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Integration of energy supply and energy demand response curves in the Process and Network Synthesis

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Abstract

The ongoing climate change, the depletion of resources and the visible environmental changes led in the last decades to a revolution in our thinking about resources.
Several technologies have been and continue to be developed in order to avoid depletion of fossil fuels by shifting the use from non-renewable to renewable resources.
One of the most important related fields of study is the energy sector: the need to pass from a fossil-fuels based energy production to the so called Green Energy has brought many opportunities of development and growth but also raised many issues to solve.
On a local scale, the main issues of this ongoing process are to meet the needs of the consumer by an optimized use of the local available resources and the economical sustainability of Green Energy production.
In the RegiOpt software the principles of Process Network Synthesis (PNS) are used to advice the stakeholders in the planning of a profitable and sustainable regional energy supply network. The software compares the possible energy supply technologies and gives as output one or more optimal sets of technologies that optimize the use of resources with regard to the economical potential and the sustainability of the single processes.
While the economical and the environmental aspects are considered in the RegiOpt, the further development of the software requires the consideration of time-dependency of energy supply and energy demand on annual basis.
Actually the time variable enters the software only as parameter in the background of yearly costs, gains and required amounts of materials and products: the program allows the assignment of a unique value to the time parameter and the variables are always represented by mean values.
As a consequence seasonal, weekly and daily oscillations are not considered at all.
The capacity of covering oscillating energy demand over time is a central issue of energy production industry: the current study focuses on the insertion in RegiOpt of time-dependency of supply and demand.
Yearly response curves of strong time-dependent supply technologies have been found and have been combined with the yearly demand response curves, in order to evaluate the gap between the existing green energy system and the regional demand.
The resulting curve has then been divided into a reasonable number of intervals representing periods of higher and lower difference between production and consumption.
Once a finite number of periods is identified, the yearly mean amounts of the variables can be substituted with the required amounts of every period introducing time-flexibility in the former stiff software.
As a result RegiOpt can be run multi-periodically achieving a higher stability of the output concerning temporal variations in energy demand.
In this way the energy security of the output is visibly improved.

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Acronyms

ARPA	Italian Regional Environmental Protection Agency
APE	Attestato di Prestazione Energetica (see EPC)
BaU	Business as Usual
BLMFUW	Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management
BMWFJ	Austrian Federal Ministry of Economy, Family and Youth
BMWFW	Austrian Federal Ministry of Science, Research and Economy
BMFJ	Austrian Federal Ministry of Family and Youth
CHP	Combined Heat and Power
DH	District Heating
EPC	Energy Performance Certificate
GHG(s)	GreenHouse Gas(es)
GME	Italian Energy Markets Authority
IEA	International Energy Agency
ISTAT	Italian Statistical Institute
PNS	Process Network Synthesis
PV	Photovoltaic
RSS	Residual Sum of Squares
SIC	Schwarz's Information Criterion
SPI	Sustainable Process Index
FVG	Friuli-Venezia Giulia
OSMER	Regional Meteorological Observatory of Friuli-Venezia Giulia)
MINLP	Multiple Integer Non-Linear Programming
ZAMG	Austrian Central Institute of Meteorology and Geodynamics

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1.Introduction

1.1 Energy issue

Since the oil crisis in 1973 the availability of fossil fuels and the future of energy supply has been one of the most discussed topics in the policy development and in the scientific community.
In addition, the ongoing climate change and the development of policies for the reduction of greenhouse gases (GHGs) put the focus on the development of a reliable and sustainable energy supply system.
In 2008 the European Union set the "20-20-20" targets:

- greenhouse gas emissions 20% lower than 1990
- 20% of energy from renewables
- 20% increase in energy efficiency[98]

Those targets are aimed to mitigate the effects of climate change and achieve energy sustainability.

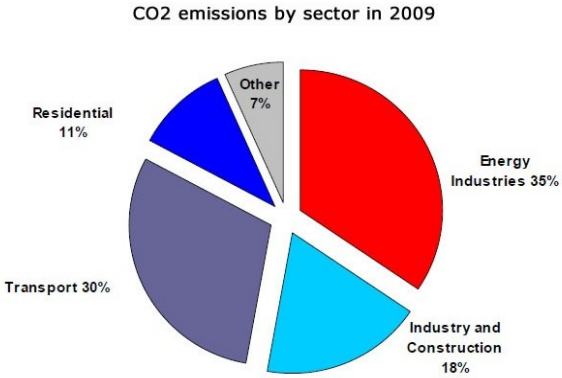


Figure 1: CO2 emissions by sector in the European Union in 2009 (Source:European commission 20-20-20 strategy [33])

The energy sector is one of the most important for GHGs emissions: in Europe 35% of the CO_2 emissions come from the energy industry[33].
As a consequence the 20-20-20 strategy is strictly related to how the energy flows are managed, how efficient the energy system is and how much renewables are used.

1.2 Austrian context

In 2009 the Austrian Federal Ministries of Economy, Family and Youth (BMWFJ)[1] and of Agriculture, Forestry, Environment and Water Management (BLMFUW) published the programmatic document: "*Energie Strategie Österreich*"("*Energy Strategy Austria*"[12]).
This document outlines the targets and the framework in which the Austrian policy makers and stakeholders have to develop common strategies in order to get to a sustainable and secure energy system.
In this document the European guidelines of the 20-20-20 strategy and the concept of energy autarky flow together: the main idea is to increase self-sufficiency and efficiency in energy demand and supply while improving the economical competitiveness of the Austrian industry and technologies.
The energy autarky is an important target for the security of energy supply and the Austrian economical competitiveness.
Furthermore the geographical position of Austria gives many opportunities of development in the European energy market.
The three main points in the Austrian energy strategy are the improvement of energy efficiency, the further development of renewables and the long-term reliability of energy supply.

[1] BMWFJ now is divided in the Federal Ministry for Science, Research and Economy (BMWFW) and Federal Ministry of Family and Youth (BMFJ)

To achieve these goals the Austrian Ministries state the necessity of an improvement of the energy supply systems on a local base and identify the local policy makers, stakeholders and society as main actors of the development process.
In conjunction to technological improvements, to achieve energy efficiency the Ministries propose to improve district heating in urban regions, to develop the use of industrial waste heat in local energy networks and to implement the use of biomass in rural regions.
These key-points lead to the necessity to integrate the energy and regional planning in a new way: the decision process about the territorial and urban development has to take into account the local energy supply system and to improve it.
The construction and improvement of district heating necessarily depends on the structure of the residential area and is profitable only in urban regions.
The use of renewables raises many issues on local availability of resources, on competitiveness of the developed technologies and on the development of a short production and distribution line.
Furthermore the long-term success of any developed strategy depends on the consensus of all actors, so much effort is made to reach society and stakeholders and to include them in the decision process.

1.3 Available Planning Tools

In order to support the energy transition process and the land-use planning, many tools have been developed.
To help stakeholders, in January 2013 the BLMFUW published a guide of the available planning tools: "*Tools für Energieraumplanung*" ("*Tools for [combined] Energy and Land-use planning*" [46]).
The study considered 20 tools free of charge and compared them.
The focus was on tools that were available for free because they are more suitable to be used by all the actors, while tools that have to be paid for could be not-affordable by all the interested parties.
Most of the studied tools deal with energy planning on small spatial scales: many tools simulate the energy output of solar and photovoltaic (PV) panels[2], the yearly energy demand of a household or the energy demand of a neighbourhood[3] but very few assess an energy system on a regional scale.
The two most important tools that operate on a regional scale are HOMER and RegiOpt ([88] and [56]).
HOMER has been developed by the National Renewable Energy Lab, a division of the U.S. Department of Energy and is currently the leading microgrid modelling software.
It focuses on the electric energy production and simulates the functioning of an integrated system over a year with resolution up to a minute.
It is capable to optimize the system and allows sensitivity analysis.
Under the point of view of electric grid and thermal load it is a complete suite with good simulation capability and high time-resolution.
Actually HOMER is no more a free-ware and has to be purchased from the website http://homerenergy.com/.
Under the point of view of use of resources the HOMER suite makes only considerations by economical means: there is no evaluation of the competition between resources and their availability is considered only under the point of view of costs.
Contrary, the RegiOpt tool focuses on the regional use of resources and the competition between technologies in their use.

[2] for example see PVGIS [36]
[3] for example : Energy Building Certificates,ELAS, Heat or Electricity Demand profile generator

The aim of the RegiOpt project is to give to stakeholders the knowledge-base for regional energy system planning and implementation.
While HOMER does not even touch issues like availability of resources and use of local potentials, RegiOpt evaluates the regional potential and the intensity of use of resources.
Furthermore RegiOpt also enhances the use of local renewable reserves by evaluating the transport costs, pushing towards a short production and delivery chain.
In conclusion, while both allow the analysis and planning of an energy network on regional and local scale, RegiOpt has a deeper impact on sustainability because it evaluates the local potentials, the length of the production and delivery chain and is capable to reach all stakeholders.

