Regional energy optimisation with RegiOpt Conceptual Planner on web

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Abstract: Key challenges in the shift from non-renewable to renewable energy systems are the economical use of renewable resources and the ecological sustainable pathway. RegiOpt Conceptual Planner is now freely accessible on the internet and can thus be used for online decision support concerning optimised technology systems in the regions, available at regiopt.tugraz.at/. After requesting specific regional data about existing energy supply, livestock, area availability, energy demand and basic economic, parameters, the programme calculates and assembles information for a sustainable development about regional energy use and resource planning. The aim of the planning tool is to provide insights of economic and ecological pressure exerted by further development of the specific region. The online tool is undergoing updating of structure and pre-defined default values. RegiOpt Conceptual Planner (RegiOpt CP) is based on two methods. Technology network systems and material- and energy flows are optimised using Process Network Synthesis (PNS) methodology. For the web based purpose of RegiOpt CP the PNS was adjusted to a web application (PNS solver web app). The ecological evaluation provides an ecological carbon footprint evaluated according to life cycle carbon analysis by the Sustainable Process Index (SPI) methodology. Based on the available energy supply and other parameters an optimum structure of a technological network is created for the region. Beside the suggested technology network, also capacities and flows of raw materials and products are shown along with economic parameters. The total revenue of the solution is calculated out of the cost of materials, investment / operating / transport costs and the revenue of products. The generated products and services are evaluated with SPI values to show their respective ecological pressure. The optimum structure is further discussed with respect to global and local energy use, value added and emissions compared to business as usual. The paper will provide a case study of regional energy optimisation in a first test run of RegiOpt CP.

Keywords: Renewable energy systems, economic and ecological optimisation, optimised technology networks, ecological footprint

1 Introduction

Shifting energy production from importing predominantly non-renewable resources to an increased share of regional renewable resources is a challenge. The detection of optimal technology networks in regions is an important step for integrated and sustainable development. This process must consider stakeholder interests and include effects forced by human activities on stability of ecosystems and resources ([6] Narodoslawsky et al., 2008).

Regional Optimiser (RegiOpt Conceptual Planner) can support politicians, other decision makers and stakeholders in gathering knowledge about the renewable resource use in the region. Finding consistent and sustainable pathways through the global trade system, resource supply, product placement and transport needs deep analysis with interdisciplinary interactions and its context.

RegiOpt Conceptual Planner is a regional planning and optimisation application freely accessible on web. It can be used by anybody who wants to get a first rough estimate of the resource and energy production situation for the specific region engaged. ([3] Kettl et al. 2011)

2 Methodology

Overall goal of RegiOpt is to use the resource potential of a region most economically and ecologically. Three methods, Process Network Synthesis, Sustainable Process Index and Carbon Footprint, are used in one single application designed to work on a regional level. The target group for the use of the application are especially regional development experts, planners, decision makers and persons in public administration. No specific background knowledge is necessary in carrying out the optimisation and evaluation.

An economic optimisation of technology networks ([11] Vance et al., 2013) and an ecological evaluation is carried out in background of the internet application. The application uses query tables to execute an online survey. Default values help filling in required information, supporting the user so that not all parameters must be known. In the end the result pages create a table describing the optimum structure and graphs describing the economic and ecological impact of the structure.

2.1 Method 1: Process Network Synthesis (PNS)

Process Network Synthesis (PNS) is usually carried out with the software tool PNS Studio working with a bipartite graph (P-graph) which has a directed graph method to set input and output flows in operating units ([10] Friedler et al., 2011). Combinatorial rules allow PNS to set energy and material flows in a maximum technology network to find most feasible technology structures within this maximum structure ([2] Friedler et al., 1995). For the purpose of finding optimal regional technology network a branch and bound algorithm executes the most feasible structure consisting of input flows of raw materials and energy used in technologies and output flows in the end of process chains show the most feasible products and services. Considered parameters are resource availability, material / energy cost, transport cost, harvesting periods, varying heat demand over the year, investment and operating cost for the technologies and capital available for investment.

The RegiOpt maximum structure is consisting of a technology network containing commonly used technologies and production chains of renewable resources and default values. From this maximum structure the user can choose technologies in use and adapt the default values. Available resources and technologies are linked with demands computing the optimal solution structure containing the most economic network.

