Nora Katalin Sandor MSc

Generating regional energy technology systems
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Web-Based RegiOpt-CP as a decision support tool for regional stakeholders

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Ao. Univ.-Prof. Dipl.-Ing. Dr. techn. Michael Narodoslawsky

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Abstract

The focus of this thesis is on regional renewable resource utilisation. There is currently a large variety of renewable resource types and a wide range of resource utilisation technologies. This can often be overwhelming for regional stakeholders who may otherwise be interested in implementing renewable resource-based technologies. It is therefore critical to support decision makers in finding the most suitable solutions for their region, especially as not all of them possess technical expertise. For this purpose a comprehensive, web-based decision-making tool, RegiOpt-CP (Regional Optimisation – Conceptual Planner) was developed and is presented in this paper.

The first part of the thesis introduces the methodological background of RegiOpt-CP: PNS (Process Network Synthesis) is used for economic optimisation of available resources, and SPI (Sustainable Process Index) is used in evaluating the results of economic optimisation from an ecological perspective. These methodologies have already been proven in several case studies prior to developing RegiOpt-CP. This thesis presents five of these case studies referenced in three publications. The first publication presents three case studies that deal with retrofit issues in industrial parks. The studies have shown that in all locations, combining regional renewable resource utilisation with existing technologies in industrial parks can lead to beneficial economic solutions. The second publication presents a potential to employ unused output from industrial processes to accommodate social needs of cities. A technology network is created to show that there is an economically feasible and ecologically favourable way to cover the communal energy supply by integrating local industries. The third publication aims to demonstrate that intercrops can be ideal complementary bio-resources for energy production in reducing competition with main crops. Although all three papers represent substantially different conditions, the common feature in all is the importance of regional characteristics. All case studies provide examples of how to enhance the knowledge of regional decision makers about regional improvements which are both ecologically and economically advantageous.

The second part of the thesis describes the process of how the methodologies were applied for implementing RegiOpt-CP with an emphasis on PNS. The significance of developing RegiOpt-CP is that PNS, originally applied in chemical processes, is now used in a substantially new context, namely in regional energy structure optimisation. The thesis illustrates the special features used in the P-graph system on which the PNS demonstration is based. A framework was also created which defines the set of possible materials and technologies for regional energy structure generation. The framework is based on the notion that regional energy demands (such as residential heating and industrial heat) must be met by using local renewable resources to the greatest extent possible. With the assistance of the University of Pannonia, the online surface of RegiOpt-CP was created which is available to users as a questionnaire for regional data input. This online surface is connected in the background with both the PNS and SPI methodologies in order to carry out economic optimisation and ecological evaluation. The results of both processes are displayed on the online surface in various tables and charts that offer a valuable decision-making tool for sustainable regional energy system structures.

Zusammenfassung

Der Schwerpunkt dieser Arbeit liegt im Bereich regionale erneuerbare Ressourcennutzung. Aktuell gibt es eine große Vielfalt an erneuerbaren Ressourcentypen und eine breite Palette von ressourcenbasierten Technologien. Diese Vielafalt kann regionale Akteure mit Interesse an solchen Technolgien oft überwältigen. Daher ist es von großer Bedeutung, die Entscheidungsträger der Regionen mit den am besten geeignetsten Lösungsvorschlägen zu unterstützen, zumal nicht alle regionalen Akteure über großes technisches Know-How verfügen. Zu diesem Zweck wurde eine umfassende, webbasierte Entscheidungshilfe, RegiOpt-CP (Regional Optimisation – Conceptional Planner) entwickelt und wird in dieser Arbeit vorgestellt.

Der erste Teil der Arbeit stellt den methodischen Hintergrund des RegiOpt-CP dar: PNS (Process Network Synthesis) wird für die ökonomische Optimierung der verfügbaren Ressourcen verwendet und SPI (Sustainable Process Index) wird für die Auswertung der Ergebnisse der ökonomischen Optimierung aus ökologischer Sicht eingesetzt. Bereits vor der Entwicklung von RegiOpt-CP wurden diese Methoden in mehreren Fallstudien nachgewiesen. In dieser Arbeit werden auf fünf dieser Fallstudien in drei Publikationen verwiesen. Die erste Publikation präsentiert drei Fallstudien, die sich mit Nachrüstungssituationen in Industriegebieten beschäftigen. Die Fallstudien haben an allen Standorten gezeigt, dass die Kombination von regionaler erneuerbarer Ressourcennutzung mit bestehenden Technologien der Industriegebiete zu einer wirtschaftlich vorteilhaften Lösung führen kann. Die zweite Publikation stellt das Potential dar, gesellschaftliche Bedürfnisse einer Stadt mit ungenutzten Produkten industrieller Prozesse zu decken. Ein Technologie-Netzwerk wird erstellt, um zu zeigen, dass es einen wirtschaftlich machbaren und ökologisch günstigeren Weg gibt, um den Energiebedarf der Gemeinde durch die Integration von lokalen Industrien zu versorgen. Die dritte Publikation soll zeigen, dass Zwischenfrüchte eine ideal ergänzend Bioressource für Energiegewinnung sind, um den Wettbewerb für Hauptgetreide zu verringern. Obwohl sich in allen drei Publikationen wesentlich unterschiedliche Bedingungen darstellen, ist das gemeinsame Merkmal die Wichtigkeit der regionalen Eigenschaften. Alle Fallstudien liefern Beispiele dafür, wie das Wissen von regionalen Entscheidungsträgern über regionale Entwicklungen, die ökologisch und ökonomisch vorteilhaft sind, gefördert werden kann.

Der zweite Teil der Arbeit beschreibt den Prozess, wie die zwei Methoden (mit dem Schwerpunkt auf PNS) für die Umsetzung von RegiOpt-CP angewendet wurden. Die Signifikanz der Entwicklung von RegiOpt-CP ist, dass die PNS Methode, die ursprünglich für chemische Prozesse enwtickelt wurde, in einem wesentlich neuen Kontext in der Optimierung von regionalen Energiestrukturen eingesetzt wird. Die Besonderheiten des P-Graph Systems, auf dem die Demonstration des PNS basiert, werden dargestellt. Eine Grundstruktur, die das Set der möglichen Materialien und Technologien für die Erzeugung der regionalen Energiestruktur definiert, wird ebenso präsentiert. Die Grundstruktur basiert auf der Grundlage, dass der regionale Energiebedarf (wie der Heizbedarf in Wohngebäuden und der industrielle Wärmebedarf) so weit wie möglich durch lokale erneuerbare Ressourcen gedeckt werden muss. Mit der Unterstützung der University of Pannonia wurde die Online-Oberfläche des RegiOpt-CP erstellt, die für Benutzer in Form eines Fragebogens für die regionale Dateneingabe zur Verfügung steht. Diese Online-Oberfläche wird im Hintergrund sowohl mit der PNS als auch mit der SPI Methode verknüpft, um die ökonomische Optimierung und die ökologische Bewertung durchführen zu können. Die Ergebnisse der beiden Methoden werden in Form von

verschiedenen Tabellen und Diagrammen auf der Online-Oberfläche angezeigt um ein wertvolles Entscheidungswerkzeug für nachhaltige regionale Energiesystemstrukturen anzubieten.

List of Figures and Tables

1. Introduction

Renewable energy sources are vital in many aspects. First, in response to climate change a reduction of greenhouse gas emissions is needed which leads to the preference of renewable energy sources over fossil fuel technologies. Second, the growth in world population, increasing living standards and required improvements in energy safety further strain the availability of natural resources and this makes any kind of restructuring towards sustainable development very challenging and complex.

To prevent the global average surface temperature increasing by an estimated 3.6°C in the long term based on current trend predictions (IEA, 2014a), urgent actions must be implemented. The most serious negative environmental impacts of climate change occur at temperature increase beyond 2°C. This can be prevented by ensuring that the global CO_2 emissions do not exceed 1000 Gt starting in 2014 (if the current emissions values remain stable, this amount is already used by 2040, IEA, 2014a). This leads us to one of the most important factors in decision-making in rethinking the future structures of the energy sector, which is responsible for around 65% of worldwide fossil fuel CO_2 emissions and directly impacts climate change (IEA, 2014b). Despite this, fossil fuel sources – the main contributors of climate change in the energy sector – still received financial support from subsidies globally that were more than four times higher subsidies provided to renewable energy sources in 2013 (IEA, 2014a).

According to United Nations estimates, global population is predicted to reach approximately 9 billion by 2040 (ESA, 2012). At the same time, global energy need is expected to increase by around 37% compared to 2013 (IEA, 2014a). Not only is it important to ensure the energy safety of our current and future generations, but it is necessary to adapt to the predicted increases in living needs as well. For example, population growth in developing countries is expected to lead to increased per capita protein consumption as a result of higher predicted income levels (OECD-FAO, 2014). This means an even higher land demand in the agricultural sector making future plans for land utilisation very difficult.

The main advantages of renewable energy sources are less harmful effects on climate change, low air pollutants emissions, and avoiding, or at least decreasing, a geographic region's dependency on fossil fuel imports or nuclear energy (EEA, 2015). Renewable resources (with the exception of geothermal resources, wind and tidal power as well as hydropower) are nevertheless predominantly based on solar energy which requires land for their utilisation. This puts most of the renewable resources for energy production in competition with other processes that require land use including food production and resources for industrial processes (e.g. paper and pulp industry) (Narodoslawsky, 2014). This is particularly true for bio-resources, which may become major elements of any future energy system as they provide storable energy that can power mobility (in the form of biofuels) as well as stabilise distribution grids by providing "just in time" energy whenever discontinuous energy providers like wind power and PV do not sufficiently cover consumer demand. Land dependency is crucial to better understand the characteristics of renewable resources and technologies that use land if we want to prove the viability of their utilisation for energy production on a regional scale.

This paper focuses on the utilisation of renewable energy sources on a regional scale. An online decision-making tool (RegiOpt-CP) is introduced which develops regional energy-technology networks based on renewable resources, and in particular bio-resources. The tool optimises the use of these resources and helps decision makers identify the economic, environmental and ethical aspects of various future scenarios needed for regional development.RegiOpt-CP is based on the Process Network Synthesis (Friedler et.al. 1992a, 1992b) and Sustainable Process Index (Krotscheck, Narodoslawsky, 1996) methodologies.

1.1. The role of renewable resources in energy production

Since the online decision-making tool described later in this paper has been developed with primarily European parties in mind, the data and trends presented in the following subsections have been sourced chiefly from European countries.

In order to achieve 2050 EU targets of increasing the share of renewable energy sources to 20% of gross European final energy consumption and to reduce European greeenhouse gas emissions by 80-95% relative to 1990 levels (EEA, 2015), renewable energy sources must be favoured over fossil fuel sources. Of the approximately 326 Mt reduction in CO_2 emissions in the European Union, 72% resulted from the renewables' share in electricity production (EEA, 2015). The most important technologies in this sector are wind power and PV (EEA,2015), both of which are discontinuous energy sources. This implies that, for instance, even if a wind turbine is ideally constructed (it is precisely designed according to the site-specific wind characteristics) the power generated will have varying volume and could come to zero production from time to time due to variable wind intensity. Similarly, there are critical factors such as night-time, cloudy and rainy hours for solar PV installations in terms of electricity generation. On the one hand, this means that whenever weather conditions are not advantageous to produce electricity using these energy sources, backup technologies are needed fill the gap in supply based on the difference between consumption and provision of electricity. The geographical conditions are not always advantageous for complementary renewable energy technologies such as hydropower and geothermal energy; hence bio-resources must play an important role here. On the other hand, the growing share of renewable energy sources in the electricity production can be regulated up to a certain level through new methods for electricity supply. Smart grids (smartgrids.at 2015) tend to reform the electricity supply by changing from a centralised to a decentralised regulated system and connecting all participants from producer to consumer via a communication network.

Another major field for utilisation of bio-resources is conceivably the production of storable energy in the form of biofuels. According to EU targets, among bio-resources transport fuels are anticipated to grow at the fastest rate until 2020. Ahead of renewable energy for heating and cooling (3,9%) and electricity (5,5%), the production of biofuels is expected to rise by 11% relative to 2013 levels (EEA, 2015). Even though road traffic as measured by kilometres covered declined by 3,6% relative to 2008 levels, road traffic was still responsible for more than 70% of transport covered distances in 2012 (EEA, 2014a). It is unclear whether this declining tendency will continue, since it is significantly influenced by temporary economic slumps which are challenging to predict in advance. Distances travelled by air traffic show a lesser decline of 1,3% in 2012 compared to 2008 Figures (EEA, 2014b).Compared to 2008 levels, a 20% drop and compared to 1990 levels a 60% drop in GHG emissions is forecasted by 2030 and 2050, respectively, from transportation activities within the EU (EEA, 2014a). GHG emissions from international shipping are regulated separately by the EU, with a target by 2050 of a 40% decline in levels relative to 2005 levels (EEA, 2014a). This means that in all transport forms (road and aquatic traffic as well as aviation) beside other renewable energy sources (like solar parks for electric mobility), bio-resources as raw materials for fuel generation represent great opportunities.

1.1.1. Characteristics of bio-resources

Bio-resources can be categorised into two types (Narodoslawsky, 2014). Primary bio-resources are available in forms of various crops and need area (be that forest or agricultural area) and fertile environmental compartments for cultivation. The dependency on land however puts the utilisation of these resources for energy and industry in competition with other land uses like provision of nutrition and settlements. Therefore careful management of the basic resource of land is required, which means for instance, that the area for covering the basic food demand of a region has to be ensured first before primary bio-resources are planted for energy production or used for industrial processes. The other type of bio-resources can be either residues or by-products of agricultural, industrial or societal activities, which means that their provision does not add to extra land need. Still, several aspects have to be taken into account to distinguish between them. Manure from the agriculture for example can be perfectly used for biogas production, which can either be upgraded later for district heating or transport fuel or used for electricity and heat production. A by-product of biogas production, bio-fertilisers can be taken back to the fields, but to keep the balance for an optimal soil quality requires thorough control, which might limit the availability of this kind of bio-resources.

The characteristics of the composition of bio-resources however present logistical challenges. This is not only generally true for secondary bio-resources but also for the majority of primary bio-resources. Bio-resources that are planned for burning (e.g. straw, wood chips) have an energy content that is still remarkably lower than that of fossil fuel sources (wood chips for instance have energy content in one m3 that is around 15 times lower than the energy content of light fuel oil). As a result, transporting these resources requires higher energy input. This is particularly true if transport density is low (e.g. in case of straw) or generally for wet bio-resources which are utilised for biogas generation. The humidity of wet bio-resources is extremely high, while their energy content is very low compared to fossil fuel resources (light fuel oil for example has a ratio that is more than 50 times more advantageous per m^3 than manure). These characteristics obviously limit the economic viability of transporting bio-resources and in general show that short transport distances (by using local materials) are preferable.

Optimal combinations, at least for purchasing raw materials, are illustrated by waste water plants when operating with biogas plants on site since the input for the biogas production is already available on the spot. However as soon as for example the consistency of the input of the fermenter should be improved, or higher capacity could be achieved by using other bio-resources, it is important that raw materials are collected from local sources as we previously argued. Possible products are cleaned biogas (if an upgrade process also takes place) or heat and electricity from combined heat and power units. Except for electricity (which can be fed into the grid) other products are beneficial for local distribution (such as cleaned biogas for local transport or gas heating and heat for district heating, local agricultural or industrial processes). This is also true for by-products, as bio-fertilisers are optimally distributed to nearby farms.

An example of utilising local industrial and societal residues is presented by the Swedish city Linköping. In this city of around 150000 inhabitants (2010) all public buses and 90% of taxis run on biogas and several initiatives exist to increase biogas utilisation as transport fuel for residents' cars (linkoping.se, 2011). Biogas is produced basically from the residues of a local slaughterhouse and food wastes from restaurants (sustainabilitywriter.wordpress.com, 2012). In this case, in addition to biogas, biological fertiliser from the process serves as an additional renewable alternative resource for agriculture.

Some other secondary bio-resources include but are not limited to materials which already have a significant trading in other recycling processes (e.g. waste paper) (Narodoslawsky, 2014). The chance is here therefore lower that new technologies for energy production would provide more viable utilisation not only from environmental but both economic and societal aspects at the same time (Narodoslawsky, 2014).

When proving the viability of bio-resource utilisation, it is important to consider the characteristics of the materials themselves, to take into account their present market positions and similarly their regional context for utilisation.

1.2. Regional utilisation of renewable resources

The utilisation of renewable resources within a region should be compatible with the characteristics of the region itself. A region can be seen as a contiguous geographic area that typically connects land with settlements that represent economically important centres. Regions however not only differ in their size but also in their infrastructure, economy, available resources, population density which can vary widely. Developing average sustainable structures for future regional development therefore would not be satisfactory in most cases. Economic, ecological and social aspects and characteristics need to be thoroughly analysed for each region. The following subsections analyse three important factors in regional development planning: agricultural activities, existing industrial processes and energy use. The aim is to show the advantages of planning on a regional scale and demonstrate how models can help with the planning process.

1.2.1. Agricultural activities

As noted in subsection 1.1.1., the provision of nutrition in a region must take priority when considering scenarios and planning regional development structures. Several future trend reports on agricultural market are available. In the European Union the total utilisation of agricultural area shows a small decline based on mid-term trend projections as seen in Figure 1 (OECD-FAO, 2014). At the same time, demand is expected to remain stable coupled with large EU exports. The implication of this analysis is that better yields should be achieved and/or crop areas should be redistributed, which can naturally only be realised on a regional level. This is also supported by the common agricultural policy (CAP) (OECD-FAO, 2014) since it favours the use of regional data over historical data. Per capita meat consumption trend data is also available, with an expectation of an aggregate 11% decline in consumption in the European Union by 2024 relative to 2014 levels (OECD-FAO, 2014).The values for the original EU-15 member states however differ from the values of the EU-N13 new member states. While the total decline is attributable to the original 15 member states, a slight increase in poultry meat consumption in all member states and a modest rise for pork meat consumption in the 13 new member states is forecast. As opposed to listing other trends it is more important to mention that the greater the depth of analysis, the greater the number of differences we would find as we move from an international to a regional level. All these trends consider the differences and confirm the viability of planning future development on a regional scale. Of course, the task of regional decision makers remains difficult as they face numerous challenges.

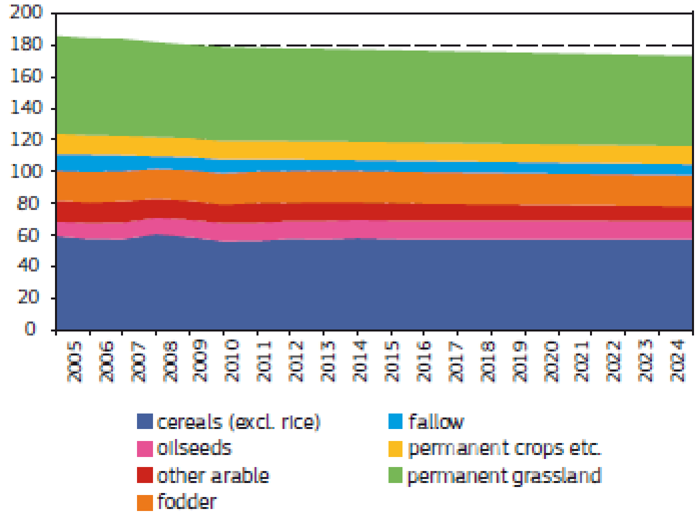

Figure 1. Agricultural land-use developments in the EU (million ha, OECD-FAO, 2014)

While arguably a very sensitive topic, decision makers must be aware when looking at agricultural production and consumption that high meat consumption correlates with high environmental pressure and may exacerbate global inequalities and certain problems. For example, according to a 2011 article, one of the considerable challenges is that 75% of animal feed in the EU is imported primarily from South America (PBL, 2011). Local decision makers have the chance to change values like the rate of animal feed import and reduce ecological pressure by supporting local feed production in their regional development plans, especially since the CAP is designed to help farmers continue their agricultural activities by enhancing direct payment methods. In addition, despite the slightly declining trend in total EU meat consumption, the average protein consumption per capita is still around 70% higher than recommended, coupled with an approximately 40% higher value for fatty acids hence making human health problems more likely (PBL, 2011). This is remarkable since 3 kg of feed (EU average) is required just to produce the average daily protein requirement of a EU citizen (100 g meat and 800 g dairy products) (PBL, 2011). Again, it is a sensitive but critical task to rethink agricultural systems, which could best be achieved by letting local participants work together and allowing them to retain the responsibility to make improvements on a regional level. Reducing food losses and, for example, supporting organic farming could both prevent excessive meat consumption (e.g. via higher prices) and lead to smaller environmental pressure (e.g. via no use of pesticides). Initiatives such as the introduction of “meat free” days in school canteens in a region is a further example of promoting a healthier lifestyle and reducing ecological pressure caused by livestocks.

1.2.2. Industrial activities

Similar to agriculture, industrial activities can also influence the available land for renewable energy sources, particularly for bio-resources. The land needed for timber, vegetable oils and fats, and pulp and paper production for example has to be deducted from the available land for energy use and future trends, especially concerning expansions, should be factored in. There is however a promising path by restructuring these conventional industries into flexible bio-refinery systems

(Narodoslawsky, 2014). In this case existing skills and facilities including infrastructure would continue to be utilised while a greater variety of products and services would be available thus adding to the adaptability of markets to future needs and changes. Other type of bio-refineries can use secondary bio-resources or bio-resources which have not been fully utilised. For example, green bio-refineries use grass silage as raw material and turn them into lactic acid (sold e.g. to industries as solvents or base chemicals) and amino acid (sold to the food industry or as animal feed). The by-product presscake can be perfectly used in biogas production which thus allows for integrating this technology into further regional use (see also subsection 1.1.1.).

By supporting cooperation among local actors, unutilised resources can become viable options for regional application. For example, waste heat from an industrial process often has its own advantages and disadvantages since its availability is solely based on the characteristics of the process itself and does not necessary align with possible utilisation demands. Even if we were to assume that this resource is free, it would be difficult to prove that utilising the waste heat alone (e.g. for district heating) would be either economically or ecologically viable if demand on the other side were cyclical (e.g. heat demand in regions where no district heating is needed during the summer months). It is more likely the case that a technology network that consists of a diverse array of technologies (supported by many local actors) could prove to be a viable utilisation method. Such methods however require considerable investment. When waste heat is not available, back-up technologies from regional renewable resources could be installed to fill the demand gap (e.g. in winter months where the heating demand is relatively constant). Similarly, extra waste heat could be used in other seasons to generate other products (e.g. dried agricultural products during the summer months). In any case, a careful analysis is necessary to prove the viability such an interlinked network, especially if there are products that cannot be sold on a regional market. Demand for these products needs to be verified.

1.2.3. Energy use

As we have seen, there are many ways to integrate industrial and agricultural activities into regional systems. Examples for utilising waste materials (e.g. slaughterhouse residues, manure, organic municipal waste, waste heat) or applying innovative technologies (bio-refineries) have already been mentioned before. When looking at an overview of finding the most suitable solutions, regional energy use is clearly a key factor of consideration. However the task goes beyond only planning the way of covering energy demand. Options for improvements or changes to current energy systems have to be part of any analysis in regional development when covering electricity, heating and transport fuel demand. The following arguments present some of these options for improvements:

Towards integrated electricity markets: Regions have the option to think in an autarky scenario and first prove whether their regional electricity production could cover demand. The advantage is that no new networks have to be implemented in this case. However, when thinking in an integrated electricity market selling "green" electricity represents revenue for the region. Even in this case, it is important to gain information on how secure the local supply is and if storage capacity is available. Such information is the basis of a reference for important decisions in a region when coordinating towards an integrated European electricity market. It is important to add that regions will play a significant role in energy policy coordination (entsoe.eu, 2015).

Regional heat demand: Possibilities for improving systems that cover regional heat demand also exist. For example, it is important to inquire about building standards in order to achieve efficiency in heating demand and in order to discuss recommendations for possible insulation methods. Information about heating demand can also be useful in extending available district heating networks or in planning new ones. Areas with individual heating for a potential district heating network should be carefully chosen especially considering the high cost of new pipes that transport heat. Alternatively, areas could be supplied with gas heating by locally produced cleaned biogas.

Challenges in transport systems: More and standardised charging stations for electric cars could facilitate a higher number of electric cars sold (handelsblatt.com, 2015). This could be particularly interesting for local distribution system operators, since any excess profits from a new market (electric charging stations) could be used to allocate to improvement of their distribution networks. This is crucial in order to meet expectations from the changing energy market especially as the percentage of renewables' share in power generation grows (reuters.com, 2015). Other than electric cars, vehicles running on bio-fuels could play an interesting role in the improvement of transport systems. The integration of such bio-fuels requires careful planning (whether for example cleaned biogas is more advantageous for district gas-heating) and accurate market prices (at what level they become economically viable).

It is considered unlikely that any of these improvements prove viable by considering only single technologies. Models which consider complex energy systems and include other local activities (such as agricultural and industrial processes) can better incorporate regional characteristics and would therefore serve as a more powerful knowledge platform for meeting decisions towards regional development.

1.2.4. Regional cooperation

The above subsections demonstrate that planning on a regional scale can best be realised through cross-sectoral cooperation and through the use of models, since future challenges can no longer be readily solved by single activities. An important factor in the planning process is the role of the decision makers themselves.

The main difference between regional development and initiatives on a national or even international (e.g. European Union) level is that regional development is done through local participants. These local participants, who include political and economic players of a settlement, operators of local industrial and agricultural activities (e.g. sewage treatment plant, brewery, butchery, fishery, crop drying etc.) best represent their respective regions. Not only can they offer precise and accurate information about each region, but presumably these participants know and rely on each other which is expected to facilitate a more effective and stronger cooperation between them. Industries however have other interests as public utilities. Taking extra responsibility and committing to new cooperation represent additional risks for these participants. Cross-sectoral cooperation therefore needs clear arguments for explaining the benefits of all interested parties in a region. The participation of a political participant in such collaboration can reduce the time for information flows and it is in the interest of each participant to foster optimal solutions for regional development.

Nonetheless, initiatives on a regional level and the willingness of residents have to be regarded as key elements for a common success, since a region can be an ideal starting point for increased education on sustainable development. The following are a few of the examples to consider: Are people aware what changes a selective waste collection can make? Can a region influence and if possible provide support for heating insulation? Is there a possibility to produce bio-fuels, and if so, how could their use as transport fuel be widened? There are several questions regional decision makers must answer and factor in when planning future scenarios but they have the best knowledge and connections to do so in order to achieve improvements in their region.

1.3. Renewable resources based technologies for energy production

One of the key arguments for utilising renewable resource-based technologies for energy production is the ecologically beneficial performance of these technologies compared to fossil driven ones. Performance however can not only differ between technologies but also within a single technology based on different conditions. A 2011 study investigates the ecological impact of different technologies that produce heat and/or power or fuels based on both renewable and fossil sources (the entire study has been attached as a reference). The study aims to compare the ecological pressure presented by the technologies where the output is energy. The method (SPI) used for this comparison is a member of the ecological footprint family (see chapter 2). In addition to the overall footprints, three main contributors (only the relevant contributors are included), the fossil-carbon resource and emissions to air and water are also displayed. For heat production, the CHP technologies are compared: CHP unit based on biogas, biomass based ORC unit and a natural gas turbine. These latter mentioned technologies are also part of the ecological comparison when considering electricity generation, along with a PV panel and a wind turbine. (A natural gas turbine was selected for the comparison as it is regarded as the “cleanest” fossil technology available today.) With regards to fuel production, bioethanol based on corn having biomass based technology for process energy, as well as bioethanol based on corn but having natural gas based technology for process energy, gasoline and diesel are compared. The study shows that in general renewable resource-based technologies represent a lower ecological pressure than those technologies that use fossil based energy sources. For example, natural gas derived electricity can have approximately 10 times larger ecological footprint than electricity derived from biogas based technologies, but even the ecologically least advantageous PV panel represents half of the ecological pressure in comparison with the fossil based method.

Despite these results it is interesting to look at the contribution to the different ecological categories when comparing technologies. It is understandable that the fossil carbon output leads within natural gas derived technologies. Nevertheless it is also evident that the contribution to fossil carbon output is also strong in renewable resource-based technologies. This amount however can be dramatically reduced by choosing for instance biomass based process energy production when producing bioethanol. The ecological pressure can be further reduced by using biofuel for transport and machinery in the agricultural sector. Similarly, solutions are needed for material production when considering wind turbines (during the production process fossil coal could be replaced e.g. by charcoal, although this switch may not be observed in the short term). All in all, technologies using renewable resources are ecologically advantageous in comparison with the fossil based ones, but it is important to revise the entire process of the particular energy production in order to produce energy in an increasingly ecological way.

Beside ecological performance, economic viability should be proven as well before investing in renewable resource-based technologies producing energy. The different forms of renewable energy are nevertheless diverse in terms of availability and type of resources as well as in the application process and distribution. It is therefore difficult to specify cost characteristics for these energy forms (Girkinger, 2014). Technologies that use direct solar energy such as solar thermal installations and PV are basically dependent not only on technology installations but directly on the amount of sunshine hours. Despite these dependencies, the management of the resource itself however can be a critical factor for technologies based on bio-resources. In the former case (when regarding technologies with direct solar use) technology innovations can have the biggest impact on cost reduction in the coming years. In the latter case (when regarding technologies based on bio-resources) it is crucial not only to pay attention to other uses of the bio-resources but also to take into account the cost at which they are produced or transported. It is nonetheless true for all renewable energy forms that the location can be a determinant economic factor. Even if one type of renewable resource-based technology is suitable for a particular location, this does not guarantee that it represents a viable solution for other sites. When looking at the economic feasibility of renewable energy production, what is more important is to regard it as part of a system in a regional context and not only as standalone technologies. Such a system can be an energy system with the aim to cover the energy demand of a region by factoring in local resources. A more complex approach is to factor in all available resources in addition to existing technologies of a region and supply not only the energy need but also the nutritional requirements and allow the production of a greater variety of market potential. This approach is presented by the decision-making tool described in chapter 4 along with more detailed economic, ecological and ethical issues.

1.4. Problem definition and research questions

The focus of this thesis is the creation of energy technology networks for regional development while utilising possible regional renewable resources to the greatest extent possible. The aim was to use methods which can prove the economic viability and show the ecological advantages of these resources for which an online decision-making tool has been developed. This tool is called RegiOpt-CP (Regional Optimiser – Conceptual Planner) and uses an existing methodology within a new context: Process Network Synthesis (PNS) is adapted for optimising the use of regional renewable resources. Following an economic optimisation process, the results are evaluated based on their ecological performance.

The thesis is based on the following research questions:

- How can we use the Process Network Synthesis as a basis for optimising regional systems?
- How does a user-friendly system look like which can be also applied by interested parties without technical expertise for regional development?