Table 1: Comparison between HOMER and RegiOpt

	RegiOpt	**HOMER**
Spatial scale:	Local, regional	Local, regional
Type of energy considered:	Electricity, Heat (all types)	Electricity, CHP
Electric supply technologies:	PV, Biomass (all types), CHP	PV, Biomass (all types), CHP, Fossil fuels
Heat supply technologies:	Solar, Biomass (all types), CHP	Solar, Biomass (all types), CHP, fossil fuels
Consideration of the existing network:	yes	yes
Economic optimization:	yes	yes
Optimization of renewable resources:	yes	no
Environmental sustainability:	yes	no
Social sustainability:	yes	no
Economic sustainability	yes	yes
Free-ware	yes	no

1.4 RegiOpt: overview

RegiOpt Conceptual Planner is a regional planning and optimisation tool freely accessible on web[56].
It can be used by anybody who wants to get a first estimate of the resource and energy production situation for a specific region.
The aim of the tool is to help stakeholders in the evaluation and planning of regional energy systems in order to cover the regional energy demand.
Both electric and thermal energy are considered.
The first step is the evaluation of the state of the art: the user is asked to give as input the regional data about population, available local resources and yearly electric and thermal energy demand.
By taking care of the actual land-use and the regional needs for food and farming, the RegiOpt software optimizes the actual network implementing it with proposed technologies.
The first output is a list that describes the optimal combination of energy supply technologies for that specific region, in addition carbon footprint and sustainability evaluations are shown.
The software returns also the estimation of yearly operational hours of every supply technology.
The scheme of RegiOpt is shown in Figure 2.
Initially the user is asked to input regional data for the assessment of local available resources and energy needs, then the optimization module (PNS, see section 3.1) evaluates available resources and existing green energy supply network as input and generates a list showing the proposed optimal network for the given region.
The optimal technologies network is the first output and is described through a table.
To assess the ecological impacts of the proposed solution, carbon footprint and sustainability index methods are used.
After RegiOpt processing the user has a complete overview of the actual system and of the proposed network with an assessment of sustainability under ecological and economic point of view.

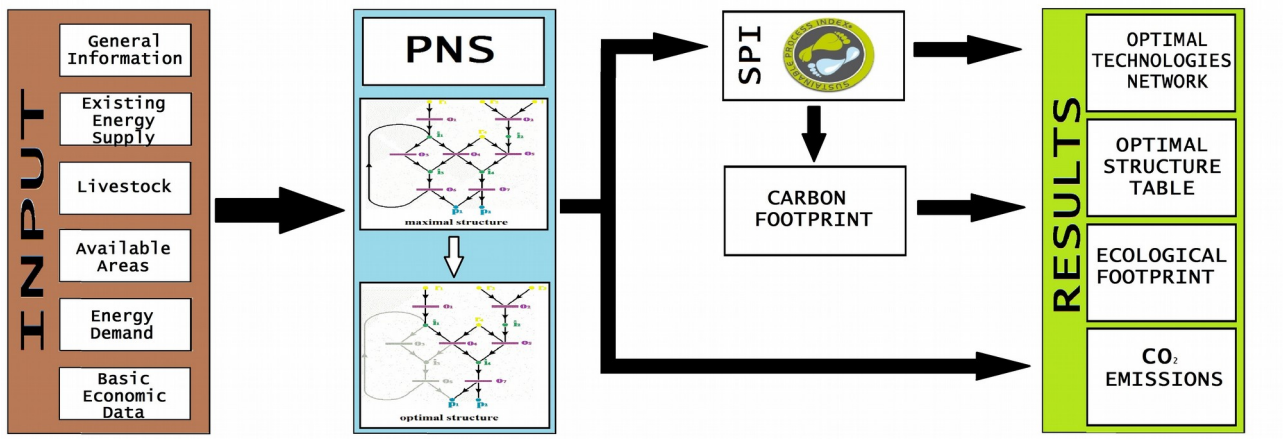


Figure 2: RegiOpt: general structure scheme

1.5 Optimization: main features of PNS

The PNS is the optimization module of RegiOpt.
The optimization problem was defined by Friedler et al. in "*Process Network Synthesis: Problem Definition" [42]* and is described in section 3.1.
To understand the current work and important choices on the evaluation of time dependencies, an overall comprehension of the functioning of PNS with the outline of critical points regarding the application on the Green Energy supply technologies is strictly necessary.
The PNS is a MINLP problem defined over a p-graph.
A p-graph is a graphic representation of a processes network.
In a p-graph an industrial network of processes is represented by:

1. raw materials
2. intermediate products
3. products
4. operating units
5. material flows

The operating units take as input the raw and/or intermediate materials and have as outputs products and/or intermediate materials.

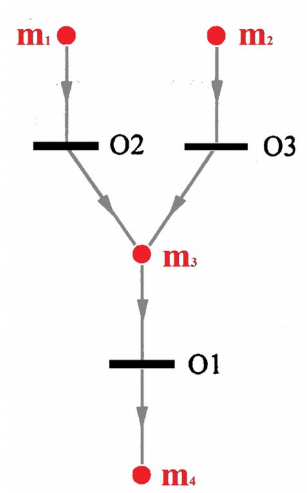


Figure 3: P-graph of a system of 3 operating units (o_1,o_2 , o_3) with 2 raw materials (m_1, m_2) an intermediate (m_3) and a product (m_4)

The relations between input and output are usually non-linear laws, but often linear approximation is applied.
Figure 3 shows a p-graph of 3 operating units (O_1,O_2,O_3) with 2 input materials (m_1, m_2), one intermediate (m_2) and one final product.
Once the possible operating units, the available raw materials and the required amounts of products are known, a maximum structure of the optimization problem can be designed: this maximum structure is the p-graph of all raw materials and all required products with all possible operating units interconnected by the material flows.
This structure has then to be optimized: the network has to deliver the required amounts of products with maximal economic gain.
This means that the optimization is done with respect to economical gain.
Theoretically the optimization can be done regarding mass or sustainability indexes but the authors of RegiOpt state that the economical means are the most suitable ones[112].
Furthermore, the association of an economic value to all materials as costs/gains leads to an implicit optimization of amounts of required resources.
Thus the PNS problem, in the RegiOpt application, considers the use of renewable resources in different competing processes and chooses the network with higher economical efficiency.
The optimization problem is well defined but the application to Green Energy supply technologies shows weaknesses.
The optimization module was developed at the University of Pannonia, Hungary and is available as software PNS Studio[20].
The PNS Studio is based on the PNS Problem definition but is programmed with algorithms that are suitable only for steady-state analysis: this means that instead of taking real material flows as input and generating output flows it takes only mean values assuming that they are representative for the industrial process.

While the steady-state assumption is proper for most industrial processes, for energy supply networks it is weak: the interaction between supply and demand is strong and influences the economical feasibility of energy networks and affects the flows of materials and products.
Furthermore, the impossibility of reacting promptly to changes in energy demand affects the economical and social acceptance of some energy supply technologies
Beside the economical feasibility, the central point in planning Green energy networks is energy security.
According to the IEA, energy security is "*the uninterrupted availability of energy sources at an affordable price*"[67].
The concept of energy security has implications in two main temporal domains: in the long term energy security is reached only by avoiding resource depletion, while in the short term the prompt coverage of energy demand oscillations is the central issue.
The uninterrupted coverage of energy demand is required as lacks of energy have deep social and economic impacts: every man has experienced the price spikes during shortage of fuels or the diseases of a black-out.

1.6 Problem definition

In the last section we saw that energy security is a central issue in energy supply and that a good planning aims to uninterrupted coverage of energy demand.
Issues related to uninterrupted coverage of energy demand affect the socio-economic acceptance of Green Power technologies: it is a big challenge to develop systems and technologies that work with non-continuous and non-controllable inputs (i.e. sunlight, wind,...) and obtain the desired amounts of energy output at the right moment.
To conciliate energy production from non-continuous/non-controllable sources and energy demand in every moment there is the need to develop storage technologies, to modify the demand patterns and to properly plan the energy networks.
The current main issues in Green Energy supply planning is the coverage of energy demand with discontinuous energy sources and the complementarity of Green Energy technologies: the graph shown in Figure 4 shows an example of compensation between solar and wind energy in Germany.
While solar energy output is maximal in summer, the wind energy production is maximal in winter and the two technologies show a certain degree of complementarity.