2.2 Method 2: Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) was made as a tool to evaluate environmental impacts of processes ([8] Narodoslawsky and Krotscheck, 1996). It is part of the ecological footprint family and works according to the criteria guidelines set in the international life cycle impact assessment ([4] ISO LCIA, 2006; [5] JRC, 2012). The result of SPI is the area needed to embed human processes into the ecosphere.

2.3 Method 3: Carbon Footprint

The evaluated share of the Carbon Footprint was taken out of the full Life Cycle and Impact Assessment (LCIA) carried out by Sustainable Process Index (SPI).

2.4 Assembled use of both methods

The joint use of the methods in the RegiOpt Conceptual Planner web solution is well-described in [7] Niemetz et al., 2012 and shown in Figure 1. The application contains default values but it is possible to change most of the input data for specific regional data. Available agricultural and forest area, resources for energy production, existing energy supply and the demand situation must be entered by the user. In accordance to the input data an optimum structure is generated according to the PNS optimisation structure and these processes undergo a SPI evaluation.

Results show a table listing data describing the PNS optimum solution. This results contain the technology network, total revenue, amounts and cost for materials, products and selected technologies. Second part of the results are values for the ecological evaluation in SPI and carbon footprint for the technology system and products. A comparison of the generated scenario with business as usual shows how much energy is provided locally and how much is provided globally and differences in the feasibility of the network. The SPI-footprint shows total life cycle emissions as well as the share of CO_2 emissions, emissions to soil, air, water and impacts to renewables, non-renewables, fossil resources and land use.

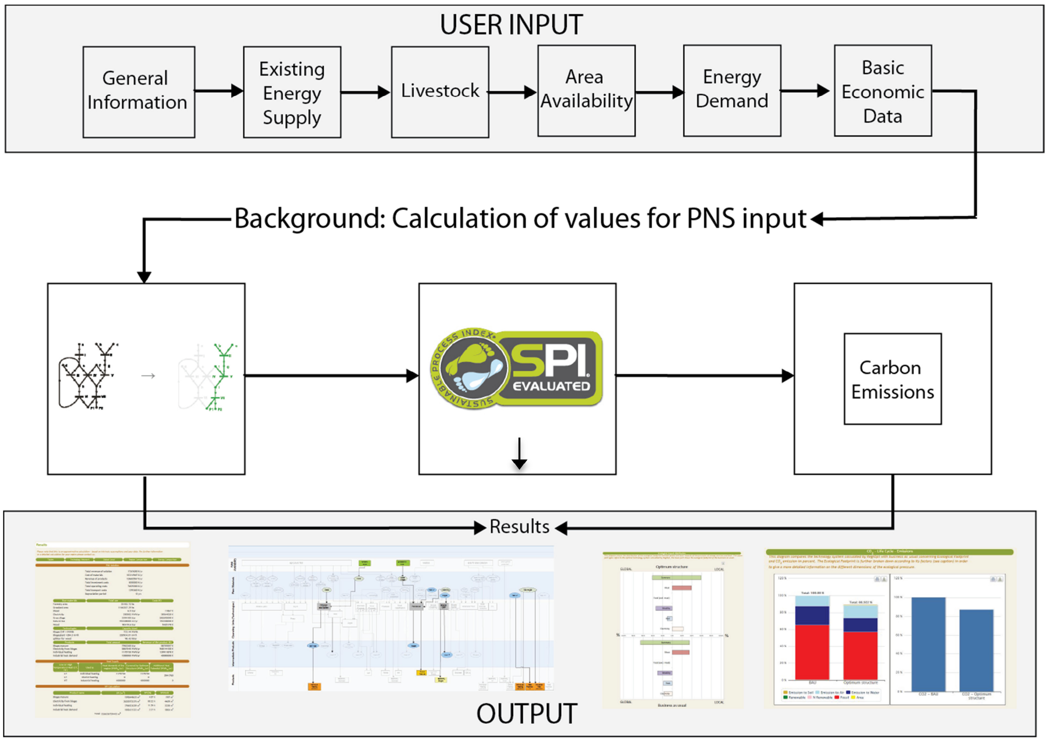


Figure 1: User interface with query tables

3 Application and case study

RegiOpt was developed to run as an online tool and is now ready to use. After explaining the basic functions of the online optimising tool will be further described belonging output and application of RegiOpt by testing it with data of a case study.