2. Methods

2.1. Process Network Synthesis

Process Network Synthesis (PNS) is a general method for the generation and optimisation of process networks based on combinatorial rules using the P-graph representation of a flow system. The method is based on three algorithms: MSG (maximal structure generator), SSG (solution structure generator) and ABB (accelerated branch and bound optimisation). The evaluation of the outcome is done via Mixed Integer Programming (MIP) and considers basic economic data such as raw material costs, product and service prices, fixed and variable costs for technological investment and operations. The detailed description in the following section is based on information provided by colleagues of the University of Pannonia during common projects, but all examples and Figures were exclusively composed for this thesis.

2.1.1. PNS origin

The PNS method was first applied in the chemical industry, where available raw materials are converted into finished products by using operating units. An example of an operating unit in the chemical industry is a reactor which converts inputs into given outputs. Since a substance can be generated by using a number of operating units or with their combination and it is also possible to generate the inputs of the operating units in several ways, the problem to face in these cases has combinatorial nature. By increasing the number of steps to reach the final product, the number of possible structures increases exponentially.

2.1.2. Process graph

A process network synthesis has several application areas. Our example is based on a continuous production system where output from a unit is produced continuously. When talking about a synthesis in this context, a new system component is created from well-known system components. In such a system we distinguish between raw materials, intermediate products, products and operating units. The system representation is done by the process graph method. A process graph (P-graph) is a directed bipartite graph, which makes it possible to build process structures through mathematical models.

The formal definition of the process graph is described as follows:

- *M* denotes the set of materials appearing in the system
- *R* denotes the set of available raw materials
  - *R* cannot be 0
  - *R* has to be a proper subset of *M*, therefore each raw material is one of the materials appearing in the system (*M* is not subset of *R*)
- *P* denotes the set of products to be generated
  - *P* cannot be 0
  - *P* has to be a proper subset M, therefore each product is one of the materials appearing in the system (*M* is not subset of *P*)
  - *P* cannot be part of *R*, therefore no product is a raw material and no raw material is a product
- *O* denotes the set of operating units appearing in the system

- *O* cannot be 0

If *o* is subset of *O* and *o* consists of α and β, which are part of *M* then α denotes the input materials of operating unit *o* and β denotes the output materials of operating unit *o*. Furthermore if *m* is a subset of *M*, then *o* operating unit is the subset of the Cartesian product of p(*m*) where p(*m*) is the power set of *m* (the set of all subset of *m*). The Process graph can be described as the pair (*m,o*). We get to its vertices if we take the union of *m* and *o*, while its arcs are represented as the pairs of the vertices belonging to the initial and terminal points.

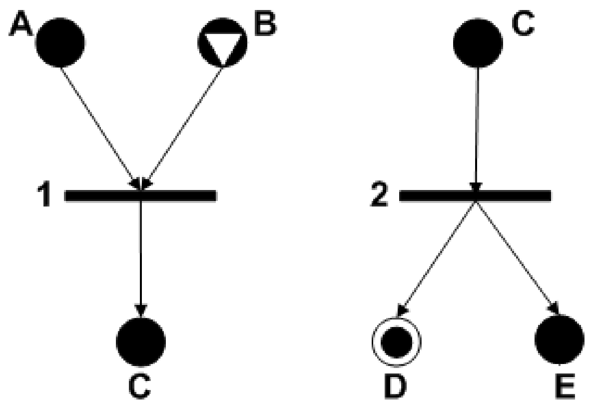

Figure 2. Examples for P-graph (Materials are A,B,C,D and E; operating unit 1 has A and B as inputs and C as output, operating unit 2 has C as input and D and E as outputs)

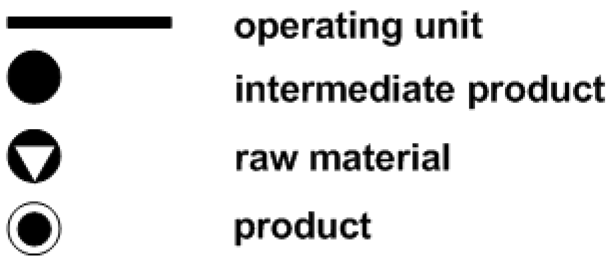

Figure 3. Symbols of the P-graph representation.

As shown in Figure 2 and according to the symbols presented in Figure 3, input can be raw materials or intermediate products, where the latter are used as inputs for further processing but are not regarded as final output of a system. It would also be possible to add a product as an input of an operating unit which would mean that we could assess whether it is viable to terminate production or whether it is more beneficial to continue production and turn this product into another one. This issue will be examined in more detail in chapter 4. Operating units denote technologies in general whereas outcomes are either intermediate products or products. In the chemical industry for example, A could be an aqueous solution from which we want to retrieve our product. B could be an entrainer which has already been produced, hence it is an intermediate product. Operating unit 1 in this case is a mixer, where the output is C to be separated by operating unit 2 (separator). Our product (marked as D) is an output of the separator. If water is separated too it could be marked as a by-product (not shown by Figure 2).

The significance of the P-graph in a combinatorial approach of process synthesis is that it makes the representation of the process network structure combinatorially simple to manipulate. Another significance is given in the following definition.

P-graph (m, o) is defined to be combinatorially feasible or to be a solution-structure of synthesis problem (P-Product, R-Raw Material, O-Operating unit) if it satisfies the following axioms.

(S1) Every final product is represented in the graph. This implies that each product is produced by at least one of the operating units of the system.

(S2) A vertex of the M-type has no input if and only if it represents a raw material. This axiom stipulates that a material is not produced by any operating unit of the system if and only if this material is a raw material.

(S3) Every vertex of the O-type represents an operating unit defined in the synthesis problem, meaning that only the plausible operating units of the problem are taken into account in the synthesis.

(S4) Every vertex of the O-type has at least one path leading to a vertex of the M-type representing a final product. The meaning of the statement is that any operating unit, included in the system, must either directly produce one of the required products or be connected via other operating units to a unit generating at least one of the products.

(S5) If a vertex of the M-type belongs to the graph, it must be an input to or output from at least one vertex of the O-type in the graph. The last axiom reflects the real-life fact that each material appearing in the system is either fed to an operating unit or produced by one. (Varbanov, 2012)

Even though these axioms do not seem to be extraordinary, they serve as important and univocal definitions that allow us to exclude all infeasible structures from a combinatorial point of view. This is especially true given that the size of the problem value must not be underestimated above a certain amount of components. It is denoted by binary variables (the binary nature refers to whether a component is included or excluded from the system) which implies that if, for example, there were only 30 operating units, the number of theoretical solutions would exceed one billion (2^{30}-1). The algorithm based on the axioms described above is defined next.

2.1.3. Algorithm MSG (maximal structure generation)

The overall network which is developed using the P-graph system, results in a so called superstructure. The set of all operating units and the set of all materials (raw materials, intermediate products and products) are contained in this structure. Out of the superstructure, the maximum structure is generated using the axioms from 2.1.2 and represents the entire network of all feasible solution structures of the synthesis problem, where infeasible operating units and materials are excluded from the system. This is important to note since it allows for an acceleration of the calculation processes. Examples for excluding materials or operating units include:

- ❖ a raw material is not an input of any operating unit
- ❖ an operating unit has no outputs (Note that an operating unit can still function without inputs but not without outputs. This aspect will be also given more attention in chapter 4.)

❖ an operating unit has no leading path to any product

A simple example will illustrate how the algorithm MSG operates. In the first step the synthesis problem is composed based on the given input data:

- P={D}
- R={A,B,F,H,J,K}
- M={A,B,C,D,E,F,G,H,I,J,K}
- O={({A,B}{C}),({C}{D,E}),({C,F}{G}),({H}{I}),({E,J}{C}),({I}{D})}={O1, O2, O3, O4, O5, O6}

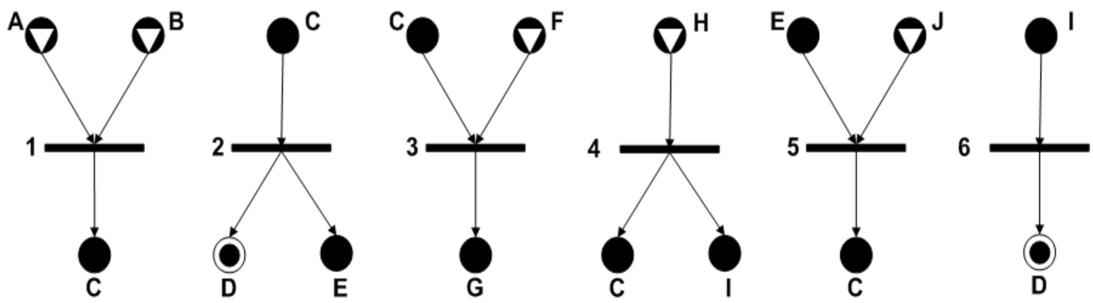

Figure 4. Possible P-graphs according to the input data

Figure 4 shows the possible P-graphs which help illustrate how the operating units factor in the input data. In the second step of the maximal structure generation (based on the set of operating units and the set of materials, including all raw materials, intermediate products and products) the following superstructure is constructed:

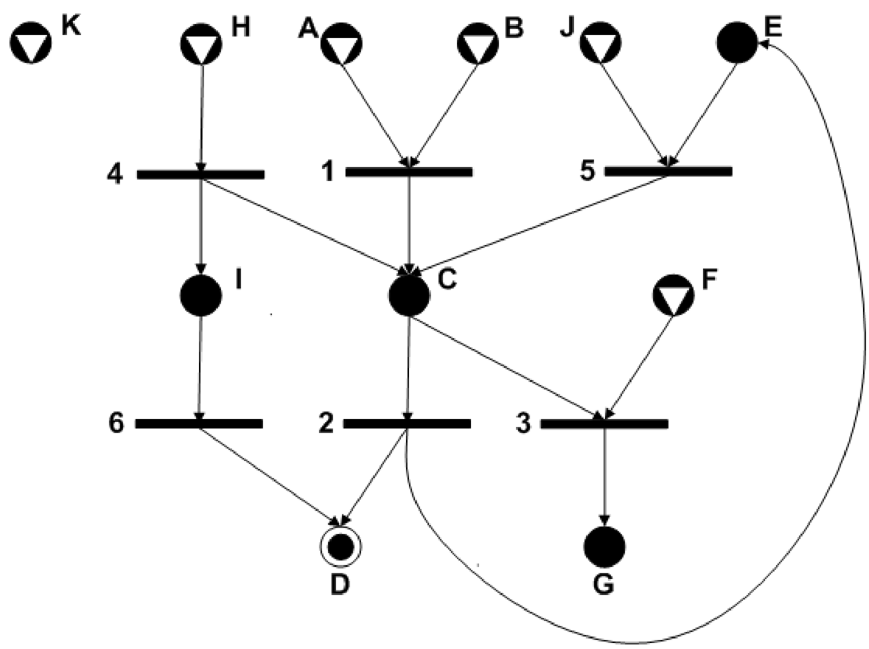

Figure 5. First step of maximal structure generation

During the third step infeasible components of the superstructure are eliminated. In our example, raw material “K” is not an input of any operating unit, therefore it is no longer part of the structure. Furthermore, operating unit 3 has no output leading to any other operating unit producing “D”, which implies that this operating unit cannot be part of the maximum structure either. Note that by excluding operating unit 3, raw material “F” and intermediate product “G” are also eliminated. In the last step the maximum structure is generated using all feasible connections, which is shown in Figure 6.

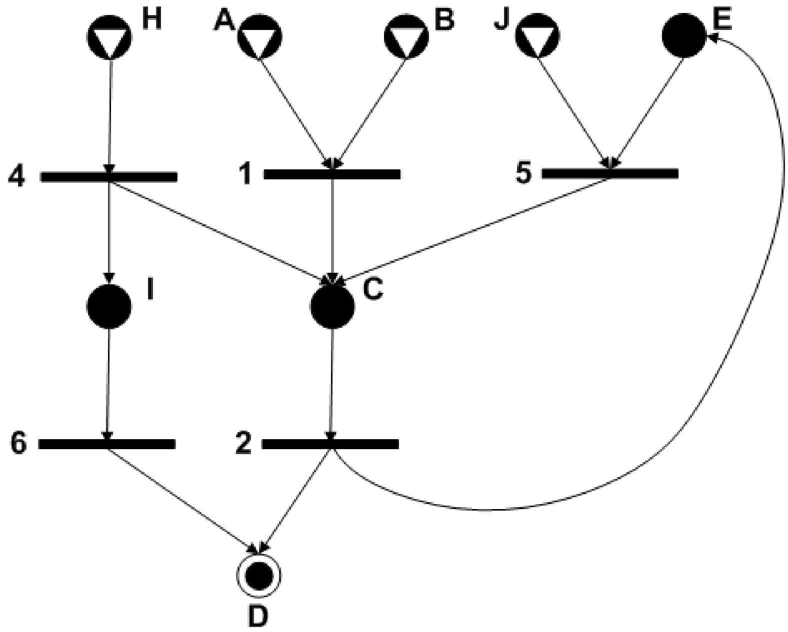

Figure 6. Final step of maximal structure generation

2.1.4. Algorithm SSG (solution structure generation)

The maximal structure represents the complete set of networks from which solution structures can be generated. Solution structures are valid structures that solve the synthesis problem, and therefore they do not violate any of the axioms in 2.1.2 and each of these structures yields the desired products from the given raw materials. The algorithm is based on decision mapping.

For each material, mapping is constructed based on the operating units which produce them. Continuing with our example in 2.1.3, we have following materials:

- M={A,B,C,D,E,H,I,J}

from which A, B, H and J are raw materials, C and I are intermediate products and D is the desired product to be generated. Based on the operating units the following mapping is provided for the materials:

- ΔA=ΔB=ΔH=ΔJ=∅ (these are raw materials, no operating unit generates them)
- ΔC={({H}{I,C}),({A,B}{C}),({J,E}{C})}= {O4, O1,O5}
- ΔD={({I}{D}),({C}{D,E})}= {O6 ,O2,}

- $\Delta E=\{(\{C\}\{D,E\})\}=\{O2,\}$
- $\Delta I=\{(\{H\}\{I,C\})=\{O4\}$

During the decision mapping phase, all sub-networks are revealed which can lead to the production of material D. The algorithm SSG takes into account the possible mapping variations based on the so-called active set. This active set represents the materials to be produced in the network in question. Using our example, an active set (m) can consist of the following:

- $m=\{C,D,I\}$

To get to our first two sub-networks the following variations of decision mapping ($\delta[m]$) are carried out:

- $\delta[m]=\delta[\{C,D,I\}]=\{\delta_1[\{C,D,I\}],\delta_2[\{C,D,I\}]\}$

In the first case we produce C and I with operating unit 4, and D with operating unit 6, therefore:

- $\delta_1[\{C,D,I\}=\{(C,\{H\}\{I,C\}),(D,\{I\}\{D\}),(I,\{H\}\{I,C\})\}=\{(C,\{O_4\}),(D,\{O_6\}),(I,\{O_4\})\}$
- This means that our first sub-network consists of operating units 4 and 6 and as it does not violate any of the five axioms described in 2.1.2, it is a valid solution structure and shown in Figure 6 as solution structure 1.

In the second case we produce C with operating unit 1, I with operating unit 4, and D with both operating units 2 and 6, therefore:

- $\delta_2[\{C,D,I\}=\{(C,\{A,B\}\{C\}),(D,\{C\}\{D,E\},\{I\}\{D\}),(I,\{H\}\{I,C\})\}=\{(C,\{O_1\}),(D,\{O_2\},\{O_6\}),(I,\{O_4\})\}$
- This means that our second sub-network consists of operating units 1,2,4 and 6 and as it does not violate any of the five axioms described in 2.1.2, it is a valid solution structure and shown in Figure 6 as solution structure 2.

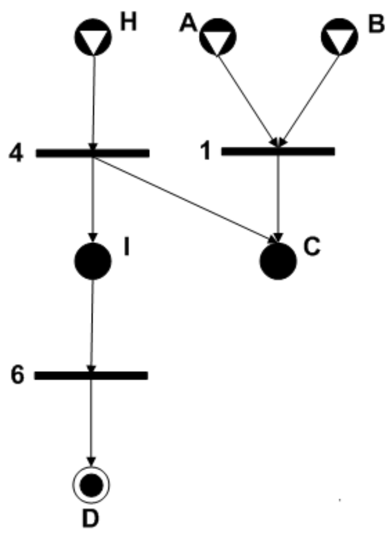

Figure 7. Invalid solution structure

Note that if we were to modify our first decision mapping variation so that C is not only produced by operating unit 4 but also by operating unit 1, and where D would still only be produced by operating unit 6, we would arrive at an invalid solution structure (Figure 7). Such a variation would violate axiom 4, since operating unit 1 would not lead to any other operating unit producing D. (To correct for this violation, operating unit 2 should be added to the system as well. This solution structure is in fact our second example, i.e. solution structure 2.)

Figures 8-10 represent all 9 (valid) solution structures which represent results from algorithm SSG. The maximal structure obviously stands for a valid solution structure as well, which is shown in solution structure 8.

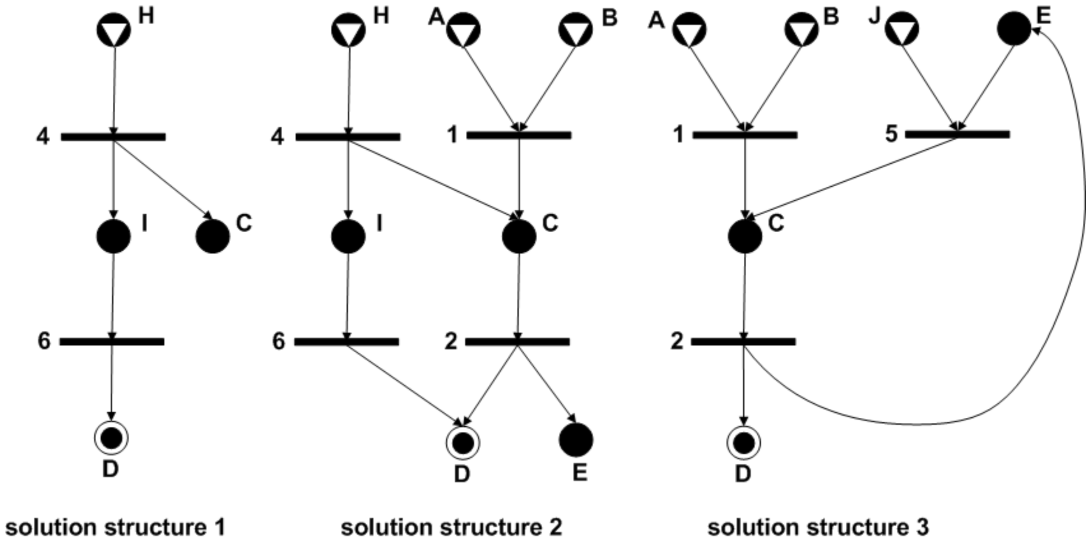

Figure 8. Solution structures 1-3

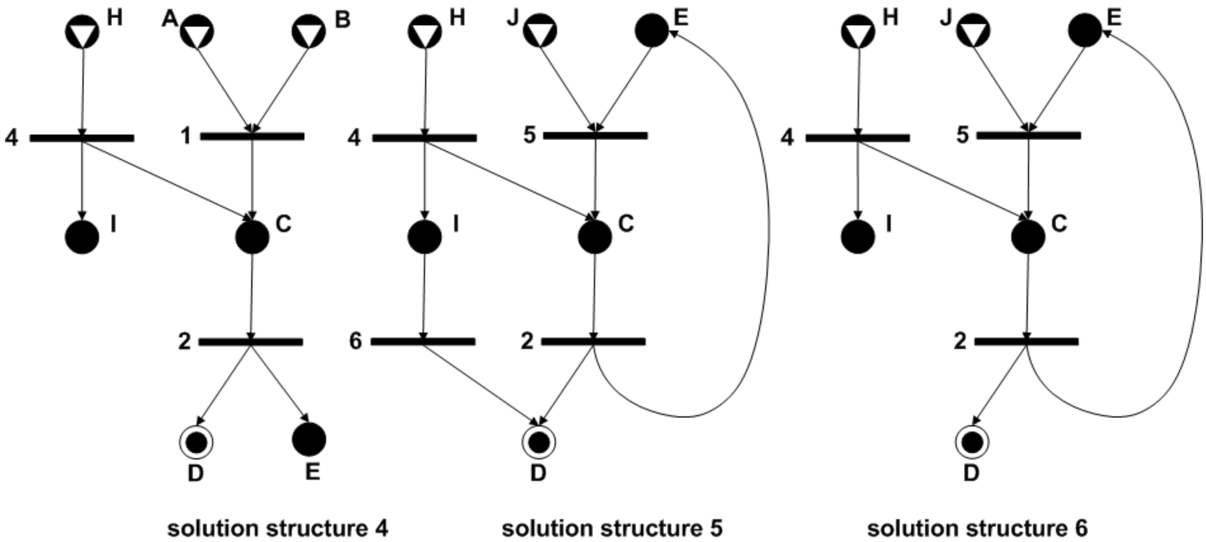

Figure 9. Solution structures 4-6

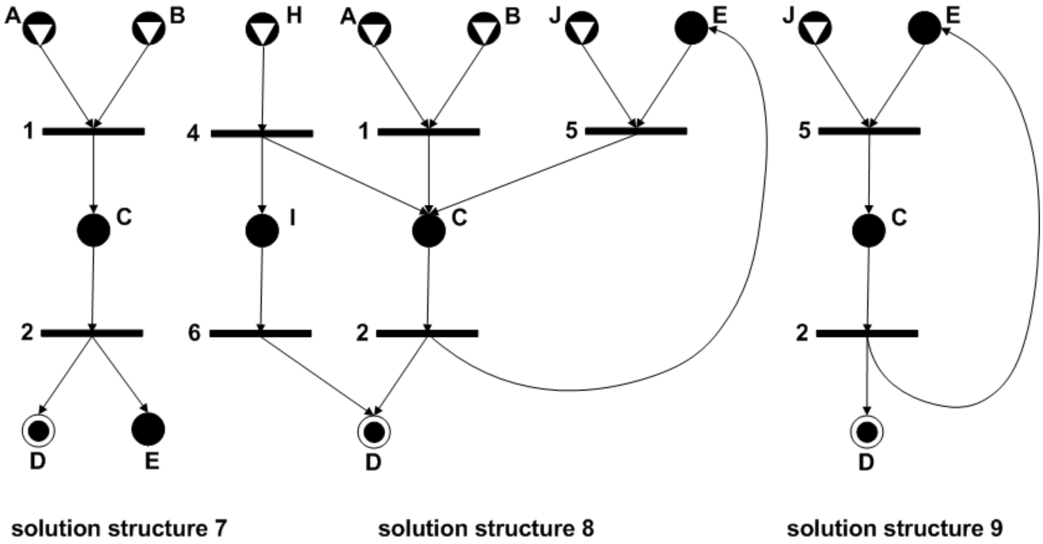

Figure 10. Solution structures 7-9

2.1.5. Algorithm ABB (accelerated branch and bound)

The number of solution structures generated by algorithm SSG can be very high. Algorithm ABB not only helps to find the optimal structure based on an objective function (in our case cost) but speeds up the process to find solution structures near to the optimum. The algorithm originates from the basic branch and bound method but it is applied here differently since it can consider structure characteristics such as the elimination of infeasible components by the maximal structure (see also 2.1.3).

To illustrate the branching process of algorithm ABB, let's consider that no bounds exist now. In our example, setting up an enumeration tree is based on the decision whether an operating unit is to be included when producing materials. The process starts at the product level of the maximal structure and results in the solutions structures of the synthesis problem which do not violate any of the five axioms of 2.1.2.

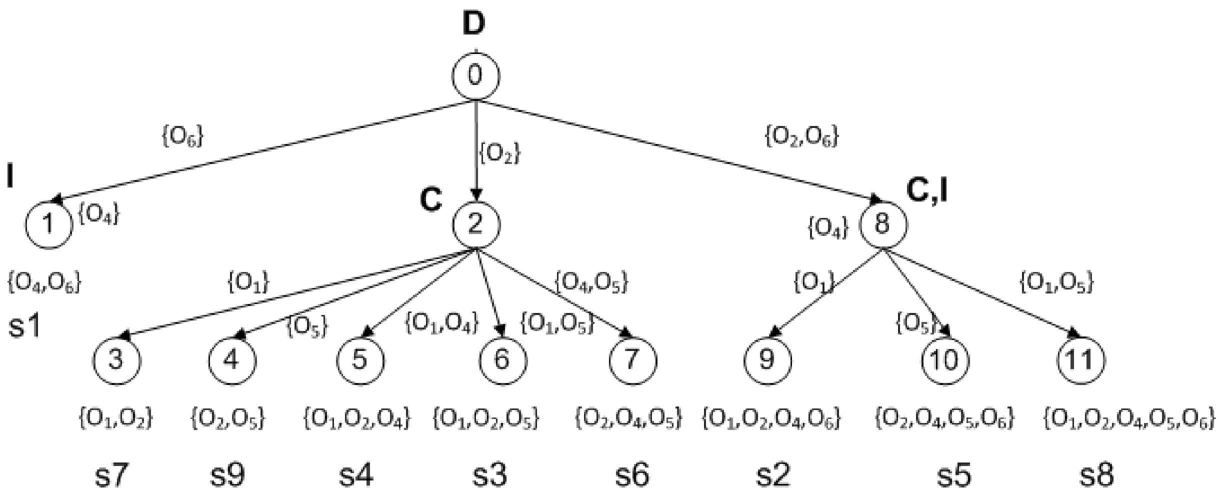

Figure 11. Enumeration tree based on algorithm ABB

As shown in Figure 11 at branching point “0” which denotes product D, 3 ways of generating the product can be identified. At node “1” operating unit 6 generates the product which automatically means that operating unit 4 is also needed. This is because the intermediate product needed in operating unit 6 is generated by operating unit 4 (see also Figure 6). At node “2” and “8” however more ways leading to product generation can be defined. This is in general true because both involve the production of an intermediate product which can be produced by 3 different operating units. (Note that at node “8” operating unit 4 is again fixed because in this case we have a combination of operating unit 2 and 6 generating the product.) The results are the same as in the implementation of algorithm SSG: 9 feasible structures.

When giving an objective function and constraints to the synthesis problem the aim is to rank the solution structures according to their closeness to the optimum. Such an objective function can be the minimisation of costs or maximisation of revenues while constraints are typically the available amount of raw materials or amount of products to be produced. Cost parameters in general consist of variable and fixed investment and operating costs of technologies, prices of raw materials and revenue of products. In this case two types of variables appear during the branch and bound process. The first one is a binary variable indicating whether an operating unit is involved or not while the second one is a continuous variable defining the capacity of an operating unit in use. The objective function (e.g. minimization of costs) according to the 2 types of variables is then subjected to given constraints (e.g. mass balances of materials). Intermediate products can be balanced meaning that the amount which is produced have to be consumed as well. (In general the amount of intermediate product obviously has to be at least the amount which is needed for the generation of the product, but it can be higher as well.) The first bounding step is to solve the problem at node “0” which is the initial phase. If it is feasible then the process is followed by branching in order to find sub-networks which are not only viable based on the constraints but correspond to the objective function as well. If this function is the minimization of costs, it means that a lower bound is taken into consideration during bounding. If a sub-network is found for which the belonging lower bound exceeds the already existing ones, the node is not followed anymore. It can be defined how many solutions are to be found after the best solution. If this number is only one, then the process goes on until the best and the second best solutions are found. If the objective function was the minimization of costs then the best solution represents the solution structure with the lowest value for (total) costs being therefore the most economic solution based on the given constraints. Sub-networks which include operating units with zero capacity are excluded from the process.

2.1.6. PNS towards regional utilisation

The thesis is using PNS for creating technology networks on a regional level where instead of chemical components and processes regional system elements are taken into account. Such elements are available resources of the region in question, existing infrastructure, existing and ongoing projects (e.g. including an existing biogas plant which is not used to its full capacity without investment costs) and market potential for outputs of the technologies within the network. The outcome of the optimisation, the so-called optimum structure is the most economic network according to given conditions (resource capacities, costs and prices, demands, market potentials). By changing certain conditions scenarios can be generated, which makes it possible for decision-makers to take future development predictions (higher or lower price for products, involvement of a new technology which is still in the design phase, lack of some resources in a particular season, etc.) into account. This methodology has been successfully applied to a number of regional cases involving renewable resource utilisation as shown in chapter 3.

The economic optimisation is carried out as part of RegiOpt-CP. As a particular feature, investment capital is taken as a resource input to the optimisation. This allows decision makers to factor realistic economic boundary conditions into their scenarios, as capital may in many cases become a limiting resource for changing regional renewable resource utilisation. This feature also helps in providing a clear picture on the investment priorities in a given regional context. Several other differences will be described in detail in chapter 4.

2.2. The Sustainable Process Index

There are several methods to calculate the ecological performance of a system and some applications even combine economic and ecological factors (Pintaric, 2015). In RegiOpt-CP however the ecological evaluation takes place only after the economic optimisation which means that the ecological performance of the most economic solution structure is calculated. The reason is that this online decision-making tool is oriented towards interested parties who might need to handle economic and ecological values separately.

The ecological evaluation is done by the Sustainable Process Index (SPI) which is a member of the ecological footprint family (Krotscheck, Narodoslawsky, 1996). The ecological footprint calculated with this method takes ecological pressure of resource provision as well as emissions and wastes into account and shows the area which is needed to embed a life cycle of a product or service sustainably into the ecosphere. The larger the ecological footprint is the less sustainable is a particular technology network. Equation 1 indicates all types of areas (representing particular ecological pressures) the method considers in order to deliver a product or service.

$$A_{tot}=A_{RR}+A_{RF}+A_{RN}+A_{E}+A_{ID}+A_{II}+A_{S}+A_{P} \qquad (1)$$

In this equation A_{RR} stands for the area needed for the production of renewable raw materials, A_{RF} of fossil raw materials and A_{RN} of non-renewable raw materials. A_E shows the area which is necessary to embed the energy demand of the process. A_{ID} means the land area which is directly used and A_{II} represents the area for supply of buildings and other related material equipment for the process. A_S denotes the area for sustaining the personnel's need, whereas A_P is the area to dissipate emissions (to air, to water and to soil). All these areas are calculated based on strict sustainability criteria, comparing anthropogenic flows with natural flows. SPIonWEB (spionweb.tugraz.at, 2015) is a software for the ecological evaluation using the method described above. Results of the evaluation with this software used to define ecological as well as Carbon Footprints used in RegiOpt-CP.

With the help of A_{RF} the CO2 emission of the process can also be calculated. This particular feature of the SPI is exploited within RegiOpt-CP to provide decision makers with the Carbon Footprint in addition to the ecological footprint calculated with the SPI.

3. Case studies

In the following three papers are presented. The first paper is dealing with three different case studies, while the second and the third ones describe one case study each. All case studies used the PNS methodology while the second and the third paper included ecological evaluations using the SPI as well. However in all papers the focus is on economic optimisation. The revenue of the optimised structure is in all cases based on a regional technology network. Costs of raw materials, investments and operating costs of technologies and prices of products of the whole structure are taken into account. The revenues of the optimised structures can therefore not be interpreted as accounting profit of a business in general. The benefit has to be seen as more of a common interest of the participating parties in the region.