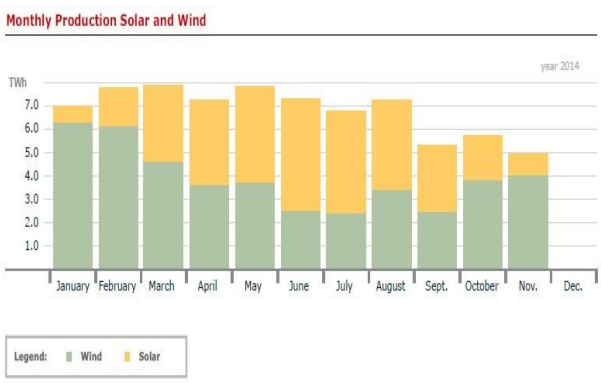


Figure 4: Solar and Wind electricity production in Germany in 2014 (monthly sums, From: Fraunhofer Institut[8])

This approach, shown for solar and wind power, has to be applied to all Green Energy supply technologies: many authors[4] state the possibility to compensate strong time-dependent technologies with manageable ones.
In general there is compensation potential of wind-power, solar and on-flow hydro-power by the use of biomass based technologies.
This approach has to be integrated in the Regi-Opt software: as first the relevant time dependent technologies of the existing network have to be characterized, then the implementation of the network can be done.

[4]an example is Kaltschmitt [84]

The main problem to deal with in Green Energy network planning is the availability of resources, but while for some technologies this means to deal with resources available virtually in aeternum but accessible only at certain times (sun, wind, water), for other technologies the problem is competition for limited amounts of resources (biomass).
So depending on the technology type the main focus has to be put on an optimization in the used amounts of resources or on the accessibility: the PNS successfully optimizes the use of available resources with the assignment of an economic value to materials, but fails in dealing with technologies that are non-controllable and oscillate with time.
As a consequence it is necessary to implement RegiOpt introducing the time variability of demand and supply in the evaluation software.
As told before, the optimization puts the focus on resource depletion and assigns to every resource an economic value, so those Green Power supply technologies which use costless and virtually in aeternum available resources like sunlight, water-flows and wind, are considered but enter in the competition process only with construction and operating costs.
Furthermore the input of the optimization module are yearly means of required materials, yearly operating costs, construction and amortization charges, thus actually there is no relation at all to seasonal and infra-seasonal oscillations in production and demand.
As a consequence the PNS is a bit out of scope when considering operating units for which time-dependent inputs and outputs affect the economical feasibility.
It is also worse when considering that the main issues on feasibility and the related social acceptance of solar and wind-power plants are the availability of the resources (wind, radiation) which affect the energy output and the economical gains.
The developers themselves point out the need to consider time-dependencies in *Regional energy optimisation with RegiOpt Conceptual Planner on web[113].*

1.7 Research Questions

The aim of this work is to answer on this big central issue about Green Energy systems:

<u>Is it possible to integrate energy security issues of time dependency and resource depletion in energy network planning?</u>

In order to answer this question, starting from an implementation of the optimization process in RegiOpt, we have to answer to following issues:

1. How does electricity and heat demand vary over time?
2. Which technologies are able to respond promptly to demand variations and how?
3. Which technologies strongly depend on outer non-controllable factors?
4. How do these technologies behave?
5. How could these behaviours be integrated in RegiOpt and at which point?
6. Is it possible to insert some degree of time-dependency without complete reprogramming the optimization software?

Thus, the aim of this work is to understand and introduce time-variability of energy supply technologies and energy demand in the RegiOpt software.
The study has to be developed considering that the aim of RegiOpt is to be a preliminary assessment software and doesn't want to substitute technical studies on feasibility and detailed dimensioning of energy plants.
In addition, RegiOpt has the aim to spread knowledge of local potentials and involve all interested parties in the decision process, thus a central point is that the software has to remain freely accessible, easy to handle and costless.
The third boundary condition is that the implementation has to maintain low computational times, thus a compromise has to be made between optimal time-dependency evaluation in PNS (which means development of new optimization algorithms and complete reprogramming of the optimization module) and a fair representation of time-dependencies in the scope of preliminary assessments.
The objectives of this work are outlined in table 2.
The insertion of time-dependencies should allow a flexibilization of the assessment remaining in the scope of a preliminary study.
The main goal achieved in this work is the integration of the two main issues in Green Energy network planning in a unique tool:

1. Time dependency of some technologies: using discontinuous sources to generate energy and successfully cover energy demand
2. Resource management

There are many tools that deal with the covering of demand integrating supply technologies with different time dependencies (Resys-tool, [4]), other tools assess resource depletion (PNS) or resource use intensity, but there is not an integrated approach of these two main issues in one-only tool.
The actual approaches can be divided into two main categories: time dependency focused and resource depletion focused.
The time dependency focused tools firstly assess the relevant time dependencies, propose integration of the network with other technologies and finally evaluate costs/gains neglecting at all resource depletion issues (ResysTool[4], HOMER[90]).
On contrary the resource focused tools assess the intensity of use of resources, evaluate economical sustainability and don't consider time dependencies (actual status of RegiOpt).

Table 2: Objectives

OBJECTIVES
Identification of technologies with relevant time dependencies
Study of Green Energy supply technologies with overall description of the behaviour of the relevant ones
Identification of the main variables that cause time dependencies
Description of time-dependencies in energy demand
Overall assessment of energy demand
Identification of the regional energy demand yet to be covered by Green Energy supply
Identification of insertion point of energy dependencies
Identification of proper resolution for the time variable
Division of the year into 5 periods
Avoiding software overload
The software has to remain freely accessible and simple to handle
Enhancing Energy Security

1.8 Structure of the work

To achieve the listed objectives, first an evaluation of the Green Energy supply technologies was done and can be found in Chapter 4.
The overall study of these technologies allowed the description of the output during time on yearly scale: the main variables that affect the produced amounts and imprint characteristic seasonal output patterns were identified and a characterization of the yearly production curve was achieved (sections 4.5 and 4.6).
As the output of RegiOpt comprehends the yearly working hours, the desired analysis has to be done at a time-resolution of daily sums (at least): monthly resolutions introduce a far too high uncertainty in the output (+/- 15 days).
Thus the analysis had to start from available data of proper temporal resolution, where the data had lower resolution models where used and integrated with the available low-resolution data (for example see the Case study 2 in Chapter 7).
Approximation curves (Fourier series) were generated to smooth the raw data and to pass from a discrete data set to continuous functions (section 2.2).
After the statistical study of data and the generation of approximation curves, the energy amounts yet to be covered by the proposed energy network was assesses (section 2.2).
The market share available for the implementation of Green Energy supply was described mathematically by proper functions and the insertion of this curves in RegiOpt was done by dividing the curve in time-intervals (section 2.4, 2.5 and 2.6) and inserting the corresponding required energy amounts.
An overview of the developed methodology is given very schematically in section 2.6.
As a result a flexibilization of the software was achieved and confidence in the energy security of the output was improved.
The scheme of results is shown in Table 7 at page 90.

2. Methodology

This work was organized in the following steps:

1. study of RegiOpt and its functioning principles
2. study of common Green Energy supply technologies
3. classification of technologies and identification of the relevant ones
4. evaluation of yearly energy supply curves
5. evaluation of yearly energy demand curves
6. approximation and generation of the overall assessment curves
7. division of the year in periods (intervals of time)

In the Introduction the overall structure of RegiOpt and the principles on which it works were described, a detailed explanation of the software can be found in chapter 3.
The insertion of a further module in RegiOpt has to take into account its structure as the point of insertion has implications on the final output of RegiOpt.
In addition, the technical feasibility, especially the computation time and the risk of overload had to be taken into account.
Considering that the time-dependencies affect the technologies structure, we see that the possible insertion points are strictly related to the optimization module (PNS).
An insertion after the PNS module would only evaluate the time-response of the proposed technologies network, thus it would only be a simulation and wouldn't be a relevant contribution to the optimization.
The optimal solution under a mathematical point of view would be to introduce the time dependencies in the PNS: the amounts of raw-materials and products would then become time-dependent flows.
As the PNS problem is defined by Friedler et al.[42] as a MINLP problem with following variables:

1. operating units
2. materials
3. fluxes

it can be written as a set of equations involving functions of these variables and their derivatives.
If we want to insert time-dependencies in the optimization problem, we need to consider:

1. the working operating units
2. the materials

As a consequence the fluxes will become also time dependent.
Many aspects of time-dependencies should be considered: on the side of products the flows depend on the demand, for the operating units boundaries on operational range and efficiency affect the output and, as least, the required flows of raw materials depend on capacity of storage, processing capacity of the operating units and demand.
When the model is constructed, the input/output relations of the operating units (usually assumed to be linear) are known, so if the input amounts vary with time a variation in the amounts of products is obtained and vice versa.
The general problem can be easily rewritten inserting the time variable but this approach would lead to a complete reprogramming and rethinking of the software because:

- all operating units would have to be reprogrammed and the input-output becomes non-linear
- the optimization run on a further variable would lead to an exponential increasing of the computational time

As a consequence a reprogramming of the algorithms is identified as non-target.