3.1 Function of the RegiOpt software tool

Figure 2 shows the main screen of RegiOpt Conceptual Planner online and the user interface with some examples of the query tables. The software starts with the query sheet General Information where basic information about the region and its consumer behaviour is prompted. All data values are calculated on a yearly basis and so has all entered data. The next category is Existing Energy Supply. The installation power of already existing technologies in the region which use renewable resources can be entered here. State-of-the-art technologies such as biomass burners, wood gasification plants, biogas plants, biogas cleaning, organic rankine cycle, bioethanol plants, solar technologies, wind power and hydro power can be selected. The sheet Livestock requests livestock units in the region. Area needed to provide fodder for breeding and the amount of energy which can be obtained out of animal manure. This sheet discusses the Area Availability defining the forest, grassland and fields and the fraction of available biomass for energy. Here biomass already in use for energy systems or other purposes is substracted. Energy Demand allows the user defining energy demand of buildings and industry in the region. The standard of buildings can be set as well as for the heat provision, separately for district heat and industrial heat demand. The last sheet is where Basic Economic Data can be entered, like material and transport cost regarding to the distances carried. Product prices for selling regionally produced renewable energy.

Figure 2: RegiOpt startpage and user interface with query tables

3.1.1 Case study

For the case study the region Christchurch was chosen. Situated at the coastline of the southern part of New Zealand in the Region Canterbury the urban area has around 380,000 inhabitants. This region suffered earthquakes between 2010 and 2012. Besides injured people the region faced a huge damage to urban structure. After the catastrophe the debate arose how the damaged parts of the damaged or razed building structures could be rebuild. After the catastrophe the region founded a special authority, the Canterbury Earthquake Recovery Authority ([1] CERA, 2014). CERA set an ambitious strategy with the goal to rebuild the city on an integrated pathway which they call Leadership & Integration containing the following components of recovery: economic, built, natural, cultural, social and in the overlapping heart the community. The state and the citizens now have the possibility to consider adaptations in the rebuilding of highly damaged city quarters. Especially fully exposed brown fields on some spots of the city offer high potential to include smarter ways of rebuilding and thinking about smart energy systems within the reconstruction concept. The government of New Zealand estimates recovery cost about 13 Billion Euros, 2 Billion Euros for infrastructure recovery ([9] Love, 2013). To get a first impression how an investment into a renewable based energy system for Christchurch could affect the region a budget of a maximum 80 Million Euros was taken as a maximum investment volume. After data input requested in all sheets the query was executed.

Out of the pre-defined maximum structure RegiOpt optimises an optimum structure. Results show all technologies chosen in the optimum structure, processes which are not in use by the optimiser are shown greyed out (Figure 3). The technologies are splitter producing split logs for individual heating demand, fermentation producing biogas and burning it in a Biogas CHP producing electricity and low temperature heat. To cover the remaining demand natural gas is supplied.