3.1. Industrial parks

3.1.1. Objectives of the case study

Industrial parks are important instruments to close material cycles as well as to raise the efficiency of industrial production. Spatial closeness allows the exchange of by-products at low costs as well as energy cascades utilising raw materials and energy resources most efficiently. This is of particular interest if industrial parks utilise renewable resources (iea-bioenergy.task42-biorefineries.com, 2015) (Stöglehner et.al. 2011). The problem arising is to create a technology network that optimally utilises resources while at the same time maximises the value added for the members of parks and minimises the ecological pressure from the production within the park. The case studies deal with three different examples of industrial parks, one in Austria, one in Germany and one in Egypt. The challenge is to present a coherent and systemic approach to find the best technology network in existing industrial parks facing a retrofit situation. The full paper is available as attachment to the thesis.

3.1.2. Case study report

A research in Eastern Styria in Austria proposed the implementation of a multifunctional energy centre based on available renewable resources of the region. There exists already a biogas combined heat and power plant supplied by corn silage with its generated electricity sold to the grid and its heat output sent to the district heating. However a part of the heat remained unused. The question was whether it is economically more advantageous to combine already existing technologies with new ones, or a completely new set of instruments should be implemented. To be able to answer this question all existing and a number of new technologies (such as corn drying, pelletising, dried wood chips production and biofuel generation) are taken into account in a so-called maximum structure where available raw materials are turned into feasible products through given technologies (for more information about this method see chapter 2). As a result of the study - besides keeping the existing biogas plant - available unutilised wood of the region is dried producing partly pellets and fuel for a wood gasification plant. Furthermore a corn dryer is also operating representing another new market potential beside the pellets. Not only more electricity is sold to the grid thanks to the gasifier but as a key factor the heat was used on a year round basis.

Another research focused on the possible extension of renewable resource utilisation for the energy supply of an agro industrial, manufacture and technology centre in Egypt. Since this centre is producing food, electricity is needed in general for cooling and heat is used for drying goods. For the economic optimisation of the existing energy supply by combining it with an extension of producing potential extra products, local renewable resources like solar energy and rice straw are also taken into account. As an outcome of the calculations one part of the conventional energy supply, the oil based heating and power system disappears completely. From the original supply structure only grid electricity is used to cover peak cooling loads, while the basic amount of cooling is now supplied by photovoltaic units, pyrolysis based on rice straw and new chillers using heat. The heat for the chiller comes on the one hand from the pyrolysis process and on the other hand from the biogas heat and power plant based on biogas production from sewage. This heat supports not only the chillers but is also used for drying products. In addition to all, the third output of the pyrolysis (beside heat and electricity), char is used to improve soil quality.

It is an interesting aspect to consider the future role of landfill sites when their capacities are getting close to be filled. As an example a study in Germany aimed to introduce a possible way to create an industrial park by taking into account that landfill gas is only available until a certain time. What regional renewable resources could be used on a long term? This study optimises the utilisation of both available resources (landfill gas and local renewable resources) by having the highest revenue as its target. As a result not only "green" electricity is sold to the grid at premium price but also pellet production based on local fresh wood represents a part of a profitable structure. Electricity is produced via two combined heat and power plants and one Organic Rankine Cycle unit. The first CHP unit uses biogas based on biodegradable waste and agricultural waste, while the second one is based on landfill gas. The ORC unit utilises local used wood. The thermal output of both combined heat and power plants as well as of the ORC covers the heat demand of the dryer producing dried pellets.

3.1.3. Conclusions

As it is shown in the three case studies of the paper, the utilisation of renewable resources does have economic viability in combination with industrial parks. It is however a common lesson that optimising single technologies based on renewable resources will not meet the future requirements of improving such parks. All studies represented complex technology networks, where success is based on the one hand on the willingness of regional stakeholders (e.g. farmers, owners of local grids, logistic companies etc.) to co-operate for their benefit and on the other hand on the presence of market for potential products. By understanding the characteristics of a region in question (e.g. resource availability in terms of land use, energy demands of industrial activities etc.) and taking into account existing facilities of industrial parks we can raise the potential to develop economically more beneficial systems.

3.2. How to link city and industry?

3.2.1. Objectives of the case study

Industries and cities have different functionalities for society but they share several energy aspects. Industries often produce excess energy (low temperature heat in particular) and cities can have a considerable heat demand. The aim of the case study is to prove in which terms it is for both sides advantageous to link cities and industries from an economic point of view. Industries can increase their revenue by selling excess heat and cities can integrate this energy in district heating. In terms of emissions there are several advantages: a central emission source for heat production which can be handled much easier compared to several small heating units, as well as the overall improvement in energy efficiency of the city-industry complex. The full paper is available as attachment to the thesis.

3.2.2. Case study report

A study in Upper Austria addresses a comprehensive economic and ecological optimisation of the energy system of a historic town centre and a brewery. A special situation applies to the ownership of the brewery: it is owned by the so called 'Braucommune', which consists of landlords from the historic city. This particular situation made it possible to take into account the historic town centre into plans to overhaul the energy system of the brewery since from an economical point of view common ownership allows the economically most advantageous structure for a system consisting of the brewery and the citizens in the historic town centre. For the brewery, the optimisation process aimed to raise the efficiency of the brewery's operations. For the town, the goal was to improve the energy supply based on renewable and regional sources in economic as well as ecological terms, taking into account that thermal insulation for houses in this area is not feasible due to historic monument preservation ordinances. At the time of the calculations the process heat for the brewery was provided by a heavy fuel oil-fired hot water boiler while the room heating within the brewery was supplied by natural gas. Electricity was always taken from the grid. The historic town was divided into two regions regarding its heat supply. In addition to the existing conventional energy supply, several local renewable energy sources were taken into account. The most economic solution structure included a gas burner for peak load supply. However, in order to be attentive to the ecological pressure as well, an optimum is introduced here where the only technology that is not solely based on renewable energy sources was a new electric cooler that had already been ordered by the brewery after having determined that an absorption cooler could not be part of the optimum structure due to high investment costs. As a basis of the optimisation process 8000 working hours are assumed per annum. In a given year, periods are determined based on two factors: the brewery's operations and the demand for heat for which multi-periodic system was used (Cabezas et.al., 2015). As an outcome the conventional energy supply of the brewery is replaced completely. The basic amount of process heat is supplied via an Organic Rankine Cycle (based on local biomass) and a microgas turbine based on locally available extra load from an existing biogas plant while peak loads are covered by the thermal output of a woodchip burner. On the weekends during the summer months, the waste heat generated by the electric cooler is able to cover the entire amount of heat needed for room heating. Whenever this demand exceeds the amount coverable from the waste heat, it is supplied by the microgas turbines. Heat demand of the historic town is covered as district heating supplied by the Organic Rankine Cycle. Electricity as output from both microgas turbines and the Organic Rankine Cycle unit is sold to the grid at favourable "green" feed-in tariffs. During the 10-year long payout period this optimum presented here stands for an approximately 23% drop in the yearly expenses and provides considerable revenue after this period. Similarly, a significant improvement is observed in the ecological pressure: the ecological footprint of the optimum network is less than half of the current footprint.

3.2.3. Conclusions

This paper examined the possibility of linking industry and city through material and energy flows. One of the main concerns during the optimisation was to avoid the unused off heat production, and to prove that linking the excess heat of an industrial process to a communal energy supply is a feasible way of improving overall performance of a city-industry complex. The optimisation was based on both economical and ecological aspects, and showed that such linkages, in addition to favouring environmentally friendly technologies, represent a profitable network opportunity for both partners. By considering these results, we can conclude that linking resources and energy lines between industries and communities will play a significant role providing economic benefits while representing a sustainable form of development. This statement is supported by other researches as well (Reiner, 2013).

3.3. Integrating technologies

3.3.1. Objectives of the case study

Planting intercrops is one way to avoid the competition with main crops planted for nutrition when considering biomass as renewable resource for energy production. These intercrops are planted during the regeneration periods of main crops. Thus not only soil quality can be improved (decrease of soil erosion and loss of nitrate) but yield of the main crops per hectare and year can be increased. However it is important to investigate the economic feasibility of planting intercrops which is done by this case study. The full paper is available as attachment to the thesis.

3.3.2. Case study report

A research in Upper Austria includes a number of small farms around a village. The idea is to build up a structure where several options are available for biogas production from both main crops and intercrops. The farms are presented in different provision groups according to their geographical positions in order to simplify transport situations. They are able to supply every fermenter every possible substrates (corn, grass silage, intercrops and manure). These fermenters to supply are available at three locations in three different sizes each time. At all location there are two possibilities:

- ❖ Combined Heat and Power Plants can turn biogas into heat (for supplying the heat demand of the fermenters) by generating electricity at the same time. Electricity can be sold to the grid as “green” electricity while additional heat can be sold to the district heating grid for which however additional pipelines would be required (and by that investment costs would be increased).
- ❖ Only a fermenter is available at the location with the possibility to send biogas via a pipeline to another location. These biogas pipeline represent lower investment costs than pipelines for district heating. The biogas can be either sent to another location with a CHP unit or to a central CHP plant which latter one has bigger capacity and a direct access to existing district heating pipelines. When having a fermenter however without a CHP unit, extra heating has to be ensured for the biogas production process (this is represented by a woodchip burner in the calculation).

When optimising this structure economically it turns out that transport distances play an important role: the optimum does not include all provision groups. One fermenter (decentralised) with enough capacity to take substrates from provision groups generates biogas. Its heat demand is covered by a woodchip burner and the biogas is transported via pipelines to the central CHP unit where the thermal output is used for the district heating of the village. The electricity output of the CHP unit is sold to the grid as “green” electricity. Even though production of intercrops appears at the provision groups that are part of the optimum, main crops (corn) are still used for biogas production because of the high biogas yield they represent.

3.3.3. Conclusions

Focus of the case study was not to identify a pathway through a huge set of different technologies which are producing heat or electricity. The goal was to prove whether the utilisation of intercrops is economically feasible or not. Intercrops did appear as part of the solution but main crops were also used for biogas production because of their high biogas yield. The study proved the economic viability of intercrops in this case but also indicated that their planting needs detailed planning in combination with main crops. A further remark is that transport distances were a key factor during the calculation which means that future work is to include transport based on time consumption and not distances. Loading and unloading to biogas plants are time intensive which results in higher costs than a kilometre of road transport.

4. Methodology application for realisation of RegiOpt-CP

4.1. Idea of RegiOpt-CP

The current work addresses the need to provide regional decision makers (who are most often lay people with regard to energy systems and renewable resource utilisation) with a tool to plan future development of their resources taking the competition for the basic resource land into account as already stated in an early study of RegiOpt-CP (see full paper as attachment). RegiOpt-CP provides compatible scenarios based on the resource structures of the region in question by using economic optimisation and ecological evaluation. The idea is that scenarios are built based on what is available in the region. The software generates feasible technology networks that utilise available resources, serving different technologies and meeting demands in the region while providing as much value added as possible in a sustainable way.

During the economic optimisation, RegiOpt-CP optimises the technology network linking resources, demands and possible regional "export" according to the highest annual revenue. The scenarios are then ecologically evaluated. This gives the opportunity to compare the ecological effects of the current situation and the economically optimised scenarios. It is important to underline however that RegiOpt-CP does not aggregate economic and ecological factors. This means, that RegiOpt-CP does not favour scenarios which represent lower ecological pressure but are less profitable, and similarly does not privilege economically advantageous outcomes that pose higher ecological pressures but leaves the decision between different futures solely to the user.

An interesting additional feature of RegiOpt-CP is that it provides ethical hints which can either be accepted or overruled by the user. Among others, ethical remarks have been added which attract people's attentions to their regional consumption and how their regional decisions possibly increase environmental pressure outside their region or add to global inequalities. The advantage of these ethical hints is that they provide the possibility for the region to lead a discourse on regional future development within a global sustainability perspective, in particular regarding competition for land between energy and food supply.

The realisation of RegiOpt-CP included several steps. First a background structure, a so called superstructure (see more in chapter 2) based on the P-graph structure was created by using the PNS Editor (p-graph.com, 2015). Afterwards together with the University of Pannonia a web-based surface was created to make the entering of regional data possible in form of a questionnaire using default values at the same time. The web based surface is connected with the superstructure and a software carrying out the algorithms MSG and ABB (see more in chapter 2) in order to perform the optimisation process. The results of the economic optimisation are also evaluated ecologically for which SPI (see more in chapter 2) data are stored. The analysis of the results therefore include several economic and ecological information as well as comparisons and are shown in tables and charts. The calculations can be saved on the website which makes it possible to create more scenarios and open them again when needed.

The idea is however not to provide a user manual (such a user manual is available on the online surface of RegiOpt-CP) but to show how well known methods (with an emphasis on PNS) are applied for the realisation. Using methodological background information the realisation steps are described in the following, while taking into account special features and differences compared to the information provided by chapter 2.

4.2. PNS methodology in combination with RegiOpt-CP

4.2.1. Process graph in a regional context

As previously described in chapter 2 and as illustrated in Figure 12, operating units of a Process graph denote technologies, and outcomes that are either intermediate products or products. Input materials in a regional context however can extend beyond just raw materials and intermediate products to also include products. This special feature will be described in the next subsection.

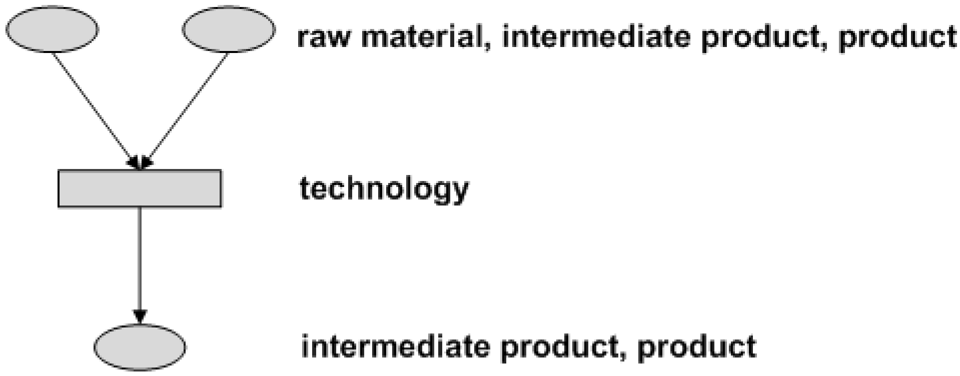

Figure 12. Process graph in a regional context

Raw materials (can) have costs per unit (e.g. €/t, €/kWh etc.) as well as a maximum flow or a required flow for a certain period of time (e.g. maximum available tons of wood or biowaste to be compulsorily collected and make further use of it in a year). Products (can) have price per unit (making their production economically viable by representing revenues) and can be also characterised by required flows or maximum available flows (e.g. heating demand in MWh per year if no less and/or no more is allowed to be produced). Intermediate products on the other hand can neither be bought nor sold hence have no price and furthermore no flow rates, but it is possible to balance them as it was already mentioned in chapter 2. In this case the amount of intermediate product produced by a certain technology has to be used later fully. Certainly it makes no sense in most of the cases to balance all intermediate products as it can impede the creation of solution structures in regional optimisation. More thoughts will be given to this problem later in subsection 4.2.1.3. Technologies are the platform for filling in mass and energy flows and they can have a lower and upper bound making it therefore possible to define different sizes of a unit. Adding working hours and the payout period of a technology are both important because they influence the total costs. While working hours are used for the calculation of operating costs, the investment costs are distributed during the payout period. The special cost characteristics of RegiOpt-CP will be described in details later.

4.2.1.1. Special features of Process graphs in RegiOpt-CP: product as input material

In a regional context it is an interesting aspect to make it possible for products to be input materials for a Process graph. It is especially true for regional economic optimisation where the target is to maximise the profit of a regional structure, meaning that if a product can be further processed to another one, it is possible to validate at which point of the production it is the most economic to stop the process. In the structure of RegiOpt-CP for example vegetable oil is produced either from dried rapeseed, from dried sunflower or from unspecified dried oilseeds, the latter ones to be freely chosen by the user when entering regional data. The vegetable oil however can be further used for biodiesel production. Both vegetable oil and biodiesel can be sold hence representing products in the structure. Figure 13 shows the vegetable oil and biodiesel production from rapeseeds in RegiOpt-CP by using process graphs and symbols described in chapter 2.

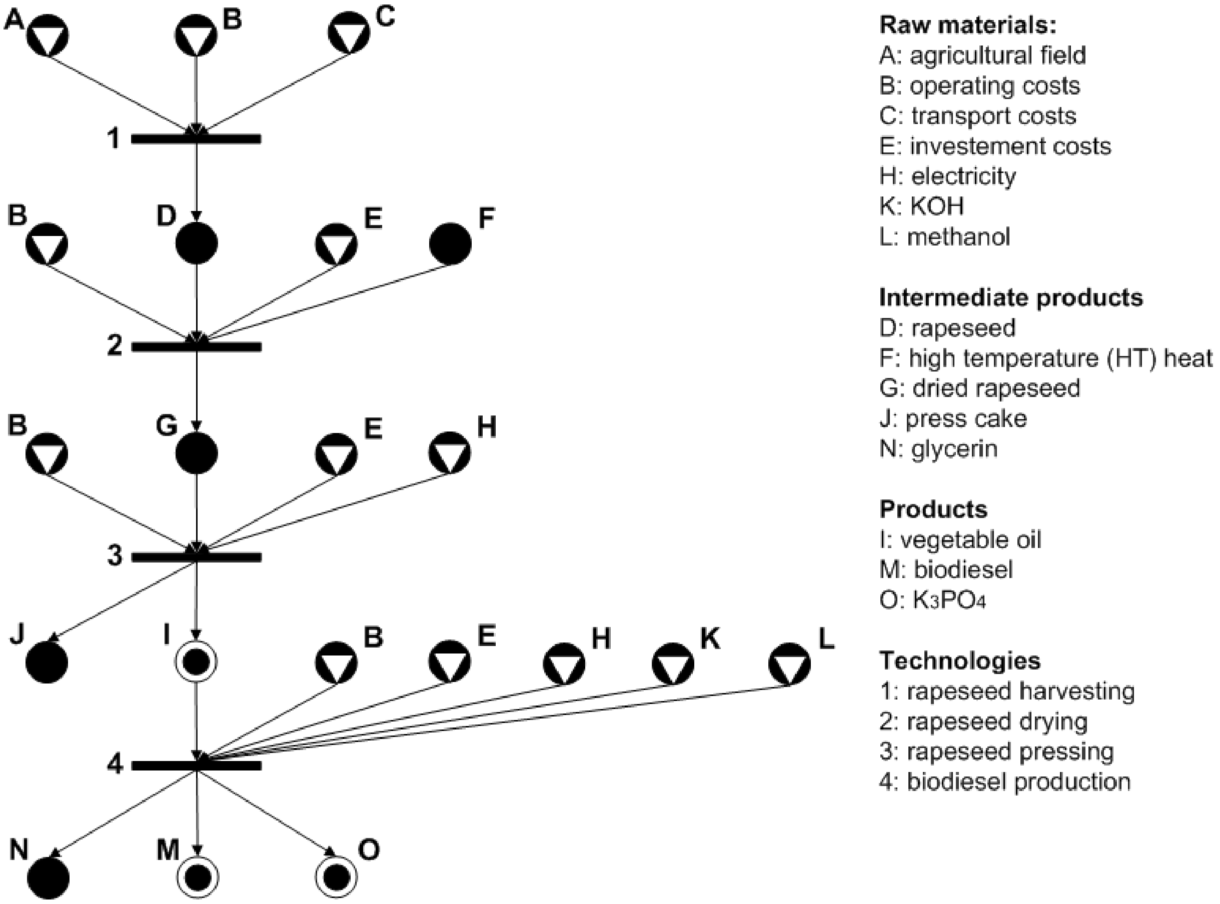

Figure 13. Production of vegetable oil and biodiesel from rapeseed as part of RegiOpt-CP

- Operating unit 1

As we can see the rapeseed itself is an intermediate product while the raw material is the agricultural field. This is because when entering data for RegiOpt-CP it is possible to choose which seeds can be harvested on the agricultural field, meaning that the raw material is the area which can be further used for plantation. This step (harvesting) is done by operating unit 1.

- Operating unit 2

After harvesting the rapeseed has to be dried which is realised by operating unit 2 representing a rapeseed dryer. Obviously process heat is needed which is typically a high temperature process heat[1] generated by other technologies in the RegiOpt-CP structure therefore marked here as intermediate product.

[1] Process heat above 100°C is regarded high temperature process heat

- Operating unit 3

In order to produce vegetable oil the dried rapeseed has to be pressed. The pressing is done by operating unit 3 where electricity as input is also needed. In contrast to process heat (which is an intermediate product), electricity is added as a raw material. The reason for this is that the electricity generated by technologies of the structure is sold as “green” electricity and whenever power is needed it comes from the grid. The idea of this general feature is based on the existence of feed-in tariff systems (e-control.at, 2015). These systems make it possible that the revenue from electricity generated by using renewable energy sources is higher than the price for electricity bought from the grid.

There are two outputs of the technology: vegetable oil and press cake. Vegetable oil can be sold therefore indicated as a product while press cake is intended for further use such as biogas production hence marked here as intermediate product.

- Operating unit 4

Operating unit 4 stands for a biodiesel plant since vegetable oil can be further processed to biodiesel. Raw materials such as electricity, KOH and methanol are also needed. As outputs we have two products: biodiesel and K_3PO_4 (while the latter one is actually a by-product); and an intermediate product: glycerin (meant for possible further use e.g. biogas input).

The task of the optimisation process done later by algorithm ABB (see also chapter 2) will be to decide whether the vegetable oil production and/or the biodiesel production should be part of the most economic structure. For this not only mass and energy flows but certainly cost parameters of both materials and technologies have to be added.

4.2.1.2. Special features of Process graphs in RegiOpt-CP: cost characteristics of technologies

There are three types of costs which can be assigned to technologies in RegiOpt-CP: investment, operating and transport costs. The special feature is that all are raw materials from a process graph point of view and are not added as cost characteristics of an operating unit (cf. chapter 2).

The mass and energy flows as well as costs of technologies are presented in Figure 14 by using operating units 1 and 3 from the previous example. It is important to add that when defining the input and output values of an operating unit during data registering, no values from connecting operating units have to be considered. This means that even if from the operating unit “rapeseed harvesting” the output is 2,12 t rapeseed, the following operating unit “rapeseed drying” does not necessarily have to be calculated for 2,12 t rapeseed as its input. Only the balances are important in each operating unit, the actual amounts are always calculated by algorithm ABB according to the output values of the previous operating unit in the structure.

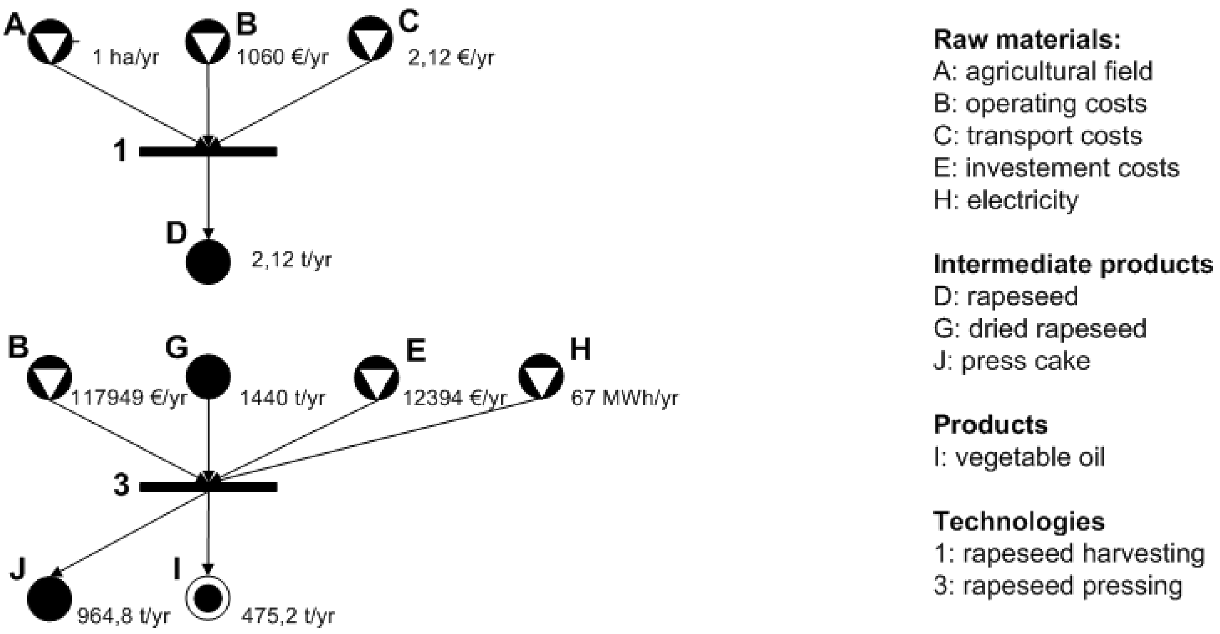

Figure 14. Mass and energy flows as well as cost parameters of technologies in RegiOpt-CP

The importance of transport distances was presented by the third case study in chapter 3 already. This was one of the considerations which led to the idea to include transport costs as separate cost parameters in RegiOpt-CP. Transport costs are typically present for an operating unit like harvesting. In Figure 14 an example is shown how much the transport could cost when harvesting rapeseeds from one hectare. It is important to use a time scale which is generally valid for the whole structure. Even though the harvesting does not take place during the whole year, the economic optimisation in this case will be carried out for that period which explains the yearly basis also for this operating unit. By changing the values for transport costs, their influence can be observed. This could be especially important if a region would like to pay attention to decentralised processing of available crops by recalculating and adding data for shorter distances or would like to include the utilisation of cheaper, locally produced biofuels.

Operating costs are typically costs that are not necessarily dependent on the size of the technology and therefore their value grows linearly with the capacity of the technology. In RegiOpt-CP mostly maintenance, personne or renting expenses are covered by operating costs. Investment costs are dependent on the size of the technology and their relative value typically decreases as the capacity of a technology grows. Obviously the more detailed calculation is needed the more operating units have to be included to cover the range of capacities. This however – as it was described in chapter 2 – increases the time for the optimisation process. The aim of RegiOpt-CP is rather to obtain an overview and regard the outcome of the calculation as a first step toward decisions of regional development. Therefore the whole structure was kept as simple as possible meaning that capacities of technologies are provided only up to three sizes. For operating costs it is less unconventional to include them on a yearly basis but it is certainly surprising for investment costs for the first look. As for the latter ones, not only the mass and energy capacities of the operating unit but also the payout period have to be considered. By adding the investment costs for the given capacities and dividing them by the payout period we get a value for one year investment.

Figure 15 shows three sizes of the biodiesel production from our example in Figure 13. The sizes of the technologies are defined by the lower and upper bounds which makes it possible that the balances only differ in their investment values. The first operating unit represents the smallest capacity by a maximum amount of 8000 tons of biodiesel to produce yearly. The second operating unit covers the production from 8000 until 25000 tons while the biggest size goes beyond 25000 tons on a yearly basis. The lower and upper bounds were calculated accordingly (e.g. the upper bound of the medium size gives 25000 tons if the output 8000 tons of biodiesel is multiplied by 3,125). The investment costs were always defined according to the upper bound of the unit (the third operating unit was calculated for a biodiesel plant with a capacity of 100000 tons biodiesel production in a year) and factored with a 10 year payout period.

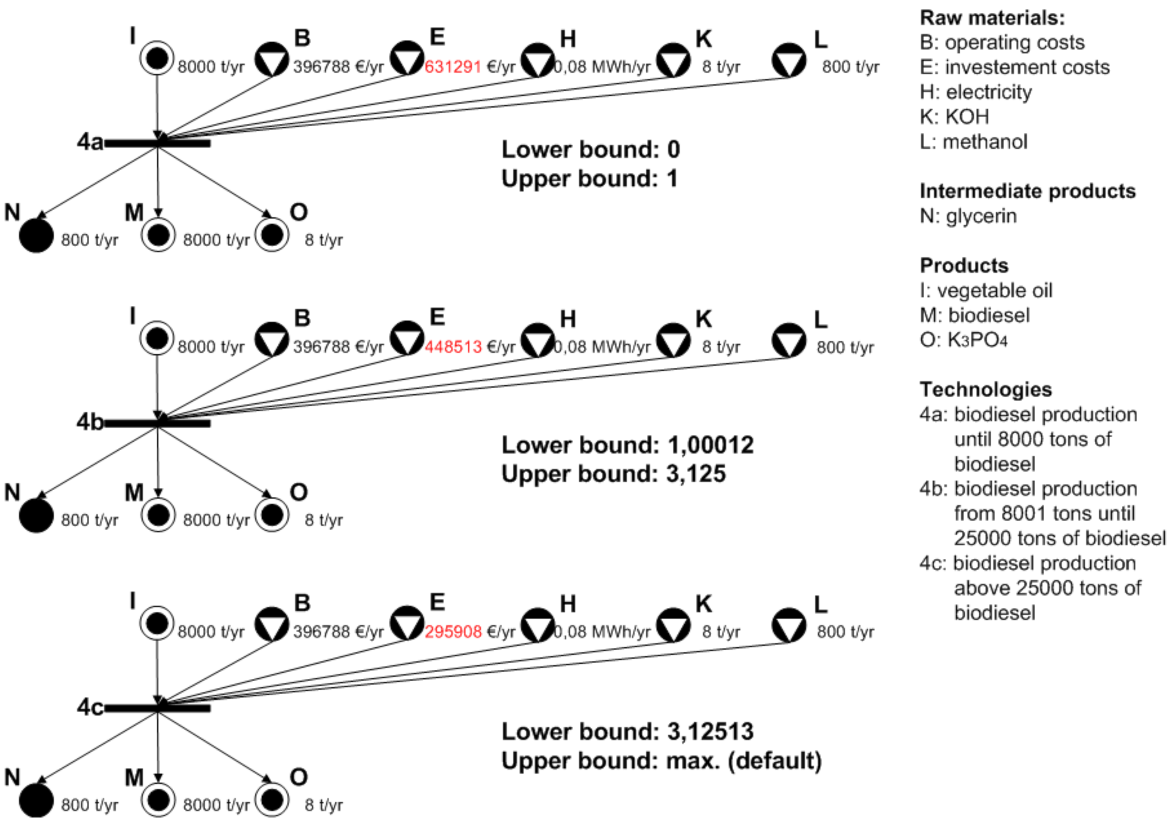

Figure 15. Decreasing investment costs with growing capacity in RegiOpt-CP

Especially for operating and investments costs it is true that their limitation can be an interesting factor for regional actors. By adding them as raw materials of an operating unit, a maximum flow can be defined. At the present stage it is possible to add a maximum value of total investments (investment costs) at the beginning of data registering in RegiOpt-CP. However, by leaving transport and operating costs also as raw materials from a process graph point of view, this feature can be extended in the future.