Furthermore, a multi-periodic approach is proposed by I. Heckl et al. [55]: in this approach the authors outline the problem of time-dependencies and show a method to implement PNS without acting on the algorithms.

The proposed method suggests a division of the year in discrete intervals for which a steady-state can be defined: the year is seen as a composition of time intervals in which the operating units of the network work with constant material-fluxes.

This means that the year is divided in a discrete number of intervals (in our case, 5) and the amounts of energy required for every interval are fed to the software.

So a set of finite production periods, on which the optimization can be run, are associated to amounts of energy to be produced and both periods and associated energy amounts are inserted to PNS.

In addition, an evaluation of the required energy as the energy gap between local existing Green Energy supply and energy demand allows a reduction of the PNS problem and the protection of the market share of the already existing technologies.

After the identification of the point of insertion, the periods have to be defined and the study of time-dependencies is focused on the production side.

The technologies that had to be considered were chosen after the study of technical features of Green Energy supply.

In the next chapters we will see that the evaluation of technical features of energy supply technologies lead to a classification in.

- controllable,
- non-controllable with constant output,
- non-controllable with strong time-dependencies.

This classification is needed because the response of the supply network to changes in energy demand depends on the output patterns of energy supply and on the possibility to regulate this outputs.

The technologies with strong-time dependencies are those processes for which there is not a possibility to regulate the output and thus depend on outer factors, as a consequence the yearly supply curves show characteristic behaviours that were studied.

Also on the demand side, the available load curves show yearly patterns that were analysed.

In order to allow a comparison and to feed the analysis in the PNS module, the curves were approximated by polynomials or Fourier series.

The generation of polynomials and Fourier series allows to pass from a discrete data-set to a time-continuous mathematical description, avoiding problems on resolution of data: it allows smoothing and interpolation at the same time.

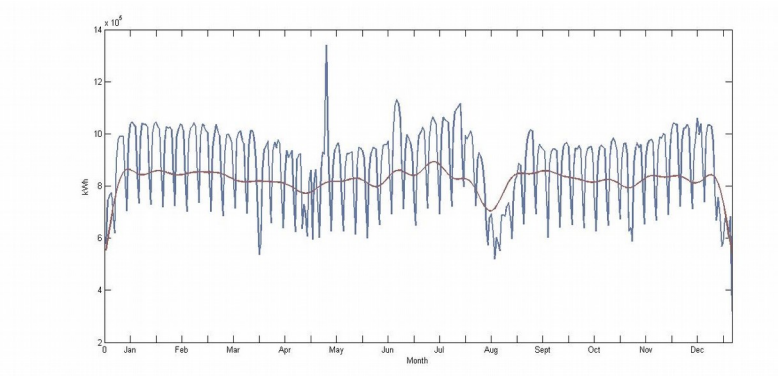


Figure 5: Approximation of data with Fourier Series (by filtering).

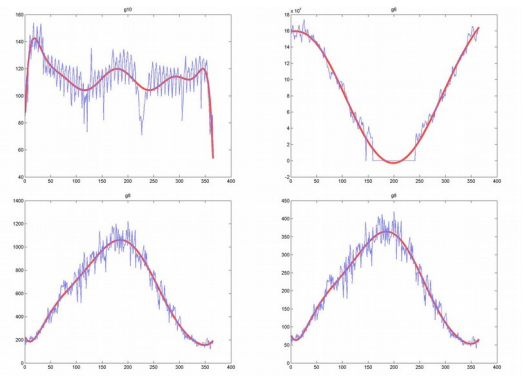


Figure 6: Approximation of data with polynomials

The background idea is to insert a module before PNS that evaluates energy demand and the existing network of solar, wind-power and hydroelectric plants in order to evaluate the remaining amounts in the optimization (the choice of this technologies is explained in chapter 4).
The gap to be filled by the proposed network is individuated by detracting the energy produced by strong time-dependent technologies from the energy demand, obtaining so an overall assessment curve.
This overall assessment curve shows the amounts of energy that have to be covered in that special region enhancing complementarity.
In order to feed the results in PNS and to avoid overload, the yearly assessment curve is divided into periods.
Preliminary tests show that the software supports a maximum of 5 periods without going in overload.
The identification of periods was done with two different methodologies: the first methodology is a division of the year in time-intervals while the second is a division of the year in production intervals.
In the first methodology the division is done along the x-coordinate time and the resulting time and energy amounts fed to PNS, while in the second methodology the division is done along the y-coordinate of energy amounts: the identified periods are always 5 but the definition occurs along two different axes and the results differ in the number of time-intervals defined.
Passing from a concept of time-intervals to a concept of production intervals enhances the resolution of the division of the year in periods, the procedures are outlined properly in sections 2.3, 2.4 and 2.5.
The complete proceeding was programmed in Simulink Matlab ®[122] and will be integrated as a module in the RegiOpt.

2.1 Data requirements

The input data have to be of proper scales.
Regarding temporal scales a resolution on day basis is the minimum requirement: as RegiOpt gives output in operating hours a year, resolutions that are grosser than daily sums lead to results with low confidence and high error.
For instance monthly sums introduce in the assesment an error of +/- 15 days, which is unappropriate for an output in hours.
The resolution of daily sums (24h) is acceptable when contextualized in the scope of preliminary assessment: while daily resolutions are unsuitable for short-term predictions as used in energy trading, they are accurate enough for the individuation of seasonal/sub-seasonal oscillations.
Furthermore the variability of energy demand and supply during weeks and days introduce further uncertainities.
The spatial resolution depends on the application of the developed methodology: the procedure can be applied on little and big spatial scales.
As the available data on energy demand is not on local scale a downscaling had to be done.
The widespread electric grid allows a simple downscaling using mean values: energy surpluses can be easily transmitted in the national grid and exported.

Aiming to a compensation of energy lacks and surpluses, energy autarky itself allows us to rescale national electric demands referring it only to the population: socio-economic factors can be neglected as every region capable to generate electricity surpluses is able and has the responsibility to trasmit them to regions with production lack, thus a tayloring of the demand on regional scale was avoided (such a tayloring is undesirable in the scope of energy transition and energy autarky).
In the heat market this type of approach is not feasible: the existing boundaries on the development of the heat transmission networks lead to the need of proper tayloring of the heat demand and local-referred data are required.
The locally produced heat can be consumed only locally and can't be transmitted, thus an approach that comprehends energy transmission is unproper and the downscaling of national data results in a weak approach.
In this case, national and international statistics in the Odyssee Database [25] show that the main use of heat are related to the residential sector and services.
Thus space and water heating are the main uses to be covered.
The main local variables that affect heating are the building stock and the climate, thus using daily metereological data and data on building stock a local heating demand curve can be generated.
Industrial heat demand can be considered only case to case: the requirements in temperature and energy vary depending on processes and management of the single industry, thus a general approach is misleading and the industrial heat demand was not considered in this study.
On the energy supply side, to protect their local market share, the energy companies don't allow access to their detailed production data, thus the data available on production plants are only installed powers and yearly means.
National production data of heat are available on quarterly scale but the relation between local and national production is not really known, in addition the main variables that affect the output of an energy plant are technology type, technical features and plant management in response to local and/or national energy demand.
In absence of local energy production data on daily basis, in some cases, the knowledge on the functioning of the energy supply technologies (which will be shown in chapter 4) allows to use simple models to construct daily sums.
In presence of additional relevant data the models can be adjusted.

2.2 Evaluation of the available market share

As seen before, the actual approach in renewable based energy network planning is to take strong time-dependent technologies and try to compensate them with manageable ones.
In practice many authors suggest to compensate solar with wind-power, or solar with biomass, but the central point is that we can't consider single technologies as we are talking about a network.
The diversification of resources used in energy supply is a requirement of energy security: in a diversificated network the lack of one ressource can be better compensated by the other existing resources.
To consider the network as a whole, excluding fossil fuels, all technologies had to be studied and the compensation potential outlined.
The existing network of strong time-dependent technologies can be compensated: the remaining demand can be covered by the implementation of the network.