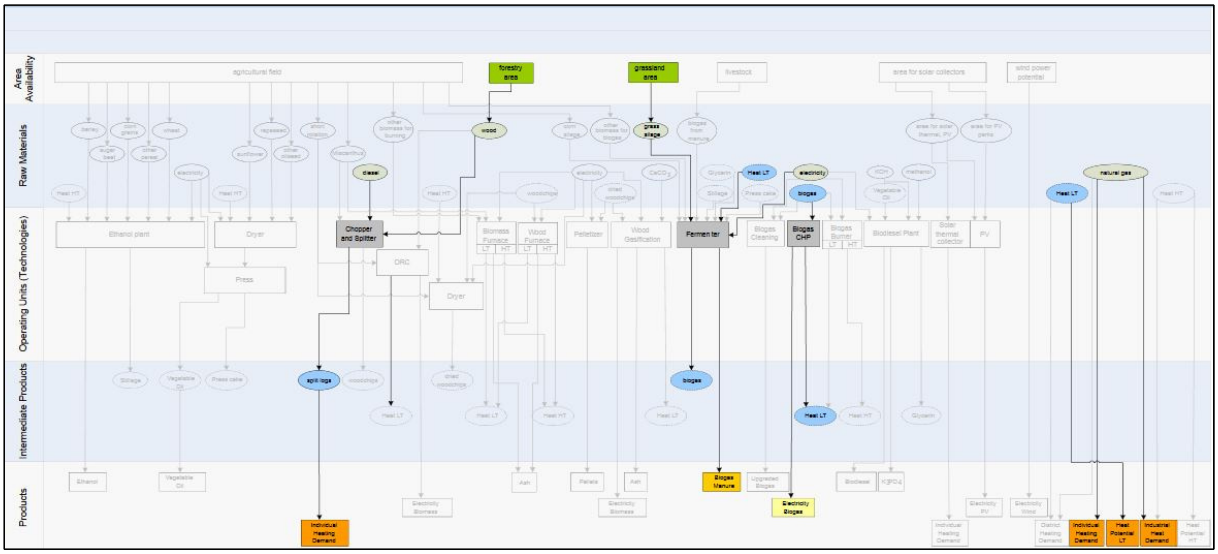


Figure 3: Results – Optimum technology network

Figure 4 shows the results. The revenue of over € 170 Million per year is the result of a very rough calculation with a depreciation period of 10 years. Only 4 % of the total land use are forests and 6.6 % are agricultural fields, so 89.4 % is grassland and the main biomass could be used over an area of 2.6 Million ha.

In the optimum structure 30 % of available forestry area and 45 % of available grassland are used and no crops from agricultural fields are used. 90,000 t wood, 3.4 Million t grass fermented to biogas. The biogas is burnt in a Combined Heat and Power plant and produces 5.8 Million MWh electricity, 1.17 Million MWh for individual heating and 1 Million to cover industrial heating demand. Approximately 8 Million t biogas manure can be used as fertiliser if appropriate agricultural fields are available.

Results

Please note that this is an approximative calculation - based on intrinsic assumptions and your data. For further information or a detailed calculation for your region please contact us.

Tables | Technology Network | Global-Local | Region Comparison | Energy Comparison

PNS Solution

Total revenue of solution	173676080 €/yr
Cost of materials	1033149487 €/yr
Revenue of products	1206825567 €/yr
Total investment costs	80000000 €/yr
Total operating costs	748292000 €/yr
Total transport costs	12953600 €/yr
Depreciation period	10 yrs

Raw materials	Total use	Costs (€)
Forestry area	35182.72 ha	
Grassland area	1166357.39 ha	
Diesel	6.5 t/yr	11867 €
Electricity	350582 MWh/yr	38564020 €
Grass silage	3394100 t/yr	282695000 €
Natural Gas	153328000 m³/yr	153328000 €
Wood	90419.6 t/yr	5425170 €

Technologies	Capacity (size)
Biogas CHP >1MWth	733.44 MWth
Biogasplant >284.3 m³/h	220934.81 m³/h
splitter for wood	90.42 kt/yr

Products	Total amount	Revenue of the product (€)
Biogas manure	7963360 t/yr	58769597 €
Electricity from biogas	5867540 MWh/yr	968144100 €
Individual heating	1175730 MWh/yr	139911870 €
Industrial heat demand	1000000 MWh/yr	40000000 €

Heat Supply

Low or High Temperature Heat (LT, HT)	Used as	Heat demands of the region (MWh_{th}/yr)	Covered by Optimum Structure (MWh_{th}/yr)	Additional Heat Potential (MWh_{th}/yr)
LT	Individual heating	1175730	1175730	2941760
LT	District heating	0	0	
HT	Industrial heating	1000000	1000000	0

SPI Calculation

Product name	SPI [m^2]	SPI [%]	SPI/Unit
Biogas manure	15906448635 m^2	4.87 %	1997 m^2
Electricity from biogas	262035733376 m^2	80.22 %	44659 m^2
Individual heating	37868236209 m^2	11.59 %	32208 m^2
Industrial heat demand	10826311223 m^2	3.31 %	10826 m^2