4.2.1.3. Special features of Process graphs in RegiOpt-CP: balancing materials

Although balancing materials – as it was already mentioned in chapter 2 – is not new in the applications of process graphs, its implementation is definitely unique in RegiOpt-CP. To introduce it, an example from the heating supply will be presented below.

As it is seen in Figure 16, one way to cover the district heating demand is to use low temperature process heat. However it is very important to know whether there is an amount of heat generated by the structure which is not used. Even if the product district heating demand would not have a price, or its price would not be high enough to ensure its supply, it has a required flow meaning that in one way or another it has to be covered (either by process heat or by natural gas). The unused heat on the other hand has neither a required flow nor a price. If we want to know the amount of heat which is not utilised a balanced intermediate product has to be implemented. In our example this intermediate product is called “input for district heating”. Thanks to the “balancing” option as soon as this intermediate product is produced, all of it has to be used. This makes it possible to have operating unit “generated heat potential” included if the process heat is not used fully. It is important to note that the graph in Figure 16 represents only a part of the whole structure used in RegiOpt-CP which means that covering the district heating is not the only operating unit using low temperature process heat[2] before its unutilised amount is considered as heat potential. (Low temperature process heat can be for instance also used for the heating of fermenters for biogas production.)

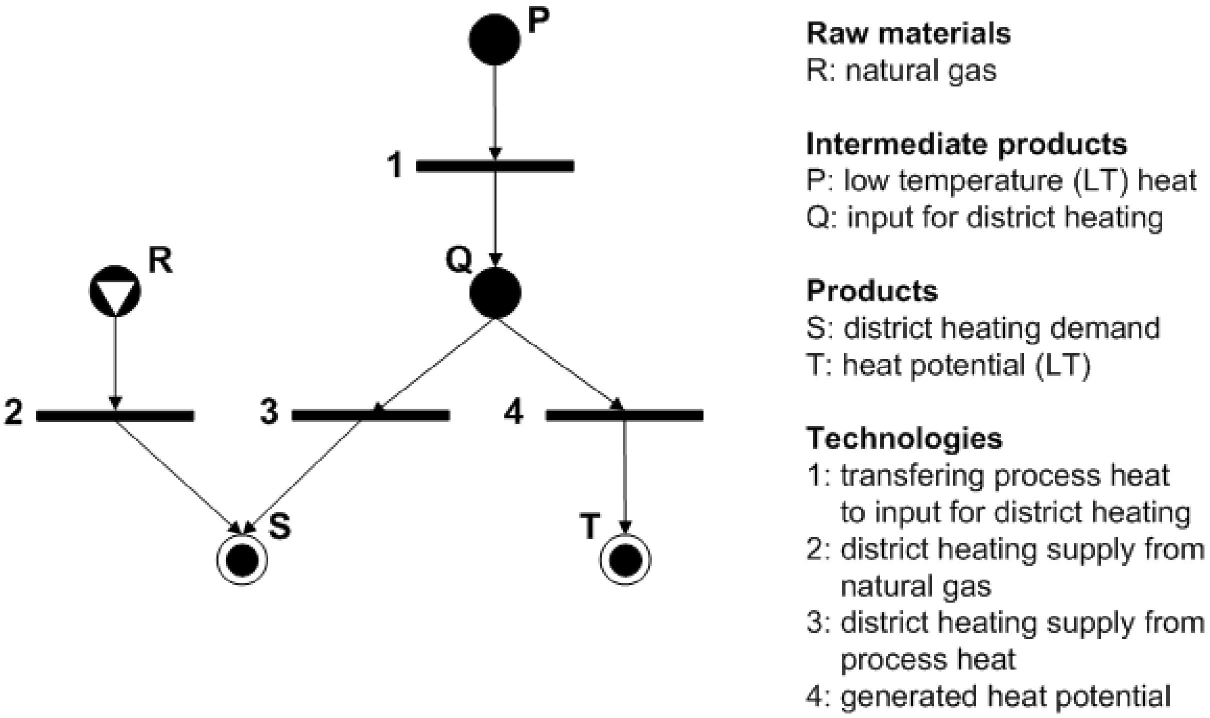

Figure 16. Balancing materials - district heat supply in RegiOpt-CP

4.2.1.4. Special features of Process graphs in RegiOpt-CP: no actual conversion

If a technology can have several raw materials as its input and these raw materials have different characteristics in terms of their output used by this technology, then each raw material would need an own operating unit with the technology customised to it from a P-graph point of view. However at some cases the single technology can use a mixture of the raw materials which means that an intermediate product can be added as an input of the technology and all possible raw materials are

[2] Process heat below 100°C is regarded low temperature process heat

converted to this intermediate product before entering the technology. The fermentation for biogas production technology is going to illustrate the example.

For biogas production several materials can be used in RegiOpt-CP: glycerin, corn silage, grass silage, manure, press cake, stillage and unspecified biomass. In Figure 17 the operating units produce a so called “biogas input” intermediate product which is going to be used for the fermentation.

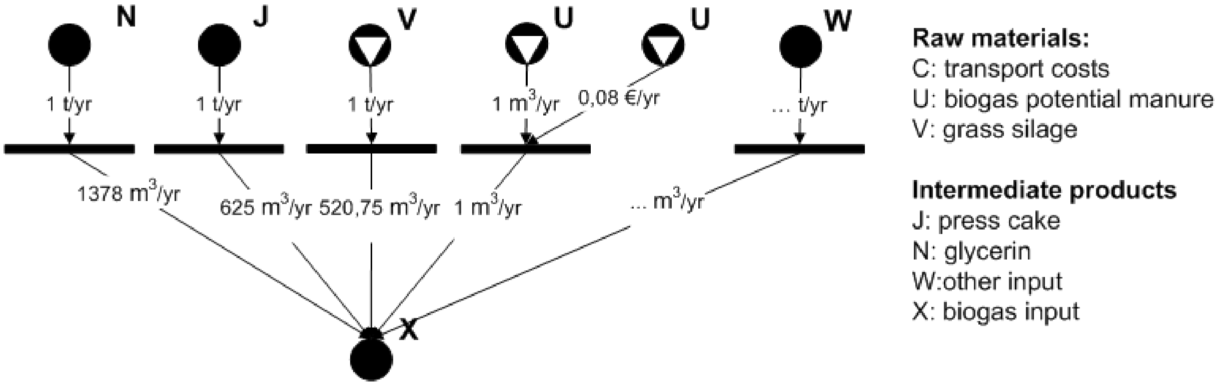

Figure 17. Biogas input generation

In separate operating units all possible input materials for biogas production are turned into an intermediate product “biogas input” according to their biogas yield as seen in Figure 17. Please note here as well that time scale is needed for the P-graph representation but these capacities do not mean that no higher amount could be turned into biogas input in a year. The multiplication takes place automatically during the optimisation process. Glycerin comes from the biodiesel production while press cake is generated via rapeseed pressing (see also Figure 13) therefore both marked here as intermediate products. Grass silage is a raw material in the structure as it is calculated from the data registering explained later in subsection 4.2.3.1. Similarly to grass silage, the biogas potential from manure is also generated by the data registering and in this case the potential value is already added in m^3. This means that already at this point no real conversion between input and output is needed. It has to be mentioned that transport costs for manure for biogas production are included twice in the calculation, because the costs of the return transport of the biogas manure to the field are also taken into account. Other input denotes stillage from bioethanol production, corn silage and unspecified biomass. Please note that transport costs for corn silage are already included at its “harvesting” operating unit. See a similar example for rapeseed in Figure 14.

Figure 18 shows the fermentation process itself. Balances for a fermenter are illustrated with a maximum capacity of 45,5 m^3/hour. This means that in one year the maximum produceable biogas is 364000 m^3 as seen in Figure 18. Note that in this case the upper limit of the unit is 1, which denotes that the balances are given as maximum capacity for a year. The special feature of the representation of the technology is that the biogas input entering the operating unit is already the produceable amount of biogas in a year. It has to be added that this variation was necessary as the input materials for fermentation have different biogas yields and because the RegiOpt-CP structure was intended to be kept simple. Naturally if it is of interest to optimise several types of fermenters with several mixtures of substrates a more detailed structure can be constructed in order to obtain more precise results. This however is not part of RegiOpt-CP and would need a separate structure generation with the PNS Editor.

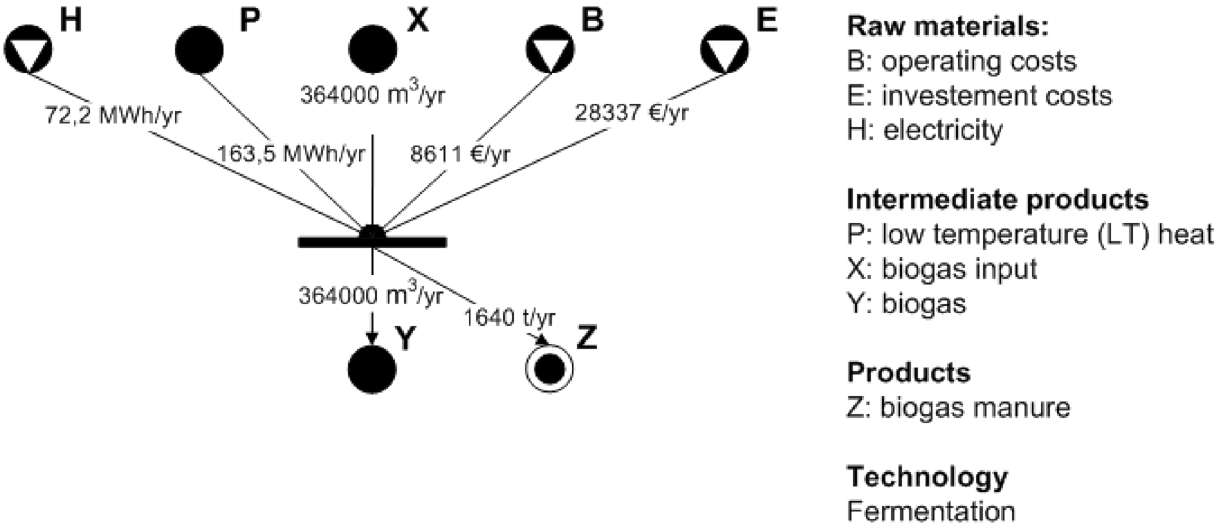

Figure 18. Fermentation with maximum capacity of 45,5 m^3/h

4.2.2. Superstructure generation by PNS Editor

As an initial phase, the process graphs were constructed into a so-called superstructure in order to provide background information for RegiOpt-CP. This means that by algorithm MSG always the same superstructure is created, which actually only consists of valid materials and operating units.

The PNS Editor was used for the compilation of the superstructure. First, default dimensions and values were defined as seen in Figure 19.

The default dimensions are important because they define the display values of each material. It is therefore advisable to select according to the most frequent scales. In case of RegiOpt-CP "t" as measurement values for mass is selected since the majority of mass flows are high enough (harvested crops, wood etc.) and only for few materials would be more suitable to use "kg" (such as KOH and K_3PO_4 during biodiesel production). This is also the surface for defining the default working hours per year and the default value for the payout period which will be displayed at each operating unit which is created. It is important to note that both dimensions and working hours as well as the payment period can still be adjusted individually later at the properties of materials and operating units.

Default values are mostly important to define the numerical upper limit of the solver and set the number of maximum solutions. As we are only interested in the most economic solution structure (optimal structure), the number of maximum solutions is one.

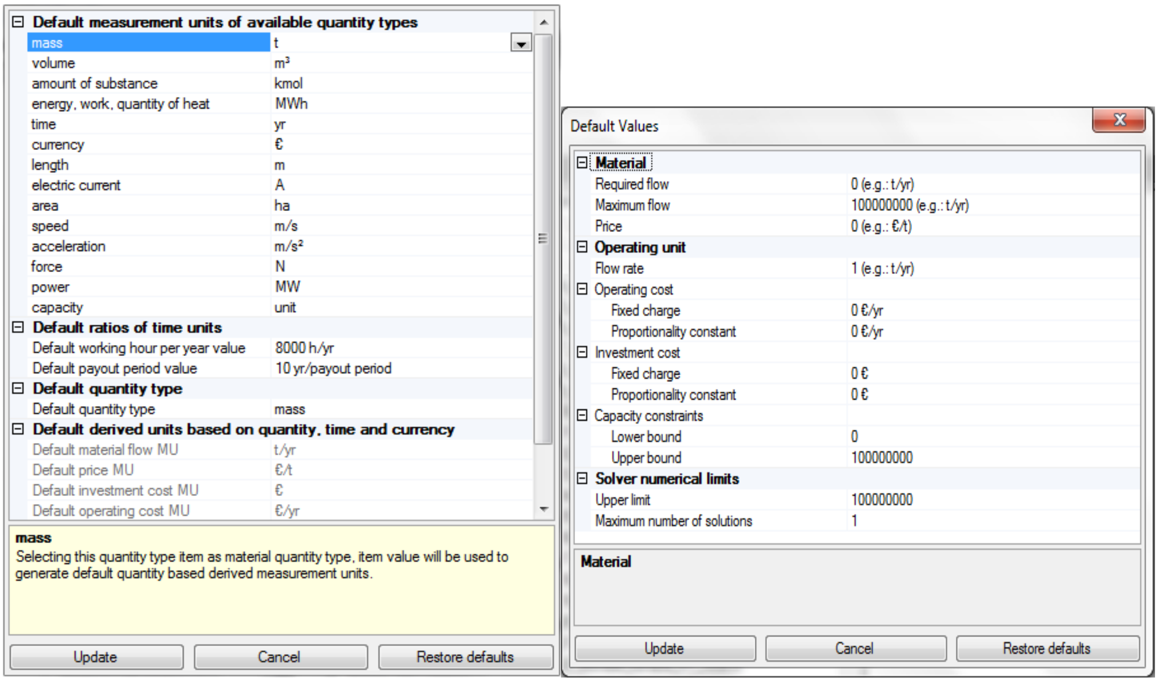

Figure 19. Default dimensions and values in PNS Editor for superstructure compilation

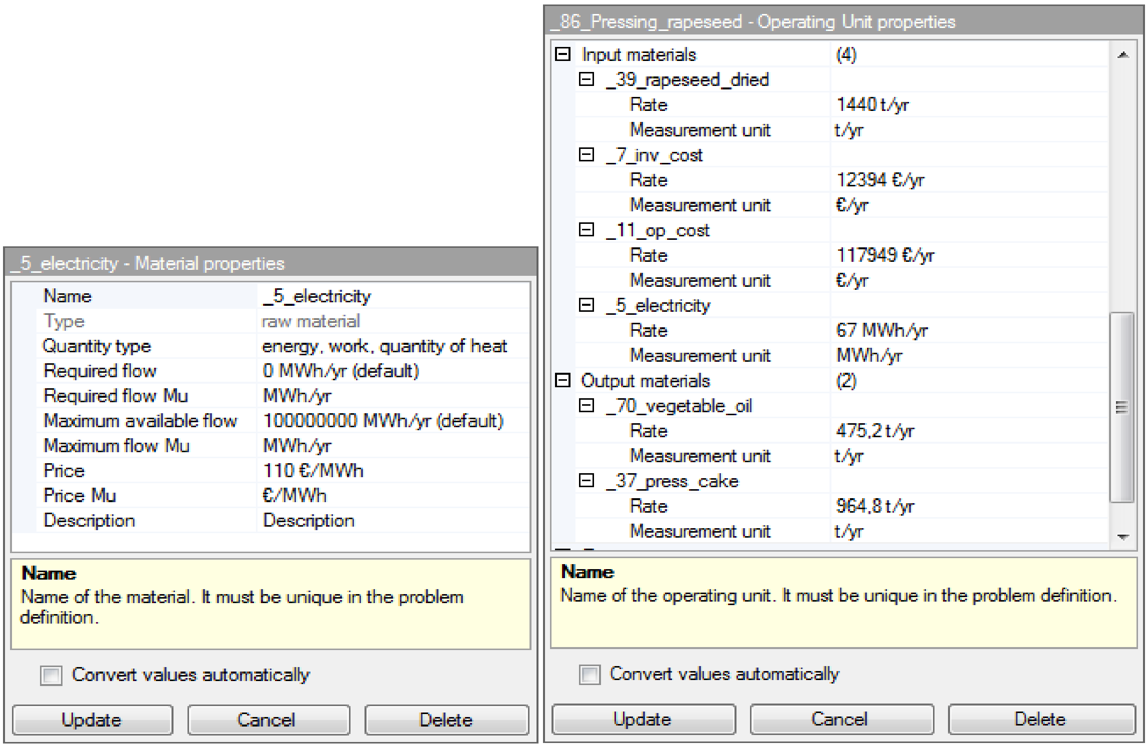

Figure 20. Adding materials and operating units in PNS Editor for superstructure compilation

After defining the default values, raw materials and intermediate products as well as products were added in the PNS Editor. An example is provided on the left hand side of Figure 20 by the raw material "electricity". As soon as the quantity type was selected, the corresponding default dimensions appeared. Obviously there was no required or maximum flow selected as this electricity is provided by the grid. However during the creation of the superstructure no maximum or required flows were selected as this is the task of the online data registering. Prices on the other hand were provided here to serve as default values, even though they can be overruled by editing them on the online surface as it will be discussed later. Note that the numbers in front of the materials are just added in order to know the number of materials used in the superstructure. Please also note that in the PNS Editor for both raw materials and products the category “price” is given. In this thesis not price but costs will be referred to raw materials.

As soon as the materials are provided, operating units can be created by selecting their inputs and output among the materials. The right hand side of Figure 20 shows an example for an operating unit which defines the pressing of the rapeseed (production of vegetable oil). Its P-graph structure was already shown in Figure 13 and 14 and this is how it looks like in the PNS Editor. It is important to mention that payback period of operating units were generally set to 10 years, except for Photovoltaic and Solar thermal where it was set to 25 years. Investment and operating costs for technologies were calculated according to the Austrian situation (“reference year 2011”).

Figure 21 shows part of the list of materials and operating units of the superstructure after adding them in the PNS Editor.

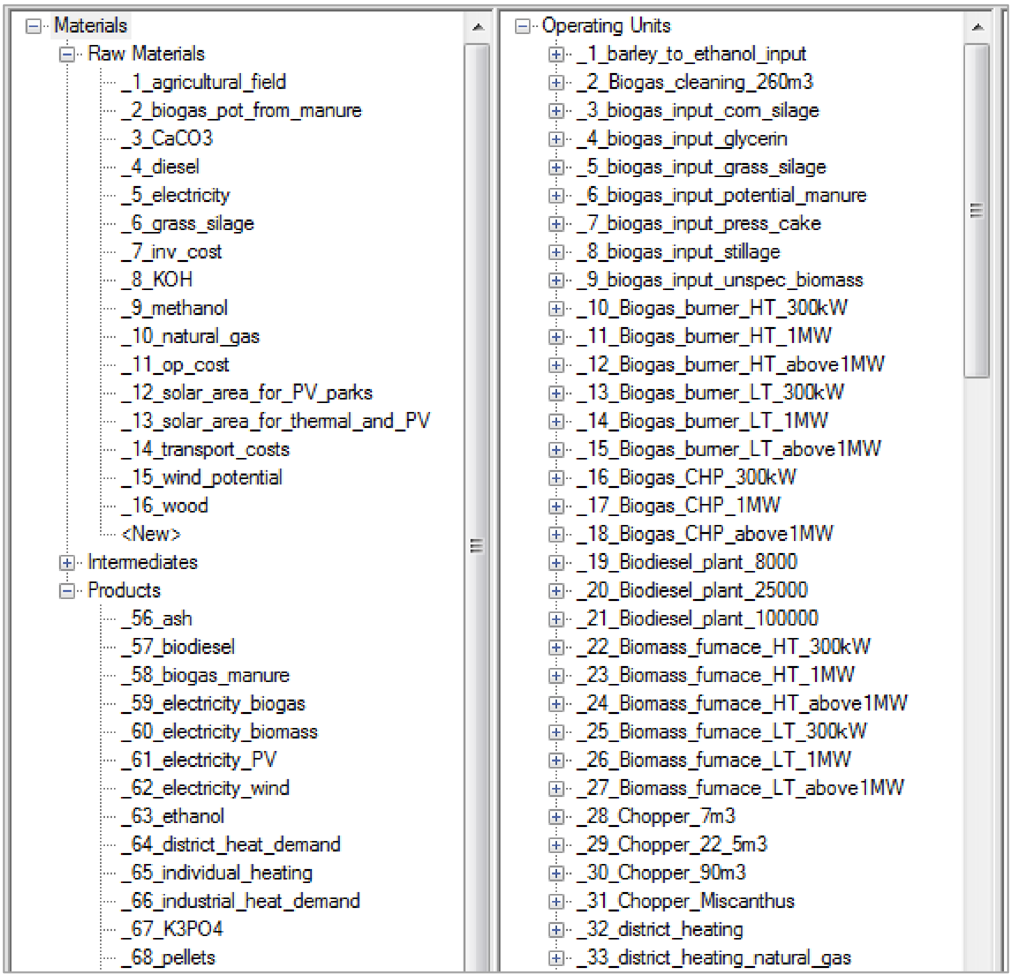

Figure 21. Part of the materials and operating units of the superstructure in the PNS Editor

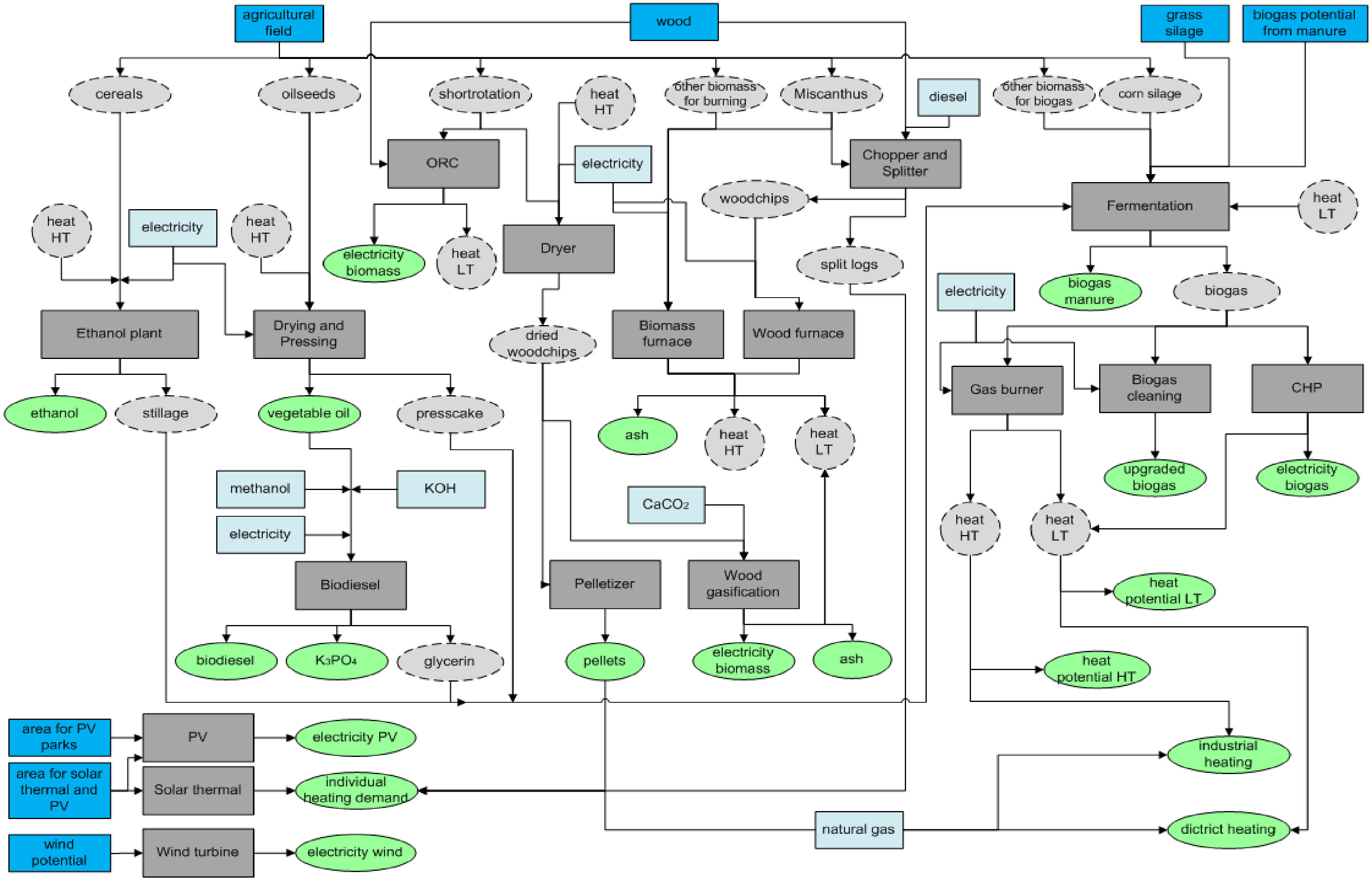

Figure 22. Graphical illustration of the superstructure created by PNS Editor

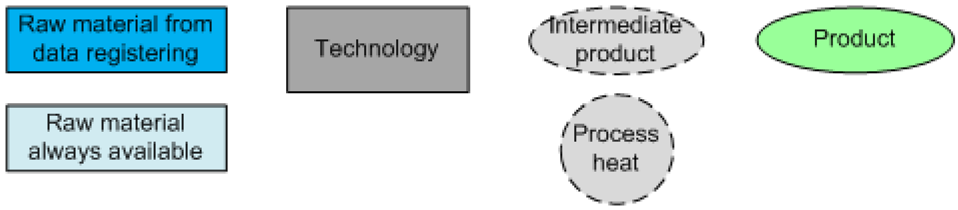

Figure 23. Symbol explanation for Figure 22

The superstructure which was created in the PNS Editor is seen in Figure 22, this time drawn in order to have a better overview of the whole structure. However some shortcuts were still necessary. Cereals for ethanol for example can be the following: wheat, barley, sugarbeet, corn grains and unspecified cereals (the latter ones can be added to the online data registering optionally if there is an additional type of cereal which is suitable for ethanol production and is not included yet). Similarly, oilseeds as a general name was used for input materials for vegetable oil production. The inputs in this case can be rapeseeds, sunflower and unspecified oilseeds, as mentioned already related to Figure 13.

The symbols of Figure 22 are explained in Figure 23. The difference between the two types of raw materials is that those coming from the data registering (wood, agricultural field, grass silage, biogas potential from manure, solar areas and wind potential) always depend on regional characteristics. The calculation of their available amount will be discussed in the next subsection. The other type of raw materials (electricity, methanol, KOH, diesel, $CaCO_2$ and natural gas) are not limited and always available for the certain technologies, however their costs are changeable via the online surface. The technologies are invisible to the user of the online surface and they can only be changed again in the PNS Editor meaning that an update in the programming site of RegiOpt-CP would be necessary.

As it is seen in Figure 22 some technologies produce both high and low temperature heat, some technologies only low temperature process heat. It is important to note that the process heat lines are not always connected and sometimes are marked only as input intermediate products of technologies in order to keep the structure transparent. In general it is true that no matter how process heat is produced, it is applicable for all kind of technologies utilising them. For example the industrial heating demand could certainly not only be supplied from the high temperature process heat produced by the biogas burner but also from the biomass or wood furnace. Similarly the district heating demand may not only be covered by the low temperature process heat from the biogas burner but also from the biomass and wood furnaces, the biogas CHP unit and the ORC (Organic Rankine Cycle). In RegiOpt-CP the ORC includes both combustion and power generation units.

It is also important to mention that some products are in general characterised by required flows in a regional supply while other represent revenues in perhaps new potential markets. Individual as well as district heating or industrial heating demand typically belong to the former while "green" electricity, ethanol, biodiesel or pellets are part of the second group of products.

It is once again necessary to allude that the structure was kept as simple as possible and its aim is to provide an overview for regional decision makers of their possibilities in their regional supply. However in order to ensure that there is an outcome of the optimisation process even if the regional resources cannot cover the regional demand included in the structure, natural gas as fossil energy resource was implemented as possible resource for all types of heating demand.

4.2.3. Regional data input for maximal structure generation

On the online surface of RegiOpt-CP regional data are collected to be able to run a region specific optimisation process. The data registering is done via a questionnaire consisting of systematically constructed pages. The user is provided by two types of support during the completion of the questionnaire. The first type of support appears in forms of tooltips and offers either useful information (e.g. how to distinguish between building standards) or ethical hints. The importance of the ethical remarks will be discussed in subsection 4.4. The second type of support is provided via default values based on the Austrian situation ("reference year 2011"). The aim of these default values is to help users filling in data if it is unknown and not region specific. Default value for fuel consumption for example can be shown based on Austrian statistics, but the number of inhabitants in the region can only be entered by the user. The pages of the questionnaire are described shortly in the following, focusing only on the information which is to be filled in. It is always listed whenever only the user can add information or alterable default values are also provided. All input values needed for the optimisation are shown at the bottom of each page of the questionnaire. It will be discussed later how these input values are calculated and used for the optimisation.

- On page *general information* the aim is to identify the project by filling in basic information about the region and its demands. The number of inhabitants, the name of the region and the country it is located in are region-specific but suggested values are shown for the electricity demand, average living space, meat demand, average individual mobility, fuel consumption and solar radiation based on statistics of the default country (Austria). Furthermore the user has the possibility to set a maximum value for investment costs, which means that this will be regarded as the highest available financial resource when installing new technologies. (See also subsection 4.2.1.2)

- The second step of the online data inquiry is to define the *existing energy supply* by describing existing renewable based technologies in the region. This page is important because it defines the amount of currently used regional renewable resources which will not be available for the optimisation process. It also collects information whether residential or industrial heat demands are covered by existing renewable based technologies. It is feasible for all technologies to enter either the input (in renewable resources) or the output (in energy) values per year. For all technologies with thermal output, the user is asked to choose whether the amount of heat is used for district heating or for industrial process heating. Only for technologies with both electrical and thermal output it is possible to allow a certain amount of the produced heat as waste heat. Input or output data of the different existing technologies in the region and the heat distribution between industrial and district heat supply can only be determined by the user while default values for thermal and electrical efficiencies are listed in advance.

- The third step within the online questionnaire is collecting information about the *livestock* in the region. The main purpose of this page is to gather information about the amounts of grassland and manure which are already used in the region and hence not available for the optimisation process. The user provides the number of animal unit equivalent and the area needed for concentrated fodder for five different animal categories: cattle, sheep, goat, pig and poultry. Grassland area for fodder is only required for cattle, sheep and goat. The available manure for biogas production is taken into account for cattle, pig and poultry, with the user providing availability of these resources. The number of animals in the region has to be added by the user whereas the necessary area to cover the fodder need is given as default value. Default values are also provided for the amount of manure per AUE (Animal Unit Equivalent, see later) of pig, cattle and poultry, as well as for potential biogas contents of these manure types.