In practice this means that the already produced amounts of green energy from strong-time dependent technologies can be subtracted from the energy demand obtaining an overall assessment curve.

$$E_{required} = E_{demand} - \sum E_{time\ dependent}$$

Where $E_{time\ dependent}$ is the energy generated by those technologies that have a non resolvable strong time-dependency.
The identification of the relavant technologies is shown in sections 4.5 and 4.6.
The energy demand shows characteristic oscillations within a year, the study of these oscillations is shown in chapter 5 and principal socio-economic factors are discussed.
The $E_{required}$ consideres the oscillations of the energy demands and the oscillations in relevant time-dependent supply, thus the optimization and the development of the network can be adjusted to compensate the supply.
The background problem is the already videly discussed compensation and complementarity of Green energy supply technologies, but this time the discussion is not focused on one or two technology types but inserted in a context of a local or regional network.
The obtained assessment curve already contains the information on time dependencies necessary to implement the network, but has now to be fed in the PNS.

2.3 Division of the year in intervals

To feed the required energy production in the PNS an approximation is needed: as long as time-dependencies are not considered in the PNS algorithms a flexibilization can be done only by acting on the inputs of PNS, in particular on the operating units and the products.
The concept is to divide the year in periods for which the required amounts of energy are known and to feed the integrals of these periods in the PNS.
The input raw materials and their amounts remain the same, while the operating units and the products are modified as follows:

- required yearly amounts of heat and electricity (h_y, e_y) are divided into the corresponding amounts of every period

  $$h_y = \sum_{period=1}^{number\ of\ periods} h_{period} \quad \text{and} \quad e_y = \sum_{period=1}^{number\ of\ periods} e_{period}$$

- the yearly required output flows of the single operating units are also divided in the amounts required for every period

Thus the PNS now sees a system where the 2 required products (heat end electricity) are susbsituted by a number n=5 of virtually different products that have to be produced in the required amounts during the year and the operating units have to divide their yearly time in the production of the n virtual different (energy) products.
In practice we are saying to PNS that it has no more to produce the product "*yearly heat*" in the amount "x_{year} *kWh*" but that it has to produce the products

- "*heat_period_1*" in the amount "x_1 *kWh*",
- "*heat_period_2*" in the amount "x_2 *kWh*",
- "*heat_period_3*" in the amount "x_3 *kWh*",
- and so on for all the periods

The same is done for electricity.
Also the corresponding operating units are modified: the equipment is dis-joined from the process and a virtual operating unit for every period is generated[55].

The information of maximal input flows, fix-costs and costs of raw materials is set in the equipment, while the virtual multi-period processes are used to represent the required amounts of products in the periods defined through the operating hours of the multi-period processes.
Let's make an example to clear the functioning of multi-periods PNS: the comparison between PNS and multi-period PNS is shown in Figure 7.

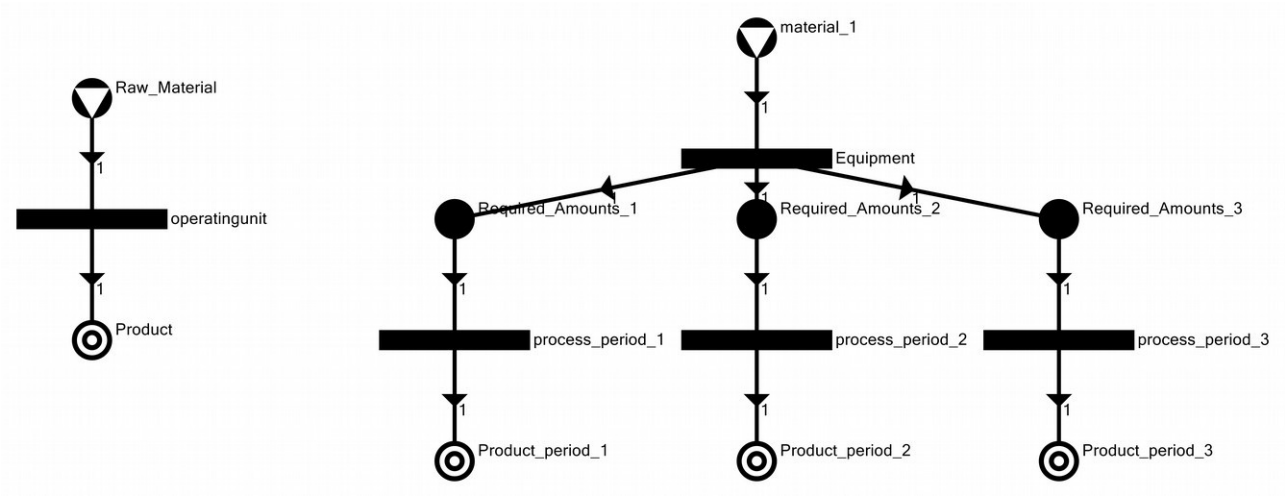


Figure 7: Multi-period PNS

The process shown on the left side takes as input the yearly available amounts of Raw_material, feeds these amounts in the operating_unit and gives as output the yearly amounts of Product.
For us, the relevant variables of the operating unit are the fix-costs, the construction costs, the maximal and minimal flows of raw-material and product with the associated costs and gains.
On the right side the input Raw_material with its yearly available amounts and associated price is given as input to the Equipment.
The Equipment has minimum and maximum flows of raw material and product.
The output of the Equipment are fictive intermediate materials: the Equipment spans its capacity over the three periods.
The fictive intermediates are fed to the corresponding virtual-operating units: every operating unit has a corresponding time-span (operating hours) on which it has to produce the required amounts of the product.
So the periods are entered in the process by setting the periods as operating hours in every virtual process and the corresponding required amounts of products in the virtual different products at the bottom.
This procedure is proposed in *"Process synthesis involving multi-period operations by the P-graph framework"* by I. Heckl et al.[55].
The division of the year in intervals is thus needed to insert a certain degree of time flexibility in the PNS.
Obviously as more the periods are, as higher is the introduced flexibility.
The idea is to introduce the total required amounts for every period, these amounts are then spun equally over the operating hours of the period: the total amount is converted by PNS to an hourly mean of required amount.
As a consequence the optimization is run over hourly means and for every hour an error can be defined as the difference between the mean value and the real required amounts of energy.

So the error between the real required amounts and the multi-periodic approach can be defined for every period:

$$E=\sum_{x=1}^{8760}\left|y(x)-y_{period}\right|$$

Where x is the date sorted time variable and y is the energy amount.
Two methodologies for the division of the year in periods where considered and are described in the followong sections.

2.4 Method 1: mathematical study of the curves

The relevant time-dependent technologies where approximated by polynomials and consequently the overall assessment curve is also a polynomial.
The curves were studied with common mathematical methods.
The derivative of a series of powers has one degree less than the series itself.
Thus, being n the degree of the series and (n-1) the degree of its derivative, in general the critical points are (n-1).
If the critical points are out of the range of interest (the year) they should be neglected.
Knowing the minima and the maxima the periods can be defined as:

$$I=\left\{x:\frac{\left(x_{crit\,(n)}-x_{crit\,(n-1)}\right)}{2}\leq x\leq\frac{\left(x_{crit\,(n+1)}-x_{crit\,(n)}\right)}{2}\right\}$$

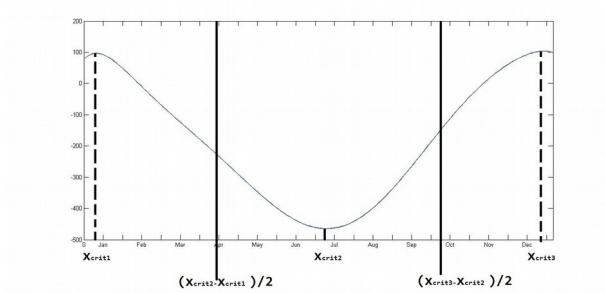


Figure 8: Critical points and endpoints of periods.

As we can see in Figure 8, once the critical points are known, the endpoints of the periods can be calculated using the formula above.
Then, the mean of every period can be calculated and a representation of the year is obtained as shown by the red line in Figure 9.
Being the degree of the power series from 1 to 10 following situations can occur:

1. there are 3 to 5 critical points
2. there are 2 or less critical points in the year
3. there are 6 or more critical points in the year

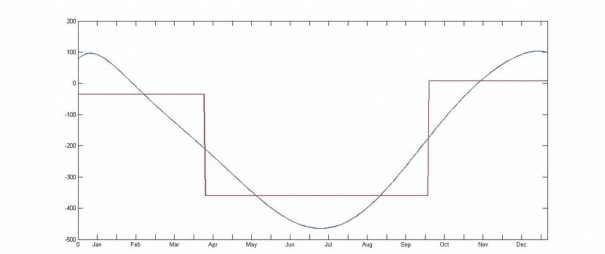


Figure 9: Division of the year in periods (red line) and the real amounts of required energy (blue line).