Total: 326636729443 m^2

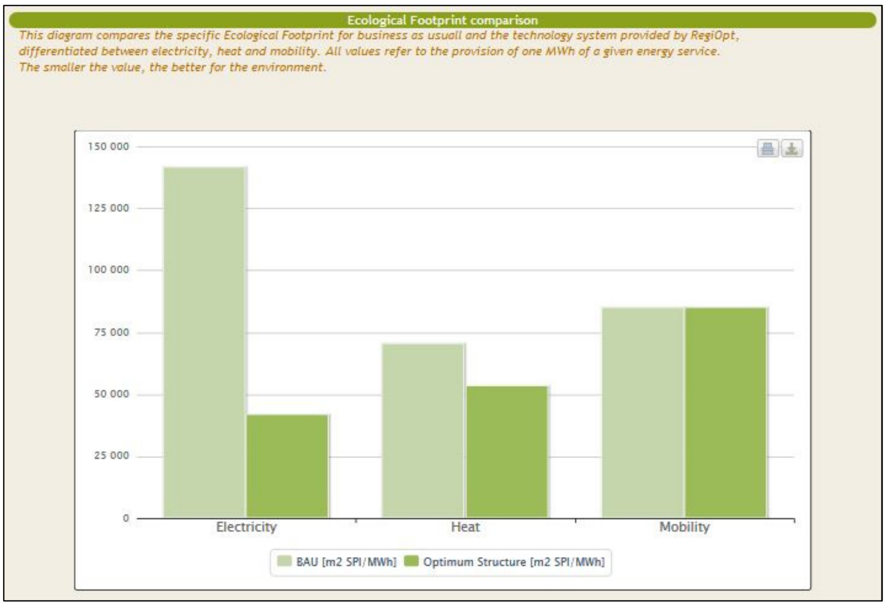
Figure 4: Results – optimum structure table

An increased use of regional biomass for energy shifts the ecological pressure from a global ecological impact to a local ecological impact (

Figure 5). Mobility slightly increases globally due to an increased harvesting where fossil fuels are typically used. The higher local footprint of meat production is due to the meat consume which is above average in New Zealand.

Figure 5: Results of optimum structure – comparing global/local

The footprint of electricity is reduced to less of a third because now much more is produced locally. The footprint of heat is reduced by one quarter. Mobility slightly increases because average fuel consumption is higher in New Zealand. The ecological footprint (SPI) is 11 % lower than average and the carbon footprint is 13 % lower than average.



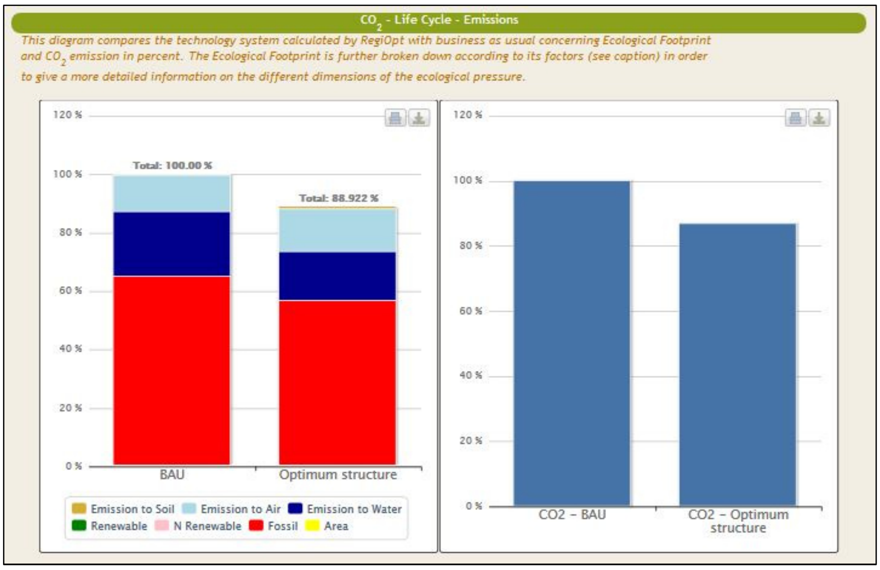


Figure 6: Results of optimum structure – ecological footprint and CO_2 life cycle emissions

4 Conclusion

RegiOpt Conceptual Planner offers general possibilities dealing with limited regional conditions. Concerning the extent of a regional technology structure and energy network resources can be a limiting factor as well as the maximum investment volume. During the development of RegiOpt the segments of the online tool have been undergoing running projects located in Austria. Default values are therefore very regional but suggestions for variations of global regions were already implemented. This concerns the query tables “differences in meat demand”, “electricity demand” and “average living space”. The case study was a suitable example of a first testing of RegiOpt for a region outside Austria. Using half of the biomass resources Christchurch can decrease its footprint and carbon emissions. An increased investment volume could further increase the amount of regional biomass use and cover more energy demand reducing the use of fossil fuels. From the financial side additional revenue for the region can be created and that can have a positive impact on the economic situation of Canterbury. After the huge amount of money that is needed after the catastrophe that can help to find regional solutions to shape an economic and ecological sustainable future for the region.

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