- The fourth step within the online questionnaire is defining the ***area availability***. Four different areas have to be distinguished: forestry area, agricultural area, grassland and area available for direct solar energy utilisation. The main goal is to define the available areas within these categories and some of their characteristics (such as available types of crops in the agricultural field). Within the *forestry area*, the retrievable wood and its heating value may be filled in (default values are available) and the user can also set the amount which is not available for energy production (e.g. timber, wood for pulp and paper). Different energy crops are available in the *agricultural area*: corn silage, corn grains, wheat, barley, rapeseed, sunflower, sugar beet, Miscanthus and short rotation. In order to let the user include additional crops, four more choices are given: unspecified biomass for burning, unspecified biomass for biogas, unspecified oil seed and unspecified cereal for ethanol production. The user can decide whether he wants a certain crop to be included in the optimisation process or not by simply setting its yield to “0” when the crop is not available in the region. He is furthermore asked to provide the yield of all available energy crops, the heating value of Miscanthus, short rotation, unspecified biomass for burning (when relevant) and the biogas yield of corn silage and unspecified biomass for biogas production (when relevant). However default values are available for yields, heating values and biogas yield. The available *grassland* is converted to tons of grass silage, for which the default value of the biogas yield can be altered. All default values for wood, energy crops and grass silage are based on dry matter. The user is also asked to refer to dry matter values whenever entering relevant data in these categories. The area available for solar energy technologies consists of area for photovoltaic and area for solar thermal collectors. In both cases efficiency rates which may be provided by the user convert the areas into MWh heat and electricity. The calculated numbers represent yearly average values. Data for solar radiation are given on page *general information*. The wind power related potential can also be added in this section but no site specific characteristics (e.g. area) will be optimised. The only resources for the optimisation are the investment and operating costs.

- The aim of the ***energy demand*** section of the online questionnaire is to quantify the amount of heat needed for residential and industrial purposes. The total area for spatial heating consists of the average living space given on page *general information* and public and other non-residential buildings defined here on page *energy demand*. A further specification differentiates between the heat demands of buildings according to their building standard and the user may alter the default climatic zones moderate cool (e.g. Austria) to moderate cold (e.g. Finland) or moderate warm (e.g. Portugal). The industrial heat demand has to be provided by the user.

- The user has the possibility to alter the ***basic economic data*** of the materials that are part of the optimisation process. The materials are divided into two parts: raw materials and products. Besides prices of the materials per units, transport costs of raw materials e.g. from the field to the transition point can also be added to the total costs. The raw materials are listed in five categories (forestry, agriculture, grassland, fossil and others) while products are categorised into three groups (forestry, agriculture and energy).

4.2.3.1. Updating raw materials

With regards to the PNS Editor input basically two kinds of information can be updated for raw materials: their costs and their maximum available flow. (It was also illustrated by the left hand side of Figure 19 which information can be filled in when adding a new raw material.) For all raw materials costs were already included to serve as default values, which are displayed in the questionnaire but they are alterable. Only for unspecified agricultural materials such as “other biomass for burning”, “other biomass for biogas” and “other cereals” no default values are available as these are to be specified by the user if any of the three types is available in the region but has not been included yet. Costs are displayed with “0” for these latter mentioned unspecified materials and they are only part of the optimisation when crop yield is filled in by the user.

The maximum available flow can be updated for the following raw materials as also seen in Figure 22: wood, agricultural field, grass silage, biogas potential from manure, solar areas and wind potential. Their calculation is done via the questionnaire and described in the following.

<u>Raw material: wood</u>

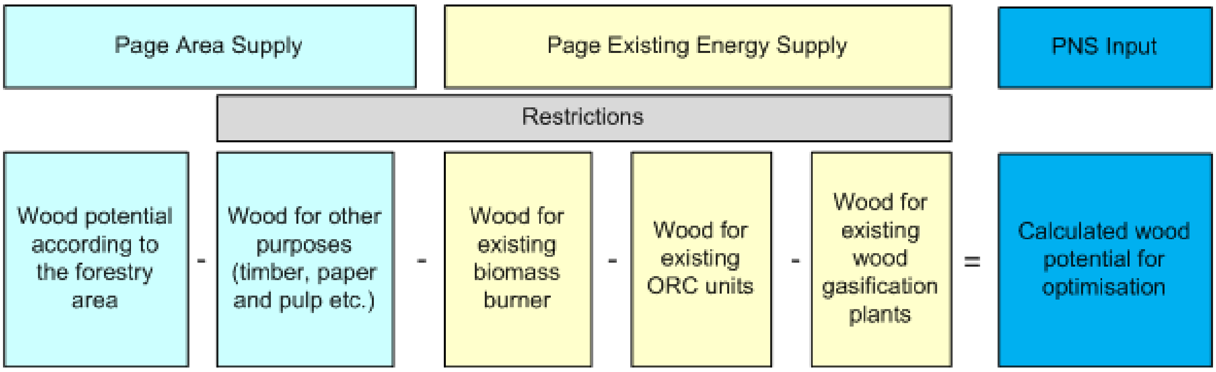

Figure 24. Calculation of wood potential for optimisation

On page *area supply* the available total (productive) land has to be given by the user in hectare. The forestry area is calculated after the user gives a percentage for it out of the total land area. The available wood is calculated either by using the default value or the value given by the user for yield (it is in dry matter per hectare per year). Still on page *area supply* when wood is used for other purposes such as industrial processes (e.g. for paper and pulp or for timber production) there is a possibility to define this other use in percentage. The calculated amount is subtracted. The amount of wood used by existing technologies is added from page *existing energy supply* and subtracted here as well. Such technologies are biomass burner(s), ORC unit(s) and wood gasification plant(s). For all technologies it is possible to add directly the input wood in tons calculated for a year or output heat or electricity values. In the latter case the amount of wood is calculated using either the thermal or the electric efficiency of the technology and the heating value of the wood (for both default values are available). The outcome using these given restrictions is the amount of wood that can be used for the optimisation with the PNS. An overview of the elements used for the calculation is provided in Figure 24.

Raw material: agricultural field

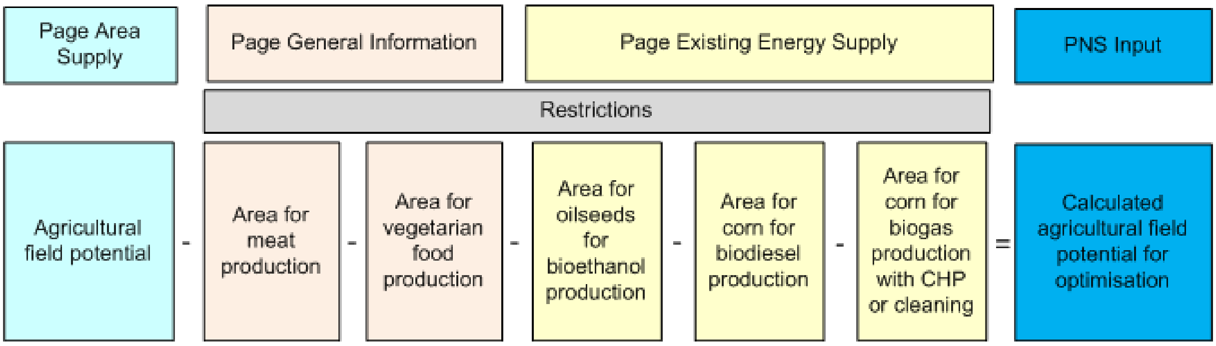

Figure 25. Calculation of agricultural field potential for optimisation (A)

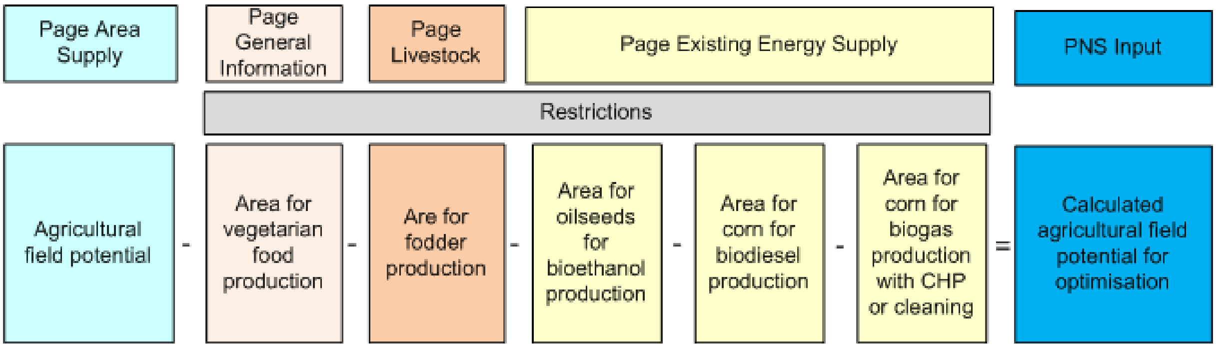

Figure 26. Calculation of agricultural field potential for optimisation (B)

Similarly to forestry area, a percentage for agricultural field out of the total land has to be given by the user in order to calculate the available hectares. Basically two types of restrictions are considered.

First, the available area which is needed for food production is subtracted. One part of it is needed for vegetable food, the other part for meat production. For all hidden calculations in the following the Austrian situation ("reference year 2011") was regarded. The area for vegetable food production for example is based on such a hidden calculation. The energy content of the average amount of food needed for a person in a year is taken into account in MJ. Out of this amount the meat demand is subtracted (after a conversion based on an average value of energy content in MJ) which is calculated according to the given input on page *general information*. Still as a hidden calculation and based on average values the area needed to produce the amount of vegetable food for the energy content is defined according to the number of inhabitants. This is the area which is subtracted from the available agricultural field as area for vegetarian food production.

The area for meat production can be however calculated in two ways. The idea is to compare the meat demand calculated by page *general* information with the meat production defined on page *livestock* and take the higher value into account. In both cases the area to provide (concentrated) fodder for livestock for meat production has to be subtracted but it is possible that the demand in the region is higher than what is actually produced (which means that meat is imported to the region). With a hidden calculation similarly to vegetarian food production, the area needed to produce the amount of meat in the region considering the number of inhabitants is defined. If this area succeeds the area calculated for concentrated fodder production on page *livestock*, then this is the area which is subtracted from the available agricultural field as seen in Figure 25. In any other cases (if the amount is the same or less) the calculated area from page *livestock* is taken into account (subtracted). To determine it husbandry information is needed from page *livestock* where data regarding five different animals can be added: cattle, sheep, goat, pig, poultry. The number of AUE (animal unit equivalents) can only be provided by the user while default values for the area for concentrated fodder production are available (ha/AUE). An Animal Unit Equivalent is equal to 500 kg live weight of a grown up cattle. All other animals are calculated according to this data (agrilexikon.de, 2015). The total area for concentrated fodder is calculated by simply multiplying the number of AUE with the concentrated fodder need by each animal and added together. This variation is seen in Figure 26.

The other type of restrictions for both Figure 25 and 26 is generated by page *existing energy supply*. If the user has chosen any of the technologies which needs agricultural field for the production of its input, the calculated areas are subtracted here. The following technologies are considered: bioethanol plant based on corn, biodiesel plant based on oilseeds and biogas plant based on corn silage with either CHP unit or biogas cleaning facilities on site. The data can be provided similarly to technologies based on wood: either the input itself (oilseeds, corn or corn silage) in tons or the input will be calculated from the given output. In case of filling in the output for a biodiesel or a bioethanol plant the input is simply defined by a conversion value, for which default values are available at both technologies. (The question is how much oilseeds in tons are needed to produce 1 ton of biodiesel and similarly how much corn in tons is needed to get 1 ton of bioethanol.) If the output is given for the biogas plant with CHP then (default) values are needed for the biogas yield of corn silage and heating value of the biogas produced from it as well as electrical and thermal efficiencies of the CHP unit. If the biogas plant operates with a cleaning facility on site and the output is provided by the user in m^3 of upgraded biogas then (default) values for biogas yield of corn silage and methane content of the biogas produced from it are necessary for the calculation of the input. In all cases however the areas used for producing the input are calculated with hidden calculations and according to the hectare needed to produce the input material (oilseeds, corn or corn silage) in question.

After taken into account the restrictions described above, the agricultural field potential is provided as input for the optimisation with the PNS.

Raw material: grass silage

The way to calculate the amount of grass silage for the optimisation process is very similar to the one for agricultural field. Again two types of restrictions are considered.

First, the grass silage used to feed the livestock has to be subtracted. If the grass silage needed as fodder for livestock in order to produce the amount of meat consumed in the region (given by the data on page *general information*) is bigger than the amount calculated by page *livestock*, then the grass silage for subtraction is calculated according to the meat consumption defined by page *general information* (Figure 27). Otherwise the grass silage needed as fodder on page *livestock* for the following animals is considered: cattle, sheep and goat. Primarily the grassland area is calculated by alterable (default) conversion values for each type of animal. The area is then added together and converted to tons of grass silage by hidden a calculation. Figure 28 shows this variation.

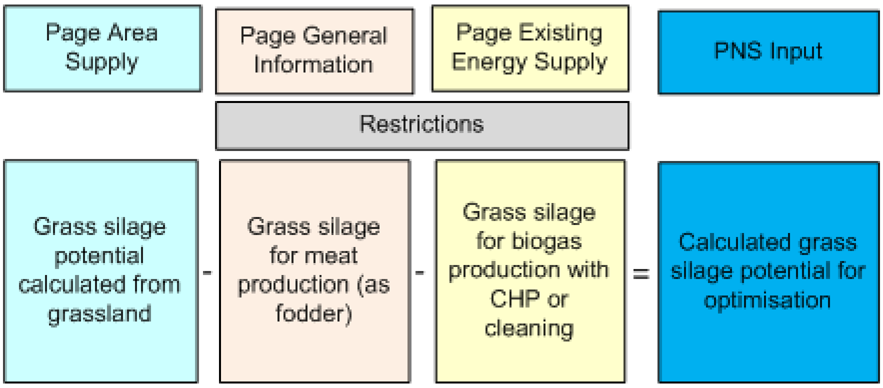

Figure 27. Calculation of grass silage potential for optimisation (A)

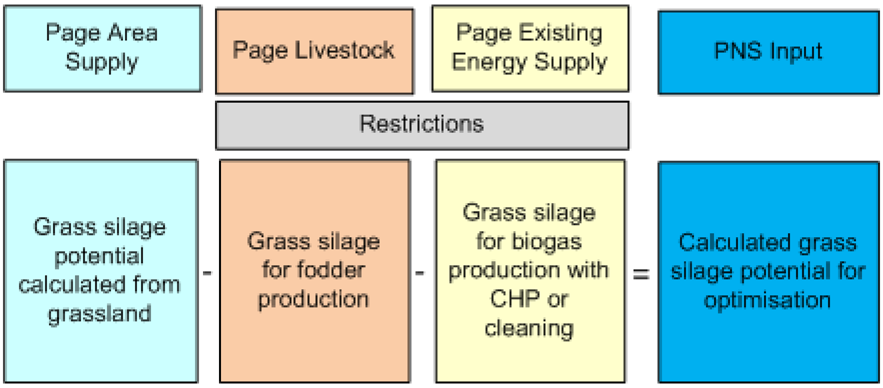

Figure 28. Calculation of grass silage potential for optimisation (B)

The second type of restrictions takes into account the grass silage used for existing technologies. These technologies can either be a biogas plant with CHP unit or a biogas plant with cleaning facilities. The calculation is carried out the same way as it was already described for the biogas plants having corn silage as input with the only difference that the amount of grass silage in tons does not need to be converted to hectares.

The amount of grass silage which is left at the end of the calculation (seen both in Figure 27 and 28 on the right hand side) is the amount that can be used as raw material during the optimisation process with the PNS.

<u>Raw material: biogas potential from manure</u>

For the calculation of the biogas potential from manure all information are provided by page *livestock*. The manure of three types of animal are taken into account: cattle, pig and poultry. To define the amount of manure for each type of animal alterable (default) values are given per AUE. The manure per AUE is always in tons of dry matter. Afterwards the user has the possibility to set a percentage of manure that can be used for biogas production (e.g. the amount of manure that is not collected for agricultural purposes). The three types of manure (cattle, pig and poultry) available for biogas production could already represent inputs of the PNS. However in order to keep the data transferring as simple as possible the biogas potential (methane content) is already calculated via the questionnaire. For this purpose alterable conversion factors are available defining the biogas yields of the different manure types. The sum of the biogas potentials from the three types of animals is the input for the optimisation with the PNS (Figure 29). This means that when the biogas potential is used as an input for the fermenter in the structure (see also Figure 22) no conversion takes place and the output is still m^3 biogas, as it was already explained by subsection 4.2.1.4.

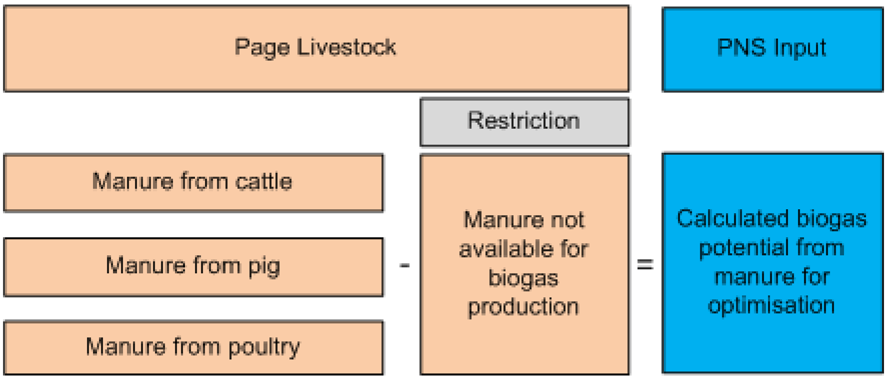

Figure 29. Calculation of biogas potential from manure for optimisation

<u>Raw material: solar areas</u>

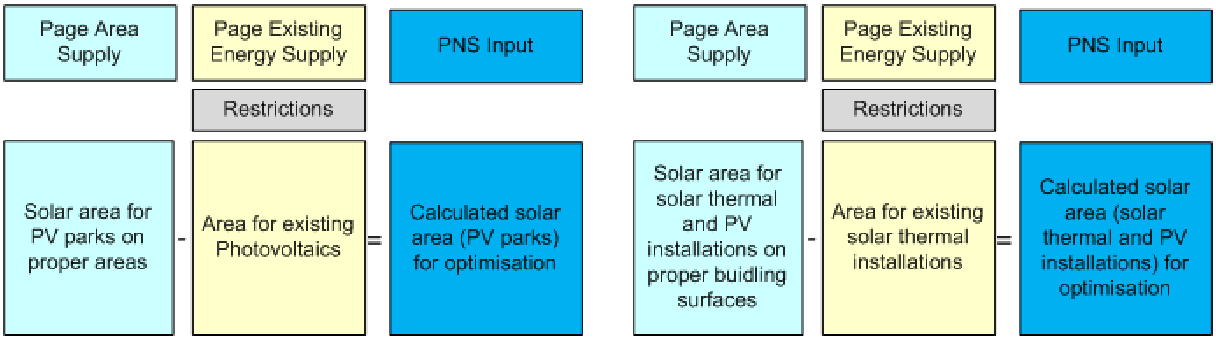

Figure 30. Calculation of solar areas for optimisation

The solar radiation per m^2 had to be defined on page *general information* (when different than the default value). On page *area supply* the user can give the areas (this time in m^2) that are available for solar parks excluding building surfaces (Figure 30 left hand side) and for both solar thermal and PV installations on appropriate building surfaces (Figure 30 right hand side). Efficiencies as alterable (default) values are available for both technologies. Restrictions are considered according to existing solar technologies defined on page *existing energy supply*. The area which is left after the restrictions is the input for the optimisation with the PNS, while the default values for conversion and the solar radiation will be used later to determine rates for operating units.

<u>Raw material: wind potential</u>

The potential wind power has to be given by the user which means that the technology wind turbine in the structure has both inputs and outputs in MWh dimensions. Only the investment and operating costs are optimised as it was already discussed before.

4.2.3.2. Updating products

Similarly to raw materials, two main types of information can be defined during the online data registering for products: prices and required flows. Default values for prices are again available and can be edited using the questionnaire. These prices already include subsidies and taxes. Only for two products (ash and K_3PO_4) the price “0” is included. Even if these products could represent “costs”, RegiOpt-CP does not consider negative prices. In the following it is explained how required flows for district heating, individual heating and industrial heat demands are calculated.

Product: district heating and individual heating demands

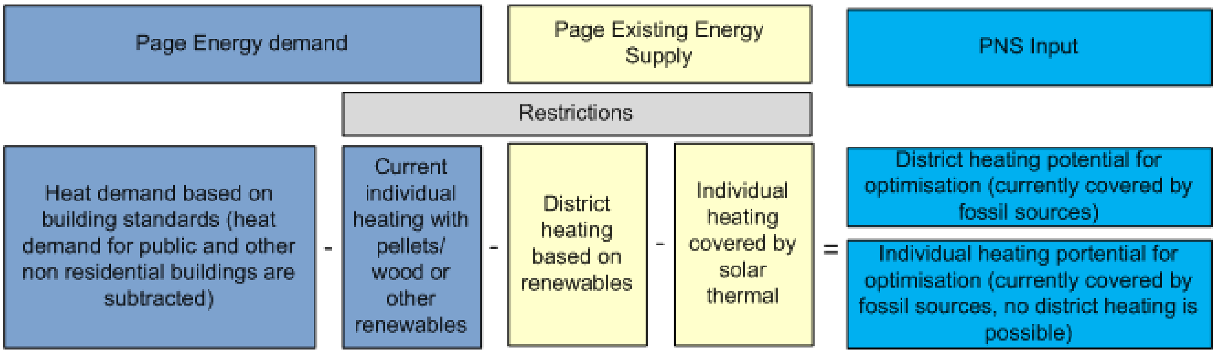

Figure 31. Calculation of heating demands

The total living space (m^2) is calculated according to the data on inhabitants and average living space entered on page *general information*. This area is shown on page *energy demand* but not alterable anymore. The user has here however the possibility to fill in the percentage of public buildings and other non residential buildings compared to the total living space as these buildings will add to the total area for heating. The user may alter in the following the distribution among old, new, low energy standard and passive standard buildings within the region, default values are only suggestions. Tooltips provide information about the characteristics of these building standards so that the user can more easily distinguish between them. The necessary heat per m^2 for the different types of buildings is determined by choosing from the following climatic zones: moderate cold (e.g. Finland), moderate cool (e.g. Austria) or moderate warm (e.g. Portugal). These values are not alterable and are referred to moderate cool climatic zone. Conversion factors are used to adjust to the other climatic zones: heat demand is multiplied with 1.35 when selecting moderate cold, and with 0.17 for moderate warm zone accordingly. With hidden calculation an amount of heating demand for hot water is added. The calculation is based on the Austrian situation (“reference year 2011”).

Out of the total calculated heating demand, the value for district heating supplied by existing technologies and the value for heating demand covered by existing solar thermal installations are subtracted (in both cases values are given on page *existing energy supply*). From the amount that is left the percentage which is currently covered by other renewables (such as wood, pellets etc.) as individual heating has to be set. Obviously the amount which still has to be covered is supplied by fossil sources at the moment. It can be categorised to either individual or potential district heating as seen in Figure 31. The optimisation process considers the following renewable energy sources for individual heat demand: pellets and spit logs produced in the region and solar thermal installations. However in case of lack of renewable energy sources the individual heat demand can also be supplied by natural gas. The district heating potential can either be covered by low temperature process heat generated in the region via various technologies or by natural gas when regional resources are insufficient. (See also Figure 22.) The area for district heating potential can be described as a rather densely populated area with an available central location for heat production, whereas individual heating typically covers heating demand of areas with low population density and without rentable area for central heat production.

Product: industrial heat demand

On page *energy demand* the industrial heat demand has to be defined by the user. The amount of heat that is covered by renewable energy sources according to page *existing energy supply* is subtracted here. Similarly to the district heating potential, industrial heating demand will be supplied either by high temperature process heat produced in the region or by natural gas during the optimisation.

4.2.3.3. Updating operating units

The online data registering via the questionnaire does not only influence raw materials and products from a PNS Editor point of view but operating units as well. This means that actually input and output values of operating units can be altered (see also the right hand side of Figure 19). In the following operating units that can be updated are described in four categories.

Updating biogas yields

It was already discussed earlier that biogas yields of input materials for the fermentation process are defined in separate operating units. (See also Figure 17.) For certain materials it is possible to alter their biogas yields via the online questionnaire as seen in Figure 32. This means that the added new value will appear in the corresponding operating unit as the new output value for “biogas input”. If the default value is not altered in the questionnaire obviously no change happens in the operating unit. It is important to mention again that the unspecified biomass for biogas production is only going to be part of the optimisation if its crop and biogas yields are filled in.

Operating unit	Input update	Output update
Biogas input of • corn silage • grass silage	Values are not changeable	Biogas yield is updated according to page *area supply*
Biogas input of unspecified biomass for biogas production	Values are not changeable	Biogas yield is only updated if crop yield is provided on page area supply

Figure 32. Changeable values of operating units defining biogas yields

Updating values for planting and transporting crops

As it was described earlier the agricultural field represents a raw material for the optimisation while the crops which can be planted on it are intermediate products from PNS point of view. Both input and output values of operating units may be updated after entering regional values in the questionnaire (Figure 33). An example for such an operating unit was presented by Figure 14. Input materials are the agricultural field, operating and transport costs, while the output material is the energy crop.

In the questionnaire two types of information are needed for defining transport costs: the transport distance and the costs for transporting 1 ton of crop (dry matter) 1 km. However, as the input of the operating unit is always 1 ha of agricultural field, not only the distance but the yield of the material has to be multiplied with the costs as well. This is how we calculate the costs of transporting a crop planted on 1 hectare agricultural field to the next processing location.

The alterable output value of the operating unit is the yield of the crop itself. If the user changes the yield of a crop on page *area supply*, the new value appears in the operating unit applied in the structure for the optimisation.

Unspecified crops once again are not part of the optimisation if their crop yield is set to "0".

Operating unit	Input update	Output update
Planting and transporting the following agricultural materials: • cereals (sugar beet, corn grains, wheat, barley) • oilseeds (rapeseed, sunflower) • Miscanthus • shortrotation • corn silage	Transport costs are updated based on costs per km and transport distances (according to page *economic values*)	Harvested values are updated according to the yields on page *area supply*
Planting and transporting the following unspecified agricultural materials: • Unspecified cereal • Unspecified biomass for biogas production • Unspecified biomass for burning	Transport costs are only updated when values are provided on page *economic values*	Harvested values are only updated when crop yields are provided on page *area supply*

Figure 33. Changeable values for planting and transporting crops

<u>Updating heating values</u>

Similarly to the fermentation process there are other technologies for which no real conversion takes place in the operating unit of the technology itself (the dimension of the resource is the same as of the output). Biomass furnace for example can also use both Miscanthus or an unspecified biomass to produce process heat. The input is then not Miscanthus or unspecified biomass in tons but an intermediate product which represents the heating value. (The biomass furnace then turns the heating value according to its efficiency into high and low temperature process heat values.)

If the user changes the default heating value for any of the materials listed in Figure 34, the new value is going to be used as input for technologies.

Operating unit	Input update	Output update
• Miscanthus for biomass furnace, • wood for ORC • shortrotation for ORC	Values are not changeable	Heating value is updated according to page *area supply*
Unspecified biomass for biomass furnace	Values are not changeable	Heating value is only updated when crop yield is provided on page *area supply*

Figure 34. Changeable heating values

<u>Updating capacities of technologies</u>

For some technologies the capacity of a resource cannot be defined only providing maximum available flows of raw materials. For solar thermal installations for example the maximal available flow of the raw material is the solar area from a P-graph point of view. However the solar radiation and the efficiency of the solar thermal installations contribute to the capacity of the resource as well. In the operating unit the inputs are the area (1 m^2) and the operating and investment costs that are not changeable. The output is then the produceable low temperature heat which also depends on the solar radiation provided by page *general information* and the efficiency added on page *area supply*. The method for updating PV installations is the same except for the output as it is in this case electricity.

Figure 35 gives an overview of the updated values which for solar thermal and PV installations after filling in the questionnaire.

Operating unit	Input update	Output update
Solar thermal installations	Values are not changeable	Output maximum heat is calculated according to solar radiation given on page *general information* and efficiency rate given on page *area supply*
PV installations	Values are not changeable	Output maximum electricity is calculated according to solar radiation given on page *general information* and efficiency rate given on page *area supply*

Figure 35. Changeable capacities of technologies

4.2.4. Maximal structure generation and optimisation

The aim of the regional data input via the questionnaire is to characterise the PNS problem based on regional specifications. The background superstructure, created by the PNS Editor is updated in terms of:

- ❖ maximum available flows of raw materials (including wind potential, available amount of wood, grass silage and biogas potential from manure and available area for agricultural field and solar areas)

- ❖ required product flows (including district heating demand, individual heating demand and industrial heat demand)
- ❖ raw material costs
- ❖ product prices
- ❖ technologies (including values for transport costs, crop yields, heating values, biogas yields and capacities of PV and solar thermal installations)

The values are taken from the online questionnaire and fed into the superstructure. The MSG algorithm is then subsequently used to build the maximal structure used which is characterised according to the provided regional data. Let's suppose that no available area is provided for agricultural field. This would imply that not only the raw material itself (agricultural field) but all technologies using only materials produced from the agricultural land would not form part of the maximal structure. Based on the superstructure (Figure 22), the maximal structure is generated using the MSG algorithm for this hypothetical example (Figure 36). Raw materials, intermediate products, products and technologies which are not part of the maximal structure are blended out.

After the maximal structure is generated, the ABB algorithm is used for optimisation based on the objective function and given constraints. Objective function for RegiOpt-CP refers to revenue maximisation (see also chapter 3) while constraints refers to the available regional raw materials and the heat demands covered. As discussed in chapter 2, the ABB algorithm starts at the product level and searches for sub-networks of the maximal structure which are valid in terms of the constraints. RegiOpt-CP considers only the best solution and therefore only one structure is generated which represents the most profitable solution structure, the so called optimal structure. This optimal structure provides the highest revenue which is possible in the given regional context.

Note that if the user selects an amount for "maximum investment volume for a new energy system" (the maximal available flow is restricted for investments costs) this also acts as a constraint during the optimisation process. It gives the user the opportunity to obtain an overview of what is possible using a certain budget for the creation of a technology network based on regional renewable resources. Such a restriction can however significantly influence the optimisation process and decrease the possibilities in terms of renewable regional resource utilisation.

Based on the optimal structure, RegiOpt-CP provides several result analyses of economic and ecological information. These analyses are discussed in chapter 4.5.

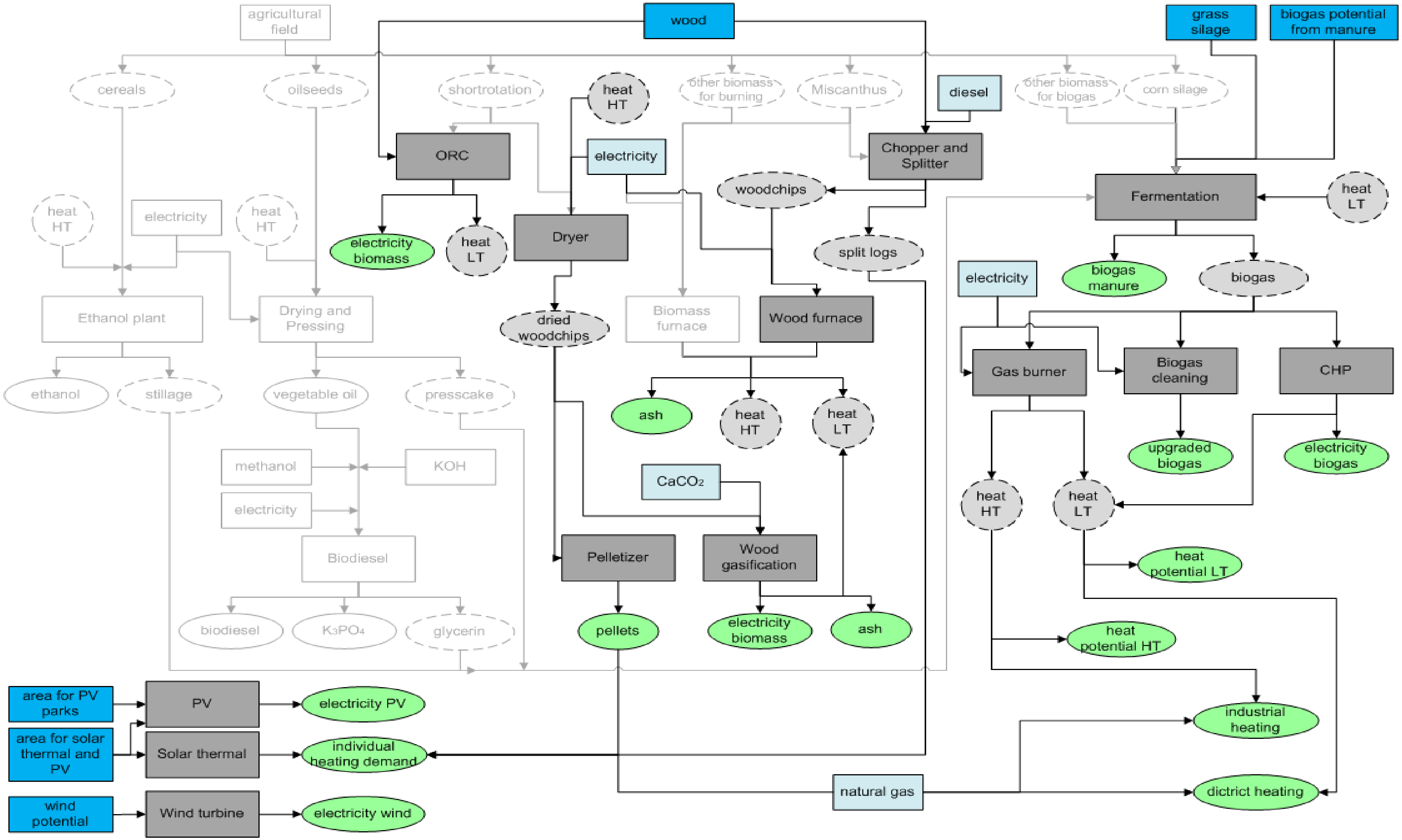

Figure 36. No available agricultural field for optimisation – hypothetical example for maximal structure

4.3. SPI data input

Information from the questionnaire is not only used for the optimisation with the PNS but also for the ecological evaluation with the SPI. The country name for instance also defines the ecological value of the electricity production. This is important since the technology mix providing electricity varies widely between nations. A database that is connected to the RegiOpt-CP stores the SPI values of electricity production for each European country. The database also stores all other SPI values that are used to evaluate the optimal structure ecologically and to define the ecological and carbon footprints. The ecological evaluation is based on products which are produced. The ecological and carbon footprints are therefore only calculated for products which form part of the optimal structure. In order to calculate the ecological and carbon footprints of the products, raw materials data and the technologies which are needed during the production must be available. The list consisting of these raw materials and technologies in the database include for each of its element the overall SPI value and the share of the different types of areas (also refer to chapter 2).

A business as usual scenario is generated out of the questionnaire which indicates to the current energy system and current land use of the region. This business as usual scenario is also evaluated ecologically as it serves as a basis for comparison when analysing results. Naturally the comparison cannot be based on all products produced by the optimal structure but only those products which are also currently provided in the region: meat and other food, electricity consumption of inhabitants (not the electricity produced via the optimal structure), heat demand (district heating, individual heating and industrial heat) and fuel consumption for mobility. If any of these demands cannot be covered by regional resources, imported materials are also factored into the process. The SPI values for these import materials are also included in the Database. Chapter 4.5 provides examples of the comparison of the business as usual scenario and the optimal structure both from ecological and economical point of views.

4.4. Ethical aspects

Users also receive ethical warnings during the online data registering. The idea is to alert the user should current consumptions have high environmental pressure and add to global inequalities.

If a region requires greater forest land than currently available (e.g. for timber production, paper and pulp production, existing technologies), RegiOpt-CP assumes there is no more available land for further energy utilisation on page *area supply*. (Note that RegiOpt-CP does not display negative values in the questionnaire.) In this case the user receives an ethical warning indicating that more area is used than is available and therefore the additional wood required is assumed to be imported. It is further noted that the ecological pressure to support regional demand is burdened on other regions and that the region adds to global inequality by using more natural resources than is warranted by its natural endowment. Similar warnings appear if there is less agricultural land or grassland than required for meat and vegetable food supply and/or for existing technologies. The user can always overrule the ethical warning however, and increase the area for energy production until the total amount of each area is reached. The same ethical warning will appear: assigning more area for energy production means importing goods for the region.

The importance of providing these ethical warnings is to draw the attention of regional decision makers to the global responsibilities of their region. These warnings aim to foster decisions within a region that consider sustainability from a global viewpoint when creating future scenarios for regional development. This is especially important for planning new energy systems which have resources in competition with other land use.

4.5. Results of the economic optimisation and ecological evaluation

The results consist of tables and graphs representing the outcome of economic optimisation and ecological evaluation. With regard to the solution (optimal structure), the tables provide information about:

- general economic data: raw material costs, product revenues, total investment costs, total operating costs, total transport costs and total revenue of the solution
- materials and technologies: total use of products, technological capacities and total product amounts
- SPI values for products (ecological footprint in m^2 / service unit, product share)

The solution is displayed as a graph. In addition, several charts show economic and ecological comparisons between the solution and the business as usual scenario (BAU). Ecological comparisons are based either on ecological footprints or on carbon footprints.

An example of the economic comparison between BAU and the solution is to compare the value added in the region. Value added in the region is defined by the market prices for the products minus the depreciation for technologies minus the operating costs of technologies minus the costs of raw materials. It includes the revenues from all energy technologies based on resources supplied in the region as well as the revenue from products or any services exported from the region (e.g. exported pellets or electricity). BAU refers to the current energy system and the current land use and represents the 100% score. The results should indicate that value added in the region with the solution is higher than the fossil driven BAU scenario alone (the score should exceed 100%).

Figure 37 presents a chart that provides an ecological comparison of three products: electricity, heat and mobility. The electricity value to be covered is calculated from the electricity demand per person in the region multiplied by the number of inhabitants. (The two values are given on page *general information*.) This leads to the question of how this value can be covered under both the BAU scenario and the solution. If existing technologies do not produce sufficient electricity to cover the electricity demand, the national average energy mix is factored into the BAU scenario. The optimisation solution, also considers the electricity which is produced by the technologies. The national energy mix is only considered when technologies based on renewable resources do not produce sufficient power to cover demand. The heat demand consists of three elements: district heating demand, individual heating demand and industrial heat demand. Table 1 shows possible resources for covering heat demands of the solution and the BAU scenario . The business as usual scenario only considers the current situation in its calculation, while the solution considers both existing technologies and technologies that cover heat demand in the optimal structure. The fuel demand for mobility is calculated by multiplying the individual fuel consumption for mobility (given on page *general information* of the questionnaire) with the number of inhabitants. Similar to electricity, the question is then how this amount can be supplied for both BAU and the solution. Biofuel production from existing technologies and a diesel–petrol mix are taken into account for BAU (the diesel-petrol mix is only considered if existing technologies do not produce sufficient biofuel to cover regional demand). Beside biofuel production from existing technologies, biofuel production from the structure is also considered in the solution before using a diesel (60) – petrol (40) mix in order to cover regional fuel demand.

<table>
<tr><th colspan="2" rowspan="2">scenario</th><th colspan="2">based on the current situation</th><th colspan="2">based on the optimal structure</th></tr>
<tr><th>renewable sources</th><th>fossil sources</th><th>renewable sources</th><th>fossil sources</th></tr>
<tr><td rowspan="3">solution</td><td>district heating</td><td>process heat from existing technologies</td><td rowspan="3"></td><td>process heat (LT) from optimal structure</td><td>natural gas</td></tr>
<tr><td>individual heating</td><td>solar thermal installations, wood, pellets or other renewables</td><td>split logs, pellets</td><td>natural gas</td></tr>
<tr><td>industrial heat</td><td>process heat from existing technologies</td><td>process heat (HT) from optimal structure</td><td>natural gas</td></tr>
<tr><td rowspan="3">BAU</td><td>district heating</td><td>process heat from existing technologies</td><td>natural gas</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>individual heating</td><td>solar thermal installations, wood, pellets or other renewables</td><td>natural gas</td></tr>
<tr><td>industrial heat</td><td>process heat from existing technologies</td><td>natural gas</td></tr>
</table>

Table 1. Possible resources for covering heat demands of the solution and the BAU scenario

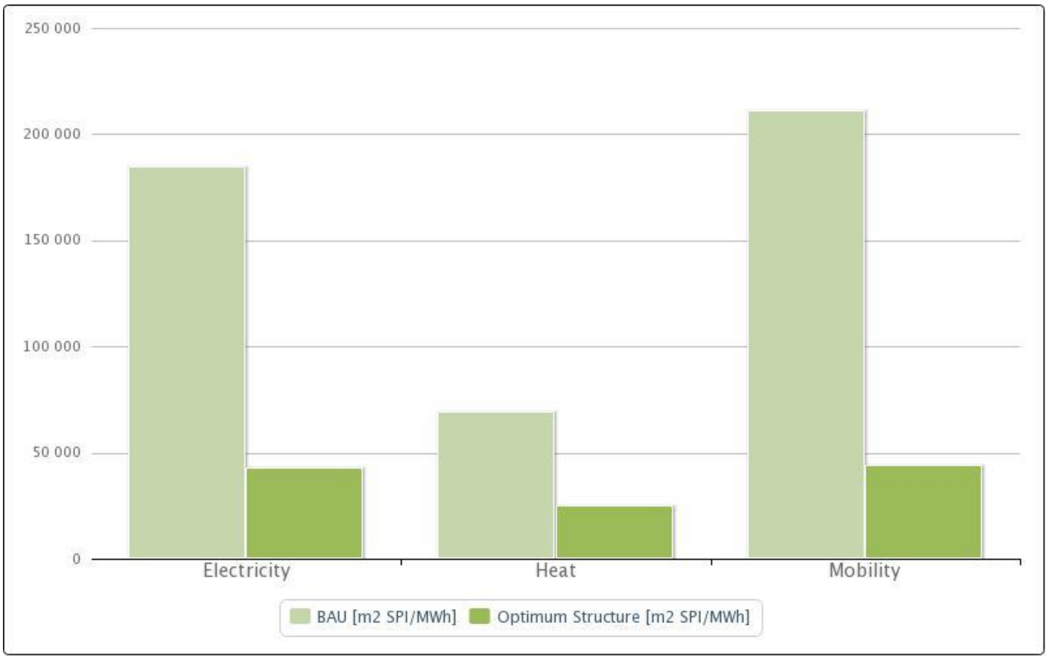

Figure 37. Ecological comparison of the solution and the BAU scenario for electricity, heat and mobility

Certainly the larger the blocks are the higher is the ecological pressure for provision of a certain category. It is clear that the optimal structure of the Figure 36 example represents a much lower ecological pressure for all the considered categories.

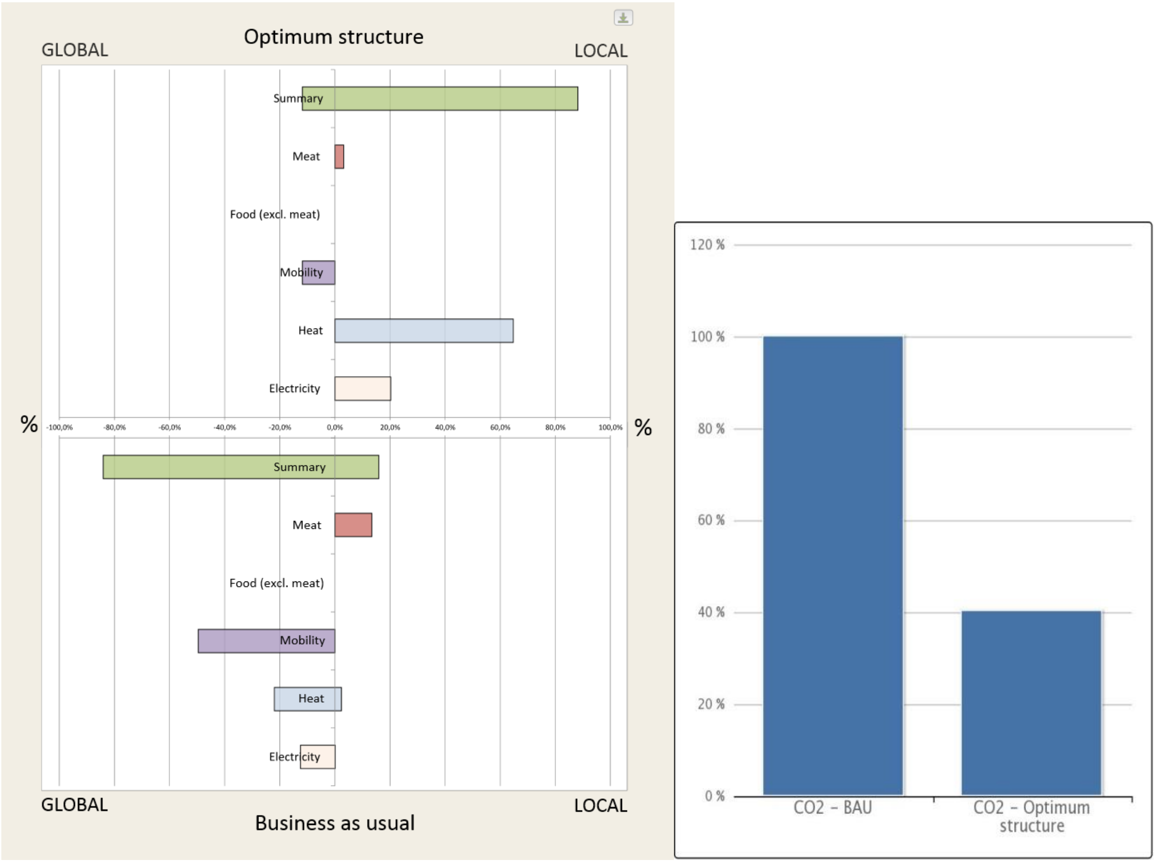

Figure 38. Examples for distribution of the cological pressure between the region and its global partners and for comparison of carbon footprints

A combined comparison between BAU and the solution illustrates the global and local distributions from both economic and ecological point of views. For this comparison the following product categories are considered: meat, food (excluding meat), fuel for mobility, heat and electricity production. The aim of the economic part of the comparison is to show whether the costs for importing the product (global part) or the generated economic value by the regionally produced product (local part) is bigger in a certain category. The bigger the “local” part is compared to the “global” part, the more favourable is the economic performance of the region (e.g. based on the “green” electricity generated by the solution). The ecological part of the comparison shows the distribution of the ecological pressure between the region and its global partners. The larger the part of the block in the "global" field is compared to the “local” field the more the region exports its ecological pressure. It is a clear moral imperative not to export ecological pressures so that other regions carry the burden of the life style and production of a region. An example of the ecological part of the comparison is illustrated by the left hand side of Figure 38. Food (excluding meat) has a very low percentage compared to the other categories of both BAU and the solution therefore not visible in the graph. It is shown in the Figure that the solution (called optimum structure here and presented by the upper part of the chart) puts a considerably lower ecological pressure on its global partners than BAU (presented by the lower part of the chart). Based on the same categories BAU and the solution are compared according to their carbon footprints as it is seen in the right hand side of Figure 38. The 100% is represented by BAU while the solution stands for much lower CO_2 emissions.

5. Summary

There are several reasons why a decision-making tool for regional energy system structures can be of increasing interest. First, there is an observable increase in the number of regions looking to implement technologies based on renewable energy sources, however the variety of both resources and technologies is vast. Second, renewable resources - especially bio-resources - are often in competition with other land use, for example with food production or industrial processes. Third, regional stakeholders, who are most likely to be in positions to invest in new technologies are often not technical experts. This thesis provides an analysis of how these different factors can be assessed in the development of a decision-making tool. RegiOpt-CP is based on the PNS and SPI methodologies, but the main focus of this thesis is on the PNS. Used primarily for chemical processes, PNS is implemented for RegiOpt-CP in a completely new context; it optimises energy networks for regions by utilising regional renewable resources to the greatest extent possible. This new context is also the main innovation of the work discussed in this thesis.

The thesis was based on two research questions. These questions are answered in the following.

- How can we use the Process Network Synthesis as a basis for optimising regional systems?

Research from several case studies contributed to the final idea of how PNS can be the best used for optimisting regional systems. The case studies examined the use of renewable regional resources and analysed process-network synthesis problems. It was shown what factors are considered in land use planning for energy production, and how industry and city could be connected in terms of energy and resource supplies. Scenarios based on economic and ecological aspects were carried out in each case in order to provide concepts for supporting regional development.

Drawing on the experiences, special features had to be implemented to make the PNS most suitable for the optimisation of regional system structures.

First, special characteristics of the P-graph system in a regional context were established based on the knowledge gained by the case studies. With these characteristics it is possible for instance to include materials which can be either sold directly or can be further processed into another product. It also became feasible to show unused heat from technologies as potential heat which is otherwise not visible as it represents no economic value. Further, it was possible to implement technologies which can have different inputs or combinations of inputs without necessarily needing to invest in a new plant as soon as a new resource is involved.

Second, a common framework, the so-called superstructure for RegiOpt-CP, was created by using the PNS Editor. This superstructure consists of well-known and proven technologies which convert raw materials into finished products. The structure was kept as simple as possible, with the aim to provide different ways by which regional energy demands utilising renewable resources could be covered by also including some of the proven products on the market for economic benefits ("green" electricity, pellets, biodiesel etc.). The only fossil source, natural gas was implemented in order to ensure an outcome if regional resources cannot cover the regional demands. By keeping the structure simple, it was possible to reduce the large number of possibilities with regard to regional renewable resource utilisation.

- How does a user-friendly system look like which can be also applied by interested parties without technical expertise for regional development?

An important criterion for such a user-friendly system for regional development was the easy accessibility: the decision-making tool, RegiOpt-CP was created using the web surface. The availability of RegiOpt-CP for users is ensured in form of an online questionnaire. The pages of the questionnaire are constructed in a way to make regional data registering simple: the user is guided through six pages that collect relevant information by providing support for the completion at the same time. Default values, useful information (e.g. explanation of the differences between building standards) and ethical hints are part of this support and help regional decision makers without technical expertise filling in the required information. The regional data that users enter through the questionnaire is used to update the superstructure; in the background RegiOpt-CP is connected with a software to carry out the optimisation process using two algorithms. The outcome of the optimisation process is the so-called optimal structure which represents the most profitable network with a requirement to cover all energy demands in the region. This optimal structure is therefore the solution for the users and is also evaluated ecologically using the SPI method. RegiOpt-CP provides several outcome analyses based on an economic and ecological evaluation of the current situation which is then compared with the solution of the online optimisation process. These outcome analyses help obtaining an overview of the possibilities of renewable resources in terms of regional energy networks and serve as a basis to make decisions towards regional development. Decisions however can only be implemented if stakeholders are willing to work together and that ideal market situations for potential products are present.

6. Outlook

The RegiOpt-CP tool introduced in this thesis is a promising application that shows how regional resources could be optimised resulting in sustainable energy structures. It is basically designed for non-expert regional participants and therefore has the advantage of providing a future energy prospect to stakeholders who lack an in-depth knowledge of energy planning. The expected effect of RegiOpt-CP is to attract the attention of regional decision makers towards renewable resource-based energy planning.

The extension of RegiOpt-CP for urban systems is already in progress. Furthermore an enhanced version of RegiOpt-CP is planned to provide more flexibility, a wider range of technologies and materials and multi-period optimisation for expert energy planners.

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Attachments

Paper 1: Ecological Impact of Renewable Resource-Based Energy Technologies

My task during the research was to provide data about renewable resource-based technologies.

Paper 2: Optimal Integration of Sustainable Technologies in Industrial Parks

I carried out optimisation processes with the PNS Editor during the research.

Paper 3: Optimising the Energy Link between City and Industry

I carried out optimisation processes with the PNS Editor as well as evaluated the results ecologically using the SPI method during the research.

Paper 4: Ecological evaluation of biogas feedstock from intercrops

My task during the research was to assist in the application of the PNS Editor.

Paper 5: Regional Optimizer (RegiOpt) – Sustainable energy technology network solutions for regions

I contributed to a great extent to the creation and implementation of concepts described in the paper.

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Research Article

Ecological Impact of Renewable Resource-Based Energy Technologies

Karl-Heinz Kettl, Nora Niemetz, Nora Sandor, Michael Eder, and Michael Narodoslawsky

Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 21a, 8010 Graz, Austria
Address correspondence to Karl-Heinz Kettl, kettl@tugraz.at

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Abstract Renewable resource-based energy technologies are currently gaining a strong interest, particularly in the light of global climate change and volatile energy markets. A major argument for their use is their ecological advantage. The paper will compare the ecological impact of various biofuel technologies, technologies providing electricity and heat on the base of different resources, both biogenic and direct as well as indirect solar energy. Sustainable Process Index (SPI) is used to compare on the same level with an consistent methodology, a comprehensive and sensitive ecological measure addressing resource provision as well as emissions and global warming with a consistent methodology. The paper will analyze different aspects of the ecological impacts of energy technologies and biofuels. On the base of this analysis, conclusions will be drawn regarding the most important factors influencing the ecological performance as well as unresolved questions for a solid evaluation for these technologies.

Keywords sustainable process index; ecological footprint; energy technologies; biofuels

1 Introduction

The quest for an energy provision that will mitigate human-caused climate change and the necessity to brace for the decline in the availability of fossil energy resources like crude oil and natural gas (Schindler and Zittel [17]; International Energy Agency (IEA) [6]) have increased interest in alternative energy technologies considerably since the turn of the century. There is a general consensus that energy technologies on the base of renewable sources such as solar radiation, wind power and biomass will not only achieve a sea change in terms of global warming but also will be inherently friendly to the environment too. Recent studies (Heedegard et al. [4]) however challenge these assumptions at cost for biofuels and call for a more careful analysis of ecological impact of energy technologies over the whole life cycle.

There is a methodological challenge in comparing different energy technologies that is caused by the fact that they are based on widely different sources and techniques to exploit these sources. Conventional energy technologies are mostly based on fossil resources like coal, crude oil and natural gas. These technologies usually exhibit their largest pressure on the environment during operation by emitting CO_2 into the atmosphere and thus changing the global carbon flow systems with grave consequences for the global climate.

Technologies based on biofuels and biomass in general exert quite different pressures on the environment. For these technologies the pressures caused by agriculture as well as transport become important, as do pressures caused by pollutants like NO_x produced during burning biogenic energy carriers. Especially fossil fuel which is commonly used in mechanized agriculture is a very important factor for the ecological footprint for biofuels. Another main factor on the emission side of agricultural crop production is the production of N_2O from the usage of mineral fertilizers (Kendall and Chang [8]). CO_2 emissions during operation however have almost no importance for those technologies as biogenic resources per se do not change global carbon flows. In general, a detailed view on the substrates, co-products and transport emissions during the life cycle is necessary.

Finally, there is a group of energy technologies that do not cause appreciable environmental pressure during operation such as wind power, solar heat and photovoltaic and to a lesser extent hydro power. For these technologies, the main environmental pressure is linked to the construction and installation of the equipment like PV panels, wind turbines and solar collectors. The task of comparing these different energy technologies in terms of their environmental pressures requires a tool that must take into account different qualities of environmental impacts yet still leads to a meaningful evaluation of the overall environmental performance of the technique.

There are several methodologies available for evaluating environmental impacts like MIPS (material input per service unit, (Schmidt-Bleek and Bierter [18])), CML-Method (Centrum voor Milieukunde Leiden, (Heijungs et al. [5])), CED (cumulative energy demand, (Ökoinstitut e.V. [13])), Energy footprint (Stöglehner [19]) and even more as Fijal [2] and Finnveden and Moberg [3] are describing in their work. For a complete environmental impact assessment, an analysis tool is needed which can evaluate material flows, energy flows and emissions. This calls for a measure that is highly aggregated (to allow comparison) but evaluates different impacts in a transparent scientifically based way. The sustainable process index (SPI) (Narodoslawsky and Kroteschek [9]) is such a measure which follows the rules of the ISO 14040 norm. The SPI has already proved its usefulness in a number of studies involving renewable resource-based technologies (Narodoslawsky et al. [11]; Narodoslawsky and Niederl [12]; Niederl and Narodoslawsky [10]) and is freely available on the internet (Sandholzer et al. [16]) via the website http://spionexcel.tugraz.at.

The SPI is a member of the ecological footprint family and measures the area that is necessary to embed a human activity sustainably into the ecosphere, taking resource provision, energy use, waste and emissions into account. By referring the environmental pressures incurred by manufacturing and construction of equipment to the economic life time of the installation, the environmental impact of infrastructure can also be considered.

2 Differing environmental pressures for different technologies

Energy provision technologies offer an opportunity to investigate the environmental profiles of technologies based on widely different resources and technological structures. There are many ways to provide heat, electricity and fuel but there is a product that is very comparable, namely the energy output in MJ. Evaluating the impact of different technologies with the SPI is therefore not only interesting from the point of view which is that technology providing the needed energy while causing the lowest impact on nature, but also interesting from the point of view of what particular impact a certain technology causes as this may be the starting point for optimization as well as supporting strategic planning against the background of changing structures in the resource base of society in the 21st century. The following figures show that "renewable resource-based energy technologies" represent a very diverse range of technologies with large differences in both their overall pressure as well as the distribution of this pressure into different impact categories. For better overview, the information rendered by the SPIonExcel program has been condensed in seven categories: the use of fossil-carbon, non-renewable and renewable resources (whereas the amount of fossil-carbon represents the impact on global carbon cycle), area utilization and emissions to air, soil and water. Despite of these 7 categories, only 3 of them (fossil-carbon resource, emissions to air and to water) are considered in this report (e.g. Figures 2 and 5) because the rest are in that case negligible. All comparative values of footprints refer to the impact incurred by providing 1 MJ of the energy form in question at the point of distribution.

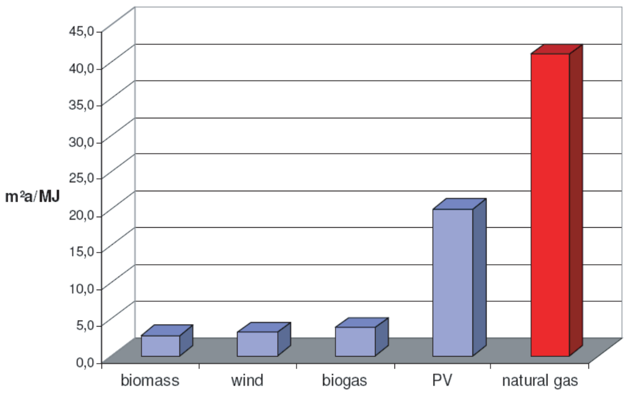

Figure 1: Comparison of ecological footprints for different electricity provision technologies.

2.1 Electricity provision technologies

Figure 1 shows the comparison between five different technologies to supply electricity. The unit m^2a/MJ from Figures 1 to 5 means footprint area per year of production and produced MJ.

Part of the diagram is a wind turbine based on data from a Vestas 3 MW turbine (Vestas Corporation [20]), a monocristalline photovoltaic panel based on data from ecoInvent (Jungbluth and Tuchschmid [7]), a biogas unit (producing heat and power through a micro gas turbine, based on a mix of grass-, corn- and clover silage), a biomass ORC (organic rankine cycle) unit powered by wood chips (Bauer [1]) and a high performance natural gas combined heat and power system (with a 90% overall efficiency and a 45% electricity efficiency with respect to the gas input).

It goes without saying that the value for the biogas unit can only be seen as one value within a range of ecological footprints for this technology as the impact on the environment is critically dependent on the raw material, fossil fuel usage for machinery and application of mineral fertilizers. The calculation for the biogas unit assumes that biogas manure is used as a biological fertilizer on the fields to substitute mineral fertilizers. Footprints may become considerably higher (by a factor of three at least) if biogas production is based on conventionally produced crops.

From this figure it becomes clear that even a "clean" fossil-based technology as natural gas turbines exert a higher pressure than all renewable resource-based alternatives. The difference here is not just percent points but factors, with natural gas derived electricity (with 41.0 m^2a/MJ) exerting 10.8 times the impact of the biogas technology (with 3.8 m^2a/MJ) and still two times the impact of the

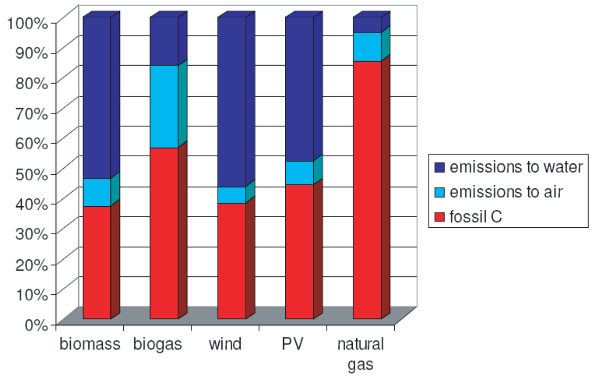

Figure 2: Environmental pressure distribution for electricity generating technologies.

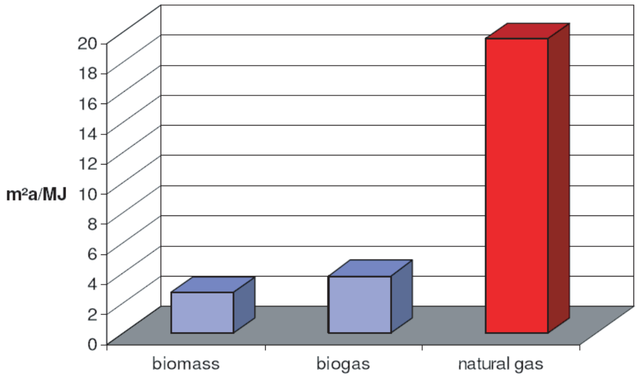

Figure 3: Comparison of ecological footprints for different heat provision technologies.

"worst" renewable based technology photovoltaics (PV with 19.9 m^2a/MJ).

It is however interesting to look at the different impact profiles of the technologies. Figure 2 shows a comparison of these pressures for biomass, biogas, wind turbine, PV and natural gas. Analyzing these, it is obvious that the pressure on climate (represented by the fossil C contributes representing CO_2-emissions) is strong in all technologies. It is clear that this pressure category dominates the natural gas technology; however it is interesting that it is also a strong influence in renewable resource-based technologies. The reason is that our current energy system is still mostly fossil based and any energy input to production and manufacturing of equipment is also causing pressures in this category.

Another interesting result is the difference in the profile between photovoltaic panels and wind turbines. A comparison reveals that the fossil carbon pressure dominates the wind turbine, reflecting the fossil contribution to steel processing. This cannot be reduced unless fossil coal is replaced by a renewable based alternative (like charcoal) in iron smelting, a change that has a low probability of realization in this century.

In photovoltaic panel production, the emissions (especially to water) are prominent, as a result of the complex chemical process employed to produce the semiconductor wafers. This points to the necessity to have a sharp eye on the emissions from this process. Moreover, it is interesting that the carbon emission pressure predominantly comes from the frames of the panels (which are made from metals), caused by the energy intensive production processes of these materials. By and large, the contribution from the raw material itself as well as the direct area use is negligible.

2.2 Heat generation processes

Figure 3 presents the comparison between three different heat providing processes. Combined heat and power technologies from Section 2.1 (biogas unit, biomass ORC unit and natural gas turbine) are sharing the ecological footprint with the electricity production part rated to their amount of output in MJ. The comparison shows a similar picture than in electricity generation, with renewable based technologies coming out on top with regard to environmental pressures.

Difference between the worst (natural gas turbine which has 19.6 m^2a/MJ) and the best technology (biomass ORC unit with 2.7 m^2a/MJ) results in a 7.3 times higher footprint for the natural gas turbine. Which is not such a big difference as in Figure 2 but again the fossil carbon technology is much worse compared to renewable based technologies.

2.3 Biofuel systems

A particularly interesting picture arises with fuels. Figure 4 compares different biofuel systems based on renewable as well as fossil resources.

The two left-hand columns in this figure represent the ecological pressure of bioethanol, with the first column on the left side showing the value for a production of ethanol from corn, using biomass for the provision of electricity and heat for the process. The column to the right shows the pressure exerted by ethanol from a process that uses natural gas as a source of process energy and again corn as substrate. The comparison shows that the energy source for the process decides about the impact of two otherwise similar ways to produce fuel.

Ethanol from corn is according to this calculation environmentally advantageous compared to fossil gasoline. As Reijnders and Huijbregts [15] show, this effect can be even increased if sugar cane is used as a resource.

The comparison of the impact profiles is shown in Figure 5 for the two bioethanol alternatives, gasoline and diesel. The main pressure for bioethanol from corn using natural gas as process energy source is clearly dominated by the fossil carbon impact. Even in the case of the bioethanol production using biomass as process energy source fossil carbon is an important environmental factor. The absolute

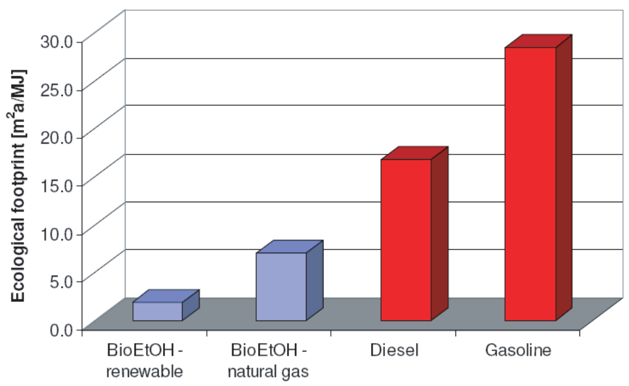

Figure 4: Comparison of ecological footprints for different fuel systems.

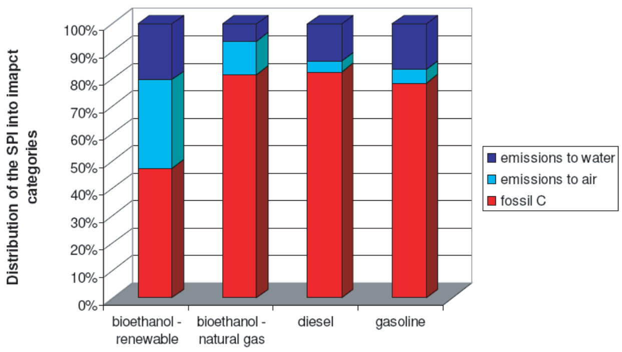

Figure 5: Environmental pressure distribution for biofuel systems.

size of the impact however is much lower and the origin is different. Whereas in the former case fossil carbon (and thus carbon dioxide emissions) is linked to the energy provision of the process, in the latter case the impact results from agriculture, especially the fossil energy to generate fertilizer and the fuel for machines. The large fraction of fossil carbon impact for diesel and gasoline is however not surprising. The fossil carbon part in biofuels can be decreased by using biofuels for agriculture machinery and transport systems by Ometto and Roma [14].

3 Conclusion

Comparing different energy technologies with the SPI reveals some interesting insights as follows.

The environmental pressure of fossil-based technologies and fuels are indeed much larger than that of comparable technologies and products on the base of renewable resources. The impact of fossil technologies is by factors larger than that of renewable resource-based technologies.

Fossil carbon plays a major role in the pressure even of renewable resource-based technologies. This is linked to the fossil orientation of our current resource system as coal, fossil oil and gas dominate the energy provision of industry as well as transport and energy provision for society.

Using fossil energy in processes based on renewable resources inevitably raises the ecological impact considerably as is evidenced by the bioethanol case.

There are large differences in between different technologies/products based on renewable resources regarding their environmental pressure. Just using a renewable source does not qualify a technology or product to become overall sustainable.

Technologies which exhibit high pressures stemming from energy provision (like photovoltaic panels) will become more attractive the more the overall energy system becomes more sustainable.

In general, the evaluation confirms that a switch towards renewable resource-based technology systems is indeed capable of reducing human pressure on the environment dramatically. This is mainly true because these technologies shift the environmental pressure away from fossil carbon impacts that currently dominate environmental considerations.

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Optimal Integration of Sustainable Technologies in Industrial Parks

L. Halász[1], M. Eder[2], N. Sandor[2], N. Niemetz[2], K.-H. Kettl[2], H. Tomo[2], M. Narodoslawsky[2]
[1]Centre for Advanced Process Optimization (CAPO), University of Pannonia, Hungar
Phone: ++36-88-624-706
Fax: ++36-88-428-275
e-mail: halasz@dcs.vein.hu
url: http://mik.vein.hu/
[2]Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 21 a, A-8010 Graz/Austria

Industrial parks are an important instrument to close material cycles as well as to raise the efficiency of industrial production. Spatial closeness allows the exchange of by-products at low costs as well as energy cascades utilising precious raw materials and energy resources most efficiently. This is of particular interest if industrial parks utilise renewable resources. The utilisation of renewable resources poses new technological but also logistical challenges (Narodoslawsky et al., 2008).
Industrial parks offer the possibility to treat different raw materials (and blends of raw materials) as input to various. The problem arising is to create a technology network that optimally utilises resources while at the same time maximises the value added for the members of parks and minimises the ecological pressure from the production within the park.
The contribution will deal with three different case studies of industrial parks, one in Austria, one in Germany and one in Egypt. It will present a coherent and systemic approach to find the best technology network in existing industrial parks facing a retrofit situation.
Process synthesis using the p-graph method (Friedler et al., 1995; Halasz et al., 2005) is employed to find a stable basic technology network, integrating existing facilities and integrating new technologies (such as CHP and direct solar energy utilisation) that utilise available resources.

1. Process Network Synthesis (PNS)

Process Network Synthesis is a method to optimize material and energy flow systems. The main aim is to find a network consisting of operations of processes technologies to transform raw materials into products (including energy). This method allows the optimization of process structures as well as energy and material flows. It is possible to

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factor in time dependencies regarding resource availability (e.g. harvesting times for renewable resources) as well as product or service demand (e.g. varying heat demand for district heating over the year). The input necessary 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.

1.1 P-Graph

The P-Graph (Process graph) represents the structure of a process system. According to Fig. 1 raw materials (B and C) are an input for the operating unit O2 to produce a product which is an input to the operating unit O1. The operating units are representing some kind of technologies. This process leads to the final product A. For every input and operating unit it is possible to define a maximum flow and the costs. The definition of all raw materials, technologies and products in a process system leads to a huge network which represents the maximum structure.
This structure includes all theoretical combination of the whole process network.
Based on input data about flows and costs (variable and fixed costs) an optimal structure is generated.

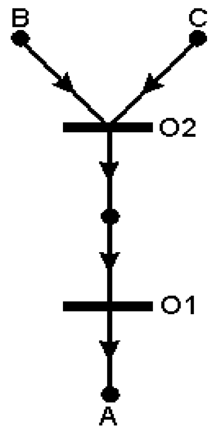

Fig.1: Sample process network path

2. Case Studies

2.1 : Multifunctional energy center, Austria

Within a research study PNS was used for the optimization of a regional-multifunctional energy center. Such a center is characterized by generating energy carriers (e.g. biofuels) or services (e.g. heat or power) as well as industrial products based on regionally available renewable resources. Multifunctional energy centers could either be linked to existing installations (e.g. a biomass heating unit serving a district heating network or an existing biogas plant) or conceived as a completely new installation.
The location of the features an existing biogas plant with corn silage and manure as input and an electrical output of $500kW_{el}$. Electricity is sold to the grid and heat is provided to a district heating grid. A furnace producer operates a research and development unit for chips and pellets furnaces that provides additional heat.
Besides district heating agriculture drying, pelletizing and an oil press may be operated based on the raw materials potential from 8 communities around the site (within appr. 10 km radius).

A generalized maximum structure comprising feasible technology pathways based on the resources from agriculture and forestry in the region was used in this project (see fig. 2). The goal of the optimization was to find a technology pathway generating the highest added value for the region based on the maximum structure in fig. 2. The optimum structure resulting from this optimization is shown in fig.3.

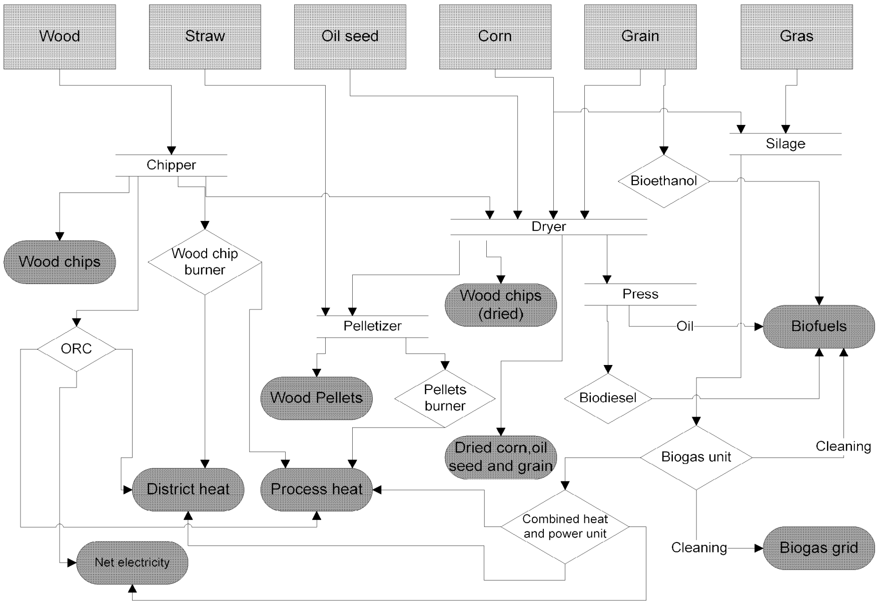

Fig. 2: Maximum Structure

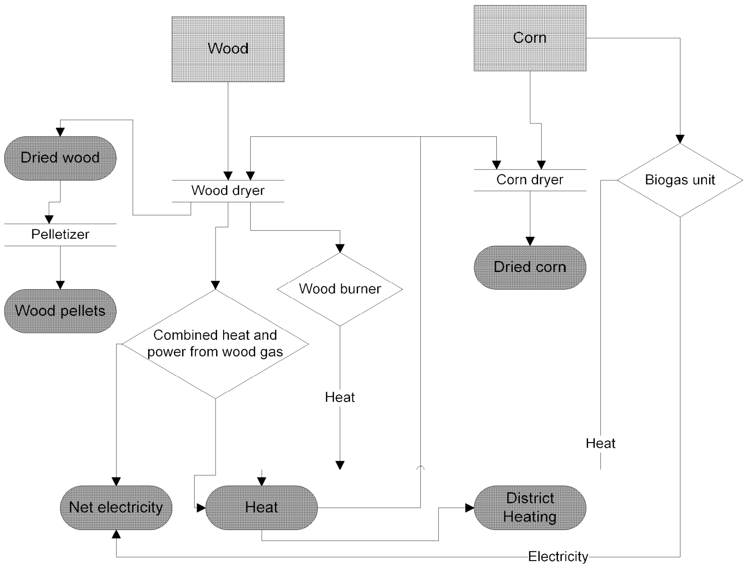

Fig. 3: Optimum Structure

The structure includes besides the existing installations of the biogas unit and the furnace test rig a gasification plant. Heat is used for district heating as well as drying, providing dry wood (e. g. for pelletizing) as well as dry corn for selling, depending on the season.

2.2 Agro-industry complex, Egypt

The study addresses an agro industrial, manufacture and technology centre in Egypt that is currently supplied mainly by conventional energy sources such as electricity from the grid and oil based heating and power systems. A new approach on energy provision, utilizing locally available renewable resources to a greater extend while increasing revenue is the goal of the study in this case. The maximum structure is generated according to existing technologies and follows to a great extend the one shown in fig. 2, including however solar energy technologies and rice straw as an additional resource. Electricity from the grid and fossil based technologies were kept in the maximum structure, too. Cooling as a demand was included reflecting the situation in this agro industry complex that produces food.

PNS generates an optimum structure (fig. 4) where sewage will be treated in biogas plant. Biogas is converted in Combined Heat and Power (CHP) unit. Rice straw is pyrolysed, producing char that is used to improve soil quality. Existing air conditioner units using electricity are included in the optimum structure but supported by new chillers operated by heat to cover additional cooling and air conditioning loads for expansion of production processes. Heat generated by the processes is utilised either for cooling (via absorption units) or for drying purposes. Additional electricity is generated via biogas as well as PV units.

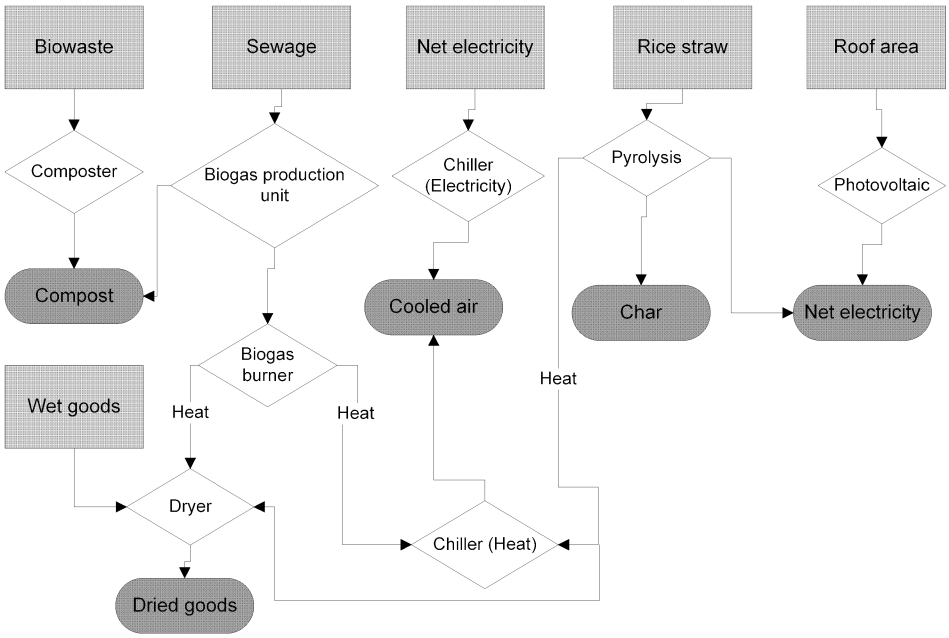

Fig. 4 Optimum structure for the Egyptian agro-industry complex

2.3 Landfill site, Germany

The site of this study has been operated as sanitary landfill since 1995 and is now nearly close to the end of its functionality. The goal in this study is to provide a structure for an industrial park on the now available industrial real estate utilizing regional resources with the highest possible revenue. The maximum structure of fig. 2 also applies to this case. Landfill gas however may be used as an additional resource for a considerable time. In addition to locally available fresh wood, used-wood (from waste collection) may be used but is restricted to thermal utilization.

Fig 5 shows the optimum structure that includes a dryer for fresh wood that will be used to produce pellets. The heat for drying comes from three different sources: (i) a biogas unit which uses agricultural waste and biowaste for the production of electricity, heat and as by-product fertilizer and compost; (ii) a landfill gas CHP for electricity and heat production; (iii) an ORC-unit which uses used-woodchips for the production of electricity and heat. The electricity is sold to the grid at premium prices for renewable resource based electricity.

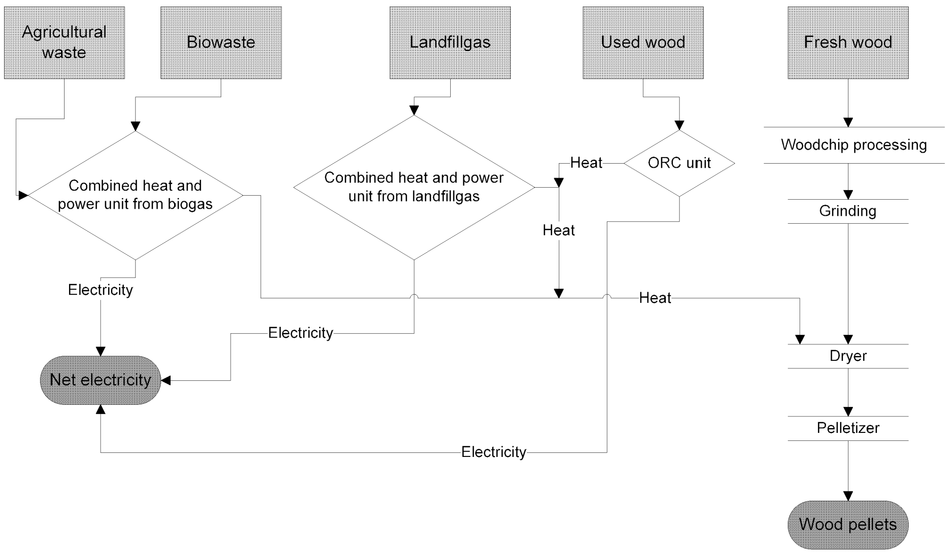

Fig. 5: Optimum structure for German landfill site

3. Conclusions

The case studies deal with very different settings of relatively small industrial parks that are explicitly based on renewable resources that are locally or regionally available. Both the supply side and the local demand for energy services differ widely for these parks. Supply may include a whole variety of crops and resources like in the Austrian case or be restricted to waste material like in the Egyptian case or with an emphasize on wood and used wood as in the German case.

The same holds true for the demand that may vary in time for each site (corn drying, wood drying and district heating, depending on the season in the Austrian case, cooling and power in the Egyptian case).
Despite these wide variety in the resource and demand framework and vast differences in the cost structure between the German/Austrian and Egyptian cases, some interesting common lessons may be drawn from the cases:

- All optimum structures show considerable revenues; this means that utilizing local/regional renewable resources is already a viable business strategy that tends to become even more advantageous as energy prices may increase over time.
- The key to profitability is the rational and complete utilization of heat generated by all technologies. Although other products (e.g. pellets or biofuels) or services (electricity) may fetch higher prices on the market, net positive revenues are only possible if heat is used completely.
- There are many ways to utilize heat rationally; among the most promising are drying (mainly of renewable resources from the region) and cooling (where appropriate).
- A major factor for success is to devise a structure that allows a year round utilization of heat, possibly by providing different services consecutively. Running energy provision technologies in a continuous mode and adapting energy users is a strategy to follow.

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Optimizing the energy link between city and industry

Nora Sandor[1]*, Michael Eder[1], Nora Niemetz[1], Karl-Heinz Kettl[1]
Michael Narodoslawsky[1], Laszlo Halasz[2]
[1]Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 21 a, 8010 Graz, Austria
[2]Centre for Advanced Process Optimization (CAPO), University of Pannonia, Veszprém, Hungary
nora.sandor@tugraz.at

Industries and cities have different functionalities for society but they share several energy aspects. Industries often produce excess energy (low temperature heat in particular) and cities have a considerable heat demand. Linking cities and industries therefore can be advantageous for both sides. Industries can increase their revenue by selling excess heat and cities can integrate this energy in district heating. In terms of emissions there are several advantages: a central emission source for heat production which can be handled much easier compared to several small heating units, as well as the overall improvement in energy efficiency of the city-industry complex.
Important factors for analyzing and optimizing such energy links are the resources for the energy production, district heating costs and time related load profiles. In a first step process synthesis using the P-graph method (Friedler et al., 1995; Halasz et al., 2005, Friedler 2009) is employed to find a stable economical technology network, integrating existing facilities and new technologies (such as CHP and direct solar energy utilization) that use available resources. In a second step this network is evaluated with the help of the Sustainable Process Index (SPI) to indicate ecological hot spots (Narodoslawsky et. al., 1995).
A case study in Austria analyses the feasible energy link between a brewery and the neighboured city including possible energy resources and district heating.

1. Introduction

In a first step of optimization, a basic technology network is generated through Process Network Synthesis, which takes into account already existing facilities and integrates new technologies based on renewable resources within the region. This application uses the p-graph method, and works through energy and material flows. During optimization, available raw materials are turned into feasible products and services, while inputs and outputs are unequivocally defined by each implemented operating unit. The aggregate of implemented operating units represents the maximum structure. By the help of an algorithm for combinatorial process synthesis, where the objective function is the revenue, a solution structure is generated out of the maximum structure. This solution structure represents the most economical technology network.

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In the second step, the generated network is evaluated by the Sustainable Process Index, in order to make the environmental pressure visible. The SPI, as a member of the ecological footprint family, calculates the area which is needed to deliver the product or service unit in question. The software SPIonExcel allows the evaluation of the ecological footprints of different processes.

2. Business as usual scenario

The Austrian case study addresses a comprehensive economical and ecological optimization of the energy system of the historic town centre of Freistadt and a brewery. A special situation applies to the ownership of the brewery: it is owned by the so called ‘Braucommune’, which consists of landlords from the historic city. This particular situation made it possible to take into account the historic town centre into plans to overhaul of the energy system of the brewery since from an economical point of view common ownership allows the economically most advantageous structure for a system consisting of the brewery and the citizens in the historic town centre. For the brewery, the optimization process aimed to raise the efficiency of the brewery’s operations. For the town, the goal was to improve the energy supply based on renewable and regional sources in economic as well as ecologic terms, taking into account that thermal insulation for houses in this area is not feasible due to historic monument preservation ordinances.

Currently the process heat for the brewery is provided by a heavy fuel oil-fired hot water boiler. In 2007 the fuel requirement of the process heat was 30.590 litres, equivalent to around 3.310 MWh/year for heat values of 39,1 MJ/l or 10,833 kWh/l respectively. The heating of rooms within the brewery, which covered an area of 13.600 m^3 in 2007, is currently supplied by natural gas. This area mainly consists of offices and a gallery. The yearly room heating demand is 136 MWh for heat values of 36 MJ/m^3 and 10 kWh/m^3. Both the oil furnace and the electrical cooler, the latter supplying the cooling demand of the beer storage, are to be changed through current development projects. These investment costs were included for the evaluation of the business as usual scenario. Furthermore the calculation involved a higher heat demand of 400 MWh, a value that is expected due to planned enlargements. Electricity from the grid was included at a price of 11 ct/kWh (Annual account of Braucommune Freistadt). Based on the current scenario and the upcoming investments, the brewery itself faces a yearly cost of 137.890 € during the first 10 y, with the 10 y defined as the payout period. Afterwards costs are projected to fall by approximately 30 %.

The historic town can be divided into two regions based regarding its heat supply. In one region a gas network that is supplied by natural gas is already in place. The yearly heat demand of this area is 11.197 MWh. In the other region with no existing network, the yearly heat demand is 2.622 MWh. Oil heating is there still the most common method of providing residential heat and represents the basis of our calculation. While natural gas for households was included at a price of 6.3 ct/kWh, heating oil was included with 5.4 ct/kWh (EUROSTAT, 2^{nd} Semester 2008). We note however that the price of natural gas differs among customers: the brewery for example only pays around 4 ct/kWh (43 ct/m^3) to supply its room heating (EUROSTAT, 2^{nd} Semester 2008).

Adding the costs of district heating to the yearly costs of the brewery, expenses add up to 978.880 €/year.

3. Economical optimization

3.1 Maximum structure

The following structure represents the feasible connections for the economical optimization. It includes technologies based on both conventional energy and renewable sources available in the region. Out of this maximum structure the most economical optimum structure can be achieved based on different scenarios.

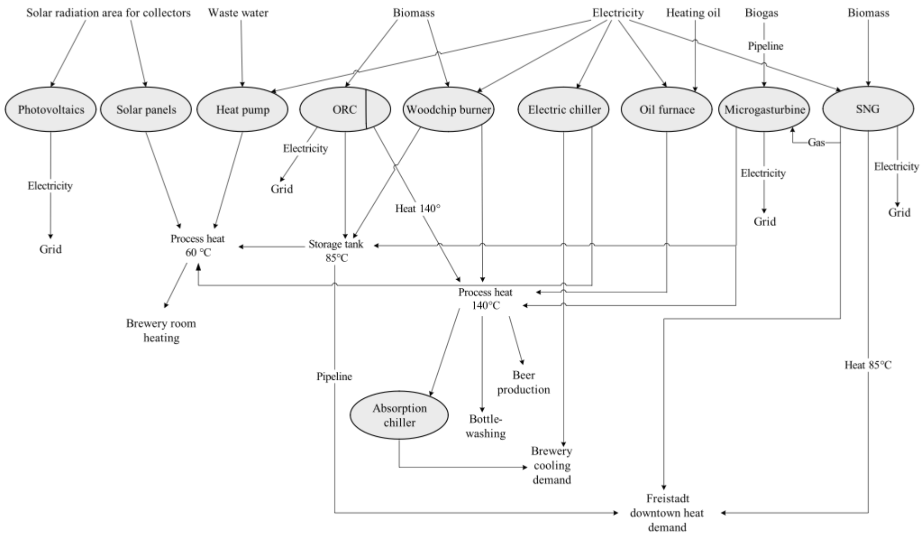

Figure 1: Maximum structure of the optimization process (source: compiled by the authors)

3.2 Optimum structure based on renewable energy sources

The most economical solution structure included a gas burner for peak load supply. However, in order to be attentive to the ecological pressure as well, an optimum is introduced here where the only technology that is not solely based on renewable energy sources was a new electric cooler that had already been ordered by the brewery after having determined an absorption cooler could not be part of the optimum structure due to high investment costs. In the calculation the biomass as the regional renewable resource was woodchips included at a price of 60.4 €/t (Hackgutbörse, 2009).

The solution structure contains:

ORC (Organic Rankine Cycle), with an electrical capacity of 700 kW and a thermal capacity of 4,200 kW supplying the district heat for the historic town of Freistadt, investment costs are 6,500,000 € (turnkey)

Woodchip burner, with a thermal capacity of 1,000 kW, investments costs are 510,000 € (turnkey)

Micro gas turbine, 2 modules, both with an electrical capacity of 65 kW and a thermal capacity of 115 kW, run by biogas, investment costs are 210,000 €
Biogas pipeline from biogas plant to brewery, 1.230 m long, 30 y of payout period, investment costs are 123,000 €/100 m pipeline
Electric cooler, 250 kW capacity, investment costs according to arrangement
During the payout period this scenario requires annual expenses of 781,470 €, around 20 % less than the amount the business as usual scenario represents. After the 10-year payout period, this structure would generate annual revenues of 35,160 €.
As a basis of our calculation we assumed 8,000 working hours per annum. In a given year, periods were determined based on two factors: the brewery's operations and the demand for heat. As for the brewery processes, the following data were estimated by factoring in ongoing projects for enlargement:
80 hl gyle/brew and up to 8 brews/d
daily 640 hl gyle or 600 hl ready-to-sell beer (4-5 % loss of volume during production)
brewhouse operation 3 d/week
The bottle washing process runs 5 d a week, while the room heating is needed every day. According to these circumstances the calculation was based on three periods each month: Monday-Wednesday, Thursday-Friday and Saturday-Sunday. The cooling demand - similarly to the room heating – is continuous during the week. This makes it reasonable to link the waste heat of the electric cooler to the room heating. Figure 2 describes the rate of each technology for the heat supply of the brewery. The available yearly biogas from a plant nearby is limited to 330,000 m^3, sold to the brewery at a price of 24 ct/m^3 (Biogas-Netzeinspeisung, 2009), and funnelled through a 1230 m long pipeline. This amount of biogas is then burned by two modules of Capstone CR 65 micro gas turbines with an electrical capacity of 65 kW and a thermal capacity of 115 kW. On the one hand the electricity produced by the turbines is sold to the grid as green electricity at a price of 15.13 ct/kWh (Energie-Control GmbH, February 2009), and on the other hand the heat produced by the turbines ensures the basic load for the process heat of the brewery. The woodchip burner provides the missing amount of the process heat demand. It has a thermal capacity of 1000 kW which was calculated as a minimum requirement to cover the peak load. On the weekends during the summer months, the waste heat generated by the electric cooler is able to cover the entire amount of heat needed for room heating. Whenever this demand exceeds the amount coverable from the waste heat, it is supplied by the micro gas turbines.
As part of our solution, the district heat demand of the city is supplied by an ORC plant with a thermal capacity of 4,200 kW and an electric capacity of 700 kW. The electricity as output is similar to the micro gas turbines sold to the grid at a price of 14.93 ct/kWh (Energie-Control GmbH, February 2009).

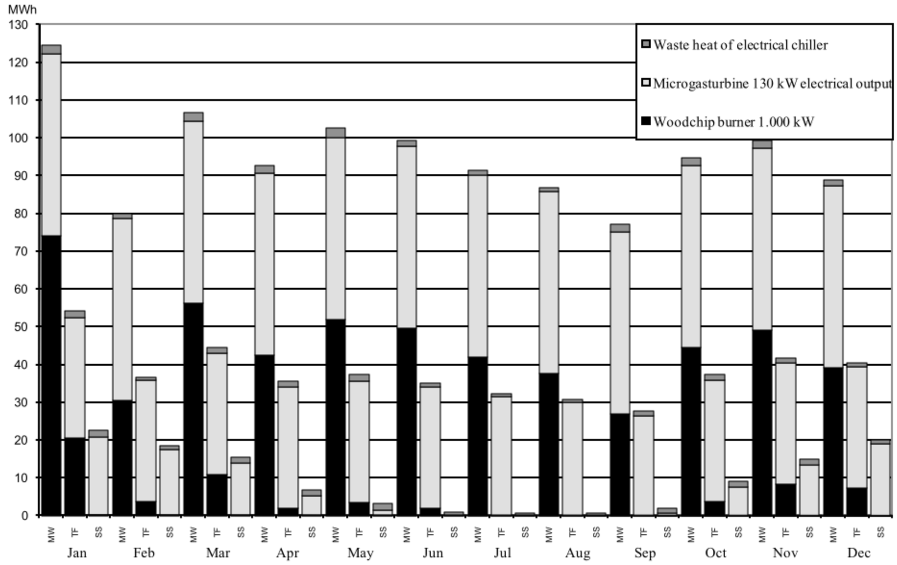

Figure .2: Heat supply constellation of the brewery (source: compiled by the authors)

4. Ecological Evaluation (SPI)

The following graph shows our economical optimization combined with the ecological evaluation.

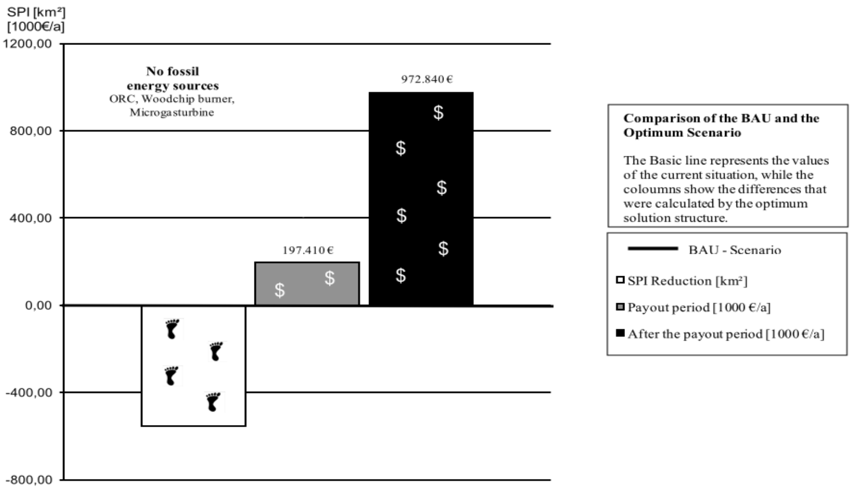

Figure3: Ecological and economical comparison of BAU and optimum scenario (source: compiled by the authors)

With the SPI, the environmental pressures between the business as usual and our optimum scenario are comparable. The SPI in both cases shows the areas needed to supply all processes presented by the scenarios. Based on the current scenario, the total area is 1,062.7 km^2. Only less than half - 503.7 km^2 is needed for the technology network of the optimum scenario. Thus this scenario is not only a profitable solution, but also an ecologically favourable process network.

5. Conclusions

In order for both cities and industries to remain competitive, it is inevitable for them to link up in terms of energy networks. The increasing consciousness of the ecological pressure of human activities on the environment however makes an ecological evaluation equally essential. This paper examined the possibility of linking industry and city through material and energy flows. One of the main concerns during the optimization was to avoid the unused off heat production, and to prove that linking the excess heat of an industrial process to a communal energy supply is a feasible way of improving overall performance of a city-industry complex. In this particular case a process network optimization of a brewery based on renewable resources from the surroundings was combined with the district heating supply of a historic city centre, with excess electricity being sold to the grid at favourable “green” feed-in tariffs. The optimization was based on both economical and ecological aspects, and showed that such linkages, in addition to favouring environmentally friendly technologies, represent a profitable network opportunity for both partners. During the 10 y long payout period the optimum structure stands for an approximate 23 % drop in the yearly expenses and providing considerable revenue after this period. Similarly, a significant improvement is observed in the ecological pressure: the ecological footprint of the optimum network is less than half the current footprint. By considering these results, we can conclude that linking resources and energy lines between industries and communities will play a significant role providing economical benefits while representing a sustainable form of development.

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Ecological evaluation of biogas feedstock from intercrops

Karl-Heinz Kettl*, Nora Niemetz, Nora Sandor, Michael Eder, Michael Narodoslawsky
Institute for Process and Particle Engineering, Graz University of Technology,
Inffeldgasse 21a, 8020 Graz, Austria.
kettl@tugraz.at

The production of biogas from renewable resources is a common technology for combined heat and power provision. Small scale plants represent de-centralized energy supply for communities and are an important part of regional development and de-central usage of renewable resources.

To avoid conflicts with the food- and feedstock provision the usage of main crops as main source for biogas production should be avoided. Intercrops are planted on agricultural fields between the periods for main crops and may be used to provide biogas feedstock fields besides main crops. This biogas can be used in decentralized biogas units to produce electricity and heat. Beside the energetic usage of intercrops possible positive side effects are analysed. The usage of intercrops instead of mulching has a potential to decrease emissions of nitrates to water and nitrous oxide to air. Especially emission reduction of nitrous dioxide, a potent greenhouse gas, is part of the analysis.

For the calculation of environmental effects of agriculture with intercrops the ecological evaluation method of the Sustainable Process Index (SPI) is used (Narodoslawsky et. al., 2008).

1. Introduction

Intercrops are planted beside main crops e.g. wheat, corn or triticale between the main crop periods. Intercrops however can also be used to increase yield per hectare besides improving soil quality. Intercrops have the potential to increase biological nitrogen fixation and rebuilding of humus. This would decrease usage of mineral fertilizers which results in a lower ecological pressure. Taking intercrops from the field may decrease this positive effect. This has to be balanced with the potential positive impact of providing energy from intercrops, if they are to be used as substrate for biogas production. For an economic analysis of different possible biogas production scenarios the well known method of the process network synthesis (PNS) (Friedler et. al., 1995; Halasz et. al., 2005, Friedler, 2009) is used. PNS is able to calculate different concepts of using fields most efficiently and also indicate if biogas should be used centralized or decentralized based on economical values.

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2. Process Network Synthesis (PNS)

Process Network Synthesis is a method to find an optimal technology pathway out of a complex technology network (maximum structure). The main aim is to find a network consisting operations of processes technologies to transform raw materials into products (including energy). This method allows the optimisation of process structures as well as energy and material flows. 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 optimisation. The input necessary for this optimisation 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.

3. Intercrops

To get raw data about soil effects a set of intercrops combined with common main crops are planted on 3 different locations in Austria. Climatic differences between the locations are used to get specific yield data for planting different kind of intercrops. One target is to increase economic output per hectare and simultaneously improve soil quality through intercrops.

Typical planting rotation is to grow the winter type of main crops (e.g. wheat, rape, etc.) and after harvesting the regeneration period starts. This period is used to plant intercrops. Decreasing effects of soil erosion, loss of nitrate and simultaneously increased yield per hectare and year are an argument for planting intercrops. After the intercrop period the main crop period starts again instead of taking a break between the main crop phases without planting anything on the acre.

4. Case study

First step of analysis was a PNS network with all possible biogas feedstock from regional providers. Several locations for biogas plants are chosen and virtually interlinked with the PNS-Solver. Transport distances are taken into account through slightly different raw material prices for each provider group of substrates.

Second step was the calculation of an ecological footprint through SPI out of the optimal solution from PNS.

4.1 Economic evaluation - PNS

Figure 1 illustrates the maximum structure from PNS of a case study from Bad Zell in Upper Austria. Every possible connection between substrates, production technology and products are illustrated. This results in a very complex maximum structure for optimisation. Detailed information about the maximum structure is listed below:

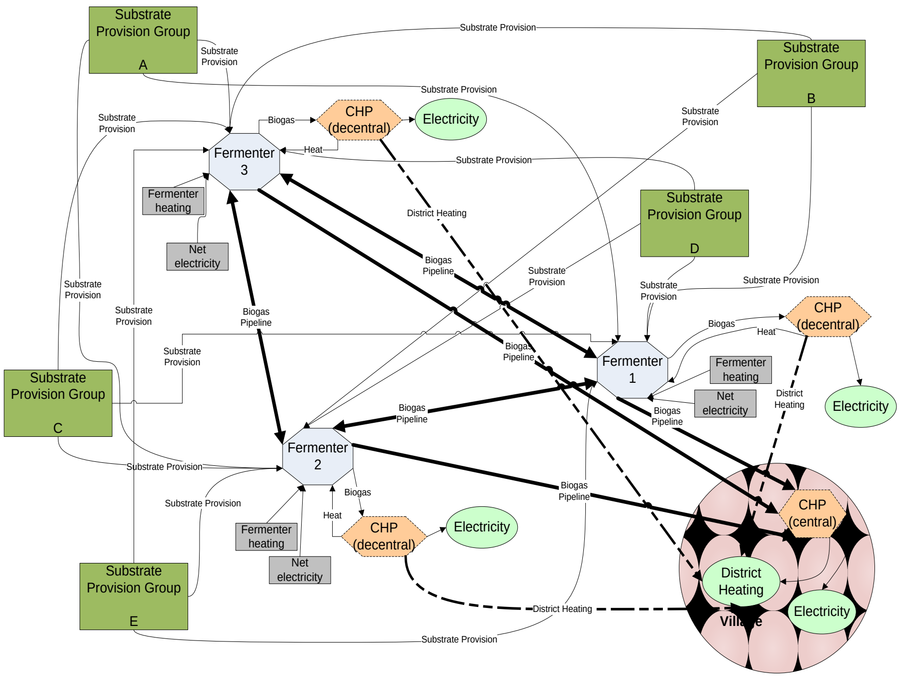

Figure 1: PNS - Maximum Structure

I. There are many small farmers in Bad Zell who can provide different substrates. These providers of main crops, intercrops and manure are grouped to simplify transport situations. Each provider group has a specific transport distance to each fermenter and they are able to supply every fermenter every possible substrates (corn, grass silage, intercrops and manure).

II. Three possible locations for a biogas fermenter are chosen. For every location also three different sizes are available (80 kW_{el}, 160 kW_{el} and 250 kW_{el}).
   - A biogas fermenter including a combined heat and power unit (CHP) could be possible. It can sell electricity to the grid, provide heat for the fermenter (for free) and additionally selling heat for the central district heating grid (DHG). To sell heat to DHG additional pipelines would be required which increases investment costs.
   - Another option for PNS would be to install a biogas fermenter excluding a CHP unit with the possibility to transport the biogas (through a biogas pipeline) to one of the others including a CHP unit or transporting it to the central CHP unit. In this case investment costs are lower for a fermenter but an additional heating for the fermenter is required (in this case a wood chip burner)

III. Because of high priced DHG-pipelines there is also the possibility to transport biogas to a centralized CHP unit (with a higher capacity) which produces electricity (for the grid) and heat (for DHG). An advantage of transporting the biogas is the low price for biogas pipelines.

All available scenarios are part of the maximum structure. PNS is used to get an optimized structure out of Figure 1 with the highest revenue. Transport situation (e.g. distances between provider groups) is taken into account through different transport prices for each route.
Out of the maximum structure PNS calculates several possibilities how to link these production options. Figure 2 illustrates which provider groups and how many substrates are taken for the optimal solution. Not every provider group is part of the final solution due to different transport distances. Only one fermenter (biggest size) excluding CHP chosen and biogas is transported through biogas pipelines to a centralised CHP. Because heat can be sold to villages DHG it increases the overall revenue although biogas pipelines are needed. Although main crops (corn) are used, intercrops are part of the optimal structure. Therefore it makes sense for farmers to plant intercrops on their fields.

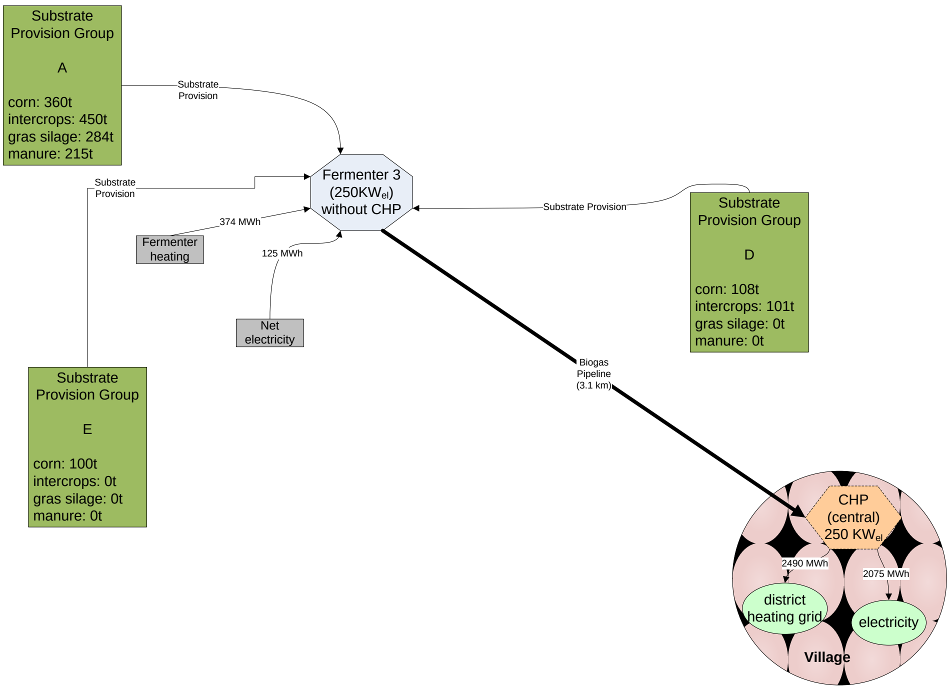

Figure 2: PNS - Optimum Structure

4.2 Ecological evaluation - SPI

Chapter 4.1 figured out how a biogas production can look like with the emphasis of highest revenue for the overall system. To rate the environmental effects of the optimal solution an ecological footprint was calculated. Due to lack of data environmental impact for biogas pipeline infrastructure is not taken into account.
Figure 3 illustrates the Process Chain for the production of electricity and heat from biogas feedstock.

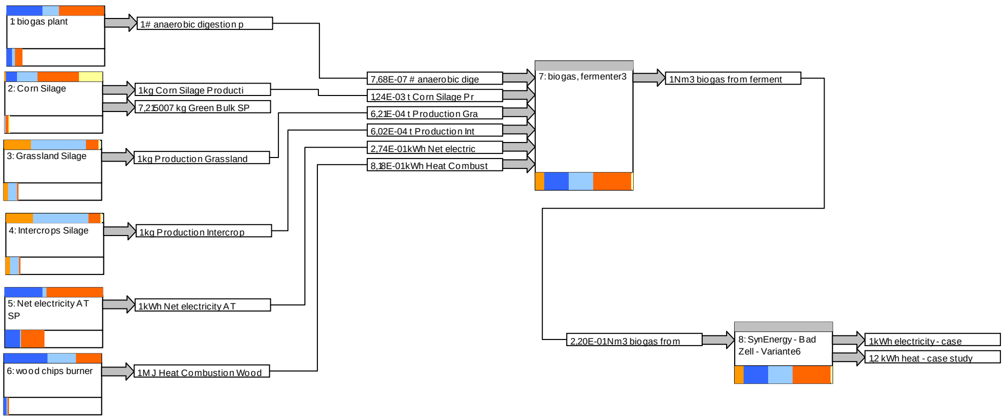

Figure 3: SPI – Process Chain

This results in a footprint of **14.35 m²a / kWh** per year. According to this result **40.7 g** of CO_2 is emitted to atmosphere per kWh of electricity or heat.

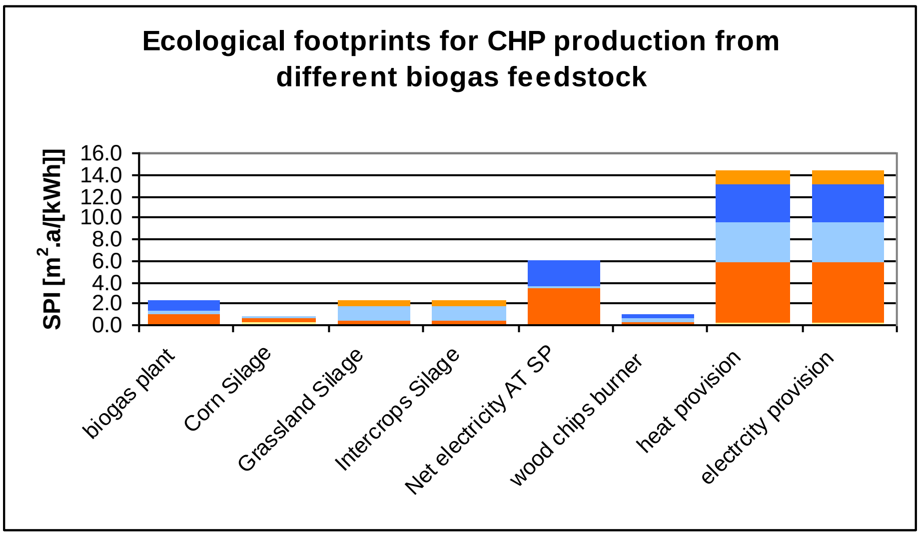

Figure 4: SPI – Process Chain Report

Figure 4 illustrates the specific footprints for different substrates, infrastructure, fermenter heating and net electricity. It is obvious that the usage of net electricity increases the footprint dramatically. From the economic point of view it makes more sense to sell electricity from biogas to the grid than using it internally.
Each footprint is shared into different SPI categories which are the different colours (orange = area for emissions to soil, dark blue = area for emissions to water, light blue = area for emissions to air, red = area for usage of fossil carbon and yellow = area for infrastructure).

5. Conclusions

Focus of the optimisation is not to identify a pathway through a huge set of different technologies which are producing heat or electricity. PNS was used in this case study to proof if the usage of intercrops is economic feasible. Main crops like corn are still used because of a high biogas yield but also intercrops are part of the optimal structure. Planting of intercrops requires a rethinking of farmers and needs subsidies for a wide introduction.
SPI evaluation gives a view on the ecological footprint and carbon dioxide emission through the whole process chain.

Outlook

Transport distances are a key factor for PNS optimisation. Because of this importance future work is to include transport based on time consumption and not distances. Loading and unloading to biogas plants are time intensive which results in higher costs than a kilometre of road transport. Manure transportation with flexible tubes will be part of future maximum structure for PNS.
Ecological footprint evaluation will be stressed until a more detailed PNS optimisation is available.

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Regional Optimizer (RegiOpt) – Sustainable energy technology network solutions for regions

K.H. Kettl[a], N. Niemetz[a], N. Sandor[a], M. Eder[a], I. Heckl[b], M. Narodoslawsky[a]

[a]*Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 21a, 8010 Graz, Austria*
[b]*Centre for Advanced Process Optimization (CAPO), University of Pannonia, Egyetem út. 10, 8200 Veszprém, Hungary*

Abstract

Developing energy strategies for the future is an important strategic task for regions and municipalities. Renewable based technologies and decentralized energy supply based on regional resources have the potential to locally and regionally increase added value, provide new jobs, decrease the dependency on limited fossil resources as well as on external energy providers and may have a positive impact on ecological stability.
Regional Optimizer (RegiOpt) software tool is based on the concept of Process Network Synthesis (PNS) (Friedler et. al, 1995 and Halasz et. al, 2005) and of the Sustainable Process Index (SPI) (Kotscheck et. al., 1996 and Sandholzer et. al., 2005). Both methodologies are combined in RegiOpt to enable the user to create economically optimal sustainable energy technology networks and at the same time evaluate them with respect to environmental sustainability.
Inputs to the software are (renewable) resources (e.g. amount of crops available for energetic use, biowaste, waste heat, etc.) and regional energy demand profiles. Both resource provision and energy demand can be provided in time dependent form. On top of that the user may supply contextual information like costs and prices of particular resources and services.
Result of the calculation with RegiOpt is the economically optimized technology network that fulfils the energy needs defined by the user and renders the highest regional added value. RegiOpt also provides the ecological footprint according to the SPI methodology. The user is able to calculate different scenarios based on different input data. RegiOpt software tool will be provided in two versions. Web based "Conceptual Planner" as a simple analysis for regional stakeholders and an "Advanced Designer" for a more detailed technology network scenario generation meant for expert use.

Keywords: Process Network Synthesis, PNS, Sustainable Process Index, SPI, Regions, energy production, electricity, heat, ecological footprint

1. Introduction

Local and regional stakeholders are increasingly interested in energy supply based on regionally available resources. Utilizing these resources increases the local or regional added value reduces economic dependencies and may also reduce ecological pressures,

in particular green house gas emissions. Local economic is supported and new jobs are provided.
Every region however differs in terms of their available resources as well as their energy demand and market opportunities. Therefore RegiOpt. should help local stakeholders and decision makers to generate feasible future scenarios for their region. The user of RegiOpt gets an optimal renewable resource based technology network in accordance with the economical context of the region that is evaluated with the ecological footprint. By varying key parameters (e.g. prices for crops or conventional energy sources, availability of renewable resources and prices for energy services and products) a user will be able to generate scenarios that render a comprehensive picture of feasible development pathways for the region in question.

2. RegiOpt – A software tool for regions

RegiOpt combines two well established methodologies for process network analysis and evaluation of ecological sustainability. Process Network Synthesis (PNS) [Z,Y] is used to generate optimized technology networks using of a predefined set of available technologies provided within the software. In this set only technologies are considered that have proven their feasibility and that have been implemented at least on pilot scale. The PNS routine will select suitable technologies for any given region depending on availability of resources and the structure of the energy demand. Economic optimization will then render the most optimal technology network that links available resources with regional demand (possibly including necessary imports and indicating surplus production). The user may define restrictions for the scenarios (e.g. demand that have to be strictly met, upper limits for market capacity to absorb certain products, etc.) as well as time profiles for demand and resource provision (at least when applying the "Advanced Designer").
This optimized technology network is evaluated in terms of environmental pressures with the Sustainable Process Index (SPI) [X,W] method. The final result provides a potential economic output (annual profit) and an ecological footprint for any given scenario.

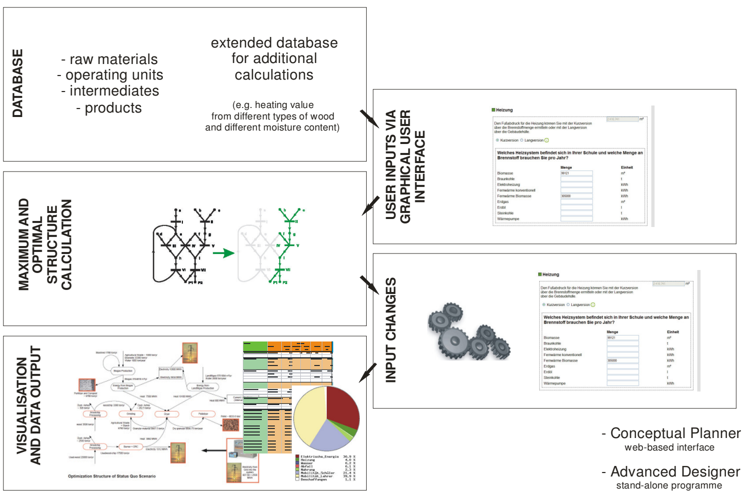

Figure 1: RegiOpt Macrostructure

The result is based on a predefined renewable energy technology list which is stored in a background database and will be up-dated in terms of performance and costs of technologies in regular intervals. Combined with contextual inputs given by the user following an input protocol the calculation is performed according to the architecture depicted in Figure 1.
Two different versions of RegiOpt will be available: a web based "Conceptual Planner" (CP) and a stand-alone program called "Advanced Designer" (AD). Both are using the same database but differ in graphical user interface. Conceptual Planner is meant for regional stakeholders and decision makers and will provide them with the ability to generate an optimized technology network based on a simple input protocol requiring non-expert knowledge on a website. AD version is dedicated for expert use only and will require more specific and detailed information of the region and will provide encompassing information taking spatial resource distribution and temporal profiles for resource provision and demand into consideration. AD and CP however are based on the same RegiOpt - Solver.

2.1. Database

A major feature of RegiOpt is an encompassing database. It includes
- raw materials (renewable resources)
- intermediates (e.g. biogas)
- products (e.g. electricity)
- operating units (technologies)

and provides basic data for each item like yields for different renewable resources, composition of materials and current prices for resources, products and energy services as well as mass and energy balances for conversion technologies and basic economic data like operating costs and investment costs (in most cases for different scales of any given technology). This list is compiled from real world projects as well as from literature data and information from technology providers. This list represent a "maximum structure" with regard to process synthesis.
For CP the database (and hence the maximum structure) is fixed and cannot be modified. AD provides the user however with the possibility to add, deleted or modify existing datasets.

2.2. Conceptual Planner CP

The CP operates as a webpage and enables users to calculate an optimized technology network for their regions based on non-expert knowledge. The user follows an input protocol that shortens the list of technologies in the maximum structure based on regionally available resources and demands. The user is asked for available areas in different qualities (crop land, forests, grassland and possible areas for solar energy technologies).
Figure 2 illustrates how the amount of available resources is deduced from this input. Forest areas are interesting for energy wood that in turn is a possible input for different technologies (e.g. biomass burner, wood pellets production, biomass based combined heat and power (CHP) plants, etc.). The user has to define how much wood is already used (e.g. timber, wood products like furniture, energy wood for existing energy supply). Any excess biomass it will be used for as a resource for the generation of the

optimised technology network generated by RegiOpt. Crop land can be used for energy crops where RegiOpt adapts the set of possible crops to the climatic zone where the region is located. Acreage necessary for food and fodder production is subtracted and the rest can be used for energy crops with RegiOpt taking care of possible competition between different crop productions.
Grassland can be used to provide input for a number of technologies, e.g. biogas production. Again acreage used by ruminants will be subtracted and the rest can be used for providing raw material to the technology network.

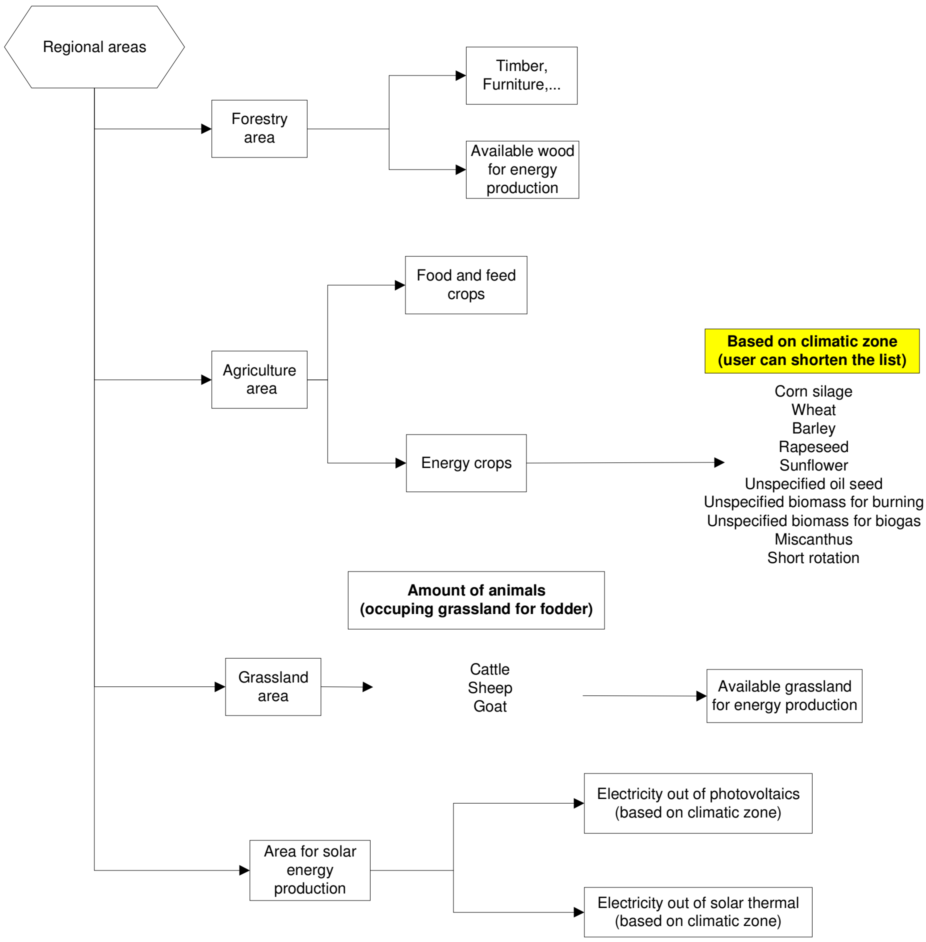

Figure 2: RegiOpt – CP; Area conversion methodology

The focus of the CP lies on providing a “quick and reliable” first analysis of the potential for a given region. It should be seen as a valuable starting point for a planning process, providing local and regional stakeholders with a solid base for discourse..

2.3. Advanced Designer AD

Detailed regional planning for future pathways towards sustainable energy systems will be supported by the AD. Although the basic database and the RegiOpt – Solver is the same for CP and AD, AD will provide expert user with a broad possibility to contextualize the data and to include time profiles as well as a first order spatial differentiation of demand and resource provision within a region. Results from the AD will therefore provide the user with additional information, in particular about the location, size and operational characteristics of the technologies involved in the regional sustainable energy system.

2.4. Results

RegiOpt-Solver (both for CP and AD) generates an optimal technology network for a sustainable energy system for any given region, using local and regional resources and fulfilling local and regional demand. The result for a given scenario based on the contextual data provided by the user will show the annual profit for the whole network as well as necessary investment costs and operating costs for the technologies involved. In addition an ecological footprint is calculated for the scenario, providing insight into possible ecological risks and highlighting benefits. Results can be stored for comparison with further scenarios, using different contextual frameworks.

2.5. Conclusion/Outlook

RegiOpt will be a powerful tool to support local and regional decision makers as well as energy experts in planning of sustainable local and regional energy systems. The web based CP part of RegiOpt will give non-expert local and regional stakeholders with a solid base for their initial discourse by providing them with a comprehensive first analysis of their chances for using local resources and meeting local demand. It also provides them with a versatile tool to develop a feasible vision for their energy future and with information about necessary co-operation between different sectors and stakeholders.
The AD part of the software will enable experts to build on the energy vision defined by non-expert stakeholders and optimize the technology network to accommodate time profiles for resource provision and demand as well as to decide about the best spatial distribution of the elements of the technology network.

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