In the first case, the construction leads to the identification of 3 to 5 periods as wanted.
In the second case the identified periods are too few and in the last case we have too many periods.
As a consequence these cases have to be further processed.
In case 2 the interval(s) can be further divided around the existing critical points leading to a number of 3 or 4 intervals.
In case 3 subsequent critical points with low oscillations can be collapsed in one only period as long as we reach the desired number of periods.
The result of this method is a construction of periods around times of high and low required energy, remaining in a date-sorted space.
The periods can now be fed in the PNS as means: this representation leads to an error that can be quantified.
For every period the error can be defined as:

$$E_I = \sum^{I} \left| y(I) - y_{mean}(I) \right|$$

And the total error is the sum:

$$E_{tot} = \sum E_I$$

2.5 Method 2: simple clustering

A far simpler method is to divide the data along the y-axis.
This method is based on the fact that the variables fed to PNS are amounts of required products to be produced in a fixed number of hours.
As a consequence the PNS has no connection between the amounts and the date in which these amounts have to be produced.
This allows to define the periods not with regard to the time variable (date), but with regard to the required amounts.

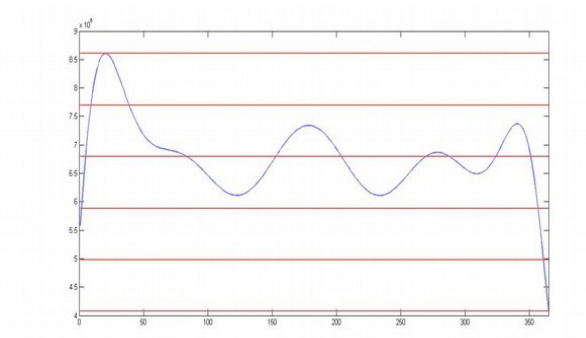


Figure 10: Division of the assessment curve along the y-axis

The production amounts are divided along the y-axis:

$$I_p = \left\{ y \,:\, y_{min} + n_p \frac{y_{max} - y_{min}}{p} \right\}$$

Where p is the chosen number of periods p=5 and n_p identifies the single period.
Let's see how this proceeding works step by step:

1. Sorting: to divide the amounts along the y-axis the data are first sorted in ascending order.
   A vector containing the y-values of the curve in ascending order is generated.
   The values that are sorted are daily amounts of required energy, thus the graph we obtain is an amount/day graph in which the day is only a time quantity of 24h and doesn't carry any information about the corresponding date.
   To keep the association of required amounts with the date in which they have to be produced and indexing of the sorting process is done;

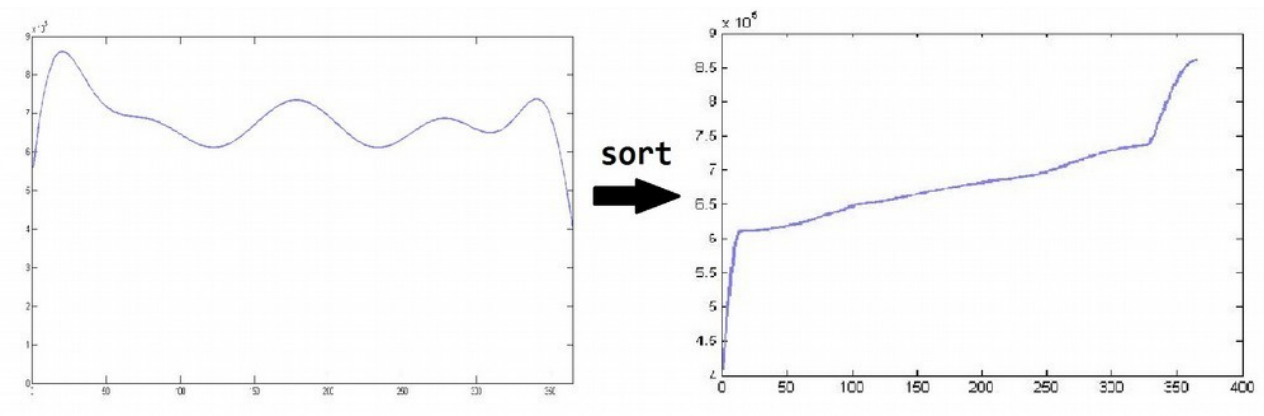


Figure 11: Data sorting

2. Division of the year along the y-axis in the desired number of periods:

the step between 2 periods along the y-axis is exactly
delta=(y_{max} - y_{min})/ NumberOfPeriods
Thus the intervals along the y-axis are

$$I_p = \left\{ y \,:\, y_{min} + n_p \frac{y_{max} - y_{min}}{p} \le y \le y_{min} + n_{p+1} \frac{y_{max} - y_{min}}{p} \right\}_{n_p = 0}^{n_p = 4}$$

where n_p identifies the single period.

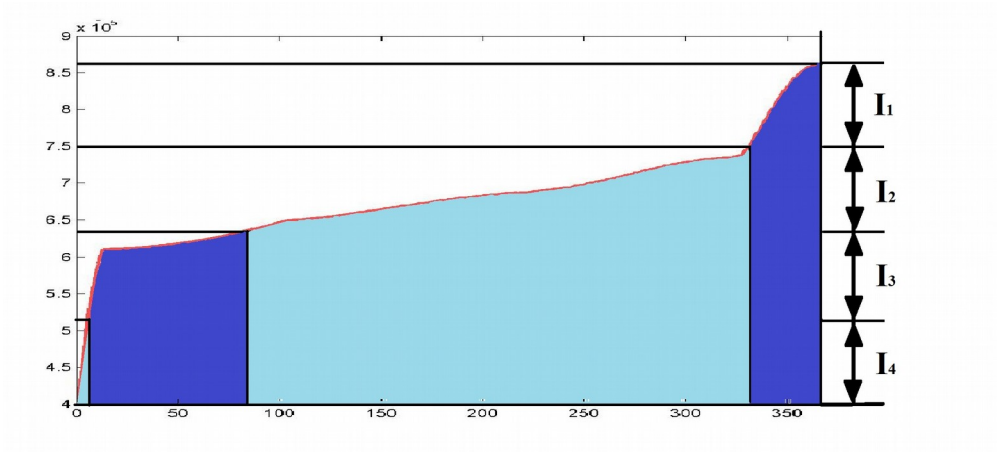


Figure 12: Definition of the intervals

3. Now, the produced amounts and the corresponding time-quantity (x-value) can be calculated: an x-value is associated to every endpoint if the intervals.
4. Representation of the new curve by mean values: the mean of every interval is calculated and associated to every interval.
   In Figure 13 we see the periods that are fed into PNS: the red line shows the sorted data while the blue horizontal lines show the mean amounts that are fed to PNS. Beside to the amounts, the corresponding operating hours (x-axis) are also fed into the PNS: the division of the year in periods is done in a space sorted by amounts and has no connection to the date on which the amounts have to be produced.

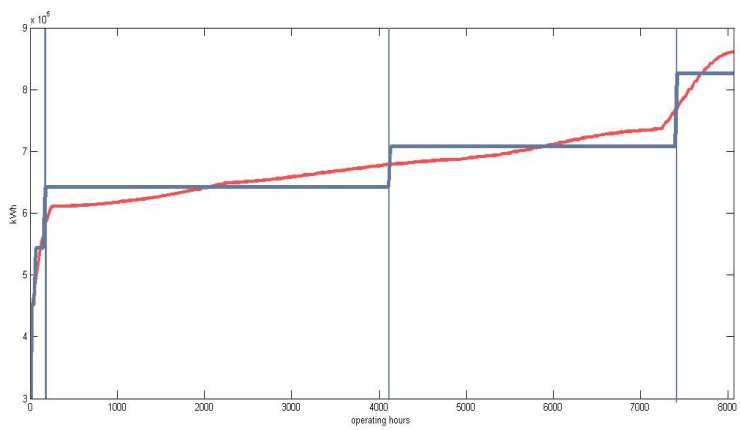


Figure 13: Mean values and intervals

5. Now that the intervals are defined a re-association of the time amounts with the corresponding date can be done: the sorting can be reverted using the index generated in the process.
   The same index is used to associate the mean amounts of the periods to the corresponding date. The obtained result is a division of the year in intervals as shown in Figure 12.

While the periods fed to PNS are shown in Figure 12, the representation of the year (date-sorted space) is shown in Figure 14: the output of PNS is able to respond to the oscillation shown in Figure 14.
The identified intervals are only 5 in the space of required energy amounts (Figures 12 and 13) but they are always more[5] in the original date-sorted space (Figure 14).
As PNS requires only amounts (y-values) and operating hours as input and doesn't account the association between given amount and date, this method allows a higher flexibility and precision of the output.
The precision achieved in representing the intervals is maximal.
The maximal error between the representation of the year in intervals and the assessment curve is exactly:

$$E_{max} = \frac{y_{max} - y_{min}}{2 \cdot p_n}$$

Where p_n is the number of chosen periods.
This method shows a higher flexibility than the first seen methodology because in the original space the identified periods are always more than the chosen 5.
This means that the wanted 5 periods can be fed in the PNS as required amounts, avoiding the overload of PNS, but obtain a better representation of the year.
The number of intervals in the original space depends on the oscillations of the assessment curve: the more critical points the curve has, then more intervals are obtained in the date-sorted space.

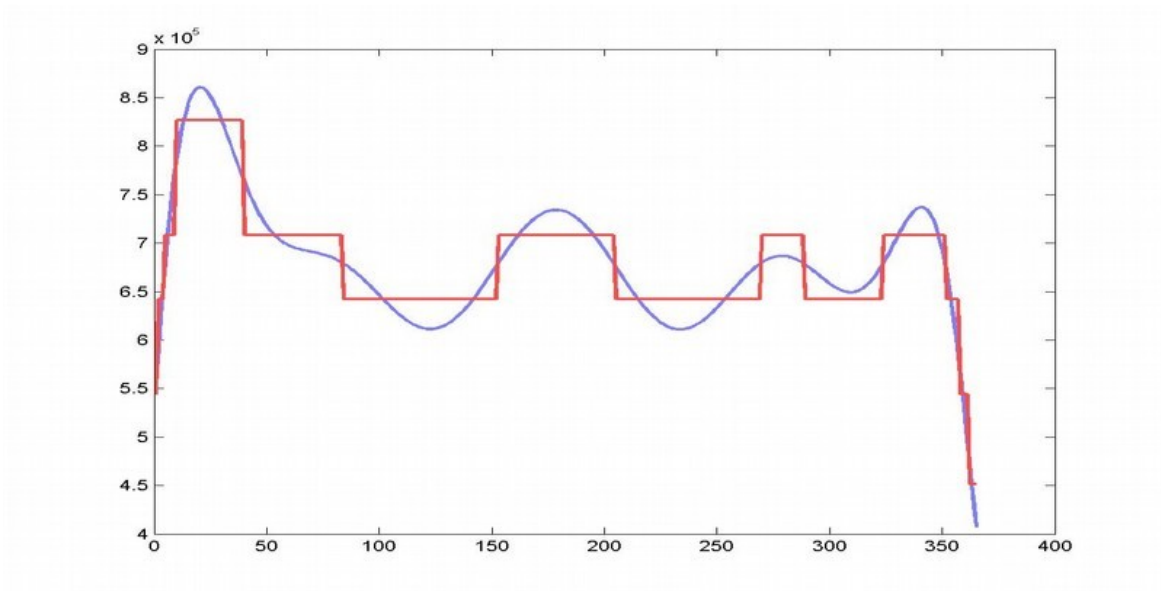


Figure 14: Identified intervals

[5] We are considering only non-linear cases: energy production and demand are non-linear

2.6 Overview of the developed methodology

A schematical explanation of the developed methodology is shown in Figure 15: as an example electricity and heat demand and solar supply are shown.
The steps are:

1. individuation of relevant technologies
2. study of supply and load curves
3. generation of a mathematical description of the curves (smoothing/filtering)
4. evaluation of the amounts of energy yet to be produced in order to cover demand: overall assessment curve
5. sorting and division of the year in periods
6. the data are ready to be fed in the PNS

The result of this methodology is the flexibilization of the PNS regarding time dependencies and the combination of the problem of time dependency with the resource use issue.

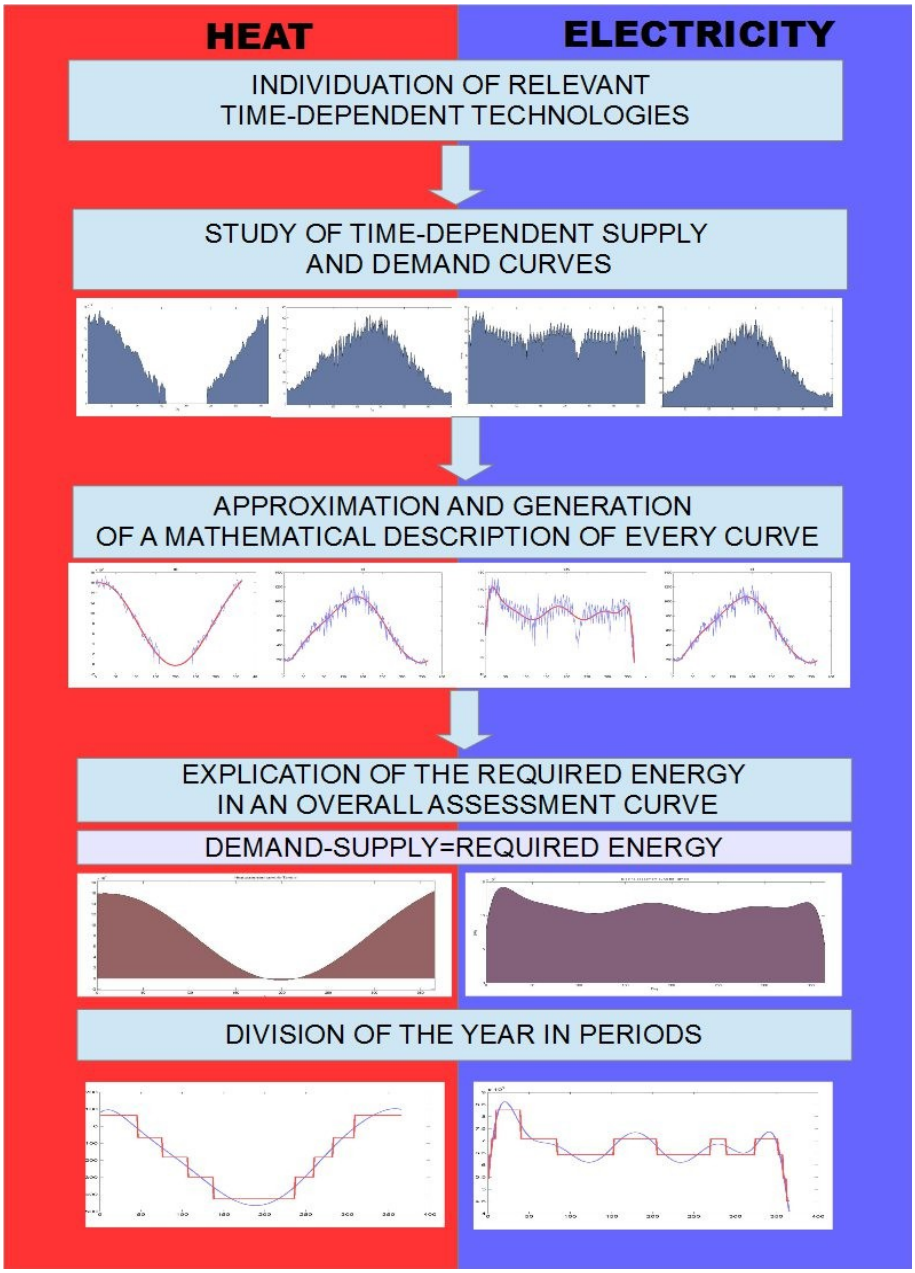


Figure 15: Scheme of the developed methodology

3 The software RegiOpt

To explain how the insertion is done and to understand the current work, background information on the software is required.
In this chapter the PNS is outlined and the features of RegiOpt are shown in detail.

3.1 Optimization and PNS

The optimization process applied in the RegiOpt software is based on the Process Network Synthesis[42].
The Process Network Synthesis is the design of the optimal structure of a process system.
In this approach the whole network is decomposed in elemental operating units which are interconnected by flows of materials and energy.
The PNS is based upon the p-graph method: every process is represented as an element in a network and the connections between elements represent the flows of energy and materials[41].

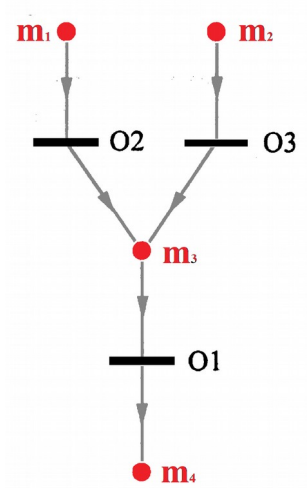


Figure 16: P-graph of a system of 3 operating units (o_1,o_2 , o_3) with 2 raw materials (m_1, m_2) an intermediate (m_3) and a product (m_4)

In the p-graph the operating units are represented by bars, the vertices are materials (raw-materials, intermediate products and products) and the arcs are the flows that connect the operating units.
A process network can be effectively represented by a p-graph, in addition Friedler et al. [42] formalize the representation by mathematical means: being **O** the set of operating units and **M** the set of the materials, the graph is defined as **(M, O)**.
Furthermore, the raw-materials (**R**) and the products (**P**) are defined as subsets of **M**.
Following are the basic properties of the graph **(M, O)**:

- **M**=(m_1, m_2, ..., m_l) are the materials
- **O**=(o_1, o_2, ..., o_n) are the operating units
- **M∩O=Ø**
- **P∩R=Ø**
- **MUO** are the vertices
- **A** are the arcs with extremities **(α,β) ϵ O**
- **(M',O')** ⊆ **(M, O)** is a subset of **(M, O)**
- if there are two subsets of **(M, O), (M_1,O_1)** and **(M_2,O_2),** the union of the two subsets is **(M_1,O_1) U (M_2,O_2) = (M_1 U M_2, O_1U O_2).** This union is also a sub-graph of **(M, O).**
- the indegree (**d^-**) of a vertex is defined as the module of the incoming arc (**ω^-**) and the outdegree (**d^+**) as the module of the outgoing arc (**ω^+**), thus the degree of the vertex is the sum of both: **$d=d^-+d^+= |\omega^+| + |\omega^-| =|\omega|$**
- every feasible process that produces the products **P** from the raw-materials **R** using operating units from **O** is a sub-graph of **(M, O)**

Even under this condition we see that we have a set of equations that have to be solved for the j operating units and the i materials.

$$\begin{cases} \sum_{j=1,2,\ldots,n} f_j\left(y_j,\ \varphi\left(\omega^-(o_j)\right),\ \varphi\left(\omega^+(o_j)\right),\ o_j\right) + \sum_{i=1,2,\ldots,n} f_i\left(\varphi\left(\omega^-(m_i)\right),\ \varphi\left(\omega^+(m_i)\right)\right) \\ \text{subject to} \\ g_j\left(y_j,\ \varphi\left(\omega^-(o_j)\right),\ \varphi\left(\omega^+(o_j)\right),\ o_j\right) \le 0 \\ g'_i\left(\varphi\left(\omega^-(m_i)\right),\ \varphi\left(\omega^+(m_i)\right)\right) \le 0 \\ y_j = \{0,1\} \end{cases} \quad (1)$$

In order to simplify the huge number of equations a reduced model of PNS has been proposed by Friedler et al.[42]: if we recall the properties of **(M, O)** we see that each solution of the system above is a sub-graph of **(M, O)**.
Furthermore, in the PNS, only feasible solutions of (1) should be searched for, leading to a reduced set of equations.
A *solution structure* of PNS is defined as all the sub-graphs **(M',O')** with following properties:

1. all final products are represented in **(M',O')**
2. a vertex from **M'** has no input only if it represents a raw material
3. a vertex from **O'** has at least one path leading to a final product
4. any vertex from **M'** has to be an input or an output for at least one vertex from **O'**

Under these conditions, the set of solutions *S* **(P, R, O)** has been proofed to be closed under union and the union of all solutions of PNS is called *maximal structure,* **(Ḿ, Ó)**.
As any optimal solution structure is included in the maximal structure, the MINLP can be based on it: the system of equations (1) is rewritten referring it to the maximal structure, i.e. using as operational units and arcs only those considered in the maximal structure.
In practice the sets are redefined as following:

$$I = \{i : 1 \le i \le l \text{ and } m_i \in \grave{M}\}$$
$$J = \{j : 1 \le j \le n \text{ and } o_j \in \grave{M}\}$$

Now the optimization can be run over the maximal structure and the system (1) becomes:

$$\begin{cases} \min \sum_{j=1,2,\ldots,n} f_j\left(y_j,\ \varphi\left(\omega^-(o_j)\right),\ \varphi\left(\omega^+(o_j)\right),\ o_j\right) + \sum_{i=1,2,\ldots,n} F'_i\left(\varphi\left(\omega^-(m_i)\right),\ \varphi\left(\omega^+(m_i)\right)\right) \\ \text{subject to} \\ g_j\left(y_j,\ \varphi\left(\omega^-(o_j)\right),\ \varphi\left(\omega^+(o_j)\right),\ o_j\right) \le 0 \\ G'_i\left(\varphi\left(\omega^-(m_i)\right),\ \varphi\left(\omega^+(m_i)\right)\right) \le 0 \\ y_j = \{0,1\} \\ \text{where} \\ i \in I \text{ and } j \in J \end{cases} \quad (2)$$

In practice, if we want to apply the PNS on an energy supply system we have to know:

1. feasible operating units (o_j ϵ **Ó)**
2. required raw materials (m_i ϵ **R** ϵ **Ḿ**)
3. desired products and wastes (m_i ϵ **P** ϵ **Ḿ**)
4. all the φ, i.e. the transformation functions that lead from raw materials to products for every operating unit and the connections between operating units

With these informations we construct the maximal structure and then optimize the network, the mathematical proceeding is graphically shown in Figure 17. Proper algorithms for the PNS were developed and programmed: the optimization software “PNS Studio” is available from http://www.p-graph.com/.

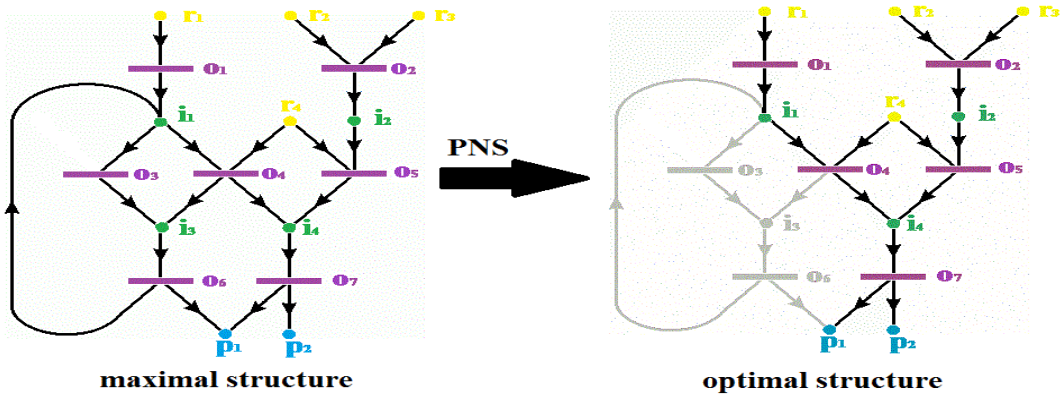


Figure 17: PNS: the optimal structure is derived from the maximal structure by the mathematical proceeding optimization.

3.2 RegiOpt: application of PNS to energy systems

Now that the optimization process on a network, the core of RegiOpt, was described, the use of PNS has to be contextualized: the application is done over a region and with regard to energy issues.
The processes considered are exclusively those involved in energy supply with special focus on use of resources.
In the RegiOpt CP (Conceptual Planner) the user is firstly asked to enter characterization data about the region under study.
In the queries default values from the Austrian national statistics service (Statistik Austria) are set for Austrian locations[56].
This last approach leads to a lower quality of data: even if the national statistics fairly represent the characteristics of a littler region in Austria, the energy demand and the potentials in energy generation depend on local variables such as population, micro-climate, land-use, industrial sites, type of industrial sites, local economy and so on.
Even if the input queries are developed with Austrian default values, with proper input data the software has been proven to work successfully also in international context [112].
Through the required input of data the user is brought to investigate the regional characteristics with particular attention on land use.
The overall structure of RegiOpt is shown in Figure 4.
As first the user is asked to enter basic regional data, then the PNS operates the optimization and gives the optimal structure as result.
This output is then evaluated with the SPI method and the carbon footprint is calculated.
The overall results of RegiOpt are the optimal technologies network, with the structure table, the SPI and the carbon footprint.
In the input phase the queries lead interested users in the evaluation of the state of the art by retrieving following informations:

1. population of the region
2. area of the region
3. quantification of grassland, arable land and forest areas
4. livestock
5. share of buildings by year of fabrication
6. heat demand
7. existing energy supply network based on renewables (fossil fuels are not accounted)
8. regional produced quantities of raw-materials and products

9. regional prices of raw-materials and products

The population and the area of the region are the first variables that influence the energy demand and the structure of the possible network: while the electric grid is widespread and reaches almost all households, the heat supply networks are still in evolution and actually show constraints on economical feasibility due to the cost of the pipelines.
The constraints on development of district heating is widely known and also the policy makers assume the future heat network as developed in residential areas, while for rural areas they foresee the implementation of biomass[12][11].
The quantification of grassland, arable land and forest is central for the evaluation of potential self-sufficiency of the region.
As the central paradigm of energy autarky is the self-sufficiency of rural regions with a surplus production to cover the demand of cities, autarky can only be reached by exact knowledge and good management of available resources.
Furthermore, