRUNs)

One may raise the question, if sustainable development and biogenic resource utilisation is somehow a contradiction (Mensah & Castro, 2004). Others clearly see a ‘food, energy and environment trilemma’ (Tilman et al., 2009) and the competition for land (Harvey & Pilgrim, 2011). It is therefore all the more important to keep those worries in mind and to take it into account as soon as the resource availability for a possible network is analysed.

3.1 Definition of SRUNs

A shift from fossil fuel driven technologies to renewable resource based alternatives will always require a pro-active, long-term, strategic political action. Harvey and Pilgrim (2011) point out that the challenge of meeting both, food and energy requirements, calls for a combined new green and bio-economy revolution. Any pressure caused by human activities and consumption, however, has to be reduced to a minimum. Hence there is the necessity not just to think about the resource availability, but about the possible products needed as well which lets by-products and waste become raw materials for a second, third or even later process within the network. This efficient management of bio-resources can increase the service, society can gain from the limited resource of productive area (ESEIA, 2014). This is what a SRUN offers, designed as a network which utilises resources in the most efficient way.

Regions normally have a wide range of renewable resources on their disposal. Decision makers expect coverage of the region’s needs such as individual heating, industrial heat and cooling, electricity and mobility (Stoeglehner et al., 2011a). SRUNs should meet the variety of demand what can only work within a network and not with a single technology or a single resource utilisation. Efficiency as part of sustainable development has to be more than a simple input-output comparison. The efficiency of SRUNs has to guarantee a balance of the sustainable development triangle. It is not a question of single technology efficiency; for sustainability it becomes important how technologies are arranged and interlinked and which stakeholders are part of the network assuming different roles from providers up to consumers.

The new efficiency model requires a systemic change and can only be ensured, if a regional demand can be covered with regional resources creating the need of services that are provided by local work force with benefits to society. With that

SRUNs reach this new efficiency within the Munansinghe's sustainable development triangle in balancing of what is socially acceptable, ecological justifiable and economic viable.

3.2 Spatial Dimension of SRUNs

A planning approach does not necessarily stop within a region; interregional connections are possible and reasonable. Interregional distribution grids as well as transport pathways for gas and electricity exist in most regions. Municipalities and regions can offer area to catch solar energy in different forms and to store resources. Within a region there are short distances from field to plant and a just in time supply is possible. A close co-operation between actors is important for the network. Hence a SRUN consists of a supply- and a demand-side. The spatial dimension has to cover both.

According to Pike et al. (2007) economic, social, ecological, political and cultural relations and processes are connected as an integral part in regions and are interlinked in regional development processes. 'Local' and 'regional' are two specific spatial scales which are specifically socially constructed (Pike et al., 2007). Regions play a key role as providers of energy and goods already nowadays. They have a selected market and a certain geographical extension and can therefore serve as system boundaries for the planning process. In 2007 the European Commission dispatched the Green Paper "Adapting to climate change in Europe – options for EU action" (EC, 2007). This document already underlined the importance of regional and local authorities regarding mitigation to climate change.

But regions are also exposed to competition. Firstly, there is an administrative competition meaning that regions compete for attention and especially for resources from the central state and on EU-level. On the other hand there is also a head to head race for private resources such as tourism, new residents, companies or investors (Terlouw, 2012). There is, however, not only a competing situation between regions. Even on intraregional level a region must attract investors and ask for support of companies, residents and municipalities. While traditional administrative regions build heavily on hierarchical power relations, regions within a SRUN are dependent on cooperation, association and voluntariness (Terlouw, 2012). For SRUNs it is necessary to define completely new or rearranged room layouts as functions change. A SRUN can only be appropriate if it is taken into account in which way the room layout fits for a network. With that spatial planning becomes an important aspect for SRUNs interlinking spatial, energy and resource planning.

However, regional proximity leads to benefits: if stakeholders are settled in a limited regional space, thus increasing the probability of face- to-face contacts. This forms the basis that on the one hand stakeholders develop common values and, on the other hand, share their implicit tacit knowledge (Bachinger, 2011). Planning situations are regional processes that need to be broken down onto local level to reach the relevant stakeholders and lead to wide acceptance. A SRUN is not imposed upon regions and municipalities. The sustainable network is based on a strong participatory process which is built up on common values and regional identity. Therefore new decision support tools are required that allow a participatory process to take place. Two model-based support tools will be described in chapter 6.

3.3 Stakeholder Process

Usually, a stakeholder is defined as a person, organisation or group, which is either affected by or may effect a problem or its solution (Hermans et al., 2011). Regional stakeholders can participate in different ways and these variable forms of involvement influence the setup of the group involved in the process. There are two main reasons why stakeholder involvement matters for the development of a SRUN: firstly the concept of sustainability itself results in a diverse setting where consensus has to be based on a discursive process and secondly a balancing of the Munasinghe triangle needs to bring different but equal stakeholders as interactive players together in one system.

Sustainable development is by its nature normative and ambiguous with subjective approaches. Different backgrounds and starting points can be traced back to the interdisciplinary and individuality of stakeholders. Therefore it can never be looked at from a single point of view, but rather by a discourse wherein stakeholder participation is needed. Therefore a discursive, consensus-oriented, participatory planning process is required for SRUNs.

Citizens may be affected by changes in land use or energy conversion and supply. Hence, the general public should be informed and involved when it comes to the development of a SRUN. In the European Commission’s Green Paper the Academy for Spatial Research and Planning (ARL, 2007) states that democratic political decisions must meet general consensus within the society. Thus it is important to build up a general acceptance throughout the society (Lewis, 2014). During the planning process there has to be an ongoing discourse like a citizens' forum where all stakeholders can ask questions and get answers. This participatory planning process cannot have the one and only technical solution in the end. In fact it requires different valid, holistic and comparable scenarios. Those are the basis of a discourse on the future of the region.

Regional actors have the knowledge about the given natural resources and the long-established know-how to manage them. They can create economic, environmental and social benefits for themselves, but also for the entire region. These benefits can arise both from collective learning processes, as well as from the fact that stakeholders can gain efficiency and effectiveness throughout the network. Stakeholders who support a SRUN built trust through similar values. The agreement on objectives is based on regional identity and shared discourse on the future in a common vision. Last but not least it can be assumed that common socio - cultural principles can accelerate the formation of clusters. It is conceivable that companies join a network to strengthen in a joint initiative the attractiveness of a region for high qualified staff (Bachinger, 2011).

In order to offer solutions which support regions to define their future role as key players a common understanding across all relevant stakeholders is important. This has to take the rigid structures of regional decision-making into account. Systems which are based on renewable resources are mainly characterised by a complex interaction between stakeholders from different sectors as well as by far-reaching decisions on economic and social structures and the impact on the environment. Therefore a participatory planning process is indispensable in which all relevant stakeholders are involved. These planning processes should include not only experts from energy sector but also providers like farmers, grid operators, local authorities and citizens of the region (Jank, 2013; Boyd et al., 2015).

In Jank (2013) local energy planning is described as a key factor in climate protection policy. As mentioned in the Green Paper (EC, 2007) detailed knowledge on the local natural and human conditions is available on a regional level. Therefore local authorities are an important stakeholder. They play a key-role from societal and political point of view not only for resource provision, but also for the use of services and commodities related to these resources. This responsibility burdens decision makers with considerable challenges. The most obvious reason for this is that every decision on this level impacts directly and indirectly on economic, social and ecological aspects and raises ethical questions, on both, local as well as global level. As administrator of the region, respectively the land with its productive area, they are key players in spatial planning furthermore in the whole SRUN planning process.

Spatial planning is defined as a cross-sectoral issue (Stoeglehner et al., 2011). Not only climate change mitigation, but also energy planning can raise the awareness among the public, decision makers and professionals which could then trigger a more proactive approach at all spatial levels. Stoeglehner et al. (2011) clearly stated in the end report of the project PlanVision[3] and in Paper 6 (Stoeglehner et al., 2011b) that the current regulatory framework opens many possibilities to develop in the sense of energy optimised spatial planning, but a consistent system still requires intervention in the legal system. There is, however, currently no driving force in this direction. The decision about the usage of productive areas is not just determined by natural conditions, but also by deliberate or implicit decisions of political decision makers, local authorities or individuals. Thus, the resource availability depends on a regionally coordinated planning strategy as well. Another aspect is that renewable resources or energy efficiency measures are often not considered economically, as external costs are not taken into account if they are compared to fossil fuels. With that the use of fossil fuels seems to be the less expensive solution. Through taxes and subsidies this economic imbalance can be reduced (Stoeglehner et al., 2011a).

The main requirement for a comprehensive energy and resource planning would mean major intervention in the legal system and the division of powers as there are currently no binding criteria. This implies that with SRUNs governance and spatial planners face a new challenge as the legal framework has to be modified including a binding regional planning for the development of local energy strategies and for resource coordination. Another important step would be the breaking up of rigid rules within the legal framework on the use of some renewable technologies, such as for wind energy where distance zones often hinder an implementation of plants or in city centres with heritage areas, where solar panels cannot be installed (Stoeglehner et al., 2011a). Until such a political opinion-forming process is completed and in transition, an implementation of energy-optimised planning with appropriate confidence and assertiveness of local and regional actors is still entirely possible (read more about it in Paper 6).

[3] The project “PlanVision” was funded by the Austrian Climate and Energy Fund and carried out within the programme “NEUE ENERGIEN 2020” (grant number 818916).

Planning tools are available to support stakeholders in the process of developing visions for energy optimised spatial planning within their decision area. In Paper 7 the software tool RegiOpt finds a detailed description. RegiOpt supports decision making in communities and regions providing optimal resource utilisation networks based on local resource availability. The ELAS-Calculator (see Paper 5), was as well developed to support mainly decision makers especially for questions which have to take both, energy and spatial planning, into account.

3.4 Drivers for SRUNs

Already in 2007 the EU set ambitious climate and energy targets that were then included in November 2010 within the "Energy 2020 - A strategy for competitive , sustainable and secure energy" communication of the European Commission (EC, 2010). By 2020 greenhouse gas emissions[4] should be reduced at least 20%, the share of renewable energy increased to at least 20% of consumption and energy efficiency improved 20%[5] across the EU. There is also the long term commitment to a decarbonisation path targeting for the EU and other industrialised countries to 80-95% cuts in emissions by 2050. By 2020, the primary energy consumption compared to 2008 should decline by 20% and by 2050 by 50% (EC, 2011).

The “Energy Roadmap 2050” (EC, 2011) describes the analysis and conclusions of the Commission, how the EU's energy system could be decarbonised. This forms the basis for the development of a long-term framework of EU policy. Communities and regions can actively contribute to fulfil these overall EU targets by implementing SRUNs within their jurisdiction as the targets are not restricted to supranational and national levels (Özcan & Arentsen, 2014). Table 1 on page 15 gives a brief overview of the 2020 targets for EU and Austria in particular (Bundeskanzleramt, 2015).

Lane & McDonald (2005) underline that a commitment of local communities to solve environmental problems certainly guarantees the motivation of the people within a region. If communities are driving forces to make a step forward on environmental protection and sustainability issues they can reconstitute the balance between human systems and the environment in a constructive way. In addition to the legal framework and the willing to act there are many other aspects which can motivate regions to think about a SRUN. This includes aspects like security of supply, effective climate and environmental protection, economically viable energy supply, sustainable

[4] reference year: 1990
[5] compared to business as usual

economic prosperity, future-proof jobs, innovation, unique selling point, future-oriented technologies, synergies, regional identity, quality of life and development paths for society (BMWi/BMU Deutschland, 2010; Bachinger, 2011; Daniell et al., 2011).

Table 1: Overview of 2020 targets, EU and Austria (Bundeskanzleramt, 2015)

	EU targets		**National targets, Austria**	
	2020	**Status 2013**	**2020**	**Status 2013**
Employment rates [%]	75	68.4	77-78	75.5
R&D investments in % GDP	3	2.02(*)	3.76	2.81(*)
Emission reduction target in the non-emissions trading sectors	-14(**)	currently not available(1)	-16(**)	-12.33
Share [%] of renewable energies in the energy gross final consumption	20	15	34	32.5(2)
Energy efficiency, stabilisation of final energy consumption	1086 Mtoe (EU-28)	1105 Mtoe	25.1 Mtoe	26.7 Mtoe(3)
Early leavers from education and training [%]	10	12	9.5	7.3
Tertiary education [%]	40	36.9	38	40(4)
Poverty or social exclusion	-20000000	--	-235000	-127000

(*) global estimate 2014 Statistik Austria , (**) base year 2005 non-ETS, (1) Value available in summer 2015, because not all GHG inventories are on hand so far, (2) Statistik Austria, (3) "Energiestatus Österreich" 2015, (4) Including ISCED 4, preliminary data

3.5 Barriers for SRUNs

Frommer (2011) discusses main constraints for adaption to climate change as a result of three deficits which can be seen as potential barriers for SRUNs as well: the deficit of knowledge and information, motivation and implementation.

There is a lack of awareness of renewable resources and renewable energy technologies among the public and there are some preconceptions or misunderstandings about it. Although there is this lacking knowledge, information which is available is often not used appropriately. Sometimes the gap between expert language and the way lay people communicate is immense which leads to frustration on the level of stakeholders who should finally make the scientific findings become real (Frommer 2011). Raising awareness is therefore an important part during the process of SRUN development. There is still limited expertise in bio-energy as discussed in the “strategic energy technology plan” (EC, 2014) that has to be overcome by energy education and training activities.

SRUNs offer the possibility to combine different technologies in the most sustainable way. It can cause a problem, if stakeholders are technology-driven and insist on a certain technology or just want to focus on one particular impact. This leads to sub-optimal decisions and makes an optimisation obsolete. The smart linkage of technologies within a network is based on combinatorial rules and cannot be forced. To find a balance of the sustainable development triangle it is necessary to integrate as many aspects as possible rather than reducing them. Situations like this can only be tackled as a whole, however, if the information flow is secured and an ongoing communication between SRUN developers and stakeholders is guaranteed. A poor stakeholder orientation of a simple top-down approach can lead to a low commitment and less motivation. If there is no general understanding of everyone involved in the process on what “optimal” means and that there will be a normative approach the outcome might be disappointing. Therefore it is important to get the participatory process started and to target stakeholders and activate them.

For the implementation of regional network concepts including new technologies and infrastructure public money is used. If the inhabitants of a region do not rallied behind the concept it can happen that the mayor will not be re-elected the next time. This is a considerable risk and it may result that developed concepts are never turned into reality. Accordingly this means civil society organisations should be necessarily involved in the decision-making processes. If no decision process is considered or if there is a lack of additional incentives the implementation of SRUNs might fail. There are still existing fossil fuel subsidies, which continue to favour the use of fossil fuels, or blunt the incentive to shift to renewable alternatives (UNIDO, 2015). To overcome this barrier it is necessary to clearly assign tasks, responsibilities and competences to support the implementation.

3.6 Criteria for SRUNs

Based on above considerations following criteria for SRUNs can be defined:

- A SRUN is developed in a participatory process with discursive stakeholder involvement.
- SRUNs have a specific spatial reference.
- SRUNs are optimally embedded in the local context and take factors like regional identity or touristic aspects into account.
- SRUNs require new spatial configurations.
- SRUNs are focused on regional resource utilisation and utilise them in the most efficient way.
- SRUNs always consist of a supply- and a demand-side.
- SRUNs include all available resources with a maximal possible utilisation ratio and integrate possibly existing infrastructure or facilities.
- SRUNs consider restrictions of raw materials and time dependencies. The latter case is obvious for agricultural areas that have different cycles over one production year. In the project SynEnergy I6 a case study exactly dealing with the topic of agricultural areas and time dependent availability of resources was analysed. Two Papers are related to this project, Paper 2 and 3.
- SRUNs are never one-sided structures which focus just on one resource or a single technology.
- SRUNs always include the demand of the considered region or municipality.
- SRUNs offer inter-regional and/or global distribution of commodities.
- A SRUN creates added value.
- SRUNs protect the natural potential of the region.
- A SRUN has a balanced sustainable development triangle and is viable for the future in environmental, economic and social terms.

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[6] The project 'SynEnergy I' was funded by the Austrian Climate and Energy Fund and carried out within the program "Neue Energien 2020" (grant number 819034).

4 Elements and Features of SRUNs

Eliel Saarinen, a finish architect, once said:

"*Always design a thing by considering it in its next larger context - a chair in a room, a room in a house, a house in an environment, an environment in a city plan.*"

This equally applies, at least from a technical point of view, to SRUNs as well. First there is the technology in a network, then the network in a region, the region in a country, the country in its global context. And in each context specific requirements have to be met. There might be one key technology within the network, for example using a special resource, but within a network there are always other technologies needed in addition to meet the criteria of a SRUN. The three main elements of a SRUN are supply-side, technologies and demand-side, visualised in Figure 4.

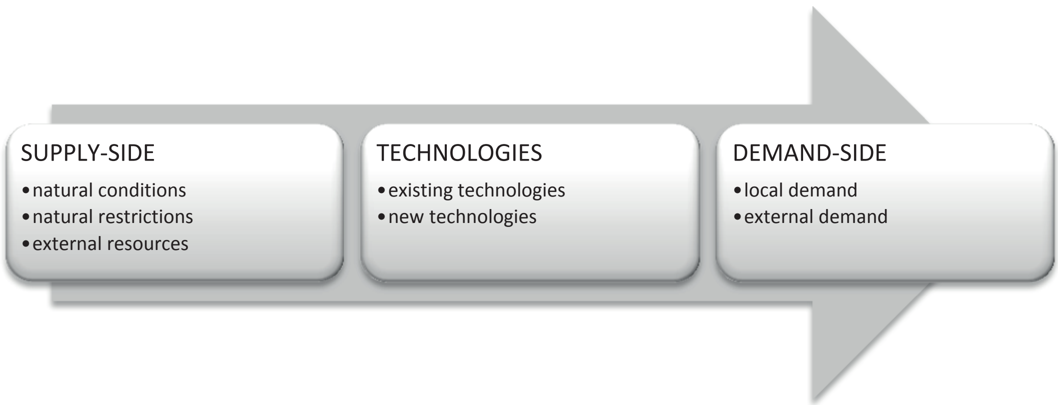

Figure 4: Elements of a SRUN

The main part of the supply-side in a SRUN is the solar radiation as natural income of society. There might be natural restrictions in the use of renewable resources to preserve the nature. With that it can be necessary to resort to external resources to compensate a gap in provision. There might be already existing facilities in the region and they can be as well part of a SRUN like new considered technologies, both interlinked in the most economical way. SRUNs have to cover the local demand, but ideally they can supply on inter-regional or global level as well which can raise the added value by selling commodities or offering services on a larger scale.

4.1 Supply-Side

The supply-side covers all external resources like electricity or gas from grid or any imports as well as internal resources like regional renewables or waste. Everything that can be utilised within the planned network has to be taken into account. Sometimes just parts of a resource can be used and a given demand has to cover other needs for example like it is described in Paper 4 within the case study "Ressourcenplan Mühlviertel"[7] (Narodoslawsky et al., 2014).

Several studies show that fossil resources may soon reach their maximum production. IEA (2013) predicts the year 2020 for "peak oil" and 2060 for "peak gas", with coal reserves supporting increasing production considerably longer. If we talk about a sustainable resource utilisation, renewable resources are being discussed as future base for society for several reasons (Narodoslawsky et al., 2008). Industries and decentralized energy systems based on renewable resources can locally and regionally increase added value, create new (green) jobs, reduce the dependency on oil and other finite fossil resources as well as on external suppliers and may positively influence ecological stability.

Bio-resources also have disadvantages compared to fossil resources which can be counteracted within a future economic system through smart interconnection. Raw material quality differs depending on a number of factors like seed quality, sunshine duration, precipitation, technology of harvesting equipment, storage etc. Renewable resources have a limited yield and are usually time dependent in their provision. Raw materials therefore have to be stored and the decentralized sources of raw materials require increased logistical effort, which can have a major impact on the process structure (EC, 2014; Olmos et al., 2015).

Bio-resources have disadvantageous logistic properties caused by high humidity and low density, two parameters that correlate with the energy density as well (ESEIA, 2014). Table 2 compares humidity, transport density and energy content of some selected resources. There are two kinds of bio-resources listed: relatively dry material for which the energy content is related to its lower heating value when incinerated such as straw or wood chips and wet material for which the energy content is defined by its low heating value of biogas received by an anaerobic fermentation like for manure. The differences in energy density between bio-resources and fossil resources are striking; the energy density of light heating oil compared to wood chips is 15-times higher. Wet resources perform poorly in the comparison, but must be put in perspective as biogas has a broader range of applications than heat generated by incineration (ESEIA, 2014).

[7] The project "Ressourcenplan Mühlviertel" was funded by the Austrian Climate and Energy Fund and carried out within the programme "NEUE ENERGIEN 2020" (grant Number 821845).

Table 2: Logistic parameters for bio-resources and fossil resources (ESEIA, 2014), modified

Conversion	Material	Humidity [%]	Energy content [MJ/kg]	Density [kg/m³]	Energy density [1000 MJ/m³]
INCINERATION	straw, grey	15	15	100-135	1.50-2.03
	wheat, grains	15	15	670-750	10.05-11.25
	rape seed	9	24.6	700	17.22
	wood chips	40	10.4	235	2.44
	split logs, beech	20	14.7	400-450	5.88-6.62
	wood pellets	6	14.4	660	9.50
BIOGAS PRODUCTION	grass silage	60-70	3.7	600-700	2.22-2.59
	corn silage	65-72	4.2	770	3.23
	organic municipal waste	70	2.4	750	1.80
	manure	95	0.7	1000	0.70
	light fuel oil	0	42.7	840	36.00
	hard coal	0	35.3	800-930	28.00-33.30

The table indicates as well, however, that bio-resources require a regional supply as the transport expense has a multiplicative effect related to the transport kilometres. For materials with low energy density a sustainable transport can only be obtained within a definite radius. The next decades will need a restructuring of process industry, both in terms of new technologies as well as new logistical concepts which enable the utilisation of de-centrally provided raw materials from agriculture in contrast to centrally provided fossil resources (ESEIA, 2014).

There is one problematic issue society has to overcome when using bio-resources: their low efficiency of converting solar radiation into useful materials no matter if used for nutrition or technical purposes. The generation rate of bio-resources is limited by limitation of production factors, mainly arable land and forest area (ESEIA, 2014). It therefore requires a smart management of these production factors, like it is done in a SRUN, to cover human demands in a reasonable and ethically acceptable way.

4.2 Technologies for SRUNs

Technologies connect the supply-side with the demand-side of a SRUN by converting available raw materials into products and services. Depending on the current technological and infrastructural setting a SRUN includes existing facilities in its structure. SRUNs are characterised by their broad access to technologies including conventional technologies with full market maturity as well as upcoming technologies like a bio-refinery.

4.2.1 Existing technologies and infrastructure

If there are existing facilities running on renewable resources which already cover some needs in the region or community they can be part of a SRUN, sometimes after slightly adaptation or maintenance. At least they are part of the optimisation process, especially because they require resources and with that lower the available raw materials on the supply-side, but diminish the demand-side as well.

4.2.2 Considered technologies and infrastructure

The choice of technologies depends on the contemplated time horizon the SRUN is designed for and on the available resources. A narrow time horizon makes a conservative selection necessary, because a breakthrough of a technology that has not reached the pilot scale at the time of the SRUN development is hardly to be expected within the next 20-30 years. Fossil-based technologies are taken into account only to the extent, as they compensate gaps that may occur in the recovery of regional renewable resources.

The size-dependent features of technologies have to be considered as well. If a facility is operated at less than its maximum capacity, in partial-load operation, the energy efficiency and other properties may change compared to those in full-load operation, depending on the type of plant. This is particularly noticeable for power plants and engines as their efficiency significantly decreases. Therefore it is important that the chosen size of technologies fits to the general conditions which can be guaranteed by the optimisation process where different capacities of a certain technology are considered.

Figure 5 shows the superstructure of the PNS optimisation for revamping a waste processing site in Western Austria (Paper 1, page 54-59). It is a waste hub that serves approximately 300000 people and processes municipal as well as commercial and industrial waste. Currently a huge amount of waste is transported to an incineration plant in Switzerland although there is a high heat demand on site, especially for the waste sorting plant. The superstructure for the PNS optimisation to find a SRUN for the company includes existing and new feasible technologies like CHP (biogas driven), biogas cleaning, biomass furnace, organic rankine cycle plant (ORC), synthetic natural gas production (SNG) and catalytic low pressure pyrolysis.

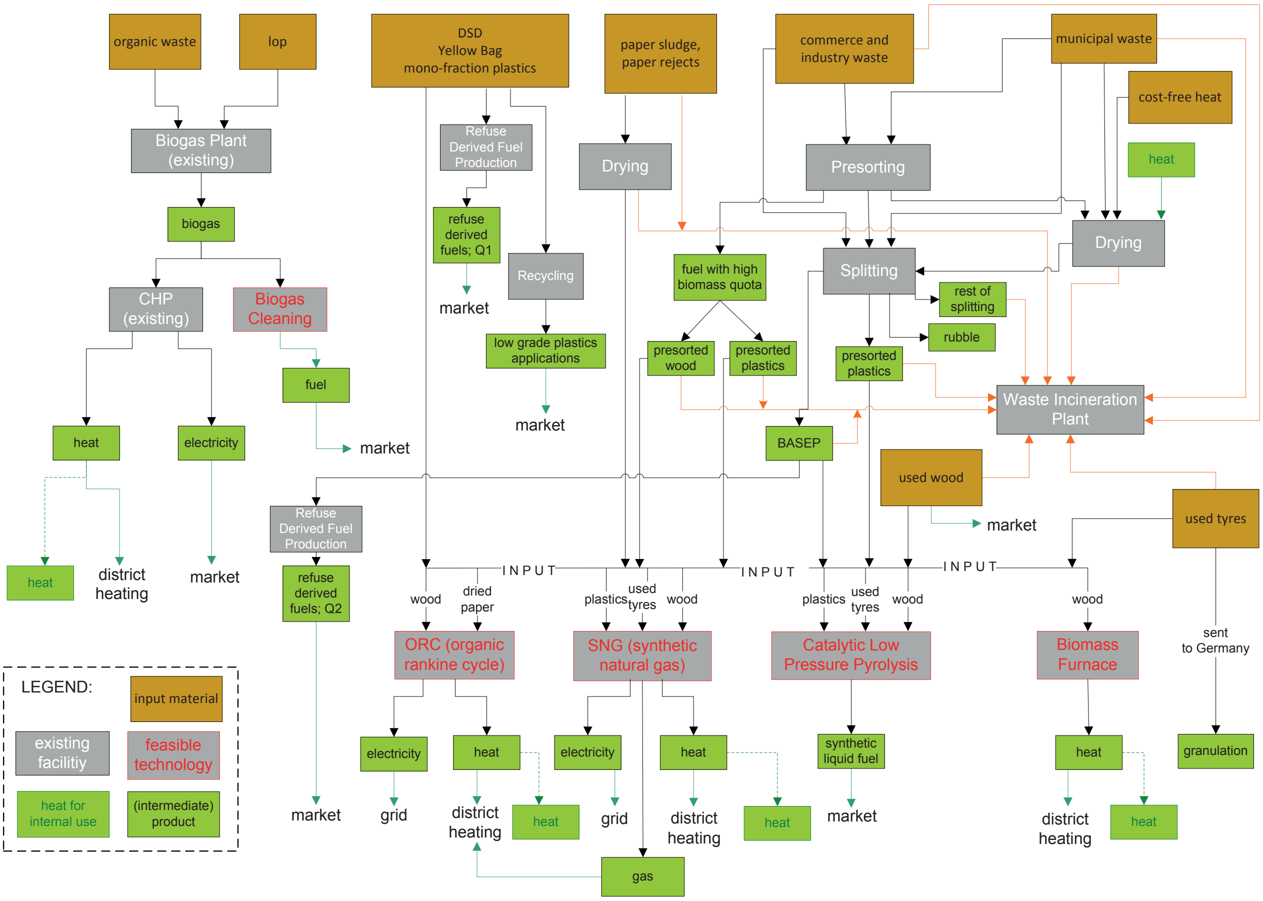

Figure 5: Superstructure for PNS optimisation, waste processing site (Paper 1)

The choice of technologies is always part of the participatory planning process and is based in this case study on the experiences of the project team, local stakeholders and the owners of the company. Since a short-term realisation is required only technologies that gained full market maturity and can be purchased immediately are taken into account. The raw materials are solely secondary and tertiary bio-resources which require technologies that can cope with lower grade resources, multi-feed and mixed-feed input.

A second case study (described in Paper 4) covered a high bandwidth of technologies utilising different kind of resources including primary, secondary and tertiary bio-resources. In contrast to the case study in Vorarlberg the “Ressourcenplan Mühlviertel” included upcoming technologies as well. Table 3 gives an overview of the technologies that are part of the optimisation and some of them become in the end part of a SRUN.

Table 3: Selected Technologies for SRUN generation (Narodoslawsky et al., 2014)

Technology portfolio, "Ressourcenplan Mühlviertel"		
Biodiesel plant	Dryer, agricultural products	Incineration plant
Bio-ethanol plant	Dryer, agricultural products	Press
Biogas cleaning	Gas burner	Press for oilseeds
Biogas fermenter	Green bio-refinery	PV panels
Biogas furnace	Incineration plant	Pyrolysis, straw
Biomass burner, woodchips	Microgas turbine	Pyrolysis, waste wood
Chopper	Oil burner	SNG plant
CHP, biogas	ORC	Solar panels
CHP, oil	Pelletizer, straw	Wind power plant
CHP, waste paper	Pelletizer, wood	

4.3 Demand-Side

Products and intermediates are, beside resources and technologies, the third element of a SRUN. Intermediates are products that are used directly within the technology network and are therefore not sold "outward". There are products that can be both. Heat for example can serve as an intermediate product or as a product which has a market price and is sold (Stoeglehner et al., 2010). The variety of products depends on the available resources and the technologies utilising them. They range from material goods like food and feed and non-food products to energy carriers and services like heat on different levels for industrial and individual heat demand, cooling and electricity. They are shown in Figure 6.

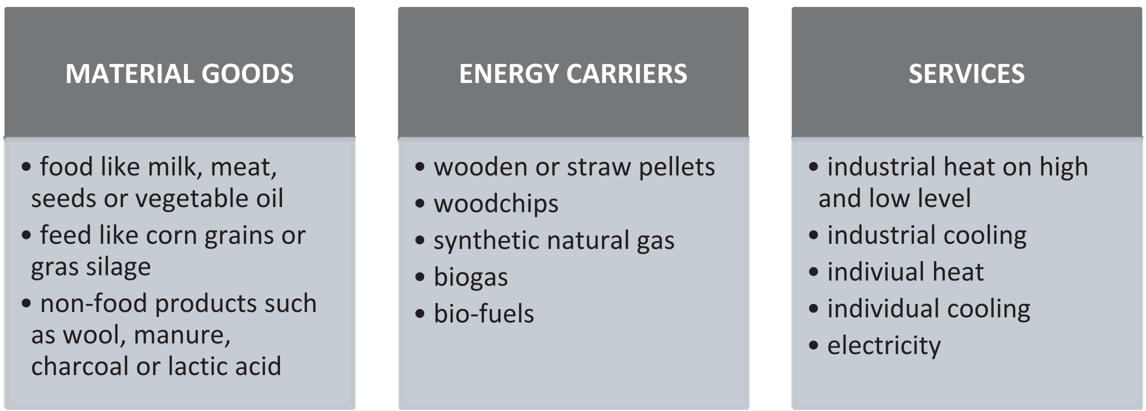

Figure 6: Products and services of SRUNs on demand-side

The demand can influence the size-consideration of technologies. As the capacity of the technologies is as well determined by transport limitations posed by resources and the quest for using all thermodynamically convertible energy. Often this means that the maximum capacity is limited by the heat demand that can be served by a certain technology.

There are two types of demand which are differently treated within a SRUN. Firstly there is the demand of the region or municipality that has to be covered as one of the main criteria of a SRUN to keep the Munasinghe triangle in balance. Secondly there is an external demand, on interregional or global level that can be covered and brings additional revenue, but it is not prerequisite. This means that a SRUN has to cover all required needs of the region or municipality and can deliver additional products and services.

Utilising products and services from renewable resources requires distribution systems where consumers can also become producers, called prosumers. They are breaking with the strictly hierarchical current distribution systems and build “smart” grids and/or supply systems. “Smart grids” cover a broad range of different concepts, from advanced meter infrastructure and greater communication between utilities and consumer loads to remote control of onsite demand response. They are often mentioned as enabler of onsite generation and storage technologies, such as PV (IEA-RETD, 2014). In case of PV residential prosumers can feed in into an overall network and can gain revenue based on the feed in tariffs for this technology. For businesses, small and medium-sized enterprises and (inter)national conglomerates it is as well attractive to supply their own energy needs through on-site generation from renewable resources. This combination of energy production and consumption offers a new business opportunity: production costs might decrease due to minimised energy prices and excess energy can be sold to the nearby municipality or to the grid (UNIDO, 2015).

5 Methodical base for SRUN generation

5.1 Planning Process and System Considerations

5.1.1 Planning Process

Often the initial motivation for communities or companies to think about a network solution is energy driven. The transformation of the existing energy system to a more sustainable solution as the general development aim is therefore in many cases the starting point for a SRUN development. Thus, as a SRUN covers more than just the energy provision part, an important step during the network design is to look at the demand-side as well. It has to be defined, if there are any synergies or other possible needs which can be covered by the network and included as a demand in the structure.

The planning process starts with the elaboration of an overarching objective and requires a common understanding of the strengths and identity-forming aspects of a region and its stakeholders. At the same time the identity of the region can be strengthened by the formulation of a shared vision. It is important to formulate an overall integrated strategy with milestones and a clear timeline in the beginning of the process.

Depending on the time frame the technology portfolio that is taken into account can differ as for short term realisations the network should be built up on well-known technologies while for a wider time range it is possible to include upcoming technologies as well. In the beginning of every optimisation a detailed resource analysis has to be carried out wherein stakeholders are involved in a participatory process to define the resources, starting from the overall natural resource potential leading to a potential, which corresponds to a realistic contribution of each resource to cover the demands.

There are several steps to plan a SRUN. Stoeglehner et al. (2010) described a methodology to plan a SRUN process. These planning principles provided the framework for the development of a sustainable energy system in industrial parks in Upper Austria. In the end report a two-phase planning process is proposed which was successfully applied in the project “Inkoba” and which is applicable for other SRUNs. The argument in this thesis follows and refines this approach.

5.1.1.1 First phase: "top-down" planning

The starting point is a broad discourse between regional political decision makers and planners to determine the general framework for the SRUN planning. This phase offers the possibility to discuss the decision-making process, to clarify the supply- and demand-side especially the renewable resource availability and to state the public interests. Thus it is possible to develop scenarios for the first public debate and evaluation. Furthermore, the results of this first phase are used to determine which other stakeholders have to be involved in the upcoming phase.

The results of this phase are a clear target definition and the definition of the basic development framework including possible resources and required demands. The system boundaries should be set and the basic scenarios determined. At the end the options for the next phase and the additional stakeholders are fixed. The range of stakeholders is broad and differs as the case arises, but can include citizens, farmers, land owners, local authority, industries, businesses, transmission or distribution system operators, producers and suppliers, operators of power plants, residential prosumers, spatial and energy planners, technical and environmental authorities, scientists, NGOs, the media, lobby groups and many more.

5.1.1.2 Second phase: "bottom-up" planning

In this phase the further planning is carried out in close cooperation within a larger group of relevant stakeholders. Out of the basic scenarios that have been defined in the first phase a greater set of new scenarios should consist of those which are mostly relevant for the region. Stakeholders determine for example how many resources can be provided with a certain quality and quantity at a given price, which amount of acreage is de facto available for the production of biogenic raw materials and how the withdrawal of residues is limited to guarantee sustainability. Furthermore it can be clarified how much heat can be provided by a SRUN for district heating and whether the heat grid can be operated economically with the available heat potential. This second phase serves as a validation and adaption of the assumptions made (Stoeglehner et al., 2010).

5.1.1.3 Third phase: optimisation, evaluation and SRUN selection

The set of scenarios that has been defined in the second step is then optimised with the PNS resulting in the most economic technology network for each scenario. The ecological evaluation allows comparing the scenarios with the help of the SPI. The combination of the economic optimisation and ecological evaluation gives the possibility to find the network which is economically feasible and ecologicallly reasonable at the same time. If there is no satisfying solution the stakeholders have to meet again and discuss other scenarios or adapt the defined scenarios. This process lasts until the results of this different optimised scenarios allow to select a SRUN that is accepted and supported, and thus can be implemented by the stakeholders.

5.1.2 Data framework

In both steps of SRUN planning the following information is needed to support optimisation of the technology network for the analysed region:

- The definition of the region in its size and coverage including intraregional / interregional market opportunities and the consolidated markets in capacity and price limits.
- The availability of resources in the region, either given as available agricultural, grassland or forest area with appropriate conditions (like crop rotation or space restrictions) or as absolute figures representing the annually available resources in the region like for waste, wind or hydro power.
- The costs, utilisation rates and yields are required too; area can be arable land, forest, grassland and land for direct solar technologies such as roofs.
- Possible by-products and waste have to be defined.
- Data on existing infrastructure such as existing bio-energy plants (biomass or biogas plants), heating networks etc.; if there is any waste heat from existing plants a time profile and the temperature levels have to be known.
- Data on existing or planned load situations for example an upgrading of heating networks, additional heat consumers, potential markets for agricultural products and processed products.
- Mass and energy balances of technologies which can utilise agricultural products, waste and by-products from technologies within the network and of the agricultural sector like straw, slurry and manure, green waste, hay, specific agricultural or commercial and industrial waste.
- Investment and operating costs of the technologies as well as payback periods; there may also be capacity constraints on technologies that need to be considered for example resulting from feed-in tariffs.
- Costs and prices of external resources, products and services that may be part of the SRUN have to be clarified; the revenues from provision of energy such as electricity feed-in tariffs, feed-in tariffs for cleaned biogas, feed-in tariffs for district heat etc. has to be established either as fixed number or range.

- Total amount of money that can be invested including repayment arrangements like interest rates may be defined.
- Any restrictions on raw materials by crop rotation, maximum use of areas for different resources, maximum resource availability from an environmental perspective (like the maximum straw removal from a field); the mass and energy balances can as well be seen as restrictions and have to be strictly adhered to in the optimisation.
- Definition of required products and services that have to be provided by the SRUN.

5.1.3 Developing Scenarios

Scenarios link resources, technologies, regional demand and markets in a way which optimises the value generated for the region based on different modified frameworks. Value in the broadest sense covers economic as well as environmental, social and cultural aspects, precisely described in Paper 4 (Narodoslawsky et al., 2014). Different cost and price structures of resources and products, other uses of resources or restrictions on investment are just three out of a number of parameters which can be changed altering the framework for optimisation.

The results of scenarios cannot be seen as forecasts, they should rather be understood as a rough direction or as a compass that indicates the course to achieve the aims under certain assumptions and designates the relevant activities. They are decision-making tools that should support actors in a region or community in the process of shaping a common future. Therefore basic conditions of scenarios are often consciously chosen in extremes to provide the widest possible view. The advantage of scenarios which are based on a fixed PNS superstructure is that the results are consistent with each other and thus a direct comparison of different “futures” is possible. Nevertheless for decision making processes it is important to develop optimised scenarios with high implementation probability (Narodoslawsky, 1988).

After an optimisation with the PNS all scenarios must be environmentally evaluated. Here it may turn out that a scenario is more appropriate than another one in terms of the objective function, for example added value, but it results in a larger footprint. If this happens a scenario should be found out of the set of scenarios that had been defined which brings the most benefit for the region, municipality or company in both senses, ecologically and economic.

Figure 7 shows a comparison of seven different scenarios within a case study in Freistadt, a city in Upper Austria. The basic idea was to change the heating system within the brewery (Narodoslawsky et al., 2009). However, at a closer look it could be figured out that the efficiency of the system can be increased by shifting the system boundaries, including a district heating for the city centre as well, making the brewery become an industrial prosumer. The hypothesis proved to be useful, because the owners of the brewery were also the owners of the houses in the city centre. This can make an implementation of a SRUN much easier, because the company is directly related with the homeowners. This example shows as well the importance of knowing the potential stakeholders and how they interact. On the left side of Figure 7 the three scenarios include only the demand of the brewery itself, on the right side the heat demand of the settlement in the city centre is taken into account in four scenarios. The optimal structures differ in the technologies that are used. The smaller the green bar (SPI in 1000 m²/MWh) the lower is the ecological footprint, the better is its ecological performance. The higher the grey bar (revenue in €/MWh) the more cost-intensive is the solution per MWh generated energy.

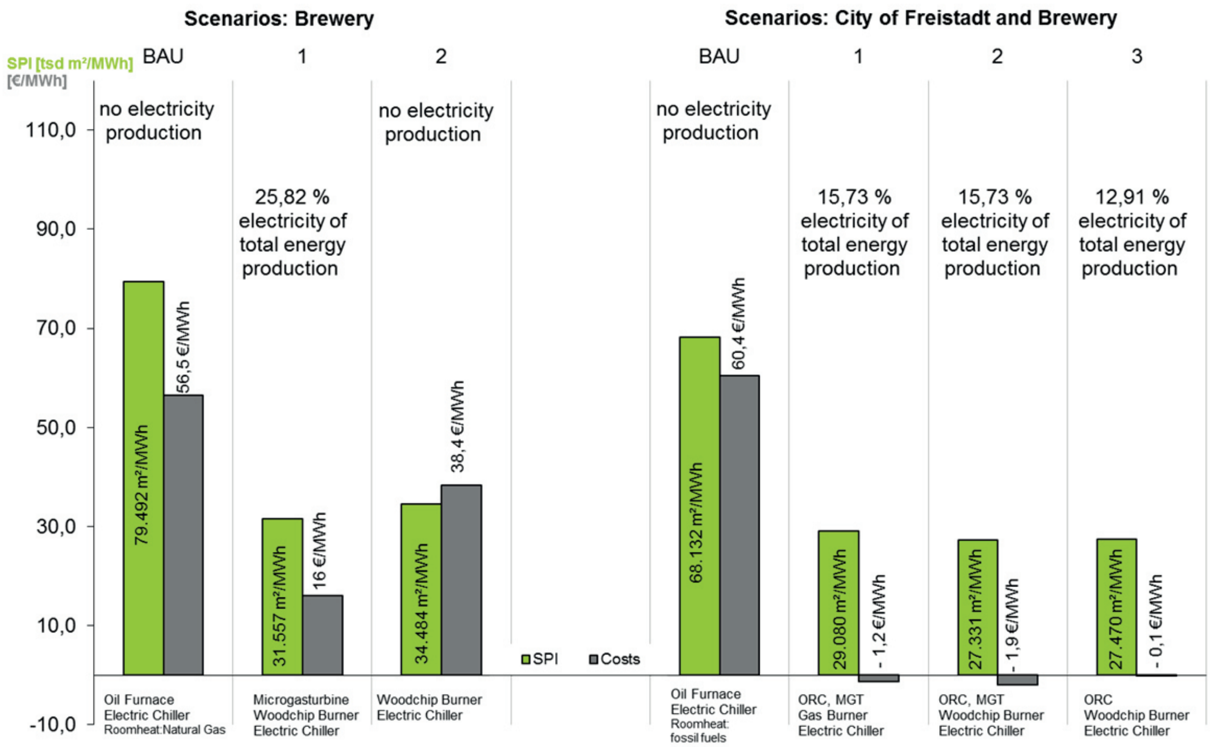

Figure 7: Scenario comparison of the brewery case study in Freistadt showing SPI and annual costs

For the scenarios which only include the brewery (shown on the left side of the figure) it turned out that “scenario 3” with no electricity production and a structure that runs on woodchip burner and an electric chiller would bring an acceptable balance between economic and ecological values. From an ecological point of view “scenario 2” would be the one performing best, where the network consists of a microgas turbine, a woodchip burner and an electric chiller and where nearly 26% electricity of the total energy generation can be gained.

For the second set of scenarios wherein the brewery would supply the settlements with domestic heat in the city centre, the brewery can only make a profit within the first ten years if they keep their old energy system which runs on an oil furnace what leads to high ecological pressure and is therefore not acceptable from an ecological point of view. There are no renewable resources used in the network which makes it unsustainable. If the brewery becomes an industrial prosumer with a network based on renewables the company would have to bear little costs within the ten-year depreciation period which would then bring profit after this time. Even the ecological pressure of the network would be lower than the one if the brewery does not become a prosumer.

The development and assessment of scenarios requires regionally coordinated targets which have to be negotiated between the stakeholders. This ensures that values and objectives of the experts, carrying out the optimisation, are not hidden somehow in the scenarios and the stakeholders get the feeling like they may impose a top-down expert decision. Only a clear separation of the factual and value-oriented level allows a transparent and verifiable comparison of scenarios and supports increasing credibility of the entire process in the region. Scenarios can therefore be designed in different ways and should be able to deliver answers to questions the stakeholders raise. There are, however, two scenarios that are used in consistently SRUN development: the “business as usual” (BAU) scenario and the “worst case” scenario.

5.1.3.1 BAU scenarios

BAU means that the current development in material and energy demands stays at the same level. This implies that current trends are extrapolated until a certain time in the future, which can be easily done for data where time series exist (such as yields or price for corn). For other values a detailed research has to be carried out to get well-grounded data which forecast future developments. The structure of the optimisation process is not changed.

The BAU scenario is quite useful to demonstrate what the retention of an existing structure would hold in the future compared to an implementation of a SRUN. This scenario can provide good arguments that positively support the integration of SRUNs and can underline its significance.

For the brewery case study in the City of Freistadt a BAU structure is optimised which is shown on the left side of Figure 8 using an oil furnace for process heat, natural gas for room heating of brewery buildings and electricity for every cooling process needed in the brewery (Narodoslawsky et al., 2009). This technology network in operation within the ten-year depreciation period runs a bill of € 137890 per year. On the right side of Figure 8 the optimal structure based on the basic conditions utilising only renewable resources is visualised. It improves the overall balance and leads to a significant reduction of the annual costs to approximately € 93919 within the depreciation period. This technology network thus reduces the costs by almost 25 % and runs the heat supply-side just on renewable resources.

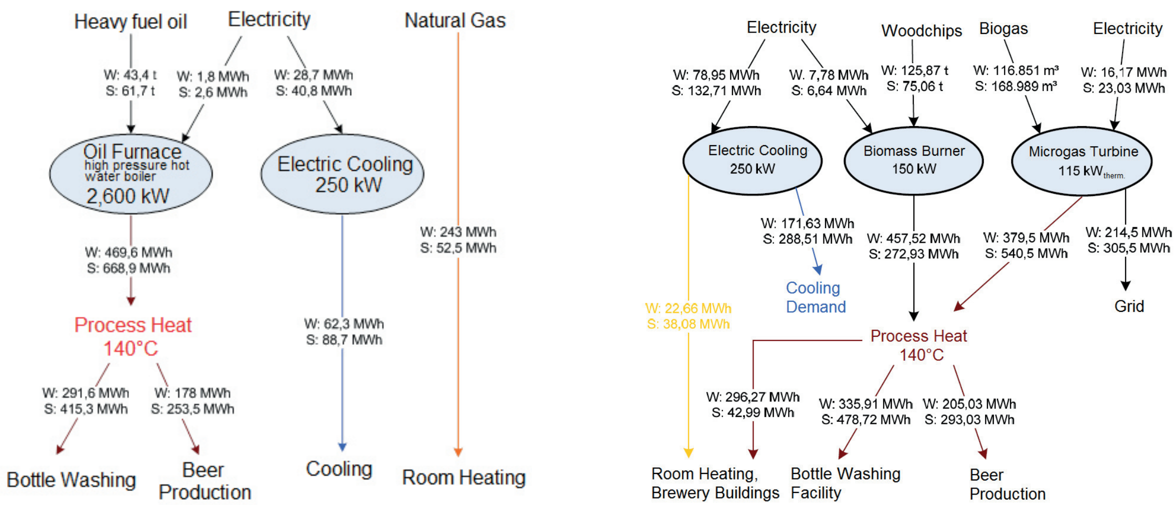

Figure 8: Structure of BAU scenario (left side) and optimal structure of a SRUN (right side) for a brewery case study in Freistadt, (Narodoslawsky et al., 2009), modified

5.1.3.2 Worst case scenario

The worst case scenario describes the network an optimisation would result in, if aspects would occur from which stakeholders think they could threaten the region somehow. A scenario of this type is presented for example in Paper 1 for the waste processing site in Vorarlberg which has already been described in chapter 4.2.2. During the discussion with the stakeholders some parameters could be identified which would be seen as negative development for the company. For the waste processing company it would be the worst situation, if there is no biogas cleaning on site, combined with a profit loss for incoming waste and a loss of cost-free heat.

Based on these developments, the basic framework changed and thus also the structure for optimisation. The optimisation was carried out with new parameters. It turned out that the structure would not make any profit and the company would have to carry a yearly loss. Using a worst case scenario can span the framework in which a SRUN ranges in terms of profitability. If the worst case scenario performs better than the BAU scenario it can be clearly shown that it makes sense in any case to take action and change the existing structure and not to keep on maintaining the current one.

5.2 Economic Optimisation and Ecological Evaluation

A wide range of process synthesis and ecological process evaluation methods exist (Connolly et al., 2010; Zeng et al., 2011) which could be directly used or modified to the criteria a SRUN has. For the generation of SRUNs, which is described in this thesis, two particular methods and their adaptation have been used.

The PNS creates a process network delivering the desired products from specific raw materials with a certain set of operating units. The optimisation leads to an optimum structure and requires data which is available of adequate quality for technologies based on renewable resources. In addition, restrictions and competition for raw materials can be easily incorporated into the model. The ecological evaluation has been carried out with the Sustainable Process Index (SPI), a member of the ecological footprint family. The application of the SPI allows an evaluation of all relevant ecological pressures linked to provision of resources and the generation of emissions and waste, including greenhouse gases, from the life cycle network. Within this evaluation the impact of nuclear energy is included as well. The SPI can be used to compare different processes regarding to their overall ecological impact (Kettl et al., 2011).

5.2.1 Process Network Synthesis (PNS) for Optimisation

In process engineering the main task is to transfer material and energy flows into products with the help of certain unit operations under restrictive conditions. This requires the optimisation of structures. A certain unit operation is either part of the solution or not. At the same time an optimisation of continuous parameters, such as material flows in a specific process unit, is still necessary. In case of process engineering there are several different approaches to solve these basic questions (Narodoslawsky et al., 2009):

- Heuristic methods use empirical data with different unit operations in order to develop meaningful and optimal process structures. These methods are usable when sufficient information about the used technologies is available. However, to take resource constraints into account, heuristic methods need to be coupled with other optimisation methods.
- Thermodynamic methods use thermodynamic principles (like the 2nd law of thermodynamics) in order to optimise process structures. This group includes the "pinch"-method which revolutionised the optimisation of heat exchange systems in process engineering (Liew et al., 2014). The use of these methods depends on the determination of the considered process units mainly by thermodynamic laws, for example heat exchange, or on processing one dominant class of substances such as in wastewater technology.
- Combinatorial methods rely on mathematical graph theory theorems and use combinatorial rules to build up process structures. These methods guarantee on the one hand that the globally optimal structure is included (all other methods can also run into a "local" optimum), on the other hand information about global material and energy flows, as well as global economic data like investment and operating costs for individual process steps are sufficed for generating an optimal process network.

Regarding the process synthesis, combinatorial methods are best suited to find an answer to the research questions of the problem definition and are used in the method called Process Network Synthesis (PNS) which has been worked with (F. Friedler et al., 1992; Brendel et al., 2000). Restrictions and competition for raw materials can be easily incorporated into the models using the PNS (Friedler et al., 1993). Within the PNS mathematical programming is used to reach the general aim of finding the optimum, such as the added value or the revenue, within restrictive system boundaries. With this the PNS is an essential method for process system engineering. The PNS has been used in Paper 1, 2, 3, 4 and 7 which are represented in chapter 9.

The PNS is based on the "P-graph method" (Friedler et al., 1992), a graph-theoretical approach. This method describes each process through a bipartite graph such as illustrated in Figure 9 showing a PNS network which involves three operating units and six different materials (Vance et al., 2012). Circles represent specific flows in the P-graph. They can be resources like electricity, wood, grass etc. or products such as electricity, pellets or fodder. Bars represent processes, such as drying in a wood dryer or fermentation in a biogas plant. The flows are defined by the direction of the arrows. Out of all possible resources, operating units and products the so-called "superstructure" or "maximum structure" is developed (Kovács et al., 2000). Through this first step using the graph theory and combinatorial rules a far-reaching restriction of the search space for the structure optimisation, without losing the structure of the global optimum, can be achieved.

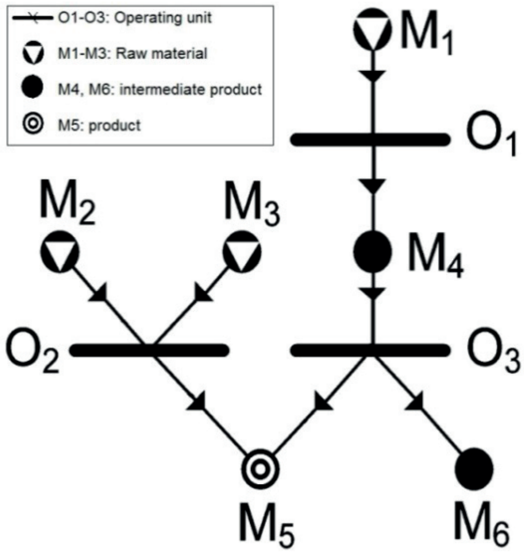

Figure 9: PNS network, Vance et al. (2012) - modified

A huge advantage of the PNS is its flexibility. Whenever a new technology comes up it can be easily implemented to the superstructure which does not mean a fundamental change of the framework. Once the basic mass and energy balances as well as the economic parameters are estimated for the new technology it can be incorporated into the PNS optimisation without major problems. This merely requires knowledge of the input methods of the PNS program.

For a PNS optimisation the structure has to include the following balances:

- Mass balance: use of raw materials (including waste) and amount of possible products;
- Energy balance: Input (raw material) and output (intermediate product or end product) of heat and electricity;
- Economic balance: cost of raw materials, price of products, investment (and operating costs) of technologies.

The PNS requires detailed information for each technology including the input parameters like types and quantities of raw materials and general information like capacity and costs of the technology. To define the products it is important to know the type, quantity and prices of products and the demand needed.

Products and intermediates have to be governed by the following principles:

- All manufactured products can be sold at market prices.
- The heat produced must be used to the maximum amount possible.
- Existing demand for heat and electricity has to be covered.
- Products have to be used (intermediate) or sold, they cannot just disappear within the network.
- If purified biogas is part of the solution structure which can be fed into the gas grid a negotiated price has to be accepted (since there is no feed-in tariff)

A characteristic of a superstructure is the flexibility to balance production with demand. This feature is often asked for by regional actors to guarantee supply of certain goods (such as food) or services (such as residential heating) from local resources. Another important feature of the PNS is that different scenarios can be provided for regional participatory decision making rather than having just one “optimal solution” as it is usually provided in process industry.

Figure 10 illustrates the superstructure of a PNS case study from Bad Zell, a village in Upper Austria (Kettl et al., 2010). Every possible connection between substrates, production technology and products is illustrated. There are several small scale farmers in the region which can provide different substrates. These providers of main crops, intercrops and manure are grouped into substrate provision groups (A-E) to simplify transport situations and to make the logistic concept more efficient. Each provider group has a specific transport distance to each fermenter. All providers are able to supply each fermenter with every possible substrate they can deliver. The four different substrates (corn, grass silage, intercrops and manure) are defined as raw materials in the superstructure.

In the discussion with stakeholders it turned out that there are three possible locations for a biogas fermenter (each 80 kW_{el}, 160 kW_{el} or 250 kW_{el}). The resulting biogas can be sent to a centralized CHP unit with a higher capacity than on decentral site, which delivers electricity for grid feed in and heat for the district heating network. An advantage of transporting the biogas is the low cost for biogas pipelines. Starting from the superstructure the next step, using an optimisation routine, ends up in a structure which optimises the objective function - in this case the added value. For the case study described briefly above the optimum structure shown in Figure 11 could be obtained. Paper 2 (Niemetz & Kettl, 2012) and 3 (Niemetz et al., 2012b) in chapter 9 describe the case study in more detail.

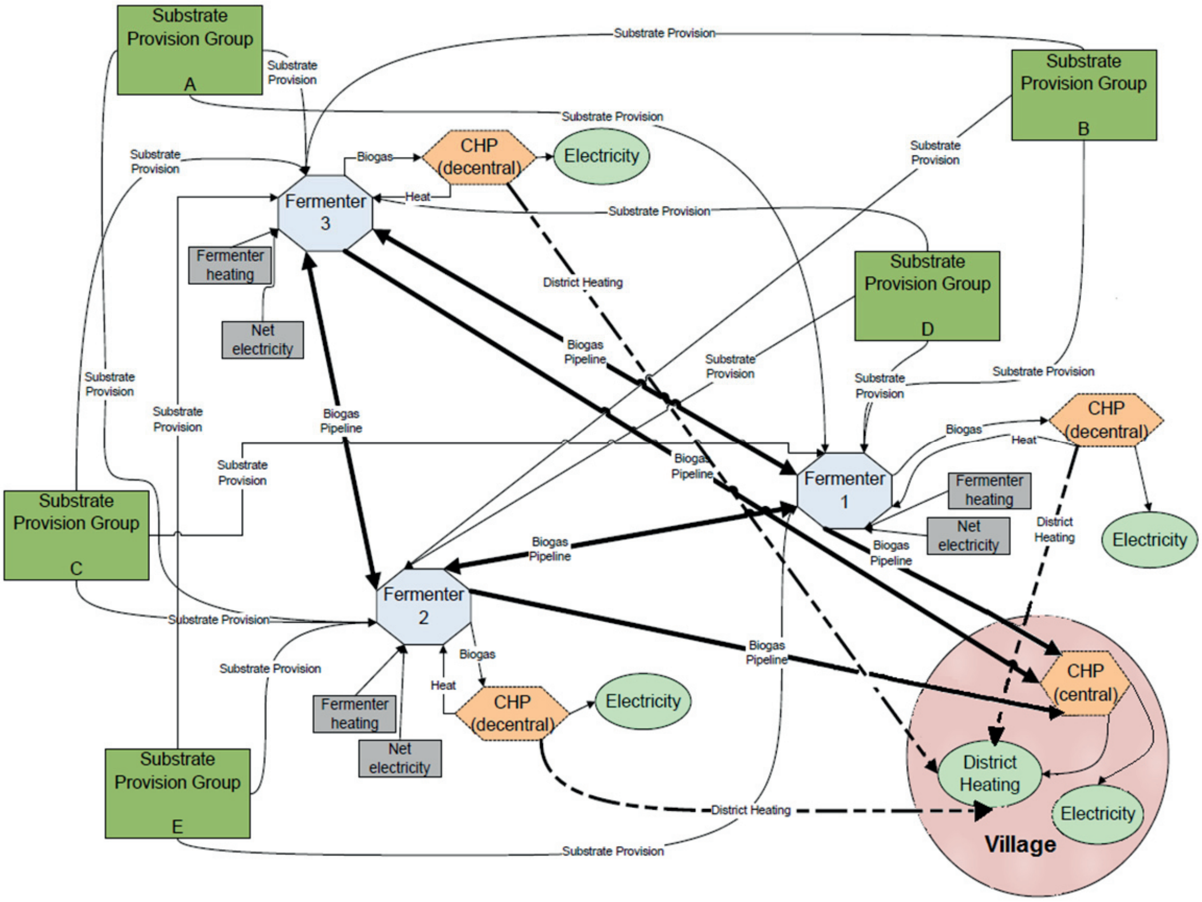

Figure 10: Superstructure of a case study in Bad Zell, Kettl et al. (2010)

Figure 11 shows the optimum structure of the PNS optimisation including three substrate provision groups. Corn, intercrops, grass silage and manure is used as raw materials in a decentral fermenter. The biogas is transported via a biogas pipeline to a central 250 kW_{el} CHP which is situated 3.1 km away. With this optimised technology network 2490 MWh/a heat can be fed into the district heating grid and 2075 MWh/a electricity can be sold to the grid.

In the case study two different scenarios were analysed. Any change in the general conditions or in costs and prices generates (based on the same superstructure) another optimum structure meaning a new technology network. Thus a consistent scenario building is possible and the differences in the optimum solutions can be compared.

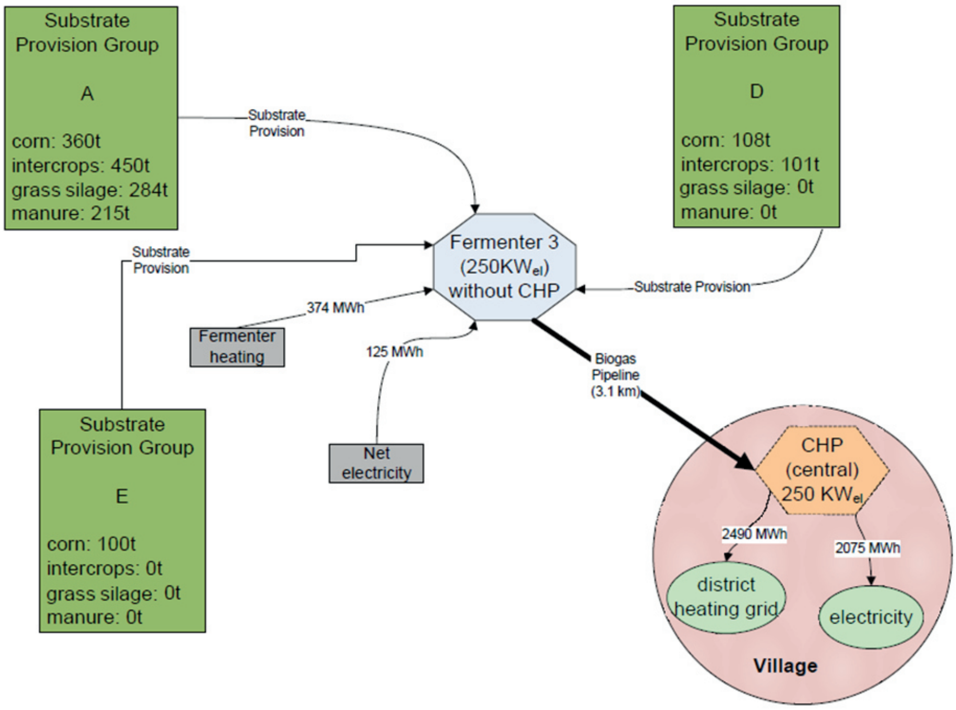

Figure 11: Optimum structure of a case study in Bad Zell, Kettl et al. (2010)

The case study as well as the papers in chapter 9 clearly shows that the PNS is an efficient computer tool for systemic optimisation while providing insights into the long term choices to be taken. Adapting process synthesis to the regional case with the PNS can help to provide decision makers with comparable scenarios that will guide the planning process. The optimised scenarios give a clearer picture about the specific challenges for regions and companies when introducing renewable energy systems.

5.2.2 Assessment of Environment Factors

There are different possibilities to analyse impacts on the environment. The "Sustainable Process Index" (SPI) can be seen as an assessment tool being a member of the footprint calculator family (Krotscheck & Narodoslawsky, 1995). It is compatible with the life cycle assessment described in EN ISO 14040 (ISO, 2006) aggregating all kinds of pressure on the environment to one number. It is the area needed to embed production of certain commodities or a service into the ecosphere in a sustainable way. As the calculations result in one number it is possible to compare different technologies no matter which resources they are based on. With this fossil driven and renewable resource-based technologies or processes can be evaluated (Kettl et al., 2011b).

The SPI was developed as a tool for the ecological comparison of different processes (Sandholzer, 2006). The calculation starts with the summation of all areas which are needed for the fulfilment of the considered process. The specific impact of a process then results from the division of the total required area for the sustainable integration of the process in the ecosphere by the amount of services the process delivers, mostly related to one year resulting in a footprint. The SPI is the ratio of this area to the statistically entitled area of each citizen. Since this entitled area is difficult to determine accurately and varies regionally and temporally depending on the population density, it is the specific footprint for each product or service which is used for most of the comparisons. The footprint of a product, such as a kWh thermal energy, also includes all the environmental pressures of the upstream chain. This means for example the footprint of one kilowatt hour thermal energy utilised from wood pellets involves the ecological pressure of forestry, transportation of the wood to the processing and ultimately the processing of wood into pellets (Narodoslawsky et al., 2014). Figure 12 depicts a footprint comparison of five different technologies for electricity supply.

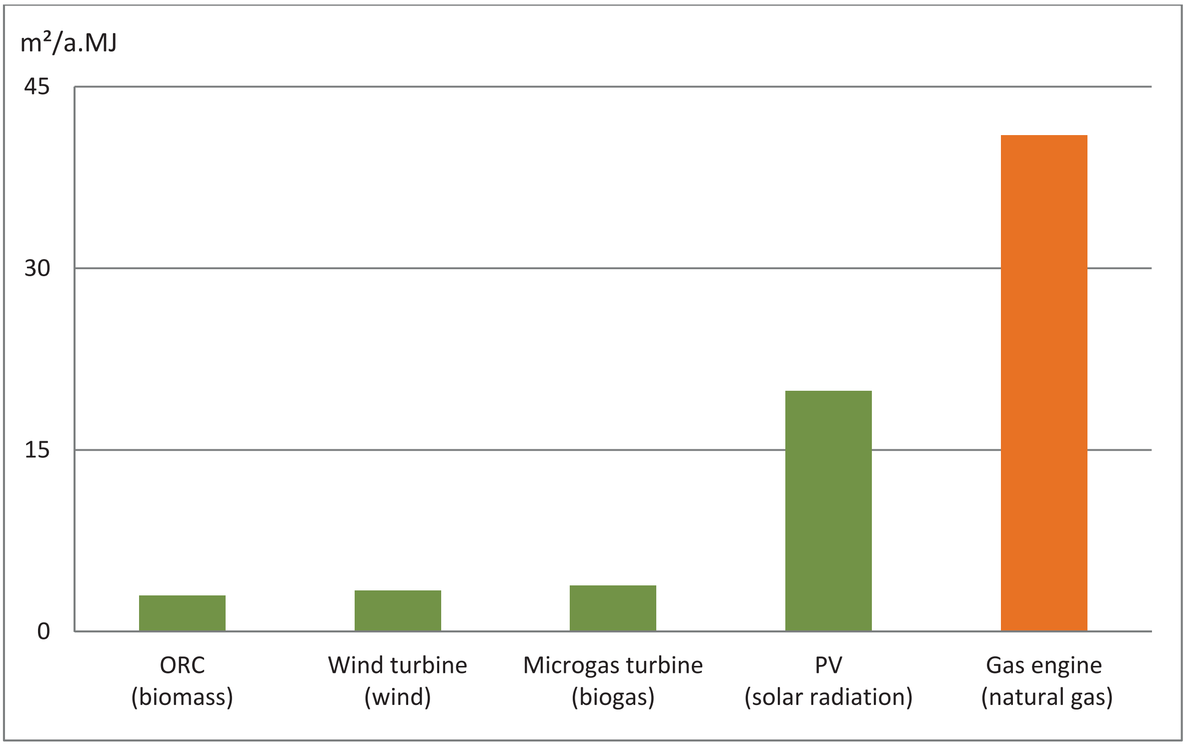

Figure 12: Comparison of ecological footprints for different electricity provision technologies (Kettl et al., 2011a), modified

The unit of the footprint is the footprint area in m² per annually produced MJ. This figure clearly points out that the fossil-based turbine, running on natural gas, has a higher ecological pressure than all renewable resource-based alternatives. The difference ranges from a 10.8 times higher impact of the natural gas derived electricity (41.0 m² /a.MJ) compared to the one of the biogas technology (3.8 m²

/a.MJ) and has still two times more ecological impact compared to the “worst” renewable based technology, the PV, with 19.9 m^2/a.MJ (Kettl et al., 2011a).

All ecological evaluations described in chapter 9 are based on the SPI. The calculation is extensive, but can be supported by the online-tool SPI on web[8] (Kettl, 2012) as a follow-up to SPIonExcel (Sandholzer & Narodoslawsky, 2007).

[8] http://spionweb.tugraz.at/, last accessed: August 2015

6 Model-Based Decision Support Tools

In general computer aided tools are often used to build up models for example of energy systems (Baños et al., 2011). It is important that support tools are easy to apply, reliable, science based and work with solid data. They should run quickly and be user-friendly in practice. Modelling tools can be online available computer programs like the ELAS-Calculator and RegiOpt, two decision support tools which are described in this chapter. The programming was carried out in close cooperation and bilateral process among the developers and the programmers.

The ELAS-Calculator implements a systemic approach to settlements regarding construction, renovation, operation, mobility and further aspects caused by different lifestyles of its inhabitants. These factors are directly linked to specific settlement patterns as well as quality of life. Thus, the application can be an important tool for both decision makers and planners by providing indicators of a settlement as a base for decision making in terms of a more sustainable society.

The aim of RegiOpt is to provide the opportunity for local and regional stakeholders to find an optimal technology network which meets local and regional demands which can be covered by utilising regional resources. In particular, a comparison between the current situation and the optimal solution in terms of regional added value and environmental pressure is offered. RegiOpt deliberately wants to encourage and support the discourse between stakeholders. Particularly in view of complex and profound changes, which are required by renunciation of fossil resources and nuclear power, the future has to be discussed on a broad scale and decisions be implemented in co-operation between all relevant stakeholders. RegiOpt contributes to this process.

6.1 The ELAS-Calculator

Currently there is a broad knowledge on energy-efficiency at the level of individual buildings, but it is still relatively patchy in terms of settlement structure aspects. Energy consumption, energy savings and energy supply are important issues in different research fields, including spatial planning. But until now, there has been no holistic view that included all aspects of settlements as a system. This is the reason why the software tool “ELAS-Calculator” has been developed in 2011[9]. As a free web

[9] The ELAS-Calculator was developed within the research project “ELAS – Energetic Long Term Analysis of Settlement Structures“. The project was funded by the climate and energy funds and carried out in the program “Neue Energien 2020” (project number 818915). Co-funding: Upper Austria, Lower Austria, City of Freistadt

application[10] it provides a long term energy analysis including electricity, room heating and mobility resulting in ecological aspects as well as economic parameters. It can be used by community leaders, planners, architects, builders and interested private people to analyse an existing or planned settlement. The calculator can run in a "private mode" and a "municipal mode". The application supports both, the business as usual analysis of existing settlements as well as the analysis of future settlement projects. Data of the settlement project like location parameters, living space, energy supply for electricity and heat, technical facilities, number of households, age structure of inhabitants etc. are filled in with the help of a questionnaire. The aim of the ELAS-Calculator is to represent all effects caused by a residential area referred to the energy consumption as conflating parameter. Based on this different effects can be easily compared for example the aggregated individual mobility or the energy demand for warm water supply. Structural, economic, social, environmental and technical parameters are included in the analysis.

Figure 13 depicts the main sectors of the calculator. The mobility data can only be modified in the private mode; otherwise it will be calculated in the background based on detailed survey data on modal split which has been carried out by the developers.

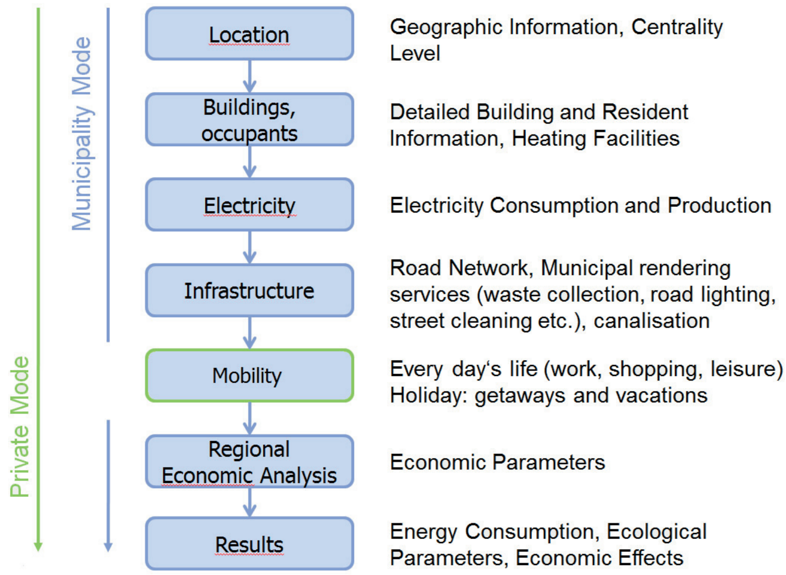

Figure 13: The main sectors of the ELAS-Calculator

The advantage of the calculator is its comprehensive consideration of all aspects which are relevant for energy consumption in settlements. This systemic approach is more than the simple sum of energy demands houses have within a residential

[10] www.elas-calculator.eu, last accessed: August 2015

estate. Energy consumption caused by individual mobility can be calculated and its influence on the total energy consumption of settlements visualized. This is possible, because the calculator works with five predefined centrality stages to estimate the location of the settlement and its transport link to administrative and service functions; the higher the centrality of a place the larger the number of services which are offered per resident. A low level of centrality means less services or poor accessibility, longer distances, less connection to the public transport system, which all leads to a significant increase of energy consumption for mobility. Considering all these aspects it can happen that a passive-house standard settlement in the outskirts has in the end a higher energy demand than a low energy house settlement in the town centre.

The ELAS-Calculator estimates the energy consumption of the residential area for construction works, heating, electricity, mobility and operation of public infrastructure. The results occur in four categories: energy consumption, CO_2-emissions, ecological footprint (calculated with the SPI) and regional economic parameters (turn over, regional added value, employment rate and imports). Further, it is possible to simulate a settlement's development by applying predefined scenarios where certain input parameters are changed. The software tool enables users to design settlement projects or single houses with respect to minimal ecological pressure, minimal energy demand and maximum added value for the municipality. Paper 5 represents the ELAS-Calculator and gives specific insight into the development and functioning of the tool.

6.2 RegiOpt

The focus of the tool RegiOpt[11] is to raise awareness for sustainable networks at a regional level. As a first step the user enters data with the help of a six pages questionnaire. The required input data covers mass and energy balances, investment and operating costs of technologies, costs for raw materials and additives, costs of infrastructure, prices for products and services as well as limitation in resource availability and the required demand. There are default values to support the user in case that some specific numbers are unknown. As the tool offers the possibility to save a project all values can be modified at a later time.

Out of the user’s input a basic technology network is generated with the help of the PNS, which takes already existing facilities into account and integrates additional

[11] http://regiopt.tugraz.at, last accessed: August 2015

technologies based on renewable resources of the region to offer the most economic solution. During the optimisation available raw materials are turned into feasible products, while inputs and outputs are unequivocally defined by each implemented operating unit. RegiOpt works on a fixed superstructure which only considers well established technologies (Figure 14 shows an excerpt of it). Technologies have a depreciation period of ten years with the exception of solar systems where it is set to 25 years.

The superstructure is implemented in the background of the tool. Transport expenses from field to facilities and specific yields per hectare are included in the optimisation. The effect of energy efficiency technologies, such as building insulations, can also be considered. Furthermore, limitations in terms of available investment volume can be specified. The optimisation considers time dependencies such as resource availability which depends on harvesting periods of bio-resources or the demand for products and services which can vary like the heating demand of a district heating network in the course of one year.

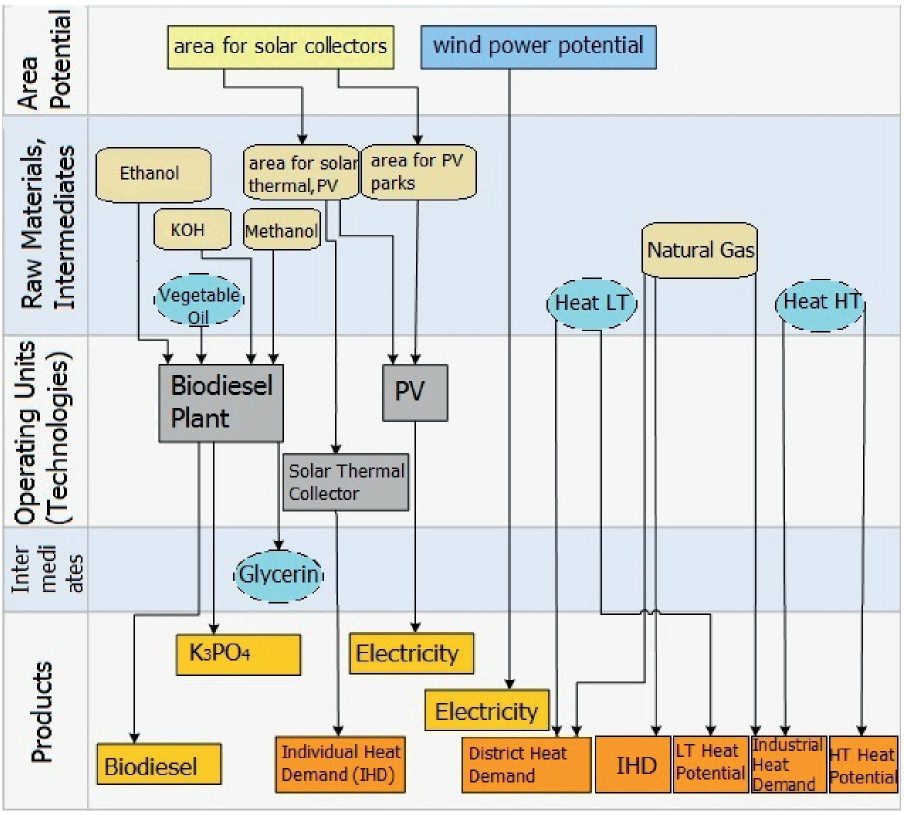

Figure 14: Excerpt of the superstructure in RegiOpt Conceptual Planner

Based on the given parameters RegiOpt suggests the most economic network which is in a next step evaluated with the SPI, in order to indicate ecological pressure. The tool offers ethical warnings as well, which can be found in each sector of the program. They appear as soon as an input data entails an ethical conflict which could negatively influence the social pillar of sustainability. The user is informed about this conflict and can think about the choice and if necessary adapt it. For example if there would be no or not enough area to produce food for the inhabitants, because all the area could be used to grow energy crops, RegiOpt opens a pop-up box and highlights this disproportion.

RegiOpt provides a quick overview about how regional resources can be utilised with different technologies which are interlinked in an optimised network that meets the needs of the region with best added value. It serves as a starting point for further planning. As social and ecological criteria are taken into account as well, a SRUN can be generated in further steps with the help of this software tool to sustain the development potential of regions and municipalities. RegiOpt is described in Paper 7 from page 123 on.

7 Conclusions

Based on the four research questions defined in chapter 2.2 the following can be concluded:

- The first research question asked for the benefit regions can gain from sustainable energy networks compared to a single technology pathway. The thesis clearly shows that sustainability cannot be reached by just replacing fossil with renewable resources or changing single technologies. The change must become systemic. SRUNs serve a variety of demands, on regional as well as interregional and global level, including material goods, energy carriers and services. This variety of demands can only be satisfied within a network of different technologies. For sustainable development a new definition of efficiency is required, taking more aspects into account than a simple input-output analysis. The efficiency of SRUNs has to guarantee a balance of the sustainable development triangle and it is important how technologies are arranged and interlinked and which stakeholders are involved. Regions can therefore benefit from an optimal exploitation of existing resources with appropriate technologies within a network which is widely accepted by the society generating regional added value with a minimum of ecological pressure.
- The second question was about the reason why sustainable energy systems should become “sustainable resource utilisation networks” (SRUNs). The results of the thesis indicate that sustainable energy systems have to become SRUNs to keep the balance of the sustainable development triangle. A balance can only be guaranteed if the network is economically feasible and ecologically viable. Social aspects have to be taken into account by a participatory, consensus-oriented, discursive planning process involving actors who have in many cases not co-operated before.
- The third research question dealt with the characterisation of a SRUN and asked for the elements a SRUN consists of. Within the thesis it can be shown that there are three predominant elements of a SRUN: supply-side, technologies, demand-side. All three elements are interlinked and can influence each other. The elements are strongly dependent on the context and a basic development framework has to be defined in the beginning of the planning process.

- The last research question asked for methodologies and the requirements for tools which can be used by multi-stakeholder for developing processes of a SRUN. As a main requirement it can be shown that decision support tools have to be flexible in their application. They must guarantee that an optimal solution structure is found. They have to provide an insight into the necessary changes which are needed to manage the shift towards a low carbon and sustainable society. As decisions need to be based on comprehensive considerations and assessments, decision support tools have to offer the possibility of scenario development. With an encompassing scenario building capacity they offer the possibility for regional actors to analyse their region and to get a feeling about SRUNs. Only by comparing different options the levels of action and cooperation can be revealed which lead the way to the future.

Finally some other aspects related to SRUNs could be identified as well. It is of great importance to invest enough time in the data analysis to optimise a structure with a huge set up of potential raw materials and products. This ensures that no promising resource or a market is left behind. The system boundaries can shift during the planning process of a SRUN, and it is important to let this happen. For SRUNs social aspects play a key role. A common vision and the will to work together on a sustainable future strengthen the community and the cooperation between the stakeholders. SRUNs result in new challenges for governance and spatial planning. They make a new legal framework for spatial and energy planning necessary.

In any case the planning process is local or regional and needs support tools to handle the process. The tools proposed and tested in this thesis combine two methodologies: the PNS for an economic optimisation of a technology network and the SPI to ecologically evaluate it. The case studies clearly demonstrate that the PNS is suited to generate optimal structures wherein resources are linked in the most efficient way meeting the required demands and offering a broad spectrum of products and services. The ecologically evaluation with an encompassing methodology such as the SPI, guarantees the sustainability of the suggested network and highlights the interplay between ecological and economic factors. From a process technology point of view, regions are complex conversion processes that transform limited regional resources into marketable products and regionally demanded services, with the goal of maximizing revenue and minimizing ecological burden associated with these activities. This is what decision support-tools based on those two methodologies offer. Open access tools like the ELAS-Calculator or

RegiOpt bridge energy and spatial planning and support decision makers in resource management and network planning.

There is still a rise in awareness needed to encourage a more responsible approach of society to the needed rapid change to a sustainable and low carbon society. Here SRUNs will play a significant role in the future.

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9 Selected Publications

Paper 1: Niemetz N, Kettl KH, Narodoslawsky M (2010): Revamping a Waste Processing Site with Process Synthesis. Chemical Engineering transactions, pp. 697–702, DOI 10.3303/CET1021117. Presented at PRES10, 13th conference on process integration, modelling and optimisation for energy saving and pollution reduction, 28.8.-1.9.2010, Prague

Contribution to Paper 1: Corresponding author – conducted the analysis and optimisation, drafted the manuscript, the other authors rad and approved the final version, presented the paper at the conference

Paper 2: Niemetz N, Kettl KH (2012): Ecological and economic evaluation of biogas from intercrops. Energy, Sustainability and Society 2(1): 18; DOI 10.1186/2192-0567-2-18. Presented at the international conference on micro perspectives for decentralized energy supply, 7.-8.4.2011, Berlin

Contribution to Paper 2: Corresponding author – constructed the network, carried out the PNS optimisation, built the scenarios, analysed the social aspects, drafted the manuscript, presented the paper at the conference

Paper 3: Niemetz N, Kettl KH, Szerencsits M, Narodoslawsky M (2012): Economic and Ecological Potential Assessment for Biogas Production Based on Intercrops. Biogas, pp. 173–188; DOI 10.5772/31870.

Contribution to Paper 3: Corresponding author – constructed the network, carried out the PNS optimisation, built the scenarios, analysed the social aspects

Paper 4: Narodoslawsky M, Kettl K, Niemetz N, Eder M (2014): Optimal Renewable Energy Systems for Regions 2(1): 88–99; DOI 10.13044/j.sdewes.2014.02.0008.

Contribution to Paper 4: carried out parts of the PNS optimisation, helped to build the network and to create scenarios

Paper 5: Stoeglehner G, Baaske W, Mitter H, Niemetz N, Kettl K, Weiss M, Lancaster B, Neugebauer G : Sustainability appraisal of residential energy demand and supply. A life cycle approach including heating, electricity, embodied energy and mobility. Energy, Sustainability and Society; DOI 10.1186/s13705-014-0024-6.

Contribution to Paper 5: intensive contribution to the ELAS-Project, developed together with the team the ELAS-Concept and the ELAS-Calculator, designed some of the figures

Paper 6: Stoeglehner G, Niemetz N, Kettl K (2011b): Spatial dimensions of sustainable energy systems. New visions for integrated spatial and energy planning. Energy, Sustainability and Society 1(1): 2; DOI 10.1186/2192-0567-1-2.

Contribution to Paper 6: contribution to the PlanVision-Project, developed together with the team the matrix with 34 elements

Paper 7: Niemetz N, Kettl KH, Eder M, Narodoslawsky M (2012): RegiOpt Conceptual Planner. Identifying Possible Energy Network Solutions for Regions Vol. 29, pt. 1,2 (2012): 517–522; DOI 10.3303/CET1229087. Presented at PRES12, 15th conference on process integration, modelling and optimisation for energy saving and pollution reduction, 25.-29.8.2012, Prague

Contribution to Paper 7: Corresponding author – intensive contribution in the development of the tool, constructed the network, responsible for the PNS part, drafted the manuscript, presented the paper at the conference

The papers are represented in there originally form of publication with adapted header or footer if necessary.

Paper 1

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Revamping a Waste Processing Site with Process Synthesis

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Improved waste stream management will play an ever increasing role among possible energy sources in the future. This paper analyses a waste company situated in Western Austria. Currently a considerable amount of waste is sent to a waste incineration plant. Costs thereby incurred have to be borne by the company. On the other hand heat is required, mainly for waste drying. Therefore an optimal network with an improved internal use of available materials should be generated. Within an economic optimization carried out by the P-graph method (Friedler et al., 1995; Halasz et al., 2005, Friedler, 2010) this network is developed. The results offer a wide range of future scenarios for the waste company, which could enhance the existing process; both from an economical and ecological point of view.

1. Introduction

The waste company analysed in this case study is located in Western Austria and serves as a waste hub for approximately 300,000 inhabitants as well as the industry in the region. Incoming waste is partly sorted and undergoes typical treatment procedures. Some unsorted waste is directly forwarded to nearby waste sorters in Austria and neighbouring countries, i.e. Switzerland. The waste hub processes about 350,000 t of waste a year. The majority stems from commerce and industry as well as from municipalities of two Austrian provinces. There is an existing biogas plant to produce heat and electricity using lop and organic waste. Furthermore, the company holds 10% of a nearby Organic Rankine Cycle (ORC) plant (Obernberger and Thek, 2008) whereto the main part of waste wood is contracted to be delivered for a fixed price until 2013.

New concepts for future pathways are presently discussed by the waste company's management. In order to find the optimum with respect to economic questions taking ecological issues into account, this analysis explores some possible future scenarios for technology networks utilising the material and energy flows at the site of the company.

2. Methodology

Finding an optimum solution for the company can be done by using Process Network Synthesis (PNS). In a first step a maximum structure of a possible technology network is set up, including all input materials and feasible processes as well as all products with corresponding prices. Any contextual conditions and plans for the future have to be

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considered and included into this maximum structure. In a next step different scenarios are created using various contexts via optimization of the technology networks within the maximum structure. Comparison of these scenarios offers a valuable basis for the strategic decision making process of the company management.

3. Case Study

3.1 Point of departure

The work on the case study started by discussing contextual parameters and and strategic questions with the waste company's management and operators. It turned out that the existing ORC plant has not necessarily to be part of a future technology network as contracts will run out soon. Preference would be to run a proprietary plant without being dependent on other partners. The biogas facility should still be included but a gas cleaning process to sell the biogas as a fuel can be investigated. An economic study concerning biogas cleaning has already been carried out. The data of this study are included in this work. At present a part of the plastic fraction is used to produce refuse derived fuel. Depending on the two different material qualities the market price for this product differs. With a mono-fraction plastics material, DSD material and the content of Yellow Bag collection (sorted plastics from municipalities) a recycle product for low-grade plastics application is produced on-site.
The splitting facility, depicted in Figure 1, constitutes the core of the waste sorting process.

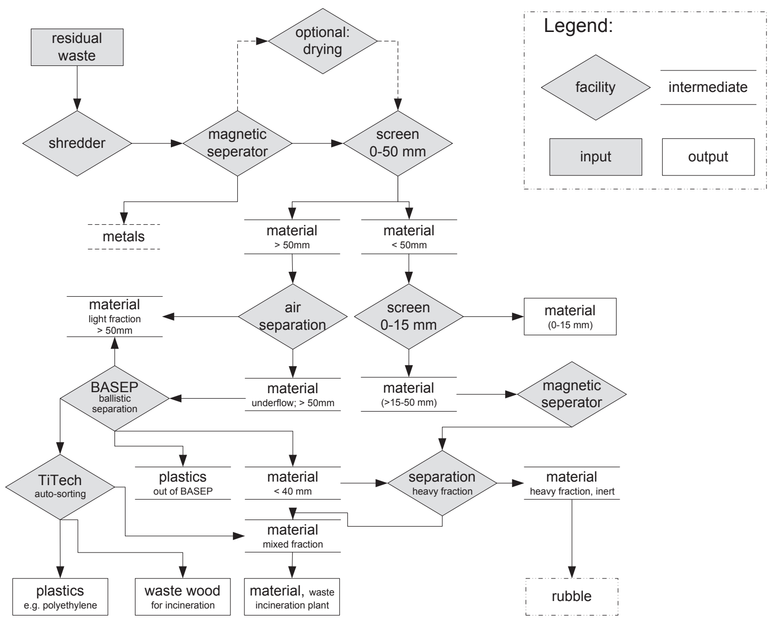

Figure 1: Splitting facility material flows

The use of the split waste streams should be utilised more efficiently as currently. The waste processing site already uses heat to dry part of the incoming waste. This heat is contracted free of charge from another company close by. One strategic aim is to increase the total amount of dried waste, as each ton which has to be sent to waste incineration increases costs. As more waste can be dried less mass is sent there, decreasing costs accordingly. Any additional heat necessary to achieve this should be produced with the available waste materials.

3.2 Feasible technologies and optimum structure

With the PNS it is possible to build up a technology network by linking different material and energy flows with respective technical processes utilising and/or producing them. A major advantage in case of the waste company is that all input materials needed are on-site. No additional logistic considerations are therefore required.

The various material fractions can be used in different processes. Biogas can be produced from lop and organic waste, which is an already existing process. The gas can either be utilised in a CHP plant with heat and electricity as products or a gas cleaning facility is considered providing clean methane. Paper sludge and reject from paper mills can be dried and used like waste wood for combustion, catalytic low pressure pyrolysis or gasification. Plastic fractions can undergo several treatments. They can be used either for recycling material, refuse derived fuel production or for combustion, catalytic low pressure pyrolysis and gasification.

Figure 2 shows the technology network resulting with the highest added value for the waste company, as a result from the PNS optimization.

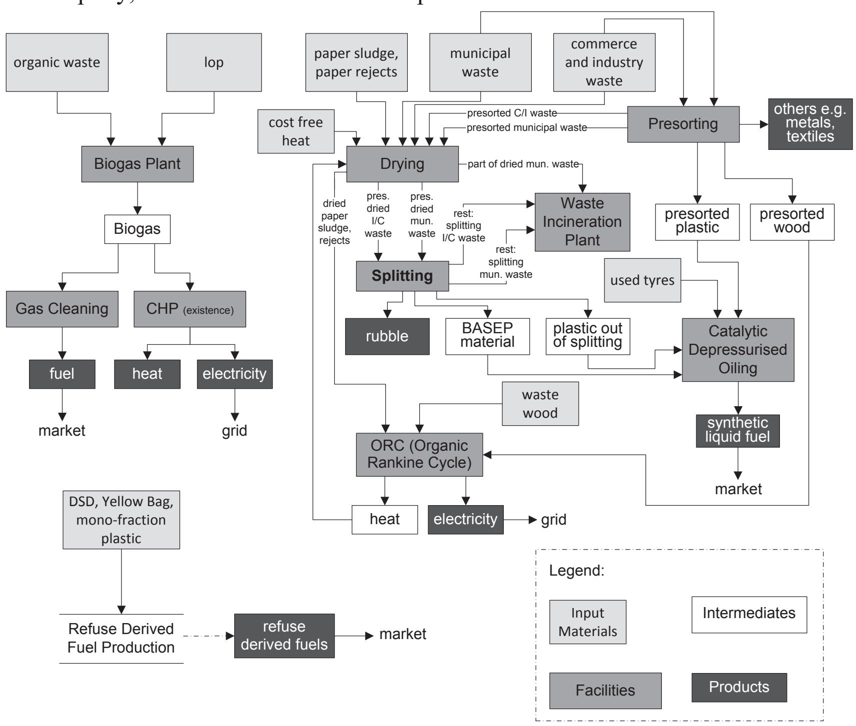

Figure 2: Optimum structure of a technology network generated with the PNS

Technologies considered in the maximum structure generated before are:

- Biomass combustion for heat production
- Biogas plant with block heating station and biogas cleaning
- Organic Rankine Cycle (ORC) as a process to produce heat and electricity. The heat can be used internally for drying. Electricity can be fed into the grid of electricity providers, thus benefiting from feed in tariffs according to the Austrian's Eco-Electricity Act gain is increased.
- Synthetic Natural Gas (SNG) Plant with gasification of biomass to heat, electricity and SNG (Mozaffarian et al., 2004; Chandel and Williams, 2009)
- Catalytic low pressure pyrolysis (KDV) to produce synthetic liquid fuel out of waste. For this technology a proven capacity of 13.600 t/a liquid fuel was taken into account (EcoKat Applied Technologies), as no experience with larger facilities is currently available and the technology is still in the stage of industrial demonstration.

It turns out that the technology network providing the most benefit for the company includes at least three new technologies, which are not part of the current process. Waste wood is used in a new ORC generating electricity which is fed into the grid and heat used to dry incoming waste. The ORC plant produces excess heat which could be used in a heating network linking either residential districts or neighbouring industrial sites with the waste company site. For this purpose a detailed demand research is necessary to identify optimal network size.

Biogas cleaning after the existing biogas plant is also part of the optimal network. This cleaning facility is restricted in its capacity, as investment costs of 200,000 € should not be exceeded. Therefore a CHP is still included in the structure although the heat is not used. Drying of fresh wood from a nearby saw mill could be a possible use for this excess heat, realising an additional profit for the waste company.

An important question for the waste company was, if keeping the splitting facility in operation is strategically sensible. The optimum structure shows that although some maintenance investment has to be done in the near future it is still advantageous to keep it in operation. All the plastics fractions sorted out by this process will be used in a catalytic low pressure pyrolysis plant as well as used tyres, producing synthetic liquid fuel which can be profitably marketed.

The production of refuse derived fuel runs on higher quality plastics than required for the catalytic low pressure pyrolysis producing a readily marketable product. The recycled plastic production is not included in the structure as the raw materials for this process are more efficiently used by other technologies.

The amount of waste to be sent to waste incineration is considerably decreased. This is desirable from an ecological point of view, too, as not only the necessary transport would be reduced but the content of the waste will be utilised in a more efficient way.

3.3 Scenarios

Scenarios based on the optimum structure described above have been devised according to the waste company's interests by changing contextual parameters e.g. by modifying input material flows or omitting technologies. This section briefly describes a selection of these scenarios.

3.3.1 Scenario 1: No refuse derived fuel production

In this scenario the production line for refuse derived fuel is cut and plastics with higher quality than those sorted out at the splitting plant are used as input for catalytic low pressure pyrolysis. No plastics recycle material is produced in this scenario. The pyrolysis has a restricted capacity, so some of the low quality plastics are sent to the incineration plant. If recycled plastic production is involved, using almost two third of DSD, Yellow Bag and mono-fraction plastics, the amount of lower quality plastics to be incinerated may be reduced. Used tyres are granulated by a different company.

3.3.2 Scenario 2: Higher capacity of catalytic low pressure pyrolysis

As already mentioned the Catalytic pressure-less depolymerisation is restricted in its capacity. The upper bound of one module is 13,600 tons of synthetic liquid fuel per year. As this is a novel technology it is still unclear how scaled-up plants using this technology operate. In this scenario therefore the PNS set up a structure wherein no upper bound on the capacity of the plant is attached in order to examine an option of a large scale pyrolysis plant for the waste company. It turned out that a plant with up to four times the capacity of the proven technology can be sustained by the resources available at the waste company site. Plastics, used tyres, dried paper and almost all waste wood are utilised in this plant. As a result there is not enough biomass available to run an ORC. The heat for waste drying in this scenario comes mainly from the biogas CHP and a small part from biomass combustion. Due to the marketability of synthetic liquid fuel this scenario has the highest revenue of any considered alternatives.

3.3.3 Scenario 3: Maximisation of biogas cleaning

In the optimum structure described above the biogas cleaning is restricted to 1.25 million m³ per year. This can be traced back to the fact that the investment costs for the cleaning facility are covered by another stakeholder with an investment limit of 200,000€. In the third scenario the biogas CHP disappears as soon as the upper limit for cleaning is taken away. All the biogas, produced out of lop and organic waste is cleaned. Although the investment costs are higher than in the optimum structure it leads to a more profitable solution, as more fuel can be sold on the market. Else, the technology network is similar to the one described in section 3.2.

3.3.4 Scenario 4: Reduction of the profit for incoming waste

Currently, the waste company is paid for each ton of residual waste it takes in. Given that the price per ton decreases by no more than one third compared to current price levels, the optimization renders a feasible structure without noticeable changes compared to the optimum structure described above – the overall revenue is lower than before, though.

3.3.5 Scenario 5: worst case scenario

A worst case scenario was discussed with the waste company's management and operators and analysed with the PNS. It includes no biogas cleaning, combined with profit loss for incoming waste and the loss of cost-free heat. The prices for incoming materials were set to zero. In this scenario the company could not make any profit. Selling excess heat to residential customers or using heat for drying of agricultural or forestry products however turns this scenario back to profitability. It clearly shows that finding customers for heat is a prime challenge for the management of the company.

4. Conclusions

Optimising an existing waste processing site using contextual parameters as well as a few innovative technologies reveals new possibilities to manage on-site material and energy flows. These structures are mainly based on technologies that increase the usage of waste and energy recovery. Resources can be used in a more energy efficient way while reducing ecological pressure. The scenarios described provide new perspectives not only for the company's management by investigating the overall process and open a wide range for decision making. Innovative process lines have been identified, leading to new perspectives for the company management. An important strategic question for the waste company could be answered as well: the splitting facility will be important in the future. In every scenario it is a main part of the technology network. An interesting fact is the importance of catalytic low pressure pyrolysis as a key technology in all developed scenarios. This novel technology has the potential to play a significant role for waste management. The case study showed that a huge amount of potential heat production is currently untapped. The optimization with the PNS indicates how this potential can be fully utilised resulting directly in higher profit. The analysis proves that if heat is produced an important necessity is to use it in the largest possible quantity on-site. Summing up the application of PNS is only one step in a strategy development process. It is the starting point to generate ideas to step forward to sustainable development in decision making. For the waste processing site in question it rendered a broad range of innovative technology networks. Choosing from these scenarios will improve the economic as well as the ecological performance of the company.

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Paper 2

Energy, Sustainability and Society
a SpringerOpen Journal

ORIGINAL ARTICLE Open Access

Ecological and economic evaluation of biogas from intercrops

Nora Niemetz* and Karl-Heinz Kettl

Abstract

Background: Biogas made from main crops (e.g., corn) is commonly used for producing electricity and heat. Nevertheless, the production of energy from monocultures is highly unsustainable and not truly renewable. Since neither monocultures nor food competition are desirable, intercrops can be used to increase the yield per hectare instead of leaving agricultural fields unplanted for soil regeneration. The extra biomass can be used for biogas production. In a case study, the economic as well as the ecological feasibility of biogas production using intercrops, cattle manure, grass and corn silage as feedstocks for fermenters was analyzed.

Methods: The set-up for the case study included different feedstock combinations as well as spatial distributions of substrate supply and heat demand for modeling and optimization. Using the process network synthesis, an optimum structure was generated representing the most economical technology constellation which included transport of substrates, heat and biogas (when applicable). The ecological evaluation was carried out by using the sustainable process index method.

Results: The application of both methodologies to different scenarios allowed a constellation to be found which is economically feasible while entailing low ecological pressure. It is demonstrated that the production of intercrops for producing biogas has so far not been regarded as a viable option by the farmers due to a variety of barriers. Sensitization is needed to emphasize that planting intercrops holds many advantages like positive effects on soil regeneration and raised nitrogen fixation, as well as increased biomass output per hectare and, last but not least, it allows the production of energy without conflicts between food and energy production.

Conclusions: Using intercrops for the production of biogas has the potential to decrease the ecological footprint decisively while still offering opportunities in the lucrative biogas market. The transfer of know how regarding this option should be taken up by agricultural training.

Keywords: Decentralized networks, Biogas, Intercrops, Crop rotation, Process network synthesis, PNS, Sustainable process index, SPI, Ecological footprint

Background

Intercrops are planted in fields between the main crop periods of e.g., wheat, corn or triticale. A typical crop rotation could be a winter type of main crops (e.g., wheat, rape etc.) followed by intercrops during the regeneration period. After the intercrop has been harvested, the main crop period starts anew. In this study, different grass species (e.g., Sudan grass, ryegrass, cocksfoot), types of grains (e.g., rye, sorghum, buckwheat, triticale, oat), legumes (e.g., pea species, vetch, horse bean, crimson clover, red clover, lucerne) and different oil seeds (e.g., sunflower, fodder radish, turnip rape) were used as examples for intercrops in corn fields [1].

The basic idea of using intercrops for energy production is twofold: using a biogenous feedstock which is strictly not in competition with the production of food, while at the same time using the nitrogen fixation potential of intercrops (via recycling biogas manure as well as by subsurface nitrogen fixation) to reduce the input of mineral fertilizer, to increase the yield per hectare, as well as to improve soil quality by humus rebuilding. Using less mineral fertilizer and achieving a higher overall yield per hectare (including the energy yield from

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intercrops) will result in lower overall ecological pressure of agricultural activities [2].

The case study, Bad Zell - a spa town in Upper Austria - forms the background for setting up the key parameters of a supply and demand chain of substrates and energy needed for biogas technologies. An important issue in this case is the inclusion of decentralized biogas production sites, a central heat demand (in the spa town) and a feed-in to the national electricity grid. This can be achieved using different structures, featuring e.g., several separated decentralized digesters that are linked by biogas pipelines to a central combined heat and power plant (CHP), using decentralized digesters serving their own CHP and providing a heat transmission to the site of heat demand or any combination of these. Additionally, some digesters may be especially equipped to utilize particular substrates or substrate combinations, leading to a necessity to transport substrates from the site of their generation to suitable digesters, which may be located further away.

This case study is the first one which tries to examine all effects of intercrops on sustainable energy production. It is part of a project called 'Syn-Energy I', in which intercrops were analyzed in detail. Field tests of different kinds of intercrops from this project were used to determine the dry mass yields for this paper. The project also included an analysis of the effects of intercrops on ground water, soil, nutrient management, as well as laboratory-scale biogas digester experiments for the estimation of the biogas potential of intercrops. The results concerning intercrop yields, biogas yields from these intercrops and the ecological impact of intercrop cultivation were applied to the case study of Bad Zell; the results also were used as database for the optimization the paper deals with [3].

Methods

Process network synthesis (PNS)

The setup for this case study included different feedstock combinations as well as spatial distributions of substrate supply and heat demand for modeling and optimization. Using the Process network synthesis (PNS), an optimum structure should be the outcome of the analysis. In a first step, a technology network is generated using the PNS [4-6]. This method uses the p-graph method and works through energy and material flows [7]. The available raw materials are turned into feasible products and services, while the inputs and outputs are unequivocally given by each implemented technology. Time dependency such as resource availability as well as product or service demand (e.g., the varying heat demand for district heating over the year) is part of the optimization. This method has already been applied to various renewable resource utilization cases, including the optimal technology constellations for green biorefineries [8], the sugar industry [9] and animal residue utilization [10], to name a few.

The input necessary for this comparative modeling and optimization includes the mass and energy balances, the investment and operating costs for the considered technologies, the costs for resources and utilities, the cost of products and services, as well as the constraints regarding resource supply and product/service demand. The investment costs will be statically depreciated over a period of 15 years.

First, the so-called maximum structure is generated, linking resources with the demands (e.g., for heat) and the marketable products (e.g., electricity) via all feasible technological structures, including transport. From this starting point, the optimization is carried out resulting in an optimum structure representing the most economic constellation of technologies and logistical pathways linking the given resources with demands and market opportunities.

A discussion with regional decision makers pointed to three decentralized locations which were suitable for biogas production. In the spa town itself, it was impossible to implement a central location for digesters as it would infringe with touristic activity there. The heat needed in the town could be either generated by a centrally placed CHP with biogas transported via pipelines [11] from decentralized digesters or by decentralized CHPs used for digester heating and/or transported via transmission lines to the town. For the optimization, three digester sizes (with capacities serving 80 to 250 kW_{el} CHP) were available for biogas production. Four combined heat and power plant capacities (from 80 to 500 kW_{el}) were implemented in the maximum structure. The digesters could be heated by decentralized CHPs or by a biomass furnace on site [12]. In this case, the biogas could be transported to a central CHP.

The fermentation was modeled to use different substrate feeds. The available substrates for biogas production were cattle manure, corn silage, grass silage and intercrops. Dependent on the feedstock digester sizes, the costs and digestion times differed. Seven different feedstock combinations (and hence types of digesters) were part of the maximum structure to find the most lucrative method for a substrate input strategy. These feedstock combinations are shown in Table 1.

The availability of resources was held constant within an amount of 18% grass silage, 16% corn silage and 34% intercrops (referring to fresh weight (FW)) of the available cattle manure in the region being available. Farmers in the considered region were allocated to eight provider groups regarding their spatial situation. The substrate costs were assumed to be the same within each group. The provider groups differ in the amount of available

Table 1 Substrate feeds for fermentation

Feed (%)	Cattle manure	Corn silage	Intercrops	Grass silage
1	100	-	-	-
2	50	50	-	-
3	75	25	-	-
4	75	15	10	-
5	50	30	10	10
6	50	20	20	10
7	75	-	15	10

Seven different digesters were part of the PNS to find the most lucrative way of using the substrates. The feeds are shown in the above table.

resources as well as in the distance to each possible digester location, which directly correlates with the transport costs. Table 2 shows the total available amount of cattle manure in the region and the distances of each group to the three feasible biogas production locations.

PNS: maximum structure

In Table 3, the substrate parameters are described. The optimization was based on two different cost assumptions (maximum and minimum) concerning substrate supply.

Figure 1 shows the maximum structure for the PNS optimization, which includes all input and output materials, as well as the energy and material flows with their economic parameters such as the investment or operating costs and prices.

The transport costs included the fixed costs for loading and unloading and the variable costs which are dependent on the distance (including the unloaded runs). For solid substrates, fixed costs of 2 €/t fresh weight were assumed. Similarly, the conversion was carried out for the variable costs, which were assumed to be 0.49 €/km. Fixed transport costs for cattle manure with 20 €/t dry mass as well as variable costs of 5 €/t dry mass per kilometer were defined.

Transportation of heat and biogas could be achieved via pipeline networks. Grid operation energy demands as well as losses caused by transporting were taken into account for the heat and biogas lines. Regarding heat, it was assumed that the total produced heat amount could be used for district heating. As location 1 and 3 are in line with the spa town, one biogas pipeline could be used for both locations to transport biogas to a central CHP. Therefore, there would not be any additional costs for a biogas pipeline from location 1 to the town, as long as location 3, which is further away, supplied the center with biogas.

For silo management 150,000 € was allocated which can be seen as a value that is strongly dependent on the location (e.g., ground conditions, silo system used, etc.). Therefore, this number is variable and might differ from case to case.

The biomass furnaces to provide digester heating (in case biogas is transported to the central CHP units) were not implemented as a separate technology in maximum structure, but a price of 5 ct/kWh heat was assumed for heating. Electricity is fed into the national grid, thus benefiting from the feed-in tariffs according to the Austrian Eco-Electricity Act [13].

Sustainable process index

The second step included an ecological evaluation of the optimum PNS structure using the sustainable process index (SPI) [14]. Being an ecological footprint method, the SPI represents the resulting area needed to embed all necessary human activities (to supply products or services) into the ecosphere. The evaluation, itself, is based on comparing the natural flows with the human-induced flows and the natural qualities of the environmental compartments of soil, water (ground) and the atmosphere; the evaluation used solar radiation (driving all natural material cycles as well as providing a sustainable natural income to society) as a reference. The SPI results allow for analyzing ecological impacts

Table 2 Total amount of available cattle manure and provider distances to three locations in kilometers

Group	Available cattle manure (t DM)	Distances from the provider group to the possible fermenter locations (km)		
		Location 1	Location 2	Location 3
1	405.9	1.6	3.4	0
2	99.0	3.3	4.7	4.0
3	188.1	2.7	4.6	1.2
4	168.3	1.9	1.4	3.3
5	79.2	0.3	2.1	2.1
6	99.0	1.5	2.9	3.0
7	158.4	3.1	3.0	2.4
8	198.0	3.8	1.9	3.7

Table 2 includes the total amount of the available cattle manure and the distances of each group to the three locations that would be feasible for biogas production. t, tons; DM, dried mass.

Table 3 Substrate parameters

Parameters	Cattle manure	Corn silage	Intercrops	Grass silage
Dry mass content (%)	9	33	24	30
Substrate costs[a] minimum (€/t DM)	5	65	50	50
Substrate costs[a] maximum (€/t DM)	10	90	80	80
CH_4 output (m^3/t DM)	200	340	300	300

In Table 3, the substrate parameters are described. The optimization is based on two different cost situations (maximum and minimum) for substrate supply.
[a]All costs decided by regional actors. t, tons; DM, dried mass.

according to land use; the supply of renewable, non-renewable and fossil resources; as well as the emissions to water, air and soil.

Footprint calculations were performed using the free-ware SPIonEXCEL tool [15,16]. For a thorough discussion of the method, the reader is kindly referred to [15-17]. As the natural carbon cycle is included in the evaluation method as a reference flow, the SPI is well suited to compare technologies based on fossil and renewable resources. The SPI has, therefore, been applied to a number of ecological assessment tasks, especially for evaluating technologies based on renewable resources [18-20].

Using the results of the SPI evaluation, the different options could be compared regarding their environmental impact. The optimum structure obtained by the PNS is not necessarily the technology constellation with the lowest environmental impacts. By comparing the different structures and taking the two parameters (revenue of the solution and ecological footprint) into consideration, a trade-off between the economic and the ecological advantages of different structures may be possible.

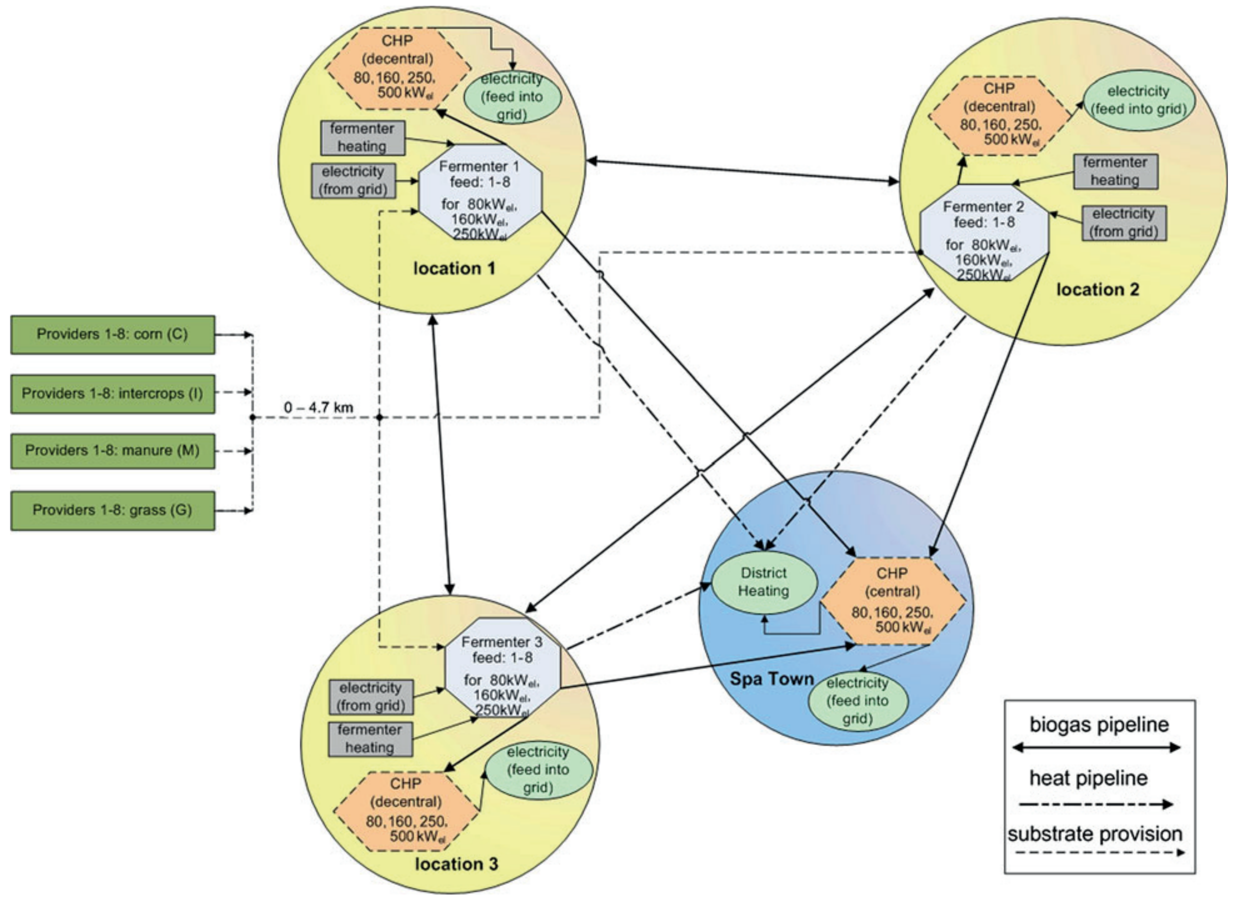

Figure 1 Maximum structure for PNS optimization. The so-called maximum structure for the PNS optimization, which includes all input and output materials, as well as the energy and material flows with their economic parameters such as the investment or operating costs and prices.

Results and discussion

PNS: basic optimum structure

The PNS optimization shows that the technology constellation providing the largest economic benefit only includes location 1 for biogas generation. On this site, biogas is produced using two different substrate feeds (6, 7 in Table 1). Therefore, two digester types are part of the optimum structure. As Table 1 demonstrates, both substrate feeds include intercrops. All provider groups can supply the digesters with at least one substrate. Figure 2 depicts the optimum structure for a situation with maximal substrate costs as listed in Table 3.

Both digesters have a size to supply a 250 kW_{el} CHP. The one with the higher amount of intercrops in the feed (f6) runs at full load, while the other (f7) runs at 96% of capacity. Altogether, around 1,116,300 m^3 of methane (CH_4) can be produced. Around one-third of the biogas generated by digester f6 is used in a decentralized 160 kW_{el} CHP (51% capacity) on site, whereas the digester f7 fully supplies biogas via pipelines to a central CHP with a capacity of a 250 kW_{el}. The rest of the biogas produced by digester f6 is sent via pipelines to the center and runs a CHP of 160 kW_{el} in full load mode. In total, around 4,130 MWh heat per year can cover the district heat demand at a price of 2.25 ct/kWh. Both CHP units feed electricity into the national grid (approximately 3,830 MWh/year) at feed-in tariffs of 20.5 ct/kWh (see also Table 4).

Using this technology constellation and a 15-year depreciation period, a total annual profit of nearly 229,000 € can be achieved (interest rates are not included). The total input costs including electricity consumed from the grid add up to 236,000 €/year with an additional 68,170 €/year for transportation. The investment costs for this technology constellation are 2,805,800 €, including the district heating and biogas network as well as the costs for the digesters, the CHPs and the other infrastructures needed.

The optimization using a minimum cost situation (see Table 3) results in the same optimum network structure as has already been shown in Figure 2. The costs for the substrates are lower (around 163,920 €/year). The profit increases to 301,000 €/year (without taking interest rates into account). Table 4 gives an overview of the monetary input and output parameters for both cost situations.

Scenario generation

Two scenarios were developed both for minimum as well as for maximum substrate cost situations: scenario 1 with a reduced maximum structure does not include corn availability (only feed combinations 1 and 7 are feasible in this scenario); scenario 2 used cattle manure as a substrate only. These scenarios rendered the following results:

Scenario 1

Biogas is produced only at location 1 with a total amount of 751,000 m^3 CH_4 per year, using two digesters (both f7). A local 80 kW_{el} CHP covers the heat demand of the biogas digesters. In the town center, a 250 kW_{el} CHP runs with biogas produced at site 1. Figure 3 shows the optimum technology constellation for scenario 1.

The optimum structure of a scenario with a maximum substrate cost constellation provides a yearly profit of 119,460 € (again excluding the interest rates). If the substrate costs are set to minimum, the structure does not change, but the annual profit increases due to the lower material costs up to about 166,000 €/year. Table 5 compares the minimum and maximum substrate cost constellation for scenario 1.

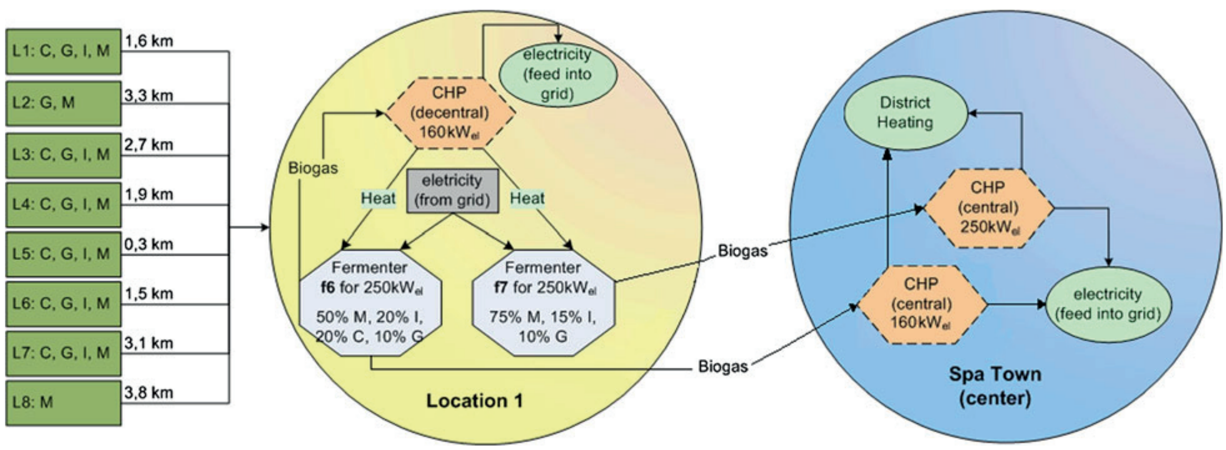

Figure 2 Basic optimum structure of a technology constellation generated using the PNS. This depicts the basic optimum structure for a situation with maximal substrate costs as listed in Table 1.

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Table 4 Comparison of monetary parameters for minimum and maximum substrate costs

Depreciation period: 15 years	Minimum	Maximum	Capacity (%)
Total investment costs (1,000 €)			
Digester f6 250 kW_{el}	850.9	850.9	100
Digester f7 250 kW_{el}	1,075.6	1,075.6	96
CHP 160 kW_{el} location 1	200	200	51
CHP 160 kW_{el} central	200	200	100
CHP 250 kW_{el} central	250	250	100
Transformer	35	35	-
Silo management	150	150	-
Biogas pipelines	44.3	44.3	-
Total investment costs	2,805.8	2,805.8	-
Yearly depreciation (1,000 €/year)	187.1	187.1	-
Yearly operating costs (1000 €/year)			
Material costs	129.5	201.6	-
Transport costs	68.2	68.2	-
Digester f6 250 kW_{el}	37.8	37.8	100
Digester f7 250 kW_{el}	37.8	37.8	96
CHP 160 kW_{el} location 1	23.3	23.3	51
CHP 160 kW_{el} central	23.3	23.3	100
CHP 250 kW_{el} central	29.2	29.2	100
Silo management	5.9	5.9	-
Electricity from national grid	34.4	34.4	-
Total operating costs (1,000 €/year)	389.4	461.5	-
Yearly profit (1,000 €/year)			
District heat 22.5 € × 4,134 MWh	93.0	93.0	-
Electricity feed in 205 € × 3,827 MWh	784.4	784.4	-
Total profit (1,000 €/year)[a] without depreciation and operating costs	877.4	877.4	-
Total profit (1,000 €/year)[a]	300.9	228.9	

Table 4 gives an overview of monetary input and output parameters for both cost situations (minimum and maximum, see Table 3). [a]Without interest rates.

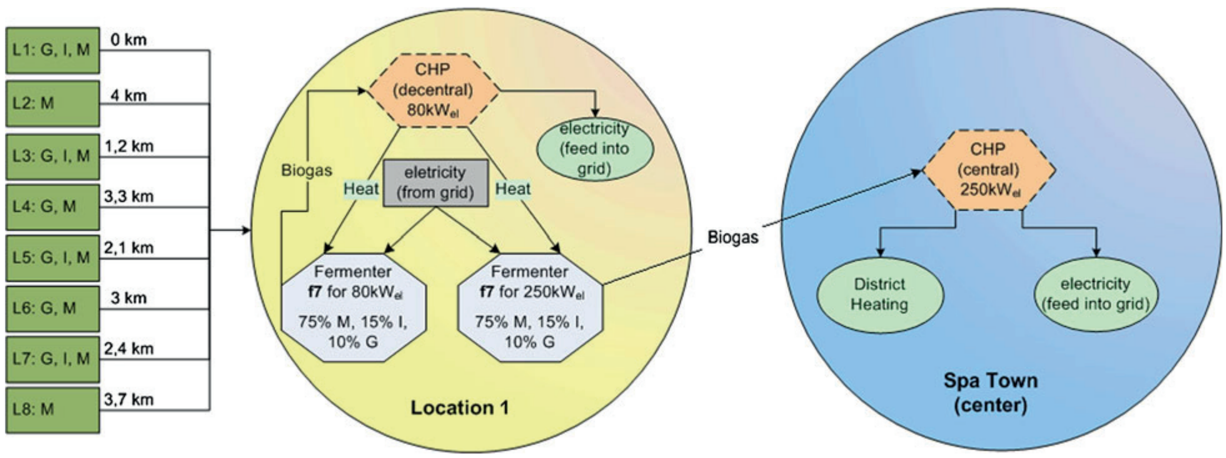

Figure 3 Optimum structure scenario 1 'no corn'. As an optimization result, Figure 3 presents the optimum technology constellation for the new maximum structure in scenario 1.

Table 5 Comparison of the results for minimum and maximum substrate costs for scenario 1

Depreciation period: 15 years	Minimum	Maximum	Capacity (%)
Total investment costs (1,000 €)			
Digester f7 80 kW_{el}	474.7	474.7	100
Digester f7 250 kW_{el}	1,075.6	1075.6	100
CHP 80 kW_{el} location 1	110	110	100
CHP 250 kW_{el} central	250	250	100
Transformer	35	35	-
Silo management	150	150	-
Biogas pipelines	44.3	44.3	-
Total investment costs	2,139.6	2139.6	-
Yearly depreciation (1,000 €/year)	142.6	142.6	-
Yearly operating costs (1,000 €/year)			
Material costs	73.0	119.6	-
Transport costs	56.6	56.6	-
Digester f7 80 kW_{el}	27.1	27.1	100
Digester f7 250 kW_{el}	37.8	37.8	100
CHP 80 kW_{el} location 1	18.9	18.9	100
CHP 250 kW_{el} central	29.2	29.2	100
Silo management	5.9	5.9	-
Electricity from national grid	23.2	23.2	-
Total operating costs (1,000 €/year)	271.7	318.3	-
Yearly profit (1,000 €/year)			
District heat 22.5 € × 2,340 MWh	52.6	52.6	-
Electricity feed in 205 € × 2,574 MWh	527.7	527.7	-
Total profit (1,000 €/year)[a] without depreciation and operating costs	580.3	580.3	-
Total profit (1,000 €/year)[a]	166.0	119.5	

[a]Without interest rates.

Scenario 2

The input materials of the maximum structure (Figure 1) are dramatically changed. In scenario 2, only cattle manure is available as a substrate for biogas fermentation. With that, only feedstock 1 can be used to produce biogas and no silo management is needed.

The optimization shows that just location 1 is feasible for biogas fermentation. Biogas can be produced in a digester of a capacity to supply a 160 kW_{el} CHP (78.7% capacity). The produced biogas with an amount of 286,420 m^3 CH_4 is used in a decentralized 160 kW_{el} CHP on site. The heat demand for the digester at location 3 is covered by this CHP. The rest of the heat (about 790 MWh/year) is sent via heat pipelines to the center where it is sold for a price of 22.5 €/MWh.

In this scenario with maximum substrate costs of 9 €/t dry mass, no profit can be gained. The optimum structure for scenario 2 results in a yearly loss of about 6,100 € (not including interest rates). If the substrate costs are set to minimum, the structure does not change but a little profit of about 900 €/year can be achieved.

Ecological evaluation

Any meaningful ecological evaluation requires a precise definition of the system boundaries. In this study, the evaluation of the field crops started at the point of crop sowing. Energy (especially fuel), fertilizer and pesticide input for all steps of cultivation (such as sowing, plowing and fertilizing), as well as the infrastructure of the technical equipment are included. For cattle manure, the system boundary includes the cattle as a manure producer, taking feed (wheat and grass) into account. Cattle are regarded as means to produce meat, milk and manure. An ecological pressure is assigned to these products by price allocation. A low footprint for manure results as the manure price is rather low (approximately 1 €/t FW) compared to the main product of milk (about 288 €/t FW). The intercrop evaluation is based on precise data from actual cultivation experiments during the project. A major part of the ecological footprint is caused by transport. In the structures described before the transport situation, the location for biogas plants is also location 1. But as presented in Table 2, the provider distances differ depending on the location, whereas the substrate amounts differ depending on the scenarios, leading to considerably different ecological pressures due to transport. Table 6 provides an overview of the main parameters for SPI evaluation [21].

Table 6 shows that the structure with the largest economic benefit entails the highest ecological pressure. This is a result of the high amount of corn (with its high SPI value of 86,216 m^2/t DM) used in this structure. The SPI values are dominated by machinery use (causing fossil fuel consumption and CO_2 emissions) and fertilizer use for growing corn. In scenario 1, the corn input is put to zero. This change decreases the SPI value considerably. Scenario 2 has the lowest SPI value because it uses only manure of a small footprint as the substrate (1,887 m^2/t DM). This scenario, however, achieves little or no economic profit.

The amount of product differs widely between the scenarios with the 3,827 MWh/year electricity in the basic optimum structure: in scenario 1, the produced electricity decreases by one-third. In scenario 2, only 978 MWh/year can be fed into the grid. Accordingly, the material input varies and with that the SPI values. Figure 4 indicates the SPI per megawatt hour (MWh) electricity produced dividing each bar into the seven SPI sub-categories. The figure shows that the most important impacts resulting from the input of fossil resources were mainly caused by the fuel for the machinery, the fertilizers and the electricity use. The emissions to air and water are mainly due to the production of electricity based on fossil and nuclear materials.

Compared to the basic optimum structure (Figure 2), the two scenarios have a lower ecological footprint per MWh of electricity. But a disadvantage of scenario 1 and 2 is that more digesters or higher capacities are required to produce the same biogas amount compared to the basic optimum structure where corn silage can be used as the substrate. This does not really affect the ecological footprint, but it is also a reason for the decreased revenue of scenario 1 and 2 as the investment costs change.

Social aspects

In general, the first reactions from actors regarding the production of intercrops show that the psychological barriers are of high importance: farmers expect low yields (as are common for intercrops) and, therefore, tend to disregard biogas production from intercrops. Because farmers have to put in additional effort and must adhere to strict timing, barriers to using intercrops are raised. Another aspect is that in order to fully benefit from intercrop cultivation via the production of biogas, large investments as well as close economic and operational co-operation between the farmers and other local actors is required. It seems like all these arguments and facts are speaking against implementing complex solutions. Therefore, it is even more important to raise awareness and to offer external incentives (e.g., funding) to convince the farmers of the fact that intercrops may contribute to a higher overall added value as the optimum structure clearly shows.

Table 6 Main parameters for SPI evaluation [21]

Yearly	Optimum	Scenario 1	Scenario 2
Corn silage (t DM/year)	537	0	0
Corn silage SPI (m^2/t DM)	86,216	86,216	86,216
Intercrops (t DM/year)	960	1,351	0
Intercrops SPI (m^2/t DM)	9,250	9,250	9,250
Grass silage (t DM/year)	711	375	0
Grass silage SPI (m^2/t DM)	7,640	7,640	7,640
Cattle manure (t DM/year)	1,393	895	931
Cattle manure SPI (m^2/t DM)	1,887	1,887	931
Electricity from grid (MWh/year)	230	154	37
Produced heat			
Total (MWh/year)	5,038	3,159	1,412
Out of that for district heating (MWh/year)	4,134	2,340	790
Electricity feed (MWh/year)	3,827	2,574	978
CHP capacity (kW_{el})	160; 160; 250	80; 250	160
SPI electricity (m^2/MWh)	53,437	19,305	18,327
SPI heat (m^2/MWh)	5,865	2,119	2,012
SPI total (km^2)	204.5	49.7	17.9

t, tons; DM, dried mass.

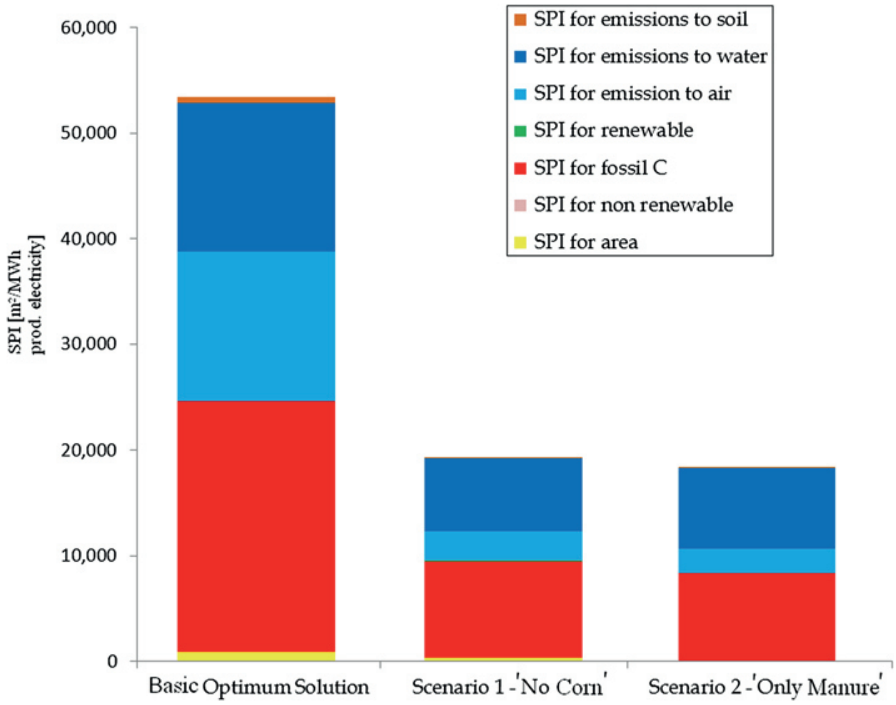

Figure 4 SPI values per MWh electricity produced. The presented table divides each bar into the seven SPI categories. The figure reveals that the major impact resulted from the demand of fossil resources mainly caused by machinery and electricity use.

Conclusions

Ecological, economic and social sustainability aspects should be considered at the same time when new concepts are introduced to provide energy from bioresources. Using the PNS to generate optimal constellations for linking resources with demands and the markets via integrated technologies, it has proven to be helpful to generate scenarios and evaluate them ecologically using an encompassing methodology, such as the SPI. The latter provided a clear picture regarding the interplay between ecological and economic factors. In this study, the applied approach highlighted the trade-off between ecology and the economy, best represented in Figure 4 where scenario 1 has been identified as the solution which optimizes economic as well as ecological benefits.

The social aspects will, however, be decisive for implementing innovative energy systems based on renewable resources. It was demonstrated that the production of intercrops for producing biogas so far has not been regarded as a viable option by the farmers due to a variety of barriers. Additional work and a strict time frame to cultivate their fields are the main counter-arguments in the discussion about intercrops, coupled with the necessity to a close cooperation and mutual dependency between farmers as well as between agriculture and other social actors on the local level. A rise in awareness is needed to emphasize that planting intercrops holds many advantages. Intercrops reduce the ecological footprint decisively. In times of green taxes, a reduction of CO_2 emissions can also decrease production costs. More biogas output per hectare raises income while a reduced need for mineral fertilizer reduces costs. This issue should be taken up by agricultural training courses, where the advantages could be demonstrated on the example of the best practice demonstrative farms.

A crucial logistical aspect would be an intelligent digester set-up and an innovative approach regarding biogas and heat logistics. All this, however, calls for a high level of organization, possibly in the form of a farmer association running the network constellation described before, to lower the investment risk and ensure a continuous operation and stable substrate availability. On the other hand, such an association has the potential to strengthen the community and the social cohesion in the region. On closer examination, it reveals that intercrops can play an important role in a sustainable agriculture of the future when developing and running a socially and ecologically acceptable network constellation still being lucrative for the operators and the region.

Abbreviations

CH_4: methane; CHP: combined heat and power plant; ct: cent; DM: dried mass; FW: fresh weight; kW_{el}: kilowatt electric; kWh: kilowatt hour; MWh: megawatt hour; PNS: process network synthesis; SPI: sustainable process index.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
NN collected the data, carried out the PNS evaluation, as well as its interpretation, and drafted the manuscript. KHK provided the SPI evaluation data and interpretation. Both authors read and approved the final manuscript.

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Paper 3

9

Economic and Ecological Potential Assessment for Biogas Production Based on Intercrops

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1. Introduction

Biogas production is discussed controversially, because biogas plants with substantial production capacity and considerable demand for feedstock were built in recent years. As a consequence, in most cases corn becomes the dominating crop in the surrounding and the competition on arable land is intensified. Therefore biogas production is blamed to raise environmental risks (e. g. erosion, nitrate leaching, etc.). Furthermore it is still discussed, that a significant increase of biogas production could threaten the security of food supply. The way out of this dilemma is simply straight forward but also challenging: to use preferably biogenous feedstock for biogas production which is not in competition with food or feed production (e. g. intercrops, manure, feedstock from unused grassland, agro-wastes, etc.). However, the use of intercrops for biogas production is not that attractive since current biogas technology from harvest up to the digestion is optimized for corn. Additionally current reimbursement schemes do neither take the physiological advantages and higher competitiveness of corn into account nor compensate lower yield potentials of intercrops which are growing in late summer or early spring. Higher feed-in tariffs for biogas from intercrop feedstock, as they are provided for the use of manure in smaller biogas systems, would not only be justified, as shown below, but also stimulating. Beyond that, the plant species used as intercrops as well as the agronomic measures and machinery used for their growing seem to provide lots of opportunities for optimization to increase achievable yields. Moreover, adaptations of biogas production systems, as discussed in this chapter, facilitate biogas production from intercrops.

Further advantages of intercrops growing are that they contribute to a better soil quality as well as humus content and reduce the risk of nitrous oxide emissions. Simultaneously intercrops allow a decrease of the amount of chemical fertilizer input, because the risk of nitrate leaching is reduced and if leguminosae are integrated in intercrop-mixtures, atmospheric nitrogen is fixed. This is important, because conventional agriculture for food and feed production utilizes considerable amounts of mineral fertilizers. Due to the fact that the production of mineral nitrogen fertilizers is based on fossil resources, it makes economically and ecologically sense to reduce the fertilizers demand.

In the case study, a spa town in Upper Austria, the set-up of the supply chain is seen as key parameter. An important issue in this case are more decentralized networks for biogas production. This can be achieved e.g. with several separated decentralized biogas fermenters which are linked by biogas pipelines to a centralized combined heat and power plant.

2. Methodologies

Process Network Synthesis (PNS) was used as a tool for economic decisions to get an optimal technology solution for biogas production with particular consideration of feedstock which is not in competition with food or feed production. Ecological evaluation of the resulting optimal PNS solution through footprint calculation was based on the Sustainable Process Index (SPI). These calculations are based on the data, which was gathered in three field tests, and the practical experiences, that were gained in the growing and harvesting of intercrops on more than 50 hectares of arable land. Besides the determination of dry matter yields of different kinds of intercrops and intercrop mixtures the effects on ground water, soil and nutrient management were investigated in the field experiments with time-domain-reflectometry, soil water and mineral nitrogen content measurement. Additionally, the potential biogas production was measured by means of biogas fermenter lab scale experiments.

2.1 Process Network Synthesis (PNS)

Process Network Synthesis (PNS) (Friedler et. al., 1995) uses the p-graph method and works through energy and material flows. Available raw materials are turned into feasible products and services, while in- and outputs are unequivocally given by each implemented technology. Time dependencies like resource availability (e.g. harvesting of renewable resources) as well as product or service demand (e.g. varying heat demand for district heating over the year) are part of the optimization.

The necessary input for this optimization includes mass and energy balances, investment and operating costs for the technologies considered, costs for resources and utilities, prices for products and services as well as constraints regarding resource supply and product/service demand. For the case study all data were provided from project partners and are specific for the considered region. First the so called maximum structure is generated linking resources with demands. From this starting point the optimization is carried out resulting in an optimum solution structure representing the most economical network.

2.2 Sustainable Process Index (SPI)

Sustainable Process Index (SPI) was developed by Krotscheck and Narodoslawsky in the year 1995 and is part of the ecological footprint family. The SPI represents as a result the area which is required to embed all human activities needed to supply products or services into the ecosphere, following strict sustainability criteria. Based on life cycle input (LCI) data from a life cycle assessment (LCA) study, SPI can be used to cover the life cycle impact assessment (LCIA) part. LCA studies are standardized and described by the ISO norm 14040 (ISO, 2006). Within the methodology there are seven impact categories defined which are indicated by different colors:

- Area for area
- Area for non-renewable resources
- Area for renewable resources
- Area for fossil carbon
- Area for emissions to water
- Area for emissions to soil
- Area for emissions to air

A high footprint is equal to a high environmental impact!

The freeware tool SPIonExcel (Sandholzer et. al., 2005) was used to calculate the ecological footprint (Graz University of Technology, n.d.) This offers the possibility to measure not only the economical performance of the PNS scenarios.

To assess the sustainability of biogas production from intercrops it is necessary to consider the whole crop rotation and the effects of intercrop on main crops. A direct comparison of biogas feedstock from main crops (e. g. corn) and intercrops is not possible, because inter crops grow with lower temperatures and less hours of sunshine. Therefore one of the systems compared, was corn as main crop, commonly cultivated with plow, and an intercrop cultivated with conservation tillage and harvested with a chopper for biogas production. It was assumed, that biogas was processed to natural gas quality. In the second system with intercrops corn was cultivated with conservation tillage whereas the intercrop was grown with direct drilling and harvested with a self-loading trailer instead of a chopper. Since a late harvest of a winter intercrop with high yields would reduce corn yields, an early harvest with an average intercrop yield of only 4 tons dry matter was assumed. In the reference system corn was grown without intercrop and the biogas produced in the intercrop systems was substituted by natural gas. The yield of the main crop corn was equal in all systems (15 tons dry matter of the whole plants per hectare for silage).

	common intercrop system		**improved intercrop system**		**reference system without intercrop**
position in crop rotation	main crop	intercrop	main crop	intercrop	main crop
tillage	plow	conservation tillage	conservation tillage	direct drilling	plow
harvest	chopper	chopper	chopper	self-loading trailer	chopper

Table 1. Systems compared with the Sustainable Process Index (SPI)

3. Intercrops

In temperate climate zones, allowing only the cultivation of one main crop per year, intercrops are planted after the harvest of the main crops (e.g. wheat, corn or triticale) or as undersown crops, while the main crop is still growing. Summer intercrops are harvested in

September or October as long as the trafficability of fields is sufficient. Achievable yields of summer intercrops are higher, the earlier main crops are harvested and intercrops are sown. The variety of plant species, suitable for biogas production from summer intercrops is very high and reaches from different kinds of millet, over grainlegumes, clover, sun flowers to cruciferae or other plants, adequate for regional conditions and the specific crop rotation of the fields. If cultivated as undersown crops, the variety of usable plant species (e. g. specific types of clover and grass) is restricted to those, not growing too fast and capable to resist a long period with shadow from the main crops.

Winter intercrops (e. g. feeding rye, triticale, different types of clover or rape) are sown in autumn and reaped before the cultivation of summer main crops (e. g. corn or soybean). The later winter intercrops are harvested, the higher are the achievable intercrop yields but the higher is also the risk of diminishing yields of the main crop. For example, output cuts of corn may be higher than additional yields of the intercrop, if intercrops are harvested in the middle of May or later. Therefore, the harvest of the intercrop at exactly the right moment with immediate subsequent cultivation of the main crop is crucial for the overall outcome of this type of crop rotation.

Dry matter yields, achievable with intercrops, vary to a higher extent than those of main crops, because they grow at the edges of the growing season and have less opportunities to compensate unfavourable conditions for growing. Furthermore, there are only a few farmers with experience and appropriate machinery for cultivation and harvesting of intercrops for biogas production at present.

Dry matter yields of summer intercrops in own field experiments in the years 2009 and 2010 averaged out at about 3 tons per hectare. After early cultivation with adequate machinery yields achieved 5 tons and more in some cases. However, intercrops did not achieve yields worthy for harvest in other cases, because of late harvest of main crops in the middle of august in connection with high precipitation and low temperatures in august and September. Under these conditions undersown summer intercrops (e. g. red clover under wheat and spelt) were advantageous and reached yields of almost 5 tons in the middle of September.

The yields of winter intercrops depend mainly on the time of harvest and the average temperature in March and April. If harvested at the end of April or the beginning of May, yields of about 4 tons dry matter were achieved with feeding rye or mixtures of rye or triticale with winter pea or rape. Yields of the following corn were equal or at maximum 10 percent lower than corn without preceding intercrop, if the intercrop was sufficiently manured with biogas digestate. A comparison with average yields found by other authors is compiled in Table 2.

	summer intercrops	winter intercrops
	dry matter yields in tons per hectare	
Own experiments	3	4 (without reduction of corn yields)
Neff, 2007	5	
Aigner/Sticksel/Hartmann, 2008	3	4,9 (middle of April)7,5 (5. Mai)
Laurenz, 2009	4,5	6 (with a reduction of corn yield of 2,5)
Koch, 2009	5	

Table 2. Average yields of summer and winter intercrops

Methane yields per hectare, achievable with winter intercrops, average out at about 1100 cubic meter with a methane content per kg organic dry matter of 310 liter. The methane yields of summer intercrops are lower and achieved 800 cubic meter per hectare in average. The methane content amounts in average 290 liter methane per kg organic dry matter. Therefore, between 4 and 6 hectare of intercrops are required to substitute one hectare of corn as biogas feedstock. This may seem little at the first glance. Considering the fact, that only rates of 10 or 20 percent of arable land should be used for biogas production at maximum, if the security of food supply should not be threatened, it becomes a considerable dimension, since intercrops for biogas production may be cultivated on 60 up to 90 percent of the arable land, if crop rotations are designed accordingly. Therefore the overall biogas potential of intercrops is comparable with the potential of corn.

However, the realization of these potentials requires adaptations of farmers' conditions for biogas production, as current reimbursement schemes and common technical equipment for tillage, drilling, harvest and biogas production make the use of intercrops profitable, only if farmers also apply for agro-environmental payments. Since these payments are only available in certain countries and are not guaranteed for the same period as biogas plants have to be operated, the risk for specific investments is considerable. To stimulate biogas production from intercrops, the physiological advantages and higher competitiveness of corn should be taken into account in the design of reimbursement schemes and tariffs should compensate lower yield potentials of intercrops. Higher feed-in tariffs for biogas from intercrop feedstock, as they are already provided for the use of manure in smaller biogas systems, would also encourage the optimization of agronomic practices (e. g. plant species used as intercrops, tillage, drilling) and technical equipment. In this way, the amount and reliability of intercrop yields would be increased additionally.

3.1 Ecological evaluation of intercrops

Based on input data for the production of main crops with and without intercrops several ecological footprints were calculated. Corn silage as main crop has a yield of 15 ton per hectare (dry matter) and 4 t (dry matter) per hectare of intercrop. SPI calculation includes

		common intercrop system	improved intercrops system	common intercrop system	improved intercrops system	conventional
		intercrop	intercrop	main crop	main crop	main crop (no intercrops combination)
	LCI input data	workings hours per ton (dry matter)				
machinery input	Tractor (<45 kW), light workload	0.40	0.23	0.04	0.04	0.04
	Tractor (<45 kW), normal workload	0.18	0.18	0.00	0.00	0.00
	Tractor (<70 kW), normal workload	0.88	0.44	0.55	0.52	0.55
	Tractor (<70 kW), heavy workload	0.00	0.00	0.13	0.00	0.13
	Tractor (70-110 kW), light workload	0.24	0.24	0.00	0.00	0.00
	Tractor (70-110 kW), normal workload	0.36	0.24	0.20	0.28	0.20
		kg per ton (dry matter)				
fertilizer	Application of N-Fertiliser	9.33				12.67
	Application of P-Fertiliser	1.57				1.57
	Application of K-Fertilisation	9.29				9.29
	Application of Ca-Fertiliser	8.43				8.43
		g per ton (dry matter)				
pesticides	Herbicide Phenmediapham	0.00	0.00	61.56	61.56	61.56
	Herbicide Terbuthylazin SP	0.00	0.00	108.05	108.05	108.05
	Herbicide Pyridate SP	0.00	0.00	6.91	6.91	6.91

Table 3. LCI data

machinery working hours, fertilizers, pesticides, agricultural area, and nitrogen fixation by leguminosae and seeds. Input data for the footprint calculation is listed in Table 3 which is derived from (KTBL, n.d.).

In terms of nitrogen fertilizer demand the use of leguminosae in intercrop mixtures reduces the demand of mineral nitrogen fertilizer through nitrogen fixation. Based on these data the ecological footprint results are listed in Table 4.

	SPI results [m²/ t (dry matter)]		
	common intercrop system	improved intercrops system	conventional
main crop	27,217.8	26,374.6	31,528.6
intercrop	13,988.1	9,250.2	--------

Table 4. LCIA results

These footprints are per ton dry matter of intercrop or main crop. In general the lower machinery input for reduced tillage results in an accordingly lower footprint which points out the advantage of this method. This effect becomes more important as the yield of the crop decreases. The yields of intercrops are inevitably lower than of main crops, because of lower temperatures and less sunshine hours. Therefore, the footprint of intercrops sown with direct drilling and harvested with self-loading trailer is 34 % lower than of intercrops grown with conservation tillage and harvested with chopper. The amount of fertilizer for the main crops can be reduced with leguminosae intercrops. For this reason the footprint of the main crop in the reference system is higher than in the first system with intercrops with common tillage. If the effect of reduced nitrogen leaching or nitrous oxide emissions would be considered in the SPI-calculation, the difference would become even bigger.

For an overall assessment of the three systems, biogas produced in the systems with intercrops was processed to natural gas quality and substituted with natural gas in the system without intercrop. With processing the average methane content of biogas from about 60 % is increased to 96 % CH_4. Of course, biogas from intercrops can also be used in combined heat and power plants (CHP). Its processing is only obligatory for the comparison with natural gas. Although the footprint per ton dry matter of intercrops, even if they are sown with direct drilling, is bigger than the footprint of main crops, it is much smaller than the footprint of natural gas, it may substitute.

Table 5 illustrates this overall balance per hectare of agriculture area. Biogas purification SPI relies on life cycle data from ecoinvent database (Ecoinvent, n.d.). This balance can be seen as a rough estimation of the footprint reduction potential, if not only agriculture but also natural gas consumption is considered.

Table 5 points out an advantage for intercrop cultivation with direct seeding and harvesting with self-loading trailer in comparison with intercrops grown with conservation tillage and harvest with chopper. The footprint of intercrops used for green fertilizing to increase soil quality, was not calculated in detail. Nevertheless it can be assumed that the footprint is worse than the footprints of intercrops for biogas production, because the efforts for drilling are the same and instead of harvesting energy is needed for their incorporation into the soil.

For natural gas the SPI value is 540.4 m²/Nm³. Although further biogas purification is needed the whole balance points out a footprint reduction potential of 39 – 42 %.

	with intercrops		conventional
	common intercrop system	improved intercrops system	
CH_4 yield [m³ / t (dry matter)]	1,200	1,200	
overall purified biogas [m³/ha]	4,800	4,800	
intercrop SPI [m²/ha]	408,266	395,619	472,929
maincrop SPI [m²/ha]	55,952	37,001	0
provision of natural gas [m² /ha]	0	0	648,480
biogas fermentation process (electricity, heat) [m² / ha]	21,074	21,074	
biogas purification [m² / ha]	193,500	193,500	0
SPI [m² / ha]	**678,793**	**647,194**	**1,121,409**

Table 5. Energy balance per hectare

4. PNS optimization

A case study, as part of the so called Syn-Energy[1] project, was carried out in a spa town in Upper Austria wherein the set-up of the supply chain was seen as one of the key parameters. Beside detailed analyses of intercrops (e.g. biogas content, yields) a main focus was to find a network in respect of a higher degree of decentralization for biogas production. This can be achieved e.g. with several separated decentralized fermenters that are linked by biogas pipelines to a single combined heat and power plant. The specific data for intercrops were used to carry out the evaluations. Of note was to show how intercrops can affect networks from an ecological and economical point of view.

4.1 Case study

Figure 1 shows three potential decentralized locations for biogas production. As there is a spa town located in the considered region it was not possible to contemplate a fourth, central location for a fermenter as it would infringe with the touristy activity there. There is already an existing district heating network in town that should be extended. The heat needed could be either generated by a centrally placed CHP with biogas transported via pipelines or heat produced with decentralized CHPs could be used for fermenter heating and/or transported via long –distance heat pipelines to the town. In the first case, with central CHP, fermenter heating is provided by wood chip furnace.

The fermentation could work with different feedstock types to find out the most lucrative way of using intercrops, manure, grass silage and corn silage. Corn as additional feedstock was taken into consideration for economic reasons, because it is favored under current economic conditions. For the optimization it was assumed that proportional to the availability of manure biomass in an amount of 34 % intercrops, 18 % grass silage and 16 % corn silage (referring to fresh weight) per livestock unit can be supplied. As there are several

[1] Syn-Energy „Klima- und Wasserschutz durch synergetische Biomassenutzung – Biogas aus Zwischenfrüchten, Rest- und Abfallstoffen ohne Verschärfung der Flächenkonkurrenz"; programme responsibility: Klima- und Energiefonds; programme management: Österreichische Forschungsförderungsgesellschaft mbH (FFG), report not published yet

farmers in and around the considered region eight provider groups (1-8 according to Table 6 and black bordered providers in Figure 1) were defined. The substrate costs were the same for each group.

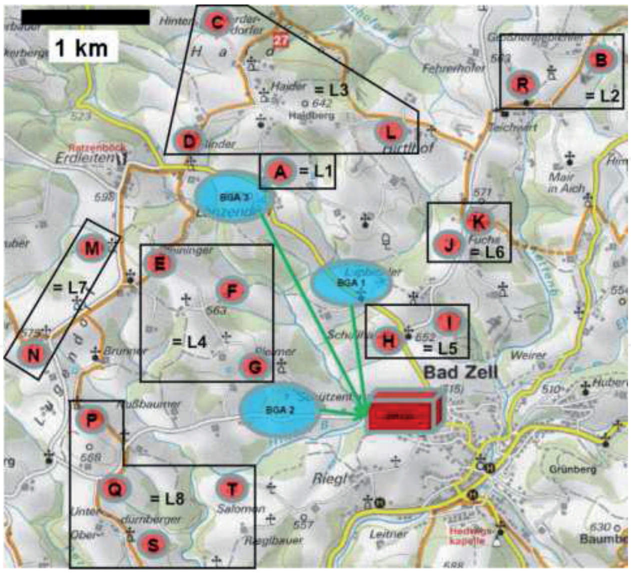

Fig. 1. Substrate providers (A-T) and possible fermenter locations (BGA1-3)

Provider Group	Distances in km to		
	Location 1	Location 2	Location 3
1 (A)	1.6	3.4	0
2 (B, R)	3.3	4.7	4
3 (C, D, L)	2.7	4.6	1.2
4 (E, F, G)	1.9	1.4	3.3
5 (H, I)	0.3	2.1	2.1
6 (J, K)	1.5	2.9	3
7 (M, N)	3.1	3	2.4
8 (P, Q, S, T)	3.8	1.9	3.7

Table 6. Transport distances for substrate provision

The providers differed in the amount of available resources as well as in the distance to each possible fermenter location, which directly correlates with transport distances and costs. Transport costs included fix costs for loading and unloading and variable costs depending on the distance (including unloaded runs). For solid substrates fixed costs of 2 €/t fresh weight were taken into account. Similarly, the conversion was made for the variable costs, which were assumed with 0.49 €/km. Fixed transport costs for manure were defined with 20 €/t dry mass with variable costs of 5 €/t dry mass per kilometer. For grass and corn silage a storage was taken into account. As it is not possible to bring the investment costs down to one number because they are highly depending on the local basic conditions a fix investment of 150,000 € for a silage storage was taken into account. As soon as a location is chosen by the PNS a storage has to be included there. Two locations mean two times investment costs to store the silage that is used for biogas production.

Transportation of heat and biogas could be achieved via pipeline networks. Network energy demands as well as losses caused by transporting were included. Regarding heat it was assumed that the total produced heat amount could be used for district heating. As location 1 and 3 are in one line to the spa town one biogas pipeline could be used for both locations to transport biogas to the central CHP. Therefore no additional costs arise for a biogas pipeline from location 1, if location 3, which is farther away, supplies the center with biogas.

Because of different transport distances the PNS could decide which provision group and amount of substrate should be used to get the most economical optimum solution. The fermentation could run with various substrate feeds. Dependent on them fermenter sizes, costs and exposure times differed. Seven different fermenters were part of the PNS to find the most lucrative way of substrate input. The feeds are shown in Table 7.

Feed [%]	Manure	Inter-crops	Grass silage	Corn silage
1	30	0	0	70
2	30	70	0	0
3	50	50	0	0
4	50	20	10	20
5	75	0	0	25
6	75	25	0	0
7	75	15	10	0

Table 7. Substrate feeds for fermentation

In Table 8 the substrate parameters are described. The optimization was based on two different cost situations (maximum and minimum) concerning substrate provision.

* decided by project partners	Manure	Corn silage	Intercrops	Grass silage
Dry Mass Content [%]	9	33	24	30
Substrate Costs* min. [€/t DM]	5	65	50	50
Substrate Costs* max. [€/t DM]	10	110	80	80
CH_4-output [m^3/ t DM]	200	340	300	300

Table 8. Substrate parameters and costs in € per ton dry matter and cubic meter methane per ton dry matter

Figure 2 shows the so called maximum structure for the PNS optimization, which includes all input and output materials with energy and material flows with economic parameters like investment or operating costs and prices. For the optimization three fermenter sizes (up to a capacity that serves a 250 kW_{el} CHP) were available for biogas production. Four combined heat and power plant capacities (up to 500 kW_{el}) were involved in the maximum structure. The fermenters could be heated by decentralized CHPs or with a wood chip furnace on site in case the biogas is transported to a central CHP.

The biomass furnace that could be a choice to provide fermenter heating was not implemented as separate technology in PNS' maximum structure, but a price of 5 ct/kWh heat was assumed (Wagner, 2008). Produced electricity could be fed into electricity providers' grid, thus benefiting from feed-in tariffs according to Austrian's Eco-Electricity Act (RIS, n.d.).

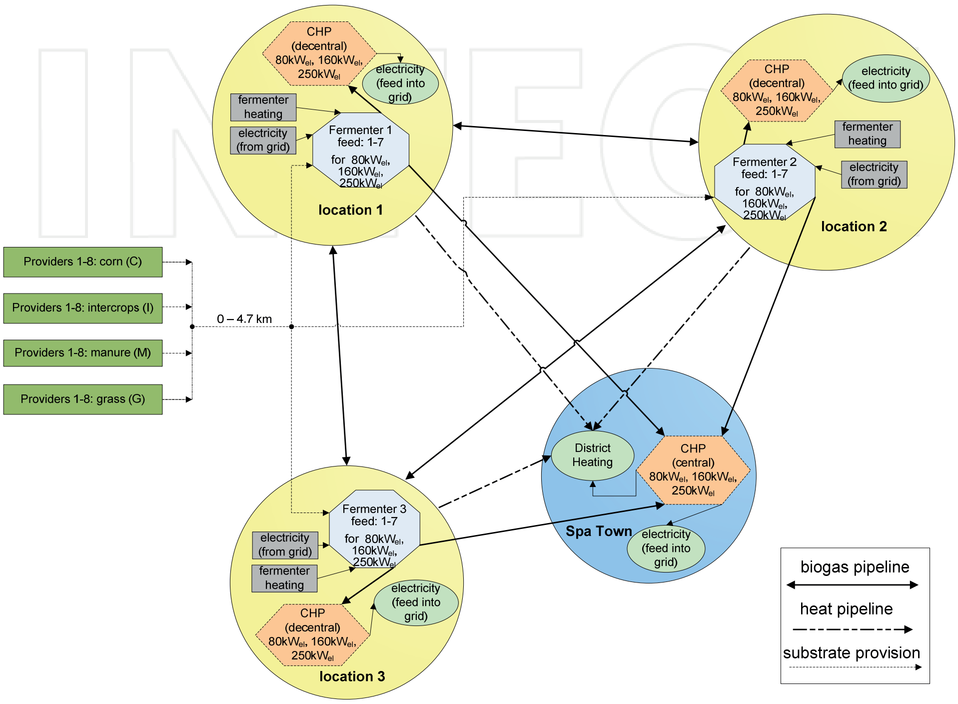

Fig. 2. Maximum structure for PNS Optimization

4.2 PNS optimum solution

The PNS optimization shows that the technology network providing the most benefit for the region includes two different locations (1 and 3) for biogas generation. At location 3 biogas is produced with substrate feed 4, a mixture consisting of manure, intercrops, grass and corn silage. The fermenter runs 7.800 full load hours and is able to provide a 250 kW_{el} CHP with biogas. At location 1 the set up includes a fermenter with same capacity but different load. Substrate mixture 7 is used for biogas production which contains manure, intercrops and grass silage. Both fermenters are heated with a biomass furnace on site. All provider groups can supply the fermenters with at least one substrate. The optimal technology network includes two central 250 kW_{el} CHPs supplied via biogas pipelines with biogas from both locations. For the pipeline coming from location 1 no additional costs have to be incurred because the pipeline would be part of the routing from location 3 to the center. The produced heat covers the central heat demand for a price of 2.25 ct/kWh. The electricity is fed into the grid and feed-in tariffs of 20.5 ct/kWh can be gained. Figure 3 depicts the optimum structure for a situation with maximum substrate costs as listed in Table 8.

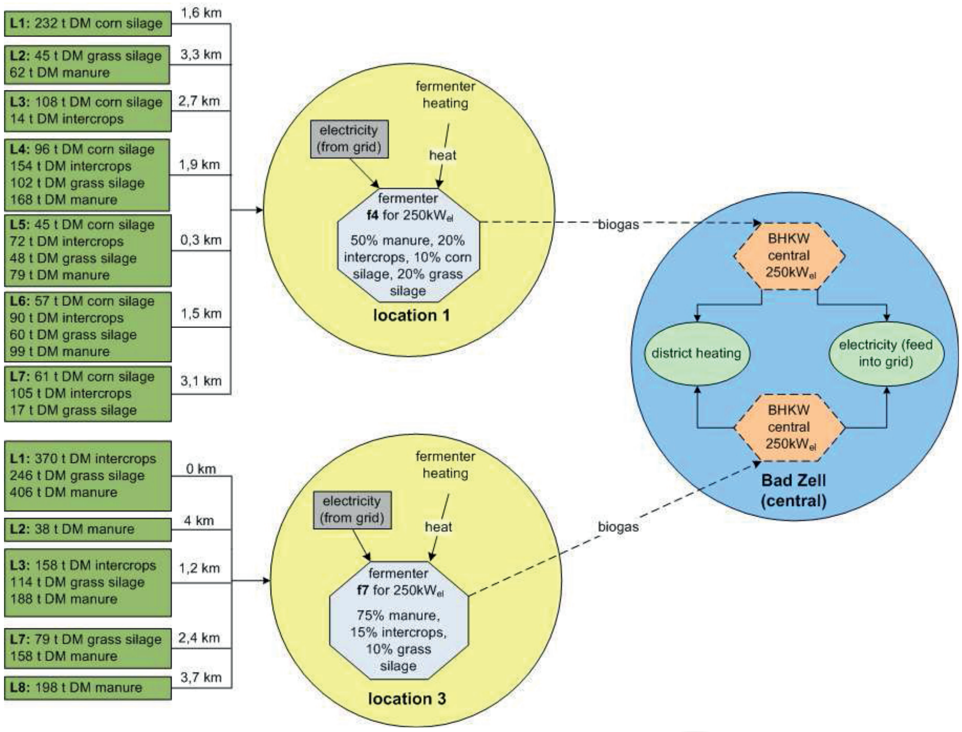

Fig. 3. Optimum structure of a technology network generated with PNS

With this technology network and 15 years payout period a total annual profit of around 196,350 € can be achieved (interest rates are not included). The total material costs including electricity consumed from the grid and costs for fermenter heating add up to approx. 438,000 €/yr with additionally 60,300 € per year for transportation. The total investment costs for this solution would be around 2,895,000 € including district heating and biogas network as well as the costs for fermenters and CHPs.

With minimal substrate costs (see Table 8) there is no change in the optimal structure, but the revenue is higher commensurate to the lower substrate costs (one-third reduction). The revenue for the structure with minimal substrate costs excluding interest accounts for a yearly amount of about 280,400 €.

4.3 Scenarios

To prove plausibility of the optimum PNS structure two scenarios were carried out, both for minimum as well as for maximum substrate cost situations. In the first case the maximum structure was reduced by taking away corn availability. With that only five substrate mixtures could be used for biogas production. The second scenario was set up to get an idea how feed-in tariffs can influence the outcome of an optimization. Therefore it was not allowed that a network set-up results e.g. in two 250 kW_{el} CHPs if a 500 kW_{el} instead could be taken.

4.3.1 Scenario I – No corn silage

As already mentioned in the beginning corn is currently a dominating substrate for biogas production. To show the potential of intercrops no corn is available in this scenario. Not to lose the comparability the amount of corn was compensated with an additional availability of intercrops. The calculation was based on the CH_4-outputs and adds up to additionally 904 t intercrops. With that 2,170 t/yr intercrops, about 1.7 times more than in the basic maximum structure shown in Figure 2, are available in the maximum structure of this scenario. Under these conditions PNS could choose between five different substrate feeds.

The optimization results in a technology network including two locations using the whole amount of available intercrops as shown in Figure 4.

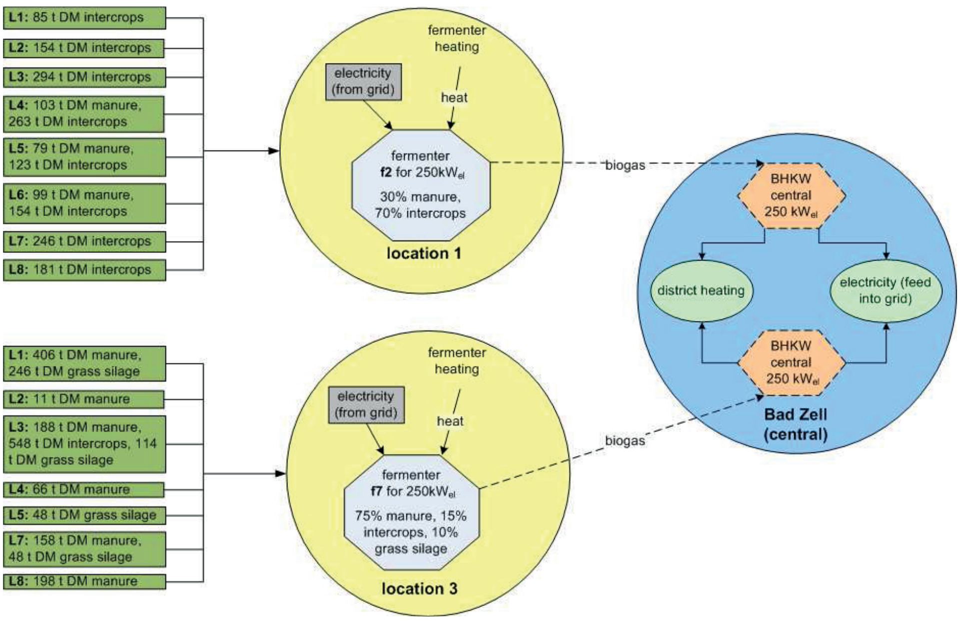

Fig. 4. PNS optimum structure for scenario 1 without corn silage availability

At location 3 a fermenter processing substrate feed 7 with a capacity to produce biogas to supply a 250 kW_{el} CHP runs 7,800 full load hours a year. A second fermenter placed on location 1 and with same efficiency is supplied with substrate feed 2 consisting of 70 % intercrops and 30 % manure. It turned out that with this structure the outcome has yearly revenue of approx. 208,000 €. Compared to the optimum structure it is higher, but the basic conditions are different. Therefore this solution did not come up in the optimization of the maximum structure in the beginning. But it clearly shows that intercrops have a great potential to produce electricity and heat within a highly profitable biogas network without being in competition with food or feed production. But the precondition would be that in the case study a higher amount of intercrops is available as feedstock.

4.3.2 Scenario II – 500 kW_{el} CHP unit

Operating a 500 kW_{el} CHP goes along with reduced feed-in tariffs of 20 €/MWh according to Austrian's Eco-Electricity Act. The positive effect of lower investment and operating costs for larger capacities is therefore narrowed by less revenue for produced electricity. If is forbidden to use two CHPs with same capacity at one location in the maximum structure to gain higher feed-in tariffs the next larger CHP capacity has to be taken although this would

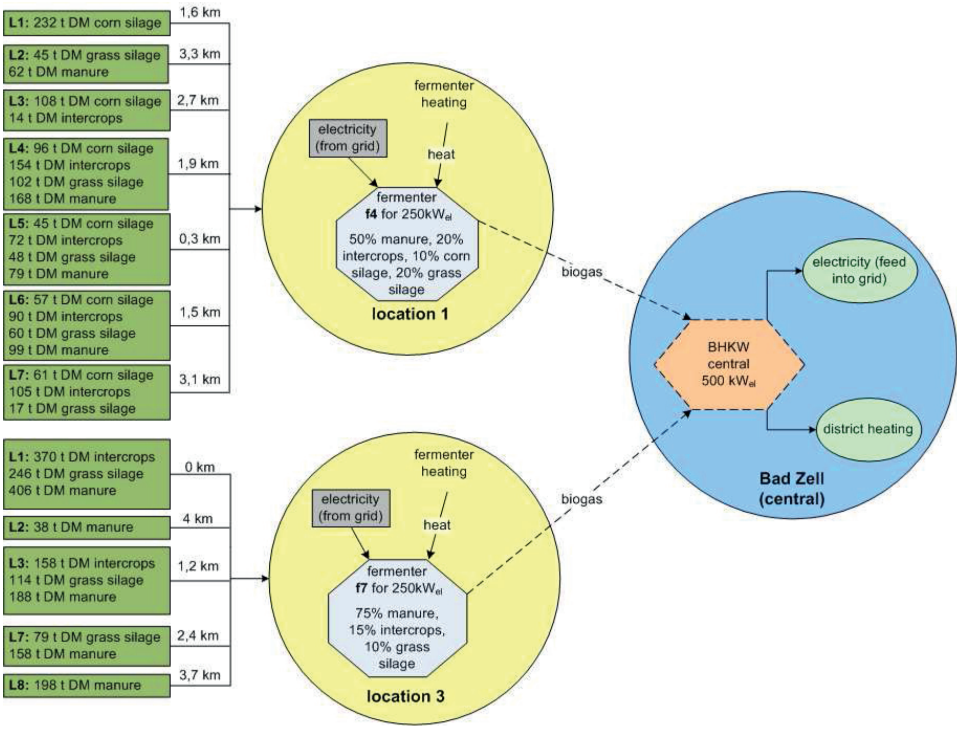

Fig. 5. PNS optimum structure with a central 500 kW_{el} CHP

go along with shortened revenue. With this precondition the optimization of the maximum structure presented in Figure 2 but with only one central 500 kW_{el} CHP unit whereas the rest of the optimum structure (Figure 3) stays the same.

The revenue is narrowed but not as much as it was in scenario 1. To use a 500 kW_{el} central CHP would cause a revenue reduction of yearly 50,000 € within a payout period of 15 years.

4.3.3 Comparison of PNS' optimum solution and the scenarios

Table 9 overviews the results of the three optimizations described before.

	Optimum Structure		Scenario 1		Scenario 2	
Substrate costs	max.	min.	max.	min.	max.	min.
Investment costs [€]						
Total investment costs	2,894,519	2,894,519	2,894,519	2,894,519	2,824,519	2,824,519
Products [MWh / yr] and Revenues [€/yr]						
Total produced electricity	3,826	3,826	3,900	3,900	3,826	3,826
Total produced heat	4,591	4,591	4,680	4,680	4,591	4,591
Revenue for electricity fed in (205 € / MWh)	784,281	784,281	799,500	799,500	707,766	707,766
Revenue for district heating (22,5 € / MWh)	103,296	103,296	105,300	105,300	103,296	103,296
Total revenue [€/yr]	887,576	887,576	904,800	904,800	811,062	811,062
Operating Costs [€/yr]						
Fermentation	114,423	114,423	116,090	116,090	114,423	114,423
CHPs	75,556	75,556	75,556	75,556	51,346	51,346
Transport	60,286	60,286	64,121	64,121	60,286	60,286
Substrates	213,561	129,488	213,400	131,740	213,561	129,488
Electricity	34,432	34,432	35,100	35,100	34,432	34,432
Total operating costs [€/yr]	498,258	414,185	504,267	422,607	474,048	389,975
Operating result without depreciation	389,319	473,392	400,534	482,194	337,015	421,088
Depreciation for 15 years*	192,968	192,968	192,968	192,968	188,301	188,301
Operating result with depreciation*	196,351	280,424	207,566	289,226	148,714	232,787

Table 9. PNS results summary

It turned out that the profitability of a fermenter on location 2 is lower than on the other locations. It was never preferred in any optimum structure. The other locations have one advantage – the shared usage of biogas pipelines whereas low additional costs for location 1 have to be born. There are never heating pipelines from the different locations to the center considered in the optimum technology networks. Just the biogas is transported; heat is produced centrally and distributed within a district heating network, although additional biomass furnaces are required. In scenario 1 the missing corn silage availability was compensated by a higher amount of intercrops, referring to the CH_4 content, and it shows the best revenue, because of higher plant utilization and higher revenue for electricity and heat production. Although in the optimal scenario the amount of corn relating to the total feedstock was not even 17 % of the total (dry matter) the compensation for corn with intercrops results in higher revenue. For more corn that intercrops compensate in the input the impact would be even higher. Therefore it is obvious that intercrops can be a profitable feedstock to run a biogas plant. For the case study the availability of intercrops would have to be raised as described before which would lead to the best technology network for the region.

The system has two limiting factors; on the one hand the distances between the fermenter locations and the feedstock providers accompanying different transport costs and on the other hand the limited resource availability. It could be shown that it is not lucrative to run a central CHP with higher capacity (500 kW_{el}) as feed-in tariffs are lower and less revenue can be gained. Nevertheless, from the point of view of sustainability, it would be preferable to substitute two smaller CHPs with a bigger one. An adaptation of reimbursement schemes to the solutions presented is recommended.

5. SPI evaluation

Based on the economic results of the PNS optimization and previous SPI evaluation of different intercrops, a footprint for the PNS results was calculated. The evaluation includes every substrate, transport, net electricity and infrastructure for fermenters and CHP units. SPIonExcel already provides a huge database of LCIA datasets which can be used for modeling the scenarios. In case of intercrops substrate the SPI value for conservation tillage + self-loading trailer from Table 4 was used.

SPI evaluation results					
		electricity		heat	
	overall SPI [km²]	production [MWh / a]	SPI [m² / MWh]	production [MWh / a]	SPI [m² / MWh]
Optimum solution	93.08	3,825	21,503	4,591	2,360
Scenario 1 - No corn	89.32	3,900	20,236	4,680	2,221
Scenario 2 - 500KW_{el} BHKW	91.51	3,825	20,876	4,591	2,539

Table 10. LCIA results based on PNS scenarios

The overall footprint points out the environmental impact for one year of production. In case of the optimum solution it would need 93.08 km² of area which has to be reserved to embed the production sustainably into nature. The overall footprint is shared between both products according the amount of output and the price per MWh (electricity: 205 €/MWh; heat: 22.5 €/MWh). Price allocation of the footprint leads to a higher footprint for the higher valued product.

Scenario 1 has a benefit from the ecological point of view and almost equal revenue according to Table 9. For scenario 2 there is only a slightly difference to the optimum solution because of two small CHP units instead one.

Main impact categories are in every case ‘fossil carbon’, ‘emissions to water’ and ‘air’. This mainly derives from the utilization of net electricity which contributes around 45 % to the whole footprint. Main contribution to this categories stemming from net electricity and machinery input in agriculture which are still mainly fossil based. This is also the main optimization potential for a further decrease of the footprint.

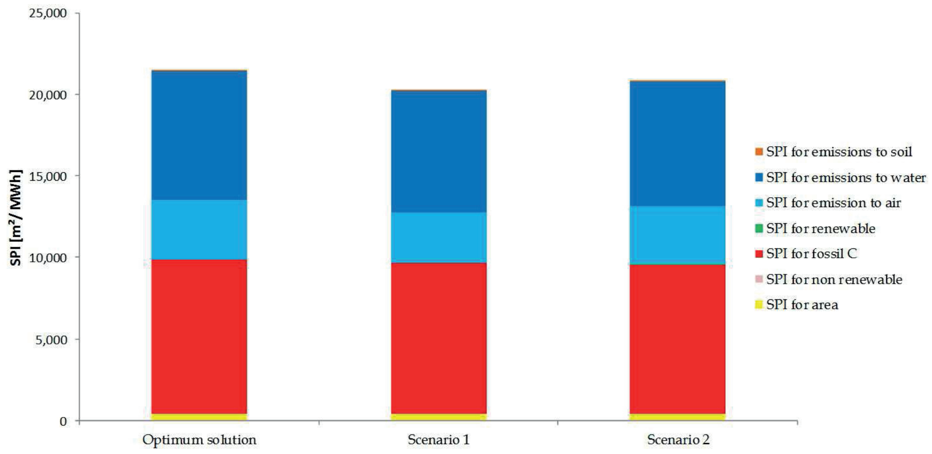

Fig. 6. SPI category comparison

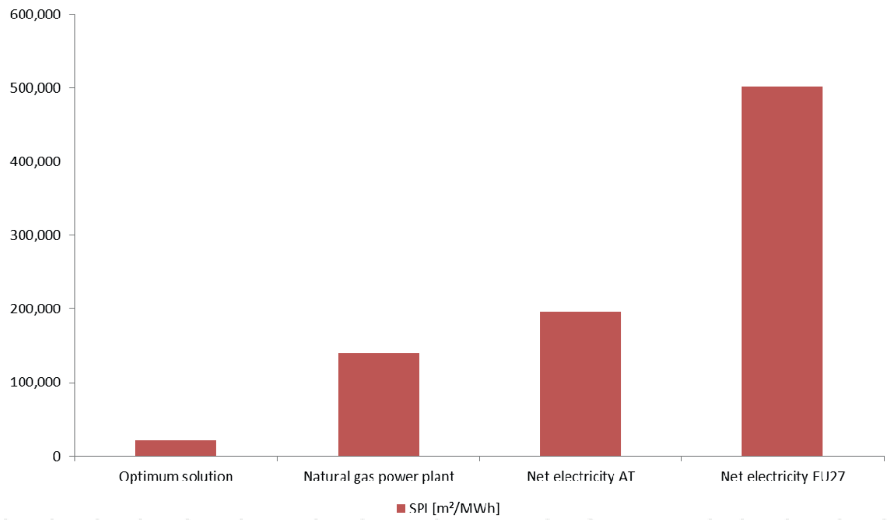

Fig. 7. Comparison of electricity production

Compared to other electricity provision system the optimum solution from the PNS has an ecological benefit in footprint ranging from 61 to 96 % which is pointed out in Figure 7. Although the footprint of the optimum solution could be optimized by using the produced electricity for itself and not selling to the grid (which has economic reasons because of high feed-in tariffs) the ecological benefit compared to other sources is obvious. Every contribution to a greener net infects simultaneously all net participants.

6. Conclusion

The three pillar principle of sustainability serves as conceptual framework to conclude this study. Not only economic and ecological factors are important to implement innovative structures. Often we forget about the social component, the third pillar of sustainability. Not to do so farmers' opinion about intercrops where taken into account. It turned out that intercrops production also abuts on farmers' psychological barriers and the need of intensive cooperation among farmers in the surrounding of a biogas plant. In conjunction with economic risk and high investments, determining farm management for at least 15 years it becomes obvious, that well-considered decisions are to be made. Therefore, it is not astonishing that farmers hesitate, if economic benefits do not clearly compensate social an managerial risks of biogas production from intercrops. Furthermore, the situation that biogas production from corn is favorable regarding practicability in comparison to biogas production from intercrops, reduces farmers motivation to decide for the latter. But even the growing and harvesting of intercrops requires additional work and the strict time frame to cultivate fields, the risk of soil compaction through harvest and potential lower yields of main crops after winter intercrops are counter-arguments to cooperate with farmers already running biogas plants. Higher feed-in tariffs for biogas from intercrops seem to be inevitable and sensitization of decision makers and farmers is needed to emphasize that the planting of intercrops holds many advantages and that intercrops reduce the ecological footprint decisively. Although a higher energy input for agricultural machines is required because of the additional workload for intercrops. In summary the energy balance per hectare including biogas production points out a benefit. In times of green taxes a reduction of CO_2 emissions can diminish production costs. More biogas output per hectare raises the income beside minimized mineral fertilizer demand reduces costs and lowers the ecological footprint. Furthermore, biogas production from intercrops contributes to a reduction of nitrate leaching and nitrous oxide emissions from agriculture. With the transport optimization in-between the network the ecological footprint decreases caused by intelligent fermenter set-up going along with less transport kilometers and fuel demand. A farmer association running an optimal network described before lowers the investment risk and ensures continuous operation and stable substrate availability. On the other hand an association has the potential to strengthen the community and the social cohesion of regions. Some of the advantages mentioned before effect the regional value added positively. On closer examination it could be shown that intercrops can play an important role in sustainable agriculture for the future by running a social and ecological acceptable network and still being lucrative for the operators and the region. Finally biogas production from intercrops does not affect the security of food supply. On the contrary it may even increase productivity in the case of stockless organic farming.

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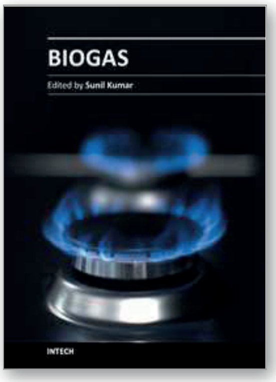

Biogas
Edited by Dr. Sunil Kumar

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Published online 14, March, 2012
Published in print edition March, 2012

This book contains research on the chemistry of each step of biogas generation, along with engineering principles and practices, feasibility of biogas production in processing technologies, especially anaerobic digestion of waste and gas production system, its modeling, kinetics along with other associated aspects, utilization and purification of biogas, economy and energy issues, pipe design for biogas energy, microbiological aspects, phyto-fermentation, biogas plant constructions, assessment of ecological potential, biogas generation from sludge, rheological characterization, etc.

Paper 4

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Optimal Renewable Energy Systems for Regions

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ABSTRACT

Most sources for renewable energy can be deduced from solar radiation as the main natural income of society. Contrary to conventional fossil and radioactive energy resources that are mined or pumped out from central point sources, solar energy is a de-central resource that requires area for its conversion to useful products and services. This requires a new technological as well as logistical concept for energy systems where regions play a key role as providers of energy and goods. The contribution will provide the conceptual framework for renewable energy system generation on a regional level, taking into account the responsibility of regions to provide goods and services to the larger society and to support urban centres. It will show how optimal resource-technology-demand networks may be constructed, using process network synthesis approaches and how the ecological efficiency of such regional systems can be measured. Application of these methods to real life case studies (in particular the region of Mühlviertel in Austria) will on the one hand prove the versatility of the methods presented and on the other hand will provide insight into the scope of necessary change if society moves towards a low carbon sustainable energy system.

KEYWORDS

Process Network Synthesis, RES, regions, Sustainable Process Index

INTRODUCTION

There is general agreement that fossil resources are approaching their production maximum. The time frame ranges up to 2020 for crude oil and up to 2060 for natural gas [1, 2], with coal remaining available for considerably longer time spans. These resource limitations have to be seen in combination with the discourse about global warming that requires a drastic reduction of (fossil) carbon emission. Taken together these two trends call for a dramatic change in the resource base over the 21st century, away from fossil towards renewable sources.

The change towards renewable resources however entails an equally drastic transformation of supply chains: whereas fossil resources are retrieved from typical point sources, most renewable resources are based on solar radiation either directly (photovoltaic) or indirectly (wind power, hydro power, biogenic resources based technologies) and therefore require area for their generation [3]. This puts new responsibilities into the hands of societal and political entities that exert control over land, most notably regions.

Interestingly enough, regions have become dynamic political players, most notably since the Earth Summit in Rio de Janeiro in 1992 [4, 5]. As the flip side of globalisation

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regional and local entities have emerged as major drivers of political change in Europe [6]. These entities however have encompassing planning objectives that not only address the purely technological side of resource utilisation but also have to bring environmental and social aspects of innovations in line with economic considerations [7] and have to address issues of spatial planning, energy provision and use [8].

It is within this framework that innovation for sustainable regional energy systems has to be discussed. This requires a comprehensive set of planning tools that will be discussed and that will be elucidated in the case study offered in in this paper.

FRAMING THE PROBLEM

Providing solutions that allow regions to address their future role as major players in the game to provide society with energy and material resources requires a comprehensive approach to resource utilisation that also takes into account the inherent mechanisms of regional decision making. Renewable energy systems are characterised by highly complex interaction between actors from different sectors as well as long ranging decisions about the economic and social structure of regions and its impact on nature. Therefore decisions on the technological solutions to utilise regional resources have to be subjected to participatory planning processes involving all parties contributing and concerned by the final outcome. These planning processes by definition involve not only experts in the energy field but also providers of resources (e.g. farmers), grid operators, regional authorities and the citizens in the region that might be affected by changes in land use and energy provision as well as energy utilisation patterns. Rather than providing fixed technical solutions participatory planning requires the provision of sound, comprehensive and comparable scenarios that form the base of a discourse about the future of the region.

From a more technical point of view this requires to provide regional decision makers with the means to generate systemic structures for utilising regional resources optimally within the framework of available sources, existing economic and technical structure and demand in the region. Any planning approach that just builds on optimising single lines of resource utilisation (say optimising the use of wood) or focussing on single technologies (say biogas generation) will be insufficient to meet the planning goal of optimal resource utilisation in a region. Regions usually offer a variety of renewable resources and require meeting different demands like residential and industrial heat/cooling, electricity and mobility. This alone requires a technology system rather than optimising single technologies or the utilisation of single resources. On top of that efficiency in resource utilisation calls for interaction of technologies, where cascades of utilisation will offer higher value added on the same (limited) resource base.

Equally suboptimal are planning approaches looking for just meeting the demand within a region. Most energy forms (with the notable exception of thermal energy) are transportable and inter-regional distribution grids as well as transport pathways for concentrated energy carriers, gas and electricity exist in most regions. This subjects these energy forms to inter-regional and in many cases global market forces. It is within this inter-regional and global playing field that decision makers have to shape the future of their regions.

The task at hand for planning of renewable energy systems for regions is therefore to generate scenarios for utilisation networks that link resources, technologies, regional demand and inter-regional markets in a way that optimises the value generated for the region. This value however is not restricted to the economic aspect but also includes environmental sustainability as well as social and cultural aspects. Changing the boundary conditions of this optimisation like different land use regimes, different price

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structures for resources, products and services as well as taking into account competition between different uses of resources (e.g. between food and energy generation) will then lead to the decision support system needed in shaping future development in regions.

Looking at this problem from an engineering perspective, there are some aspects that can be supported by existing methods especially used in process engineering. The generation of regional technology networks is similar to the generation of optimal process networks, solved by process synthesis approaches. Both aim at generating a network of process steps that convert material and energy resources into valuable products where both resources and product demand may be limited and where different chains of process step may compete for the same resources, leading to similar products. Providing insight into the ecological pressure of regional technology networks is, at least on the metabolic level that takes into account mass and energy exchange with the environment, similar to the problem of environmental evaluation of industrial processes. It is therefore sensible to adapt the methods already well developed for process industry to the new task of providing decision support systems for regional renewable energy systems. It has to be reiterated at this point however that the results generated by these methods aim at providing scenarios for regional participatory planning rather than "optimal solutions" as they usually do in process industry.

ADAPTING PROCESS SYNTHESIS AND ECOLOGICAL PROCESS EVALUATION METHODS

There exist a wide variety of process synthesis and ecological process evaluation methods that can be adapted to the requirements of supporting planning for regional renewable energy systems. The current paper will discuss two particular methods and their adaptation and apply them to a case study.

Process network synthesis (PNS) using the P-graph method

The PNS method [9] has been successfully applied to develop optimal process networks for renewable resource utilisation processes [10-12]. This method derives maximum structures (encompassing all feasible structures fulfilling the given boundary conditions) via combinatorial rules using the bipartite graph representation of processes, arriving at optimal structures (that optimise a given target function e.g. value added generated by the process network) using a branch-and-bound optimisation routine. Besides short computation times this method has the advantage to securely find the optimum structure even for complex problems. This advantage is important in the application to regional renewable energy systems as it guarantees that all developed scenarios are actually optimal within their boundary conditions and therefore directly comparable. The method requires knowledge about the energy and material balance as well as economic parameters like operating costs, investment costs and depreciation periods for each technology included into the considerations.

A comprehensive description of the method is out of scope of the current paper; the reader is kindly referred to the original literature as well as to the very informative web-page of the PNS method [13]. The following paragraphs will be dedicated to the explanation of necessary changes and amendments to the method, if it is to be applied to regional renewable energy systems.

The main challenge by applying the PNS to regional energy systems lies in defining new "technologies" that play major roles in any resource-technology-demand network. This is in particular true for all activities within the primary sector like agriculture and forestry. Here we have one basic resource which is land. This resource is then the "input" to competing "primary technologies" i.e. different ways of land use which generate the

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material resources then utilised in energy technologies, be they crops, wood, grass also including residues like straw. Restrictions on land use to be considered are on the one hand climatic: not all crops may be grown in all regions. This is best handled by providing a regionally adapted set of primary technologies that generate the agricultural and forestry products amenable to the individual regional context. All these primary technologies have to be described in terms of their material and energy input (e.g. fertiliser and machinery use per hectare for a certain crop, yields per hectare and year) and their cost factors (cost of fertiliser, investment for farm equipment, etc.). Different agricultural practices (e.g. conventional and organic farming) can easily be integrated by changing the material and energy inventory as well as the prices of crops accordingly, leading not only to scenarios describing the most optimal land use but even giving decision support for the way the land is actually managed.

On the other hand there are restrictions regarding the land use as such as fields, grass land and forests are not interchangeable in regions without limitations and maintaining fertility in many cases requires crop rotation. This can be handled in partitioning the basic resource land into sub-resources such as fields, forests and grass land, each serving a particular set of primary technologies that generate the respective products, wood for forests, crops for fields and grass for grassland. Partitioning even further can be used to include crop rotation. If for instance oil seeds may only be grown every fourth year, it means that a fourth of the field area is open as a resource for the primary technology of growing oil seeds whereas the other land is not defined as a resource for this primary technology.

Finally energy technologies compete for products from primary technologies with other uses, most importantly the food sector. Therefore these products will also be assigned prices and a set of secondary technologies (e.g. husbandry, food processing) has to be included to decide between different pathways for utilising bio-resources. In many cases these technologies may also provide input to energy technologies (e.g. manure that may be used in biogas fermenters) further interlinking the maximum structure for regional applications of the PNS.

Besides including the primary sector regional renewable energy systems are critically dependent on logistics. Many biogenic resources, especially residues (e.g. straw) and wastes (manure) have dismal logistical properties like low transport densities and high water content. This means that transport is a major factor in the design of regional technology networks and has to be factored into the decision about the optimal sizes of energy provision technologies. This may be accomplished by implementing transport as intermediate technologies between biogenic resources (as products from primary technologies and/or technologies from the food sector) and different sizes of energy technologies: smaller size technologies may then be served by (local) tractor transport over a mean distance defined by regional context, installations with larger capacities require transport via road or rail according to the mean distance to their resource base, which again is dependent on regional context.

Providing heat (or cooling) for industry and residential areas is always a major factor of regional energy systems that has to be integrated into any synthesis of technology networks. This factor has two aspects: on the one hand energy provision here competes with energy saving measures and on the other hand thermal energy may only be transported over short distances via heat/cooling distribution grids. The former may be tackled by introducing “efficiency technologies” like insulating buildings. These technologies “provide” the energy difference between the situation in status quo and a situation when the optimised technology network is implemented. Investment cost, operating cost (if applicable) and material balance for these technologies, as well as

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energy saving per unit of technology (e.g. kilogram of insulation) have to be defined. The latter may be given for different applications (e.g. buildings of different standards).

The particular logistic property of thermal energy that it can only be feasibly transported over relatively short distances by heat/cooling distribution grids has to be factored in by indicating the heat/cooling load that might be covered by district heating/cooling. This thermal load may then be supplied either by central heating/cooling installations or by off-heat from Combined Heat and Power (CHP) plants or by excess heat from industrial plants. Conversely high temperature process heat may either be provided directly or as excess heat from CHP plants.

Another important feature of the PNS method is the possibility to balance production with demand. This is particularly useful for implementing boundary conditions often asked for by regional actors: to guarantee supply of certain goods (e.g. food) or services (e.g. residential heating) from local resources.

The Sustainable Process Index (SPI)

This index describes the aggregated ecological pressure of a certain process by the area needed to embed this process sustainably into the ecosphere, rendering a kind of "ecological footprint". The SPI identifies the area A_{tot} necessary to embed a life cycle providing a certain goods or service sustainably into the ecosphere. The life cycle comprises all activities from raw material generation to the final conversion and, when applicable, end use of a product. A_{tot} is calculated according to

$$A_{tot} = A_R + A_E + A_I + A_S + A_P \quad (1)$$

The areas on the right hand side are called "partial areas" and refer to impacts of different productive aspects. A_R, the area required for the production of raw materials. A_E is the area necessary to provide energy. A_I, the area to provide the installation for the process, A_S is the area required for the staff and A_P is the area for sustainable dissipation of products and by-products. The reference period for these partial areas is one year. All material flows and energy flows exchanged between the life cycle to provide a good or service in question and the environment will give raise to an according area under the categories identified above. The SPI method is based on the comparison of natural flows with the flows generated by a technological process. The conversion of mass and energy flows into area is based on two general "sustainability principles":

Principle 1: Anthropogenic mass flows must not alter global material cycles; as in most global cycles (like the carbon cycle) the flow to long term storage compartments is the rate defining step of these dynamic global systems, flows induced by human activities must be scaled against these flows to long term stores.

Principle 2: Anthropogenic mass flows must not alter the quality of local environmental compartments; here the SPI method defines maximum allowable flows to the environment based on the natural (existing) qualities of the compartments and their replenishment rate per unit of area.

Whenever a life cycle produces more than one product or service (e.g. in CHP technologies where heat, electricity and material products like manure from biogas plants or ash from incineration are produced) ecological pressures have to be allocated to them according to an allocation rule. In this case study ecological pressures were allocated to all products produced in the region. Allocation was based on the income calculated at market prices.

The SPI already draws on an extensive data base concerning energy and efficiency technologies that is accessible on the web page [13] or from previous work [14, 15]. A

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particular tool for evaluating the impact of primary sector technologies was recently developed and is accessible via [16].

The advantage of using the SPI method for evaluating regional renewable energy systems is twofold: on the one hand this measure offers a comprehensive, life cycle wide evaluation that rates very distinct impact like CO_2 and heavy metals emissions on an aggregate level, allowing for comparison on the base of sound sustainability principles. On the other hand the SPI clearly distinguishes between renewable and fossil resource based technologies which is of high importance to regional actors.

CASE STUDY MÜHLVIERTEL

The case study will provide insight into the application of the methods described above in a real world development process on the regional level in Austria. The task at hand was to provide regional decision makers with a reliable base for deciding about the future pathway to utilise their renewable resources and restructure their energy system in order to reduce the overall ecological pressure.

The region in question is the Mühlviertel, a region spanning from the Danube to the German and Czech boarder, close to Linz, the capital of the federal state Upper Austria. The region encompasses 3,080 km² with a population of approx. 268,000 citizens. It is a highly agricultural region with particularly strong emphasis on grass land and forestry.

In co-operation with regional actors three main scenarios were defined:

- Optimal scenario: maximum value added for the region;
- Autarky scenario: total autarky for food and energy;
- Supply Linz scenario: optimal value added with responsibility to keep supply of food for the urban centre of Linz slightly above current levels.

Based on the climatic situation of the Mühlviertel and in consultation with local experts a list of possible agricultural products, their yields and limitations was defined. The current status and number of buildings as well as information about existing energy installations, waste flows and industrial energy demand was collected from a survey among all involved communities. In consultation with decision makers in the region the list of eligible technologies was defined, using a conservative approach by including only technologies that are either already state of the art or proven in industrial size demonstration plants such as the “Green Biorefinery”, a technology that uses pressed juice from silage to obtain amino acids and lactic acid [17]. Together, all render a maximum structure employing the PNS method as given in Figure 1.

By setting the demand according to the boundary conditions of the scenarios and using market prices for all products and services (if not stated otherwise in the explanation of the scenarios below), the three scenarios were then calculated using the PNS editor from the homepage given above. The definition of all boundary conditions and technology parameters is however out of scope for the current paper. The interested reader is kindly referred to the end report of the project [18]. The following paragraphs will be dedicated to describe the results of these calculations as well as the ecological implications revealed by the evaluation with the SPI.

Optimal scenario 1

The boundary conditions for the optimal scenario resulted in two almost equally attractive structures for the regional technology system:

- A “biogas fuel” scenario (scenario 1A);
- “High price beef” scenario (scenario 1B).

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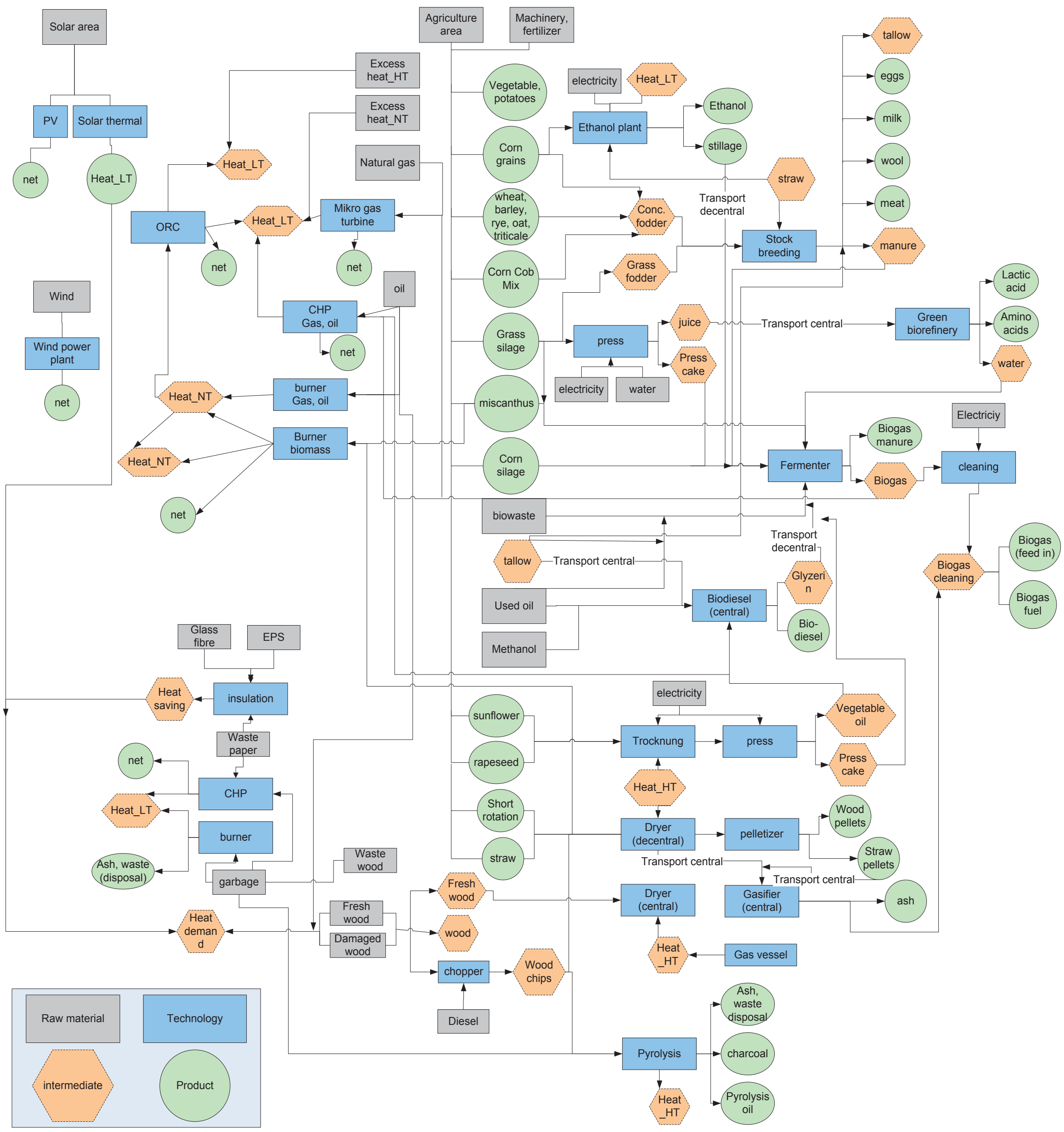

Figure 1. Maximum structure for the Mühlviertel case study

If the price for biogas is set to a level currently paid for as fuel (65 €/MWh), almost the whole grassland is used to provide input for biogas fermenters. Silage is produced from grass, then pressed, with the juice going to the green bio-refinery and the press cake is utilised in biogas fermenters. The biogas is then cleaned and fed in the grid to be distributed to fuel stations within and outside the region. Fields are mainly used to support (organic) pork breeding, with most of the pork being exported out of the region. Vegetables for regional consumption are also grown on the fields.

Almost as much added value can be achieved for the region if beef is produced with organic farming and the price for this product will be in the upper range for high quality meat (4,030 €/t). In this case grassland will be used to support cattle breeding. Manure is collected as much as possible and processed in biogas fermenters, again cleaned and fed to the grid. This scenario however has lower biogas production and no production of chemicals from the Green Biorefinery. Fields support mostly cattle breeding, with the

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remainder going to organic pork breeding and vegetable production for regional consumption.

Both scenarios use the available forest products for provision of residential heating as well as process heat. Wherever possible district heating based on wood chips is preferred, with firewood furnaces supplying houses outside the range of district heating distribution grids. Buildings are insulated as much as possible. All waste wood and a small portion of fresh wood are utilised in pyrolysis plants, generating oil that is subsequently refined into bio-fuel. Fat from slaughterhouses is also processed to bio-diesel in both scenarios. Wind-power, hydro power and photovoltaic are utilised to capacity which means in the case of PV a steep increase of installed area, up to 30 fold the amount used currently.

Autarky scenario 2

Autarky requires a different strategy as all food and energy have to be produced in the region. In this scenario heat for individual buildings outside the range of district heating grids is again provided mostly by wood, but here material utilisation of wood for regional construction is competing for this resource. Grassland supplies, besides the necessary amounts for cattle breeding and milk cows, biogas fermenters, with silage juice going to the Green Biorefinery although at reduced rates compared to the scenario 1A (as much silage goes to husbandry). Biogas is used for CHP, generating electricity for regional consumption (which can be covered if photovoltaic, wind power and hydro power are utilised to capacity). Part of the biogas is again cleaned and used for transport fuel however this part is considerably lower than in scenario 1A. District heating uses excess heat from these CHP-plants with the shortfall filled by using miscanthus grown on fields in heating plants. Food for regional consumption can be supplied by local agriculture.

The use of waste wood, fat from slaughtering is the same as in the optimum scenarios, buildings again are insulated as much as possible. Transport fuel however cannot be supplied in an amount to meet transport needs at the current level.

Supplying Linz scenario 3

Supplying the urban centre of Linz with food (cereals as well as meat) at a slightly higher level than today of course requires land that is then not available for either energy resources or other ways of utilisation that increase the added value in the region. Although regional heat demand can be met by using wood and employing insulation to increase energy efficiency of buildings, neither electricity demand nor transport energy can then be supplied in the amount to meet current levels of consumption. In general this scenario calls for a similar technological structure like scenario 1A, albeit with lower capacities for biogas fermenters and Green Biorefineries as fewer resources may be allocated to energy and industrial use.

COMPARING SCENARIOS

The scenarios differ regarding the supply of energy for the region. Heat demand can always be met; however transport and electricity demand vary in their degree of regional supply as shown in Figure 2.

Regarding the economic parameters the scenarios differ widely, especially with respect to the ratio between investment and revenue. Figure 3 shows this for all scenarios.

Figure 3 shows that scenario 1B shows a slightly lower revenue than 1A (roughly 3%) however needs 16% less investment. Autarky requires almost the same investment as the optimal technology network however achieves only 63% of the revenue. Supplying a major urban centre with food decreases revenue dramatically, to below 60% of the

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optimum level. This scenario however also requires the lowest investment with only 70% the amount necessary for the optimum scenario.

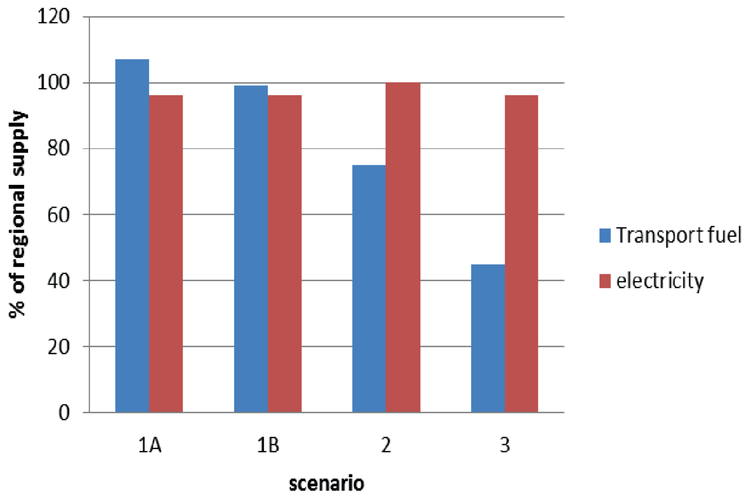

Figure 2. Regional coverage of transport and electricity demand in the scenarios

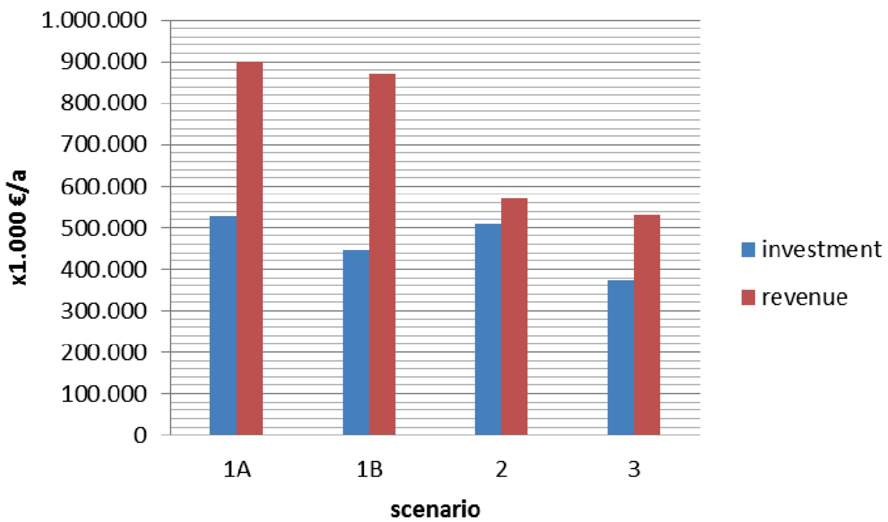

Figure 3. Investment (annualised with 10 years depreciation time) and yearly revenue for all scenarios

Concerning the ecological pressure, all scenarios presented here are reducing the ecological footprint against the status quo considerably as Figure 4 shows. This figure also shows the reduction in the ecological footprint for providing energy in the different scenarios using the different technological pathways defined by PNS optimisation.

Figure 4 shows that as all scenarios change the energy system of the region mostly towards renewable resources, overall ecological pressure of the region is reduced to a third (scenario 1 and 3) and even a quarter (scenario 2). All energy services provided by regional resources show massively reduced ecological footprints, with heat at only 20 % of the current status in all scenarios. The differences in the footprint of fuel are mostly due to the percentage of cleaned biogas used in the scenario, with scenario 1A showing a relatively high (but still much reduced) footprint for this energy form. By and large,

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autarky shows low ecological footprints. That has to be contrasted with the low economic performance of this scenario.

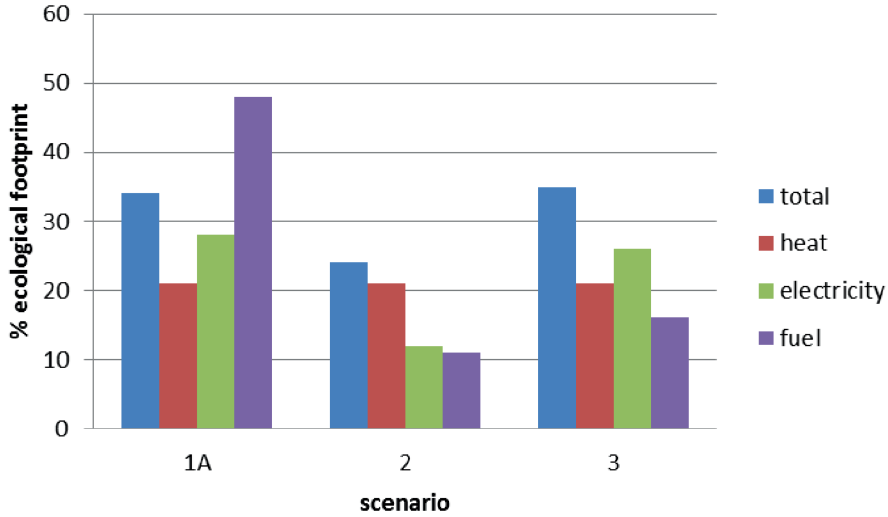

Figure 4: Comparison of ecological pressures using the SPI evaluation of all scenarios against the status quo (footprint for energy referring only to regional provision)

What regional decision makers can learn

As stated earlier, applying PNS and SPI to regional renewable energy systems must be seen in the context of encompassing decisions about the future of regions. The scenarios presented here (which are only a fraction of the scenarios calculated in this process) delimit the decision space for the development of this region and provide insight into the choices as well as stable elements of any future technology structure based on regional resources.

First stable elements that show up in every scenario can be analysed:

- Wood will become the base for heat provision in the region; this means that all measures to mobilise wood resources and establish energy logistics for wood are safe decisions for the region;
- District heating should be developed to capacity;
- PV as well as wind and hydro power should be developed to capacity;
- Insulating all buildings to low energy standards is necessary to gain energy efficiency;
- Biogas mobility shows great potential in all scenarios; this means that logistics for this form of fuel as well as measures to increase the car fleet that may use bio-methane as fuel are safe decisions for the future.

As interesting as the stable elements are the stark choices that the scenarios reveal. Amazingly enough, the future of the Mühlviertel critically depends on the utilisation of grassland and only to a minor degree on all other land resources. There is a choice to orient the region towards energy export and industrial utilisation of renewable resources (scenario 1A) or intensify marketing of existing agricultural products, in particular beef (scenario 1B). Both require major efforts to open new markets and to build up the necessary infrastructure and marketing structure. Whereas a focus on energy and industrial utilisation promises the highest revenues it also requires the highest investment.

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Autarky as well as supply of a nearby urban centre will diminish revenue for the region considerably. Autarky in particular couples low revenues with high investment requirements.

All scenarios show much lower ecological pressures than the status quo, with the lowest overall environmental impact exerted by autarky. The environmental pressure for heat will be reduced to a fifth of the current level and stays relatively constant in all scenarios as the way heat is provided is stable throughout the scenarios. Both fuel and electricity footprints vary considerably, depending on the different pathways for their provision associated with the scenarios.

CONCLUSION

Regions will become major decision levels for the energy change necessary in the 21st century. As regional resources as well as demands are quite diverse, technological solutions will have to be adapted to the individual regional context. Utilising renewable resources to gain maximum regional revenue while exerting minimum ecological pressure will always require technological systems rather than single technologies, taking into account the framework and boundary conditions resulting from the ecological, logistical, economical and societal aspects of utilising renewable resources as discussed in this paper.

Implementation of radically new technological systems that entail major changes in business models and logistics require careful and participatory planning processes involving actors that have in many cases not co-operated before. This needs efficient tools that allow for systemic optimisation while providing insights into the long term choices to be taken. Adapting process synthesis and ecological process evaluation to the regional case can help to provide decision makers with comparable scenarios that will guide the planning process.

The case study shows that these tools will lead to a much clearer picture about the specific challenges for regional development when introducing renewable energy systems. It also shows clearly that using regional renewable resources lead to considerable chances for increasing regional revenue while cutting ecological impact dramatically.

ACKNOWLEDGEMENTS

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Paper 5

Energy, Sustainability and Society
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ORIGINAL ARTICLE Open Access

Sustainability appraisal of residential energy demand and supply - a life cycle approach including heating, electricity, embodied energy and mobility

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Abstract

This paper introduces the concepts, methods and the implementation of a calculator for the energetic long term analysis of residential settlement structures (ELAS). The freely available online tool addresses, on the one hand, the complexity of the environmental impacts of buildings and settlements including embodied energy and on the other hand, the mobility of the inhabitants and the necessity to provide ecological and socio-economic valuation on the base of a coherent data set. Regarding the complexity of ecological impacts, housing was represented as a life cycle network, combining the life cycles of energy provision as well as buildings and infrastructure depending on the location and supply structure of the settlement. Comprehensive inventories for these different aspects were included. They were then used to evaluate the whole system of activity linked to buildings and settlements with three different ecological valuation methods and then coupled with a socio-economic appraisal. With the ELAS calculator, a *status quo* analysis for existing settlements can be carried out, as well as planning alternatives can be assessed which include new developments, the renovation of buildings in the settlement, the change of energy supplies as well as the demolition of settlements with reconstruction on the same or a different site.

Background

The Energy Roadmap 2050 of the European Union aims at 80% to 95% greenhouse gas reduction until 2050 [1]. Energy saving, energy efficiency and the shift towards renewable energy supplies have to be jointly applied in order to reduce the environmental overshoot of the current energy systems. This environmental overshoot is due to the high energy intensity of society and the extensive use of fossil and nuclear energy sources [2-4]. All sectors of society and economy have to contribute to achieve this shift in energy supplies.

Households are important consumers of energy in the European Union, using up about 27% of the European energy demand within the settlement infrastructure plus a considerable part of the 33% of transport energy. Finally, 24% energy is consumed in the industrial sector, which can also be attributed to the consumption of private households to a large share (all figures based on 2009 data from Eurostat, [5]). Much of this energy demand is related to the dwelling itself, and concerning the mobility of persons, to the site of the residential area.

Planning decisions of settlements and houses have considerable impacts on the energy demand and the technological options for the energy supply of residential areas, and, therefore, on the energy consumption of society. These decisions are not only confined to the energy consumptions of households but affect the transport sector and, via embodied energy in goods and services, many industrial sectors as well. As spatial structures are long lasting, planning decisions determine the energy consumption of society in the long term and include, *inter alia*, the choice of a site, the determination of the infrastructure, the building densities aspired, the energy

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standards and the construction materials of buildings as well as the energy sources and energy provision technology.

In order to reach sustainable development, such decisions should be made on the sound assessment of alternatives including the aspects of energy demand and supply and their related environmental and socio-economic effects. Furthermore, the sustainable construction and operation of buildings and settlements will have to become a fundamental part of any sustainability oriented energy strategy.

Therefore, planning tools are required that empower decision makers to recognize the long-term consequences of their actions regarding the environmental and socio-economic impacts of buildings and settlements along their life cycle. Such planning tools have to offer a sound estimation of the energy demand of settlements, and an evaluation of the environmental and socio-economic impacts depending on the energy supply. Various tools that help optimizing buildings, are already available in great number (see e.g. BREEAM [6], baubook [7], WECO BIS [8]). Yet, these tools still have to be complemented by further approaches in order to support a comprehensive, sustainability-oriented quantitative assessment of planning decisions related to the energy demand and supply of housing that includes not only buildings but also technical infrastructure and the mobility of residents. In order to fill this gap, we developed a model to calculate the energy demand of households related to dwelling and location, as well as its overall environmental and socio-economic impacts, based on a life cycle approach: the **E**nergetic **L**ong term **A**nalysis of **S**ettlement structures (ELAS). This model was transferred to a freely available online decision-making tool that allows assessing and optimizing settlements, the ELAS calculator (www.elas-calculator.eu). The aim of this article is to introduce the complex ELAS model and the ELAS calculator and to show how this model can support stakeholders in planning processes to take more sustainable decisions about residential development.

When characterising the dwelling-related energy demand of settlements, the following components of energy consumption have to be taken into account:

- Energy demand and supply for the construction of buildings and public infrastructure like roads, sewage systems, water supply systems, street light etc.;
- Energy demand and supply for the maintenance of public infrastructure;
- Energy demand and supply of buildings for room heating, warm water and electricity; and
- Energy demand for the mobility of residents, which depends on the demographic structure of the population, the supply structure and the location of the settlement.

Based on these categories of energy demand and supply, an overall sustainability assessment is calculated with the following fundamental indicators: (1) environmental indicators: ecological footprint (as sustainable process index, SPI), life cycle CO_2 emissions and; (2) socio-economic indicators[a]: regional economic turnover, revenue, regional imports as well as jobs created. This fundamental assessment has the quality of an 'unsustainability' test [3]: Planning alternatives, that fail this test, should not be followed. If the alternatives pass, more detailed issues have to be covered applying further quantitative as well as qualitative indicators in order to guarantee sustainability in a broad perspective. Therefore, the ELAS model can help to reduce the information load on decision-makers by sorting out alternatives that do not provide the chance to strive for sustainable development from the perspective of climate change mitigation and sustainable energy supplies. ELAS can achieve that task by just using a few indicators that can be easily generated by the end users, even though the models behind this assessment are complex.

The model can be applied to existing settlements as well as to planned projects spanning from (1) new settlements as greenfield developments, (2) renewal and renovation of existing settlements with/without expanding them and (3) tearing down and reconstructing settlements on the same site or on a different site.

The ELAS concept

Content of the evaluation

As already pointed out in the introduction, activities to provide housing permeate through all economic sectors. Basic decision like the site chosen for a building and the technical standard of a building will have considerable impact on the energy consumption during its life cycle. This has to be reflected in any reliable decision support tool. The life cycle in this case therefore more resembles a 'life cycle-network' with the dwelling in the centre. Figure 1 shows the life cycle network includes the construction, maintenance and operation of buildings and infrastructure like roads, sewage systems, energy provision grids. The respective life cycles consist of the provision, transport demolition and final disposal or recycling of building materials as well as of building materials with the life cycle of infra-structure, and the life cycles of the energy supply of the buildings for electricity, heating and cooling. Furthermore, the life cycle regarding the mobility of residents is taken into account.

The concept realized in the ELAS calculator is to evaluate the impact of a building or settlement as well as any planned changes to a building or a settlement (including radical changes such as demolition and construction at a different site with a different technological standard) on this 'life cycle-network'. That means that all energy demand-and-supply-relevant impacts generated

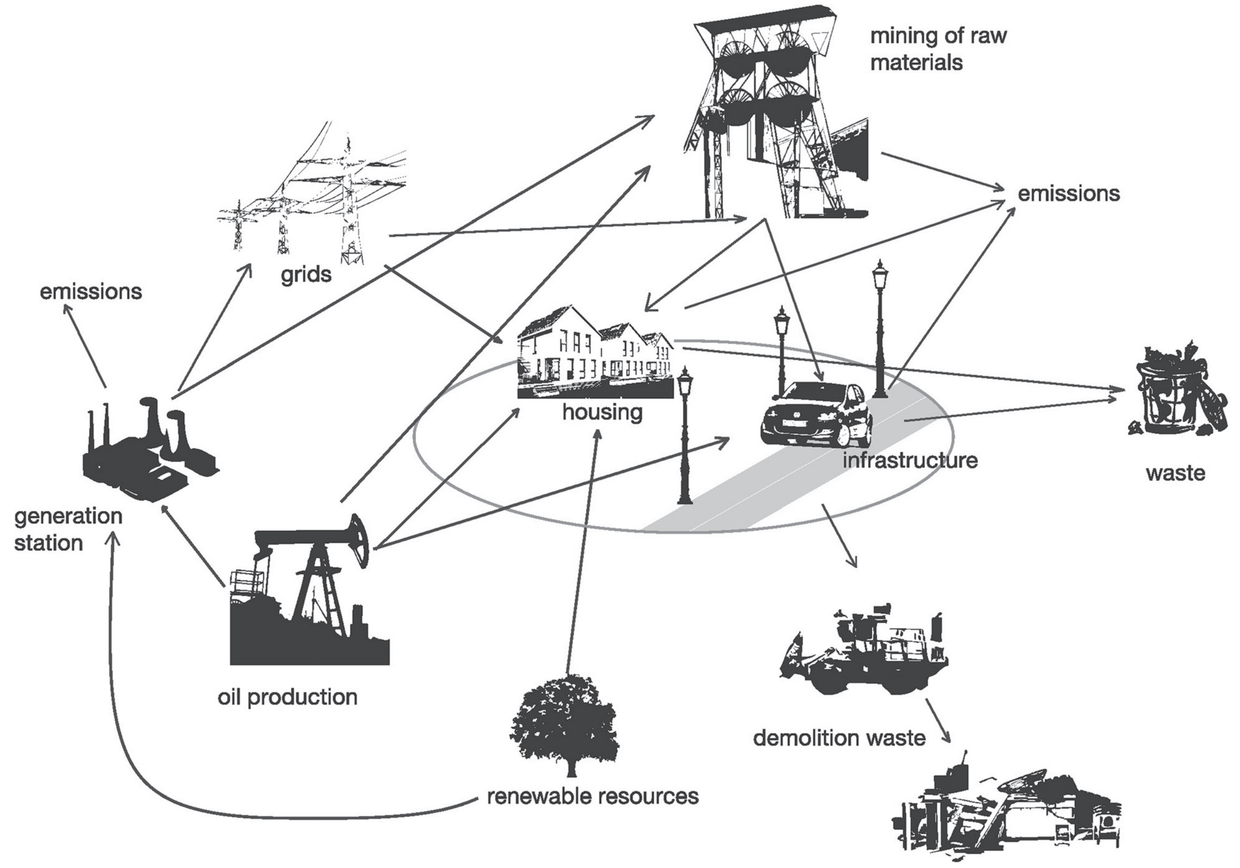

Figure 1 'Life cycle-network' as the base of the ELAS calculator.

along the life cycles constituting this network are calculated and made transparent, not only in environmental but also in economic and social terms. This applies to current operation as well as to planned changes to the existing structure. As resource consumption already took place in the past, the *status quo* of buildings and infrastructure are not rated according to their environmental, economic and social impacts. By this approach, the users of the calculator can assess not only the direct impacts of their decisions but may also gain a comprehensive view on the consequences of their action on nature, economy and society.

The ELAS calculator is designed to support informed decisions about design and operation of buildings and settlements by all relevant actors. It therefore addresses different audiences in order to provide actors on different levels of decision taking with coherent information, thus enabling a discourse within as well as across different levels of actors. In particular, the ELAS calculator is designed to be used by the following:

- Single households in order to assess their individual decisions regarding design, operation and maintenance of their houses and flats, also including the impact their behaviour has on construction, operation and maintenance of infrastructure supporting their buildings and mobility induced by their choices;
- Municipal administrators in order to assess the ecological, economic and social impacts of existing settlements; and
- Planners in order to assess consequences of their activity regarding design and changes in settlements (enlargement, change of technical standards, changes regarding supporting infrastructure and measures concerning energy efficiency and energy provision systems, etc.), including impacts generated by necessary supporting infrastructure and induced mobility by residents.

This requires that the necessary data as well as the representation of results must be adapted to the needs of these actor groups. Figure 2 shows the overall architecture of the calculator. The two principal modes, the 'private mode' and the 'municipal mode' refer to the two main user groups, private households and professional users, respectively. Within the 'municipal mode', the separation

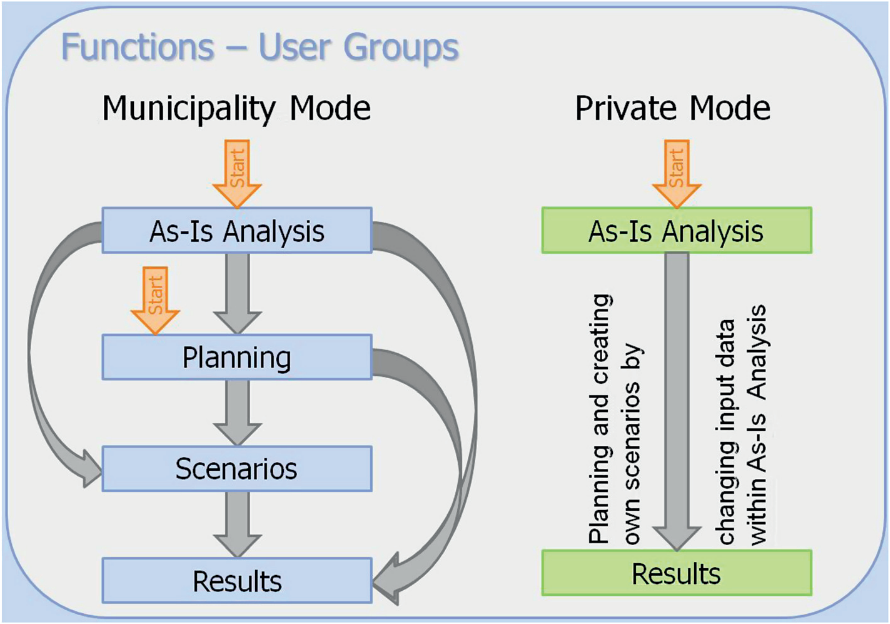

Figure 2 Architecture of the ELAS calculator.

of assessment of an existing settlement (*status quo* analysis) and planning of a new settlement (planning mode) represent the realization of the two tasks, analysis of impacts of existing settlements and planning of new settlements. It is however possible to change from the analysis of an existing settlement to the planning mode and thus assess changes for an existing settlement. Using this option, municipal administrators as well as planners can evaluate not only direct impacts of enlarging of settlements and/or upgrading of technical standards of buildings and infrastructure but also impacts of measures of spatial planning and zoning.

Besides the assessment of the impacts of housing under current conditions, the ELAS calculator offers the option to calculate these impacts under future scenarios (with a time horizon of 2050):

- Trend scenario: The trend scenario is based on studies by Kratena and Schleicher [9] and Friedl and Steininger [10] who estimate that the total travel distance per person will increase by 25% and that energy sources will change: biogas will hold a share of 10% of the fleet and electricity 15%. The electricity demand will rise at 2.2% p.a. Both studies yield insights into the development of gross output in Austria for different business sectors. In the 'Baseline-Szenario' of Kratena and Schleicher [9], the rise in energy prices is modest at most, and the results are comparable to the baseline scenario presented by Friedl and Steininger [10]. It must be noted, however, that future economic projections in both models are not the result of changing energy prices as such, but are due to policy choices regarding the use and production of energy [9] or the sustainability of the transport system [10]. Furthermore, projections in both models are made up to 2015/2020. In order to establish long-term effects up to 2050, we use information about long-term scenarios from Bollen et al. [11]. They calculate future projections of energy use and production based on the 'Four futures for Europe' model of the Dutch Central Planning Bureau.
- Green scenario: In the green scenario, the energy demand of settlements can be reduced by 33%, and the electricity supply is 100% based on renewable energy sources. As in the trend scenario, individual mobility will rise by 25%, but the share of environmentally friendly means of transport will increase and the car fleet will utilize renewable energy sources: 70% based on biogas and 30% based on electricity. The green scenario is based on several studies like Arpaia and Turrini [12], Polasek and Berrer [13], and the economic analysis of energy price shocks by Kilian [14].

These scenarios enable the user to estimate the bandwidth of future impacts of the settlement within reasonable boundaries.

Taking the location of a settlement into account

Any evaluation regarding the sustainability of a settlement has to consider the spatial situation in relation to locations providing all necessary functions for residents living in it. Construction and maintenance of infrastructure as well as mobility requirements for residents depend critically on the distance between settlement and the provision of functions such as retail stores, educational institutions, health provision, administrative centres, etc. The ELAS calculator meets the challenge of systematizing this fundamental factor for the evaluation of settlements by defining different 'levels of centrality' that define what services are provided in the community the settlement is located in, according to Table 1. Higher levels of centrality refer to communities offering a broader spectrum of functions. The calculator offers a step-by-step help function to support the user in defining this fundamental set of data[b]. Using the distances to the different locations providing basic functions for residents (and using demographic information and modal split information explained later), the ELAS calculator is able to evaluate the part of the impact of settlements and buildings related to their locations.

Sustainability evaluation methods used in the ELAS calculator

With the ELAS calculator, a quantitative evaluation of settlements can be carried out from the viewpoint of sustainable development. The ELAS calculator is grounded on a coherent and consistent model and database that allows for an appraisal of environmental and socio-economic aspects. Therefore, the ELAS calculator has the strength to quantify decisions regarding residential development including spatial planning decisions. Yet, the ELAS calculator is not designed to evaluate qualitative issues of residential developments, which are as important as the numerical issues addressed by the ELAS calculator. Such aspects include, e.g. effects on biodiversity, landscape, quality of life, social and inter-generational equity or gender issues.

Overall environmental appraisal

The overall environmental appraisal allows for a general assessment of the environmental impacts of settlements within the life cycle network according to Figure 1. The ELAS calculator uses the same database in order to provide a comprehensive, multidimensional appraisal of the environmental impacts by using several general indicators. Therefore, the ELAS calculator offers a comprehensive planning and assessment tool that relieves the users from considerations about the conclusiveness of life cycle limits or data provision, as the ELAS calculator secures coherence of the life cycle assessment. Furthermore, information overload of the users by too many indicators has to be avoided, as the ELAS calculator is designed to be used by decision-makers at the municipal level, who are often voluntary politicians and non-experts in urban planning and energy planning. Therefore, only few indicators have to be selected that provide a complex assessment and a clear picture about the environmental effects of a proposed settlement development concerning the building stock and/or new settlements. Therefore, measures were carefully selected. Finally, the following three measures are applied:

Table 1 Definition of 'levels of centrality'

Level of centrality	Description
1	Community without centrality, no basic function and no local supply available
2	Community without centrality, no basic function but local supply available
3	Small centre
4	Regional centre (e.g. main municipality of a county)
5	Supra-regional centre (e.g. main municipality of a federal state)

- Cumulative energy demand: This measure reveals the energy flows related to the life cycle network of a settlement and includes embodied energy from construction, renovation and infrastructure provision, energy for operation of the buildings and settlement as well as the mobility of residents. The measure expresses the fact that energy use causes an important share of environmental pressures and drafts a clear picture about the impacts of energy efficiency measures.
- Life cycle CO_2 emissions: This measure was chosen to express the effects of settlements on global warming and to assess the impacts of planning decisions regarding settlements on greenhouse gas reduction policies. With this measure, not only energy efficiency but also the contribution of different alternatives of energy sources and energy provision technologies for a settlement can be assessed.
- The sustainable process index (SPI) method as one calculation method for ecological footprints: the SPI method shows environmental pressures from all material and energy uses of the life cycle network by calculating the area of land which is associated with the supply of resources and the dissipation of emissions and wastes. The SPI method is applied to compare the overall environmental impact of a wide range of planning alternatives.

The three methods are described in more detail below.

Cumulative energy demand

Energy is a major factor of the ecological pressure exerted by a settlement. The ELAS calculator accounts for all energy flows generated by the whole life cycle network. This includes the energy to operate the buildings (heating, cooling, electricity demand of appliances), the necessary supporting infrastructure (energy to operate sewage systems, street lighting, road service etc.) and mobility of residents. The calculator however also includes all 'embodied energy' that is necessary to provide the materials of construction for buildings and infrastructure or used in construction, renovation or demolition and disposal (when appropriate) for any planned changes to the current structure. This embodied energy is calculated using the methodology of the 'Kumulierter Energieaufwand - KEA' according to [15]. Embodied energy input will be related to 1 year by taking lifetimes of buildings and infrastructures (66 years) into account.

Life cycle CO_2 emissions

The calculation of CO_2 emissions is directly coupled with the calculation of the ecological footprint (see below). All fossil carbon inputs across the whole life cycle network as explained by Figure 1 form the base of the calculation. This includes also CO_2 emissions from synthetic materials used in construction of new buildings and infrastructures as well as in renovation, depreciated over the life time of the building and the renovation interval, respectively.

Ecological footprint as sustainable process index

SPI is a method to calculate ecological footprints that takes emissions to air, water and soil besides resource provision into account [16]. This method compares anthropogenic and natural flows according to the following sustainability criteria [17]:

- Principle 1: Anthropogenic mass flows must not alter global material cycles and;
- Principle 2: Anthropogenic mass flows must not alter the quality of local environmental compartments.

The results of the footprint calculations are broken down into partial footprints for direct area consumption, fossil resource consumption, renewable resource consumption and emissions to air, water and soil.

Socio-economic appraisal

The socio-economic appraisal is based on regional economic input-output analysis [18]: the impacts of specific economic activities on the whole economic system are estimated by modelling the economic interaction of the different economic sectors. The model applies input-output coefficients that connect the different sectors. The sectors of this input-output analysis are based on the NACE systematic of economic sectors [19], dividing the sector 'electricity, gas and water supply' into non-renewable energy, renewable energy and water supply. The economic effects of building, maintaining and operating settlements are attributed to building construction, building operation, public infrastructure construction and operation as well as external effects (primarily related to mobility).

A special challenge is the regionalisation of socio-economic impacts taking the economic structure of the region - the province - into account where the settlement is situated. Applying techniques in accordance with Clijsters et al. [20] and Baaske and Lancaster [21], the regionalisation of the economic input-output coefficients are based on the national data provided by Eurostat [22]. With the techniques applied, problems of common regionalisation techniques, like the overvaluation of transformators and multipliers, can be avoided.

As a result of the socio-economic appraisal, the ELAS users are provided with estimations of the regional and national turnover and revenue, the imports induced as well as the regional jobs created with the construction, renovation, operation and the maintenance of settlements[c]. In this way, the socio-economic appraisal complements the environmental appraisal using indicators at the same degree of abstraction.

Appropriate role of the ELAS calculator in planning tasks

Any meaningful evaluation tool must correlate with the requirements of a certain task within the course of taking decisions. The ELAS calculator is designed to support decisions within a planning process for buildings and settlements from the vantage point of sustainable energy systems. Stoeglehner and Narodoslawsky [3] provide a critique of proposed requirements for sustainability evaluation within planning processes and offer a framework for allocating evaluation methods to different assessment tasks, summarized in the indicator pyramid shown in Figure 3. The representation of this indicator pyramid reflects the fact that the information load and solid data increase along the decision pathway in planning. Evaluation should help to distinguish between alternative pathways, eliminating those that will in the end not lead to the desired goal of sustainability. The 'tip' of this pyramid is formed by general indicators that allow eliminating alternatives that clearly contradict the objectives of sustainable development. According to this framework, these general indicators should have a strong environmental bias, screening for alternatives that in the long term harm the natural base for human development. In order to facilitate elimination of unsustainable alternatives, highly aggregated indices (like the ecological footprint) are advantageous at this level.

As fewer alternatives remain in the planning process, information on the performance of each alternative increases, allowing to evaluate environmental impacts in more detail as well as adding other dimensions to the decision support provided by evaluation tools. This level of evaluation rates alternatives within the different

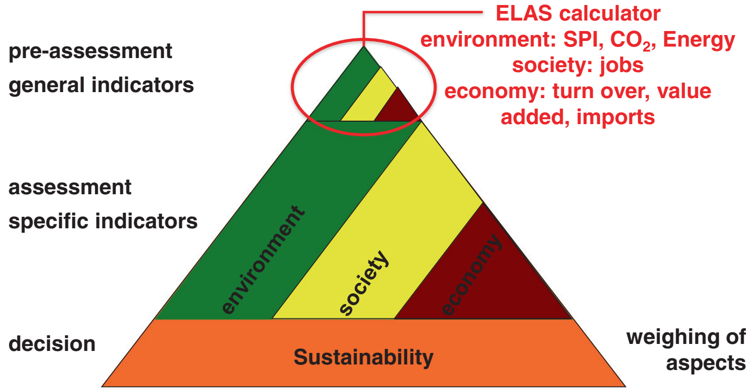

Figure 3 Position of the ELAS calculator in the 'indicator pyramid', adapted according to [3].

dimensions of sustainability but aggregates data only within their particular field. The result of this evaluation then forms the base for the discourse between relevant actors who then weigh the different aspects to finally reach a planning decision for a certain alternative.

The ELAS calculator is intended as a planning tool for the 'pre-assessment level' in the indicator pyramid according to this framework. True to its objective to support planning of buildings and settlements to conform to sustainable energy systems, it has a strong energy and environmental fundament whilst providing numerical evaluation of economic as well as social aspects of projects regarding renovation, extension or greenfield development of buildings and settlements.

Database of the ELAS calculator

The ELAS calculator draws on a large and comprehensive built-in database. Describing this database in detail would exceed the scope of this article by far. The reader is therefore kindly asked to consult the extensive background material provided on the ELAS calculator homepage at www.elas-calculator.eu for specific information regarding data sources and statistical material behind the ELAS calculator. The purpose of this chapter is to explain the general approach for data acquisition followed in the development of this tool.

Evaluating the complex life cycle network linked to operating and changing buildings and settlements requires a comprehensive database that must be adapted to the many specific aspects of individual buildings and settlements. It is the general approach of the ELAS calculator to allow the user as much leeway as possible to individualize his/her data in order to provide reliable decision support whilst at the same time reduce amount of data required from the user in order to increase user-friendliness of the program. Wherever possible, the program will provide sensible default values.

Besides striking a delicate balance between individualization and generalization of data, the ELAS calculator strives for data coherence. This means that life cycle data are taken only from one source [23] whenever possible, SPI-related data where taken only from the SPIonExcel (homepage: http://spionweb.tugraz.at). Statistical data underlying socio-economic evaluation are all taken from the material provided by Eurostat as already mentioned.

Specific data base of the ELAS calculator

Many data required to evaluate the impact of the life cycle network underlying the ELAS assessment method are not available in existing statistics. This applies in particular for individual mobility of residents according to the levels of centrality that form the base of characterising the spatial interaction between settlements and services used by residents. As this aspect is a prominent factor for the sustainability of settlements, great care has been applied during the development of the ELAS calculator to come up with reliable and recent data for evaluating mobility of residents.

Mobility associated with a building or settlement is influenced by a complex set of factors. Besides the distance to particular service providers (represented by the different levels of centrality and the distance from the settlement to the nearest cities associated with these levels), the demographic structure of the settlement has to be taken into account as residents within different age brackets show vastly differing mobility requirements and behaviours. The modal split used by residents to travel to service providers is in turn dependent on the centrality level of the settlement as the fraction of public transport increases with a higher level of centrality. Finally, the modal split also depends on the age bracket the individual resident belongs to.

In order to obtain realistic data for evaluation of crucial aspect of the sustainability of settlements as well as to verify statistical data from other sources, a thorough analysis of ten Austrian settlements in seven municipalities, representing all levels of centrality, was undertaken (see Table 2). The settlements ranged in size from 20 to 428 households. Within this analysis, all relevant parameters about buildings and infrastructure used in the ELAS calculator were gathered. In particular, this analysis encompassed a survey of households, inquiring the demographic set up of the household, consumer behaviour and technical building standard.

Questionnaires inquired the mobility behaviour of individual residents regarding frequency of travels, leisure mobility and modal split for all categories of mobility. This analysis was coupled to a participatory evaluation process in all settlements, involving all residents as well as stakeholders and political representatives, with public auditing events throughout the process. Local actors distributed the questionnaires and helped with additional information. Due to this participatory nature of the analysis, 37% of the 1,585 (i.e., 587) household questionnaires could be recovered, on top of 1,047 individual questionnaires. This statistical material allowed the formulation of 75 different modal splits linked to all 5 levels of centrality and 5 age brackets.

User-provided data

The user has to provide all data that define the building/settlement in sufficient detail to allow for reliable sustainability evaluation. The ELAS calculator offers extensive help functions to guide the user through the evaluation exercise as well as realistic default values wherever possible. A thorough discussion of the input data is outside the scope of this paper, the user may however draw extensive support material offered on the web page of the ELAS calculator.

Figure 4 offers a schematic overview over the input that has to be supplied by the user, differentiated into private mode and municipal mode. The calculator is available in German and English language version. In general, the input to the private mode is less complex and geared towards an audience of interested lay persons. Using the municipal mode and in particular the planning mode requires detailed knowledge about the infrastructure of the settlement and/or about planned changes.

Most sections in the private mode are in line with corresponding sections in the municipal mode (although the detail and volume of the required data differ). Starting the calculator requires decision about the language and the mode used, with the municipal mode differentiating further more into *status quo* analysis and planning mode.

A first set of input data requires the user to identify the site in terms of the level of centrality and distances to cities of higher level of centrality. Following the site definition, the user is asked to define the buildings in terms of age categories, size and technical status, number of households and residents as well as demographic distribution of residents. On top of that, the user has to define the technology used to provide heat and warm water. In this section, buildings with the same age and technical status are subsumed in ‘building groups’.

The next section deals with electricity demand, electricity provision technology mix and (if applicable) production of electricity via photovoltaic panels on the building or within the settlement.

In the subsequent input section, the user may define the situation of the building/settlement within the municipality in terms of distance to the town centre as well as municipal services like road service, street lighting, waste and wastewater disposal.

Following that section, users of the private mode may define their mobility behaviour in detail. The last input section allows the user to change prices and flows of goods to adapt the regional economic analysis to the actual situation regarding the settlement to be evaluated.

In the municipal mode, the user may chose the ‘trend scenario’ and the ‘green scenario’ to estimate the impact of the building or settlement in the midterm future. Following the presentation of the results, the user in the municipal mode may then switch to the planning mode,

Table 2 Analysed settlements

Number	Settlement/municipality	Level of centrality	Characteristic building type	Number of households
1	Holzstraße/Linz	5	Multi-storey apartment buildings	233
2	Pregartenteich/Freistadt	4	Row houses	39
3	Billingerstraße/Freistadt	4	Multi-storey apartment buildings	109
4	Petringerfeld/Freistadt	4	One family houses	248
5	Row house settlements/Gallneukirchen	3	Row houses	42
6	One family house settlm./Kottingbrunn	3	One family houses	291
7	Whole town/Laab a. W.	2	Miscellaneous	428
8	Centre/Vorderstoder	1	Miscellaneous	25
9	Periphery/Vorderstoder	1	One & two family houses	20
10	Großnondorf/Guntersdorf	1	Miscellaneous	150

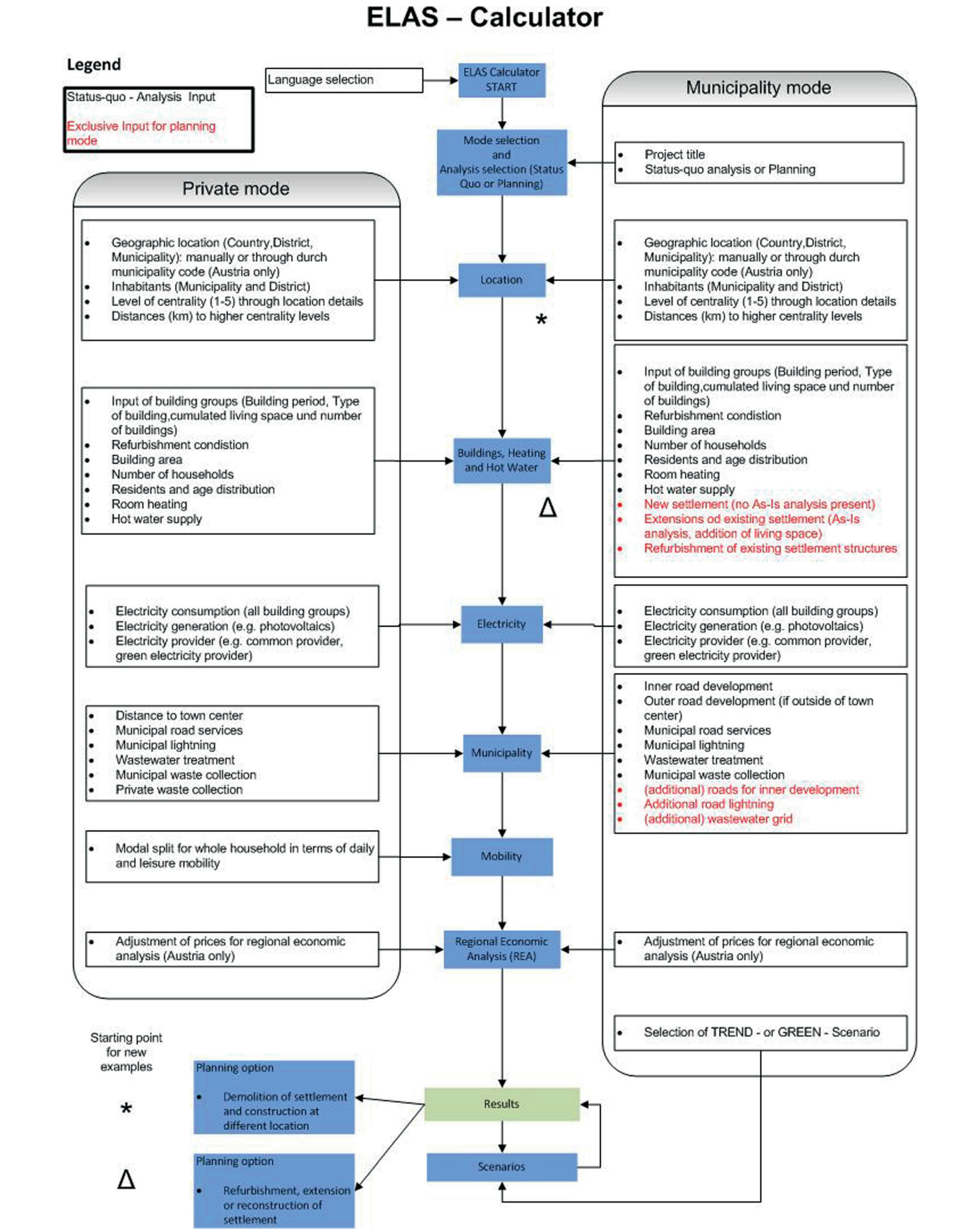

Figure 4 User-supplied input to the ELAS calculator (white entries apply to the planning mode).

adding more groups of building and additional infrastructure or evaluating the impact of any energy efficiency measures. The user may also evaluate the impact of dismantling the whole settlement and rebuilding it at a new site.

Results from the ELAS calculator

Ecological evaluation results from the ELAS calculator are represented in terms of total energy consumption, life cycle CO_2 emissions and SPI in graphical as well as tabular form. Using either the private mode or the 'As-Is Analysis' of the municipal mode will provide life cycle wide ecological impacts corresponding to 1 year of the operation of building or settlement. Results of the planning mode will always include the ecological impact of the planned infrastructure, both for buildings, renovation (summarised in the category heating) and municipal services and, if applicable, for demolition of buildings. Infrastructure will also be referred to 1 year, taking the life time into account.

Graphical representation for all valuation methods will be broken down into heating and hot water provision, electricity, municipal services daily mobility and leisure mobility. In case of the SPI valuation, an additional graphic will provide the breakdown of the ecological footprint according to infrastructure, fossil resources, renewable resources, non-renewable resources and emissions to air (excluding CO_2 which is rated in the fossil resources part), water and soil (see Figure 5).

Tabular results provide overall results as well as more detailed information, breaking down results of energy consumption into different energy forms (for heating) and applications (heating/warm water provision), electricity into grid provided and own production via photovoltaic panels, municipal services into waste and wastewater disposal, street lighting and street services. Mobility is differentiated according to the modal split and depicted for daily as well as leisure mobility. Tables relating to the SPI will also provide details about the breakdown of the ecological pressure of the different aspects of the life cycle into impact categories.

Socio-economic analysis shows turnover, value added, import and jobs created, differentiated to the national and regional level in tabular form. Results will also provide a breakdown for economic effects of different aspects such as construction, operation of buildings, municipal services and external effects (in particular mobility) on the categories defined above (see Figure 6). In addition to that, imports induced by the building or settlement will be shown in the overall summary of results. The results have to be interpreted carefully, because the logic of 'more is better' cannot necessarily be applied to the regional economic analysis: 'more' in the energy sector could mean that the regional population might be restricted in other areas of consumption which would be more effective in the regional economy. Therefore, we added the imports in relation to turnover and revenue. If regional renewable resources are used, the money spent on energy aspects of a settlement will be regionally operative.

A multitude of ELAS calculations shows that the impact of spatial planning decisions, such as developing mixed-use structures with sufficient daily supply and social infrastructure, as well as pursuing settlement density

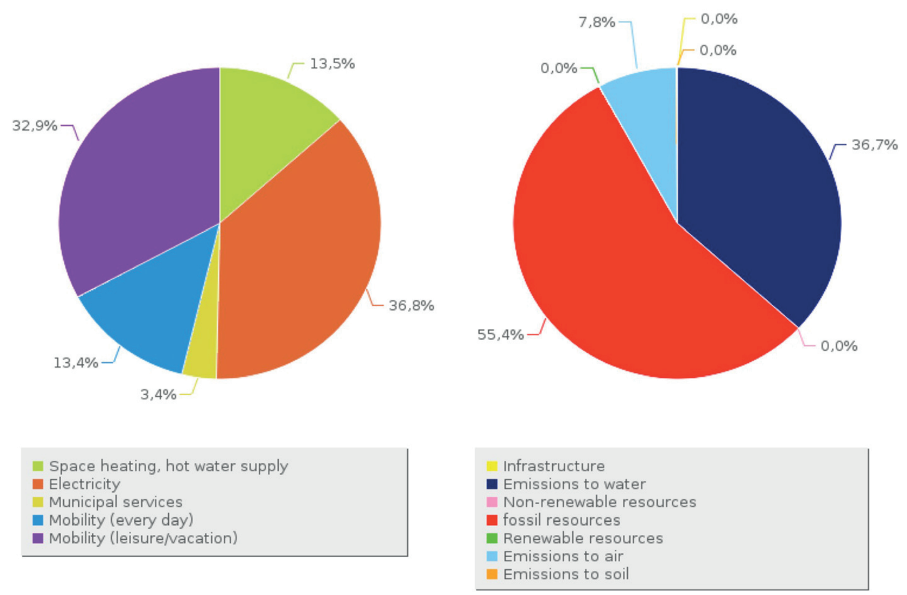

Figure 5 SPI result for case study settlement 'Pregartenteich/Freistadt'. Left diagram: footprint breakdown referring to activities; right diagram: breakdown into impact categories.

Value added effects according to initiator - Austria

Category	Turn over	Value added	Imports	Jobs
Living Space, construction	0 €	0 €	0 €	0.0
Living Space, operation	85,137 €	38,274 €	13,731 €	0.3
Municipal Infrastructure, construction and operation	11,738 €	6,541 €	1,217 €	0.1
External Effects (Mobility)	210,229 €	97,010 €	35,049 €	1.4
Total	**307,105 €**	**141,825 €**	**49,996 €**	**1.8**

Value added effects according to initiator - Oberösterreich

Category	Turn over	Value added	Imports	Jobs
Living Space, construction	0 €	0 €	0 €	0.0
Living Space, operation	76,975 €	32,227 €	19,778 €	0.3
Municipal Infrastructure, construction and operation	9,886 €	5,415 €	2,342 €	0.1
External Effects (Mobility)	168,268 €	67,200 €	64,858 €	0.9
Total	**255,130 €**	**104,842 €**	**86,979 €**	**1.3**

Figure 6 Socio-economic results for case study settlement 'Pregartenteich/Freistadt'.

has an important effect on the energy demand and the environmental pressures related to the energy supply of residential areas. The efficient supply with renewable energy sources can be supported, and the energy demand for the mobility of the residents can be reduced as people in more central residential areas drive less and are able to cycle, walk and use public transport.

With the optimisation function for existing settlements, we explored that through integrated spatial and energy planning measures enormous positive environmental effects can be achieved. Such measures combine spatial developments based on mixed-use, short-distance supply and (moderate) density with innovative energy technologies as well as energy efficiency measures in buildings and infrastructures. They make it possible to reduce the energy demand by 30% to 50% and the associated negative environmental effects in terms of footprint and life cycle CO_2 emissions up to 80%.

In new developments, we found out that in low-dense settlements relying on stand-alone single-family houses, the energy demand for streets, sewage systems and other related technical infrastructures in the settlement can exceed 50% of the total energy demand of a settlement, causing up to 90% of the life cycle CO_2 emissions and up to 80% of the ecological footprint. The construction of houses plays a relatively low role with around 5% share on the total energy demand. By more dense settlement structures like four- to five-floor apartment buildings, the share of infrastructures can be reduced to about 10% to 15% accounting for less than 50% of the life cycle CO_2 emissions and 40% of the ecological footprint. Further determinants of the energy demand of settlements are the degree of centrality of the municipality and the distance of the settlement to the supply centres within the municipality.

Discussion of the ELAS applicability

Decisions concerning construction and operation of buildings and settlements are pivotal to achieving sustainability and in particular to arrive at a sustainable energy system of society. This is due on the one hand to the large fraction of energy used in buildings (in particular in Europe) and on the other hand to the considerable influence the way settlements are situated has on other energy uses, in particular by shaping mobility requirements of residents and modal split of travels. As such decisions, due to the longevity of buildings, have long ranging consequences, thorough and reliable decision support is necessary.

Providing such comprehensive decision support for individual house owners as well as for municipal administrations and planners was the goal of the 'energetic long term analysis of settlement structures' study that forms the background to this article. Based on a thorough analysis of ten settlements in different spatial situations and featuring a variety of building types and demographical set-ups of residents, a web-based calculator was developed that evaluates buildings and settlements from the point of view of their sustainability. The ELAS calculator can support decision-making in spatial planning in the following situations:

- Comparison of settlements of the same type on different sites;
- Comparison of variants concerning the design of settlement on one site, e.g. concerning the size and density of the settlement, efficiency of buildings, the selected energy sources and technologies and on-site renewable energy production;
- Comparison of renovation of existing buildings, with re-densification and enlargement of settlements; and
- Iterative optimisation of settlement site and settlement design.

Therefore, the calculator can be used in different stages of a planning and design process. In planning processes, decisions are taking place at least at three different levels, which can be explained by the types of alternatives included in the planning process [24]:

- System alternatives: choice of demand, size of projects, density, technological networks etc.;
- Site alternatives: choice of sites for projects; and
- Technical alternatives: choice of technical implementation of a project on a given site.

The ELAS calculator allows to 'jump' between the scales: sometimes, the quality of the available sites or certain site-specific limitations hinder the implementation of system alternatives. Therefore, the ELAS calculator can be used at different stages of planning processes: (1) to evaluate system alternatives with few assumptions about technical aspects of potential energy systems concerning their overall energy demand and supply and the related environmental and regional socio-economic effects; (2) to evaluate and rank site alternatives for given kinds of projects, e.g. multi-storey housing, terrace houses etc.; and (3) to assess technical options, e.g. certain insulation or energy sources and technologies for project implementation. Finally, objectives for site-specific design processes can be set from the perspectives of SPI, life-cycle CO_2 emissions and overall regional socio-economic effects.

By applying the ELAS calculator, users can assess if their decisions are in line with energy policies and climate change policies promoting energy saving, energy efficiency and the use of renewable energy supplies and can optimize planning decisions to reduce energy demand and environmental impact in depending on the chosen energy supply technologies and sources. This is valuable for the following different target groups the ELAS calculator is intended to address [25]:

- Legal bodies (municipal mode) are enabled to assess based on case studies, how legal proposals in spatial planning, housing subsidies, building codes etc. might impact the energy demand and supply of settlements and might contribute to achieving international and national energy policy and climate protection targets.
- Municipal decision-makers and planners (municipal mode) can assess local spatial planning activities (land use plans, master plans, zoning plans) concerning residential developments with respect to the environmental and socio-economic impacts of energy demand and supply. They are enabled to choose planning alternatives with a high potential to be sustainable for detailed assessments, e.g. in strategic environmental assessments.
- Developers (municipal mode) are able to estimate the energy demand as well as environmental and socio-economic impacts of their future dwellers. In doing so, they can assess alternatives of sites and optimize the design of their settlement projects. Furthermore, they might use the results in marketing their products to customers interested in low energy demand and sustainable energy supplies.
- Single households (private mode): Individuals can also assess their choices regarding their dwellings taking the structural aspects of the settlement and their individual behaviour into account. Especially interesting decisions situations for the ELAS application might be the comparison of different flats when intending to move, decisions about thermal insulation, change of heating devices or PV-installation, change of mobility patterns etc.
  so that interested individuals can choose planning options that help them to lead a more sustainable life and contribute to climate protection and the shift of energy supplies towards a renewable resource base. In the private mode, less knowledge and information is needed. Only information has to be entered by the users that is within their decision scope.

Conclusions

Within the research carried out, it became obvious that building and infrastructure construction and maintenance as well as site-induced mobility are crucial for the sustainability of settlements. The site of the settlement is a determining factor for both. The ELAS approach addressed this by introducing different levels of centrality, differentiated according to the services available in the town the settlement belongs to. Thorough studies linking these levels of centrality and the demographic set-up of residents with daily and leisure mobility allow the evaluation of these factors within the ELAS calculator without requiring excessive data acquisition from the user. The ELAS calculator offers free accessible evaluation for stakeholders involved in long ranging decisions regarding buildings and settlements. With this tool stakeholders can readily integrate aspects of sustainability in their decisions, both regarding the operation of buildings and settlements as well as in planning renovations, enlargements or even relocation of settlements. As can be seen from the list of target groups and their potential benefits from ELAS applications, the ELAS calculator supports consistent decision-making from the policy level via the regional and local planning levels to the household level.

Endnotes

[a]In the current version of the ELAS calculator, the socio-economic evaluation is only available for Austrian cases.

[b]For application of the ELAS calculator to settlements in Austria, the user may only supply the ZIP code to define the distances to cities with other (higher) level of centrality as the calculator will draw on a database based on [25,26]

[c]In the current version, regionalized input-output tables are available for Austrian Federal States.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors have contributed to the ELAS project, GS as project manager. All authors read and approved the final manuscript.

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Spatial dimensions of sustainable energy systems: new visions for integrated spatial and energy planning

Gernot Stoeglehner[1*], Nora Niemetz[2] and Karl-Heinz Kettl[2]

Abstract

The turn to sustainable energy system is a major societal goal at the global level. In this paper, we argue that this radical shift in energy provision towards increased energy efficiency and the use of renewable resources can only be achieved if its spatial dimensions are taken into consideration. Spatial structures have considerable influence on different aspects of the energy demand, and with spatial planning, the resource availability and use are influenced. Further, we propose that different spatial types need different strategies for the implementation of sustainable energy systems and that integrated spatial and energy planning is needed to support this change. Visions for four types of spatial structures: the city, the suburban area, the small town as well as the rural areas define their roles in the "space-resource-planning continuum", which are the foundation to shape an integrated spatial and energy planning system.

Keywords: spatial planning, rural development, energy, renewable resources

Background

As energy systems are key infrastructures of society, they are also an important issue of spatial planning. So far, the link between spatial planning and energy systems is mainly dealing with the problem that the energy provision of the built environment is guaranteed, may it be for residential, commercial or industrial development. Energy is a "hard" factor for zoning, especially for commercial and industrial areas [1]. Besides the fact that energy has to be provided - which usually has no strong restriction because of the possibility to use is easily available and readily transportable fossil energy - the link between spatial planning and energy planning is underdeveloped. We propose to look at spatial planning and energy planning not as distinct "two sides of a coin" but as a continuum because intellectual separation and sectoral analysis leads to sub-optimal solutions. In the project PlanVision[a], an analysis of the interactions between spatial planning and energy planning was carried out. This is the basis for this paper.

As can be derived from previous studies, there are substantial contributions spatial planning can make in shaping sustainable energy systems. Spatial planning sets frameworks for energy consumption, production and distribution [2], no matter if this is done consciously in planning processes or accidentally - often with negative effects concerning energy efficiency and environmental pressure.

Spatial planning decisions have major impacts on the energy demand of the built environment as well as mobility connected with the spatial structures (see, e.g. [3-7]). Several initiatives of urban planning point out, that energy-efficient settlement structures also lead to a high quality of life and have several features in common like de-centralised concentration, multi-functionality, nearness within walking and/or biking distances as well as certain densities (see, e.g. [8-16]). Although these relations between settlement structures and energy demand are well known, real developments more often do not comply with these concepts which leads to an increase of energy demand even in spite of more energy-efficient buildings, appliances and vehicles (see

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for Austria, e.g. [17-19]). Besides spatial organisation, spatial planning decisions also influence energy demand by choosing sites with a certain topography and exposition as well as by framing the built structures in building schemes (see, e.g. [5,20-24]).

Research has also been done on spatial dimensions of energy conversion and distribution as energy provision (especially in the case of bio-based energy carriers) causes land demand and, therefore, calls for core issues of spatial planning like zoning, securing of land uses and resources as well as minimisation of spatial conflicts. Several studies have contributed to questions which spatial developments, land use conflicts and/or impacts of the utilisation of specific renewable resources might arise (see, e.g. [1,25-28]). Furthermore, process designs for energy planning on the local and regional level have been elaborated. (see, e.g. [29-41]). Within the project PlanVision, an in-depth system analysis of the spatial-resource-planning continuum was carried out identifying four elements (out of 34), namely multi-functionality, density, siting as well as resources that dominate the system.

The aim of this article is to examine in detail which implications the use of renewable resources for energy supply has for spatial planning. We also include the assumption in our considerations that in the long term also industry might switch to renewable resources and, therefore, additional pressures on limited renewable resources, especially biomass, will arise. Therefore, we will discuss spatial planning implications of an extensive sustainable use of renewable energy and introduce a new vision for the spatial organisation of energy and resource supply under sustainable conditions. Finally, we make a proposal for shaping integrated spatial and energy planning.

Methods

We develop the train of argument in the following way: First, we define spatial dimensions of sustainable energy systems. From these dimensions we develop a generic vision for spatial development considering a spatial-resource-planning continuum. Within this continuum we ascribe functions to four archetypes of spatial structures urban areas, suburban areas, small towns as centres of rural areas as well as rural areas based on the characteristics of different products and services. Furthermore, implications of the vision concerning the four dominating system elements are derived for the four spatial archetypes leading to specific objectives that should guide future planning. Finally, we deduce integrated spatial and energy planning instruments to achieve these objectives.

Spatial dimensions of sustainable energy systems

Sustainable energy systems, their generation as well as their utilisation are intrinsically linked to spatial management. Contrary to a society based on fossil resources to meet its energy and material demand, a sustainable society based on renewable resources will have to draw on space as its ultimate fundament for wealth. The reason for this prominence of space is that almost all renewable resources, solar radiation, wind and hydro power as well as bio-resources may be tracked back to our ultimate sustainable natural income, solar energy.

Solar energy is the quintessential area-dependent resource. It can only be "harvested" from earth's surface or by harnessing processes, such as wind and water power, that emanate from interaction between solar radiation and earth's surface. This makes spatial management and planning tantamount to resource and energy planning in a sustainable society.

Another aspect of renewable resources is of importance when analysing the link between spatial planning and resource provision: renewable resources are notoriously de-centralised resources. This is of course a logical result of their dependency on space for their generation. Contrary to all fossil (and nuclear) resources that emanate from point resources like mines and wells, renewable resources emerge on every square metre of earth's surface in the form of solar radiation and/or bio-resources.

Needless to say that this increased importance of space as the ultimate resource for sustaining life and economic activity of mankind has major implications for spatial planning. Spatial planning and energy planning cannot be separated anymore. From the point of view of planning, the reliance on sustainable energy sources creates a "spatial-resource-planning continuum" that can only be approached in an integrated way.

One particular consequence is the need to guide spatial planning and development according to the functionality of the space involved: the double role of space as the ultimate resource provider as well as habitat for society requires a more differentiated look on different spatial categories and their particular role and development framework.

This is in marked difference to the current situation of a fossil-based society. As these resources are point resources (exploited usually far from areas of intensive human settlement), all spatial elements away from the singular exploitation areas (mines, wells, etc.) have comparable access to external resources. This in turn leads logically to the postulate of equal development opportunities for every location as there are only minor functional requirements in terms of resource management on a spatial level. Economic development is mainly driven by resources that have no immediate link to the space subjected to planning and hence spatial planning (with very few exemptions) is not linked to resource management. From a resource point of view in a fossil society, spatial planning deals with a mostly amorphous, unstructured matter.

A differentiated framework for spatial planning from the resource point of view must take into account

- the main characteristics of renewable resources;
- the structure of the distribution pathways for different qualities of energy in particular;
- archetypal categories for spatial development and their functionality within the spatial-resource-planning continuum.

Main characteristics of renewable resources

Solar radiation is an abundant resource that lacks however the high energy concentration of fossil resources. Harvesting this everlasting energy form therefore requires relatively large areas. A society based on renewable resources will thus have to manage its spatial resources in the most careful way.

Besides requiring space renewable resources by and large show in some cases (solar energy) cyclical and in other cases (wind power) erratic time dependency in their emergence. This requires storage to align energy provision with energy demand. In any case, storage is costly, either in terms of money (e.g. for batteries) or in required area (when biomass is used to "store" solar energy). The imperative to provide storable energy for stabilising energy provision as well as for particular applications (namely mobility) assigns biomass in its various forms a privileged role among other sustainable energy forms. This in turn increases the spatial requirements considerably because biomass has a much lower yield compared to other sustainable energy forms such as thermal solar energy, PV or wind power. The utilisation of arable land as well as forests and hence spatial planning becomes much more intricate in a society based on renewable resources as a result of the intrinsic need for energy from biomass.

Finally logistical considerations become central to the energy system. Many renewable resources (in particular low-grade biomass like grass, wood chips or straw) have low transport densities, in some cases (e.g. wood chips, grass) paired with high humidity. This restricts feasible transport distances considerably, requiring de-central conditioning and/or utilisation of such resources.

Structure of distribution pathways for sustainable energy

Besides the characteristics of sustainable energy resources, the structure of distribution pathways is an important factor in the spatial-resource-planning continuum. Different energy qualities such as electricity, heat/cooling energy, gas and oil are distributed via large-scale infrastructures and show widely different ranges and distribution densities. On top of that, energy qualities may be transformed into each other following restrictions defined by laws of nature: electricity may readily be transformed to heat/cooling energy, gas and oil may be partly transformed into electricity but always render heat as a by-product in this transformation, low temperature heat can only be transformed into cooling energy.

Table 1 shows the characteristics of different distribution grids. This table already assumes that these grids are "smart" in the way that they accommodate feed-in from different providers than central sources where appropriate.

Generic visions for spatial development within the spatial-resource- planning continuum

A sustainable energy-based society requires highly efficient management of the space as the ultimate resource. Efficient management however entails differentiation between spatial elements and insight into the functionality of these elements. A generic categorization of spatial elements within the spatial-resource-planning continuum renders the following four archetypes (Table 1):

- Urban centres
- Suburban areas
- Small towns as centres of rural areas
- Rural areas

These archetypes are assigned vital and widely different functionalities within the spatial-resource-planning continuum. From a resource/product point of view the generic visions - independent from the state of development of the four archetypes and the gap between state and vision - may be described as follows:

Urban centres are the main consumers of energy in all forms. Conversely, they are the main providers of complex (industrial) goods (e.g. electronic devices, machinery, cars, etc.) and services.

Suburban areas form the spatial reserve for urban centres and take over a major supply function for them, namely the supply with fresh products of daily consumption (e.g. high-quality food).

Small towns as centres of rural areas have the function to convert in particular bio-resources into easily transportable commodities and form crucial nodes in the distribution grids for energy, linking them and shifting energy from one to the other (e.g. by using biomass to generate electricity and heat or to generate (bio-)gas that may be distributed via the grid).

Rural areas are the ultimate provider for crucial bio-resources, both for sustenance as well as storable energy carriers.

In order to obtain a clearer picture on the interaction between these archetypes, at least on the level of

Table 1 Characteristics of different energy distribution pathways

Energy form		Density	Range	Feed-in	Utilisation
Electricity	Low voltage	Very high	10 km	Everywhere	Everywhere
	Medium voltage	High	50 km	Everywhere	Everywhere
	High voltage	Medium	500 km	International, urban centre, suburban, small city	Urban centre, suburban area, small town
Gas	Low pressure	Very high	20 km	Urban centre, suburban, small town, selectively in rural areas	Urban centre, suburban area, small city
	High pressure	Very low	1,000 km	International, urban centre	Urban centre
Heat		Very high	10 km	Everywhere	Everywhere
Oil		Very low	1,000 km	International, urban centre	Urban centre

material products, Table 2 provides an overview on what type supplies what product to society.

The nature of the spatial-resource-planning continuum however requires not only to take energy aspects into consideration but to match them with the basic functions the described archetypes have to provide from the social and economic point of view. Taken together these different functions can then be used to provide a comprehensive set of planning goals for sustainable spatial development. Table 3 provides this overview.

In the following sub-chapters the visions for the spatial types are described in more detail along the dominating system elements multi-functionality, density, siting as well as resources as base for the production and distribution of sustainable energy.

Urban centres

As urban centres are the main user of energy and resources and production areas for primary production are limited, questions regarding the generation of energy take a backseat to those concerning efficiency (including energy saving by structural, technical and behavioural change), distribution and transport. Efficiency is the highest premise for sustainable urban development in order to reduce material and energy input in the first place. This requires also conscious material management, including collection and transport of waste combined with recycling of materials and thermal use which might substantially contribute to the energy supply of the city. In addition to waste a city's resource portfolio may also include solar energy utilisation.

Multi-functional, densely populated areas are an important precondition to guarantee for the efficiency of complex infrastructures like energy supply, public transport, high-quality social infrastructures as well as for economic advantages. Multi-functional and dense areas are also an important precondition for the levelling out of dynamics between consumption and production as well as cascade use of energy over time. Concerning siting and zoning of different land uses on the system level multi-functionality and at least medium dense agglomeration are keys to ensure energy efficiency, both from the mobility point of view as well as according to the preconditions for energy (and resource) cascades. In particular, heat cascading needs short distances (as heat losses in grids are considerable) and diversity in heat quality demand (provided by multi-functionality) to utilise energy in the most efficient way with energy intensive industries at the top of the cascades and residential heat and cool at its bottom. Details like local climate conditions or urban design questions might just lower energy demand and might contribute to fulfil the efficiency paradigm (Table 3).

Suburban areas

In this vision presented here, suburban areas are perceived as spatial reserve for urban areas dedicated to the following functions: primary production of fresh goods with maximum production within environmental capacity limits.

Table 2 Matrix of provision and consumption among archetypical space categories

Product type	Consumer	Provider
Fresh products of daily consumption	Urban centre	Suburban area
	Suburban area	Suburban area
	Small town/rural centre	Rural area
	Rural area	Rural area
Commodities	All	Small town/rural centre
Bio-resources for commodities	Small town/rural centre	Rural area
Complex industrial goods	All	Urban centre

Table 3 Generic visions - elements for spatial categories

Urban centre		Suburban area		Small town/rural centre		Rural area	
Basic function	**Goal**	**Basic function**	**Goal**	**Basic function**	**Goal**	**Basic function**	**Goal**
Living space for majority of people	Highest quality of living	Spatial reserve for urban centre	Highest logistic efficiency for people and goods	Attractive living space for de-centralised industrial society	High quality of living	Sufficient population density for primary production and sustenance	Basic provision of:
	Sufficient leisure time opportunities				Excellent leisure time opportunities		Goods (daily consumption)
	High environmental quality		High environmental quality		Highest environmental quality		Education (primary level)
							Social services
							Cultural services
	Comprehensive provision of:		Basic provision of:		Advanced provision of:	Recreational space	Highest environmental quality
	Goods		Goods (daily consumption)		Goods		
	Education (up to tertiary level)		Education (primary level)		Education (up to secondary level)		
	Social services (health/care)		Social services		Social services (health/care)l		Sufficient touristic infrastructure
	Cultural services		Cultural services		Cultural services		
	Research				Research		
Main energy/ resource consumer	Highest efficiency of use		Highest utilisation efficiency	Resource conversion	Lowest pressure in resource conversion/ utilisation	Sustainable resource provision	Highest efficiency in space utilisation
	Lowest pressure in energy provision/ utilisation		Lowest pressure in energy provision/ utilisation				Max. long-term yield per area
	Lowest resource consumption		Lowest resource consumption		Highest conversion efficiency		Stable eco systems
Provider of complex (industrial) goods and services	Highest resource conversion efficiency	Space reserve for provision of complex goods	Highest resource conversion efficiency		Linking the distribution grids		Highest logistical efficiency for renewable resources and by-products of conversion processes
	Strong societal interaction	Provision of fresh goods for urban centre	Highest efficiency in space utilisation				
	International interconnectedness		Maximum long-term yield per area				No resource import

Furthermore, suburban regions will provide space for "spill-over" complex goods production close to urban centres adhering to the high-efficiency principle like in urban centres.

In our vision, just basic supply should be covered in suburban areas, whereas for more specialised supply demands, the suburban area shall be oriented to the urban centre. Suburban shopping centres or hypermarkets do not comply with our vision as they clearly violate the highest efficiency principle postulated for urban regions (mainly because of the necessary individual mobility induced by them as well as the sealing of productive areas) as well as the necessary multi-functionality in cities by concentrating commerce.

This concept calls for high logistic efficiency for people and goods which means orientation of siting and zoning for the built environment in medium dense mixed use areas located on high-capacity public transport lines as well as siting industrial and commercial facilities for complex products on regional and supra-regional distribution grids (electricity, gas, heat, transport) complying with ideas of de-centralised concentration.

Suburban areas are important locations to produce fresh products for the urban centres (again against the backdrop of highest efficiency for the provision of urban centres) and may as well be the location of autonomous production of energy (especially drawing on solar energy technologies and the wastes from the production of fresh products for cities), whereas suburban areas have little importance for large-scale commodity production.

In this spatial archetype, the restructuring process according to this vision requires the most intense changes of actual developments as suburban areas are arguably the farthest from sustainability considering the spatial-resource-planning continuum.

Small towns as centres of rural areas

Rural small towns are designated to a completely new role in a renewable resource economy. They become the platform of resource processing for commodities which lies in the nature of renewable resources: as they often have little durability and low transport densities, transport distances have to be kept short from the harvesting area to the sites of transformation into commodities. This is dictated by the need to mitigate land deprivation (by returning nutrients from by-products of biogenic raw material conversion to the land) and to high energy demand for transport of biogenic raw materials and wastes from processing them, usually featuring either low transport densities or high water content or both. In this sense, the utilisation of a renewable resource base means to find an optimum between an "economy of scale" - which means that the bigger the commodity production plant is, the more efficient is the resource conversion - and the "ecology of scale" - the smaller the plant is, the more efficient is the transport logistics [42]. In order to find this optimum in a generic way, we suggest that medium-sized commodity production in small towns might best fulfil this task.

To efficiently produce commodities, rural small towns will become nodes between different grids like information, electricity, transport, district heating. They have labour and supply functions for the regional population (in contrary to suburban areas which are oriented towards the urban centres in most of these aspects). Furthermore, innovation capacity in research in development concerning commodity production has to be built up. As resources differ in different regions, there will be considerable differences in the means and ways commodities are offered. Concerning energy conversion, rural small towns will have to be treated similar to urban centres, meaning that mainly solar energy and thermal energy recovery of waste materials from the commodity production will be the main sources of energy.

Following this vision, rural small towns might become an attractive living environment of a de-centralised industrial society. Efficiency principles apply in particular to resource conversion and optimal management of supply grids, e.g. for the utilisation of material and energy residues from the commodity production. Again, multi-functionality and density are important features to establish to ensure efficiency in energy use like short supply grids for district heating and to sustainable transport. Because of nearness in small towns, transport will often include walking and biking, whereas public transport is mainly important to reach urban centres as well as the surrounding rural villages. The role of siting and zoning can be argued in the line with urban centres.

Rural areas

In this vision, rural areas have the task of supplying resources for society as supply area of all other spatial types. This is accompanied by securing of daily supply (e.g. food, schools, childcare) as well as by the function as recreation area. The long-term securing of biological productivity and stable ecosystems includes mixed-functions of primary production within environmental capacity limits as well as re-introducing of materials and nutrients from conversion processes and from harvest. In order to utilise "economy of scales", to guarantee efficiency of transport logistics and to utilise waste heat in energy grids, the processing of raw materials on rural sites is not desired in this vision but is concentrated in small towns as centres of rural regions.

Concerning settlements, this means providing living space mainly for the population needed to keep up primary production, basic supply and recreational uses. Density for settlements is important in order not to waste bioproductive land and secure ecological compensation areas as well as for organising efficient public transport to small towns and urban centres and other supply infrastructures. It would even be desirable to increase bioproductive areas at the cost of underused sprawl settlements and infrastructures.

Results and discussion

The generic vision presented above may not only guide planning decisions or provide additional backup of long-desired planning visions like multi-functional settlements, de-centralised concentration, density, nearness, etc. as presented in the introduction section. This vision also adds further notions to terms used in spatial planning. For instance, the concept of multi-functionality is normally addressed to the seven basic spatial functions housing, working, nourishing, recreation, supply and disposal, transport as well as communication [15]. Considering resource use, supply and disposal has to be more specified along the production chain of renewable resources - commodities - convenience products and further re-feeding of residues to production sites. Further notions of multi-functionality or density or zoning are added by the fact that in order to utilise energy most efficiently, the loss of waste heat has to be minimised, which means that energy cascading has to be exhausted. Therefore, district heating is very important which is most efficient in multi-functional and dense areas as reasoned above.

Many aspects to implement the vision presented here can be covered within existing planning schemes especially when it comes to energy-efficient and energy-saving settlement design. Most design principles to reduce energy demand are state-of-the-art in the planning discourse but far from state-of-the-art in planning practice. Dependent on the current status of the planning regulations of a specific country additional planning instruments might be useful to be introduced like legally binding planning objectives for "structural" energy efficiency of settlements, coordination of regional planning, zoning, subsidies, tax payments, possibilities to influence real estate markets, legally binding frames for building schemes like minimum (and maximum) densities, etc.

Additionally, we propose holistic, spatially differentiated energy and resource planning on national, regional and local levels that has to spatially assign resource utilisation and environmental protection measures. Such integrated energy and resource plans should comprise at least the following contents:

- energy-efficiency and energy-saving targets;
- renewable material and energy utilisation targets under consideration of environmental capacity limits, environmentally friendly production techniques and non-use of ecological compensation areas;
- spatially differentiated area based material flows in order to enforce re-introduction of nutrients into primary production areas;
- determination of the demand for energy conversion and distribution facilities.

The demand question for energy conversion and distribution facilities operates on the system level, where necessities, size and technological options are clarified before specific sites are designated and projects developed. In this model, the development consent for energy supply facilities could only be approved if the demand for a certain plant or grid can be derived from the integrated spatial and energy plan. Furthermore, also existing spatial plans like regional plans or local spatial development strategies would be feasible to secure renewable resources by zoning respective areas, whereas the main contents of the integrated energy and resource plans sets the frame for spatial planning and goes beyond its competence.

Conclusions

The turn towards a renewable resource and energy base of society will introduce new challenges not only for the affected infrastructure systems, but also for spatial planning. These impacts are causes by the nature of renewable, especially biomass-based resources which are characterised, inter alia by low transportation density and short durability if unprocessed. Designing viable supply chains around biomass resources means to structure spatial organisation in a different way with implications for urban and regional planning way beyond the supply infrastructures.

Taking spatial dimensions of the transition to sustainable energy systems into account, major challenges arise, inter alia, (1) in cutting back energy demand by re-designing cities, towns and villages as well as related infrastructures in order to achieve, inter alia, multi-functional, dense and structurally energy-efficient units that allow for energy-efficient individual lifestyles; (2) in enhancing sustainable energy and material resource production by securing sufficient areas and keeping them free of land uses that compromise resource production and utilisation, e.g. by preventing urban sprawl; (3) in guaranteeing for energy and resource production within environmental capacity limits; (4) in a spatial differentiation of energy and resource production and processing according to natural production conditions; (5) in coordinating energy and resource planning and spatial planning to reach optimal exploitation of already conversed energy by cascading and the connection of different grids.

With the visions for the spatial-resource-planning continuum, we draft a potential future for managing this transition to a renewable resource base and to sustainable energy systems. The inevitable transition to a sustainable resource base, with resources that are both limited and linked to spatial conditions, requires profound change in planning practice as resource constraints might become dominating guardrails for human development. Spatial structures set effective frameworks for resource systems both on the demand and the supply side, which at the moment often do not comply with resource efficiency. Spatial structures are, although not unchangeable, persisting over time, so that a re-direction of practised planning paradigms towards more sustainable spatial development is pivotal for society.

Endnotes

[a,b]Stöglehner G, Narodoslawsky M, Steinmüller H, Steininger K, Weiss M, Mitter H, Neugebauer GC, Weber G, Niemetz N, Kettl K-H, Eder M, Sandor N, Pflüglmayer B, Markl B, Kollmann A, Friedl C, Lindorfer J, Luger M, Kulmer V: PlanVision - Visionen für eine energieoptimierte Raumplanung. Projektendbericht. Gefördert aus Mitteln des Klima- und Energie-fonds. Wien; (2011) [not published yet].

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Authors' contributions
All authors contributed - among others (see endnotes[a,b]) - to the PlanVision project which is the base for this paper. GS was project manager, NN and KHK were project team members. The article was jointly elaborated between the authors.

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The authors declare that they have no competing interests.

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Paper 7

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RegiOpt Conceptual Planner - Identifying Possible Energy Network Solutions for Regions

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Energy production systems are changing in its structure all over the world. The shift from fossil resources which are point sources to renewables is also forcing new ways of energy transformation. Because renewable resources are area dependent harvesting, logistics and also usage in small scale power plants are key areas of renewable based energy networks.
Regions are in the focus for the provision of energy carries like wood, cellulosic material and energy crops. Different regions have a variable setup of resource availability. RegiOpt tries to simulate possible energy network solutions based on the local conditions of every problem definition. The idea is to combine two proven tools to a single user friendly program. RegiOpt – Conceptual Planner (RegiOpt-CP) is a web based program which is intended to be used by regional actors and decision makers. It offers the possibility to get on a simple way an optimal energy technology structure based on PNS optimization. In addition the optimal solution is evaluated automatically with the SPI method and the results present the ecological footprint information. A continuous adjustment and variation of calculation values improves the capability of RegiOpt-CP for calculating a set of different scenarios which might be applicable for the specific region.
Because of the fact that not every technology can be used in each region and a huge set of technology options exists on the market, RegiOpt-CP offers objective technology network solutions to decision makers.

1. Introduction

Renewable resources for energy utilization are becoming more and more important. The substitution of fossil resources to reduce carbon dioxide emissions is a major challenge all over the world. Due to the fact that renewable resources are area dependent (e.g. biomass needs area to be grown and harvested) regions come into the role of energy carriers producers. Thus the development potential for regions is of public interest. In terms of renewable resource based energy provision there can not only be one specific successor technology substituting the fossil based ones. It is rather a combination of different technologies, linked in a mature network, utilizing several resources. Regions differ considerably in their structures like e.g in the availability of resources. For this reason every single region might need a specifically designed technology network for its energy provision.
To achieve those individually adjusted networks for regions the software RegiOpt-CP has been developed. A first basic concept has already been described by Kettl et al. in 2011, now the application is already near completion. It is a simplified decision making tool for optimizing sustainable energy structures at a regional level. In several projects during the last years of research there was one approach to create and evaluate technology networks (e.g. Birnstingl et al., 2011; Robeischl et al., 2012). In a first step the network itself was developed with the help of the Process Network Synthesis,

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PNS (Fiedler et al., 1995). Out of a given maximum structure, which parameters are strongly linked to the basic conditions such as available resources in a region, an optimal solution could be found. This result of the p-graph method represented the technology network with the highest profit for a region. In a next step scenarios were run through and a setup of possible structures with different revenue of the solutions could be collected. After PNS optimization the ecological assessment was carried out. The technology network with all in- and outputs provided the data for the Sustainable Process Index, SPI (Krotscheck and Narodoslawsky, 1996). In the end the results of both tools were brought together and an overall solution with high profit and low ecological footprint could be described.

2. Methodology

The main idea was to combine PNS and SPI to a single application. The overall goal is to use the regional resource potential in the most economic and ecological way. The target user group comprises regional development experts and planners e.g. decision makers. RegiOpt-CP can be handled without any specific background knowledge as all necessary calculations for the optimization and evaluation are carried out in the background by the program itself. The user just needs to answer questions, asked by an online survey. The questionnaire is prepared to fit for the target user group and provides default values to help filling in the required information if some parameters are not known to the user. All calculated values needed for the PNS optimization are listed at the bottom of each page of the questionnaire. Optimization and evaluation result in graphs, figures, tables and text and create a solid basis for decisions.
The economical optimization is achieved with Process Network Synthesis (Halasz et al., 2010) and these results are ecologically evaluated by the Sustainable Process Index (Sandholzer et al., 2005).

2.1 Process Network Synthesis (PNS)

PNS uses the p-graph method and works through energy and material flows. Available raw materials are turned into feasible products and services, while in- and outputs are unequivocally given by each implemented technology. Time dependencies like resource availability (e.g. harvesting of renewable resources) as well as product or service demand (e.g. varying heat demand for district heating over the year) are part of the optimization. The necessary input includes mass and energy balances, investment and operating costs for the technologies considered, costs for resources and utilities, prices for products and services as well as constraints regarding resource supply and product/service demand.
In the case of RegiOpt-CP there is an already given maximum structure with default values in the background. With help of the user input this structure is adapted by adapting values or, if necessary, deleting some branches (e.g. if there is a resource not available in the region). In the end of the questionnaire this structure, linking resources and demands with different technologies, is the starting point for the optimization resulting in an optimal solution structure representing the most economical network.

2.2 Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) was developed by Krotscheck and Narodoslawsky in the year 1996 and is part of the ecological footprint family. The SPI represents as a result the area which is required to embed all human activities needed to supply products or services into the ecosphere, following strict sustainability criteria. Based on life cycle input (LCI) data from a life cycle assessment (LCA) study, SPI can be used to cover the life cycle impact assessment (LCIA) part. LCA studies are standardized and described by the ISO norm 14040 (ISO, 2006).

2.3 Methodology interaction

Both methodologies are interconnected and work invisible to the user (see Figure 1). The user is guided through a web based survey which is intended to gather input data which is needed to start a PNS optimization. The survey is focused on regional specific data to get information about available productive areas, existing energy supply and demand situations. Based on the survey data and a pre-defined PNS maximum structure the so called PNS optimal structure is generated. It includes all material and energy flows as well as all costs and prices of the suggested technology network. In the next step the SPI evaluation is done automatically with the values out of the Optimization and results in an Ecological Footprint. The SPI results allow analysing ecological impacts according to land use, renewable, non-renewable and, fossil resource provision as well as emissions to water, air and soil.

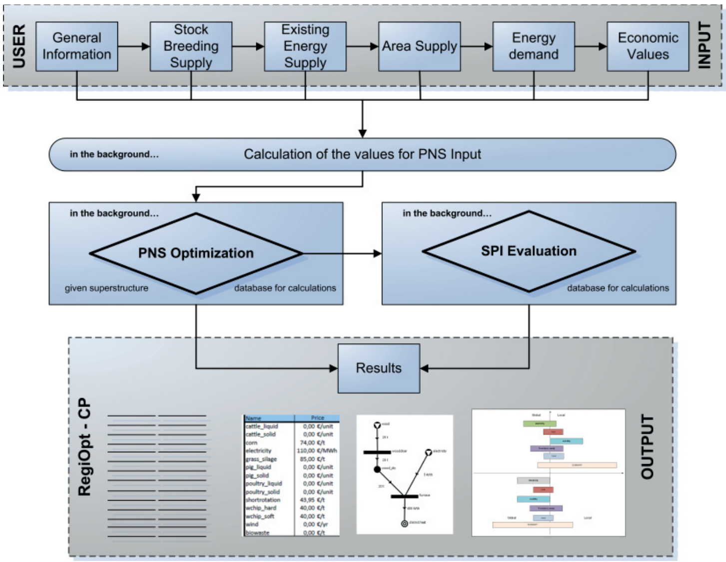

Figure 1: Schematic representation of RegiOpt – CP with its main functional parts

3. Functionality

Using RegiOpt-CP is simple and somehow self-explaining. It is mainly a questionnaire guiding the user through six input pages wherein all data and information are collected that are in a second step needed for background calculations done by the program without any notice of the user. Figure 2 has its focus on the questionnaire which is a data and information collector for the evaluations. The results are again visible for the user and offer a broad range to work with.

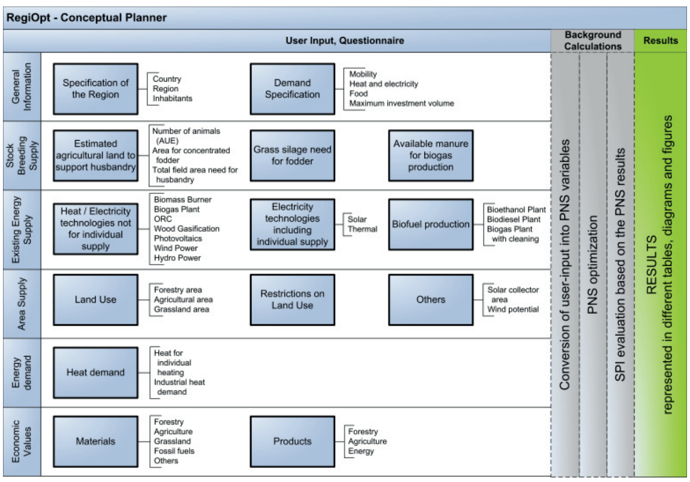

Figure 2: Data and Information Collection with the help of RegiOpt – CP questionnaire

3.1 General Information
In the beginning the user defines the project itself. Within this page main information about the structure of the region and the demands can be obtained. For example the country attribution defines the SPI value of the electricity that the system needs for the processes, because in every country the electricity mix and thus the impact on the ecological footprint differs (IEA, 2012). The SPI value itself depends on the different sources that the electricity is produced from.
The number of inhabitants is used in order to calculate the total amount of electricity need, meat and vegetarian food consumption and living space in the specific region. The demand specification is used to calculate this numbers in detail. RegiOpt - CP compares the demand for food with the existing potential to supply meat and vegetarian food and determines import of food to the region if necessary. The fact that high meat consumption means high environmental pressure may add to global inequalities and certain problems, therefore a warning is provided for sensitization.
These are so called ethical warnings that can be found all over the RegiOpt - CP as soon as there might appear an ethical conflict driven by the input parameters. These warnings are denoted by a separate button with an ‘e’ on it. There is an ‘i’ button as well where the user can find by mouse-over general information like default values or explanations what is meant by the developers in a certain case.
There is as well a possibility to set a limit of investment costs the user wants to spend for the project. As new energy systems are costly this function is implemented to avoid that a solution is offered that might exceed the regional financial capacities.

3.2 Existing Energy Supply
RegiOpt-CP takes into account, if some existing energy facilities based on renewable resources already cover some energy needs in the region. Therefore it is important to know the capacities of these technologies to consider the total amount. The existing technologies are not depicted in the optimal structure in the end, they just minimize the demand. The input page includes some well known technologies to produce heat, electricity and biofuels. The input is flexible and can be based on the input or output side of each technology.

3.3 Stock Breeding Supply
These data are required to determine the necessary agricultural area to support husbandry in the region as well as the degree of self-sufficiency in vegetable and meat production. The values are also used to estimate manure flows for possible biogas production.

3.4 Area Supply
For optimizing a region with RegiOpt–CP the starting point is the area that a region has on its disposal. The total area can be divided into three main categories; forestry, agricultural land and grassland. For each it is essential to define the area that is available to use the grown resources for energy provision. The restrictions on land use can be e.g. that some forestry area is needed for pulp and paper industry, for timber or for already existing energy technologies. Agricultural area can be reduced e.g. for growing vegetables or the fodder production to feed the animal needed to support the meat demand. There is a list of crops presented for the optimization process. Grassland area might be reduced e.g. if there is an existing biogas plant that runs on grass silage. To find out the solar thermal and photovoltaic potential the available area is asked as well. For wind energy the limiting factor is the wind power potential and the investment volume defined. RegiOpt–CP does not attach any area to wind power generation.
In this section it is possible for the user to add new materials and to define the lower heating value for unspecified oil seed and unspecified biomass for burning, for ethanol or for biogas production.

3.5 Energy Demand
This page is needed to get data about the heat demand, both for industrial and individual heating. The electricity demand given in RegiOpt–CP is calculated for all inhabitants of the region, but does not take industrial demand into account.

3.6 Economic Values
This page includes cost and price parameters of the different raw materials and products. Default values are based on the Austrian situation in the year 2011. The prices for crops include the costs for agricultural production (machinery, fertilizers and pesticides). Transport costs cover the transportation

from the farm to any plant. The transport costs for manure for biogas production are automatically included double for the calculation, because the costs of the return transport of the biogas manure to the field are also taken into account. Electricity is taken from the national grid. The ecological impact is calculated according to the national distribution of supplying technologies. The payback period for all technologies that are part of the optimization process is set to 10 years, except for photovoltaic and solar thermal where the period is 25 years.

4. Results

After the last input page of the questionnaire the user can see the results for his region. It is not only a list of numbers; RegiOpt-CP offers several diagrams for interpreting the results as well as a fully drawn structure. With the help of the input data given by the user a business as usual scenario is calculated to compare the optimized structure with the situation in the user's region at the moment. With that the improvement that can be achieved with an optimized technology network gets obvious. Due to the amount of results and their different representation forms (diagrams, tables and figures), a navigation bar will help users to find their way through. Aim of the navigation bar is to guide the user from results which are directly related to the structure, to more advanced results which connect the optimization and evaluation results in the regional context.

4.1 Tables

There are two tables within the result section that show the cumulated PNS optimization results (total revenue of the solution, cost of materials, revenue of products and total investment costs) as well as results of the SPI evaluation (ecological footprint in m² / service unit, share of products).

4.2 Technology Network

The optimal PNS structure is represented as an automatically drawn figure that can be exported and adapted by the user. Raw materials, intermediate products, technologies and end products are indicated by different symbols which are linked with related flows.

4.3 Region Comparison

In the focus of region comparison results are the comparison of the overall economic and ecological improvement compared to BAU (see Figure 3).

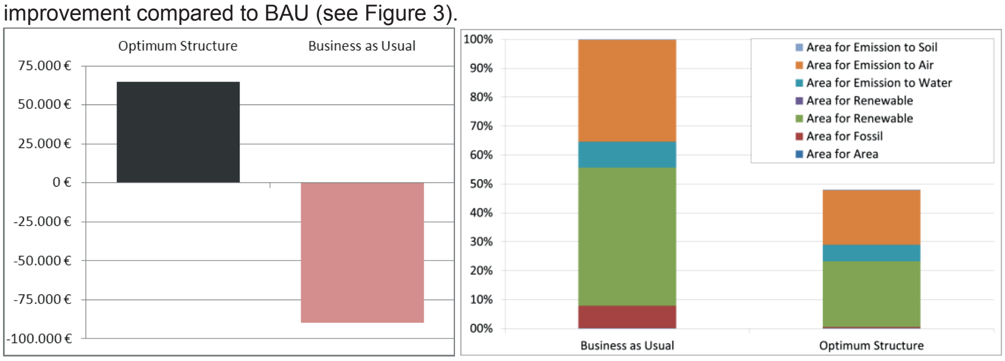

Figure 3: Regional comparison – Economic (left) and ecological (right) results within one year

Additionally the Ecological Footprint is divided by its 7 partial areas defined by the SPI methodology. Users are able to see life cycle Footprint information and the share between resource impacts (e.g. fossil and renewable), land occupation and emissions into air, water and soil.

4.4 Global – Local

According the SPI evaluation out of the PNS optimized structure, the SPI footprint of the region is presented in context to the regional information available. The user gets a diagram within the SPI values are presented in percentage and the position of the bar for each sector indicates which amount is produced locally and what has to be imported from outside. The diagram covers a business as usual (BAU) part as well which includes electricity, heat, biofuel, food (excl. meat) and meat production. On the right hand side, the so called local part, the SPI impact caused by regional available production is shown. The opposite left side (global part) represents imports which are needed (assumed as fossil imports) as the region is not providing these services by itself. After PNS optimization a shift might happen from global to local SPI footprints caused by more activities within the region. Nevertheless it is important to keep in mind that due to reduced fossil imports the overall SPI value after optimization can be lower compared to BAU. With this way of representation, it should be visualized how the optimized structure can contribute from the ecological point of view, to reduce the ecological footprint. In the same way a diagram is given for the economic distribution between global and local production to highlight the economic improvement for the regional economy.

4.5 Energy Comparison

Finally some more detailed diagrams are presented related especially to electricity, heat and mobility. Because RegiOpt-CP does only propose an optimized energy technology network, the relation between BAU and PNS optimal structure is described in more detail.

5. Conclusions

RegiOpt – CP is a user friendly online - tool that shows how a regional energy technology network can look like. The user has to go through a questionnaire, but default values are always available if some specific data are unknown. After answering the self-explaining questions a total set of input parameters for an optimization is generated. With the help of PNS and the p-graph method as well as the SPI the best solution structure is calculated in the background in between a few seconds. The optimized network covers demands by using technologies mainly based on renewable resources that come from the region itself. By changing input parameters scenarios can be generated and compared by the user. As there is the possibility to save several projects the data is always available for the user as soon as an account is created. The data are treated completely anonymous and are just used within RegiOpt–CP. The results offer several possibilities to see the economic and ecological benefit of the suggested optimal network compared to the business as usual in the analyzed region. With the given tables, graphs and figures it is possible to prepare a good argumentation base to initiate innovative projects in a region that will be both; economic and ecological feasible.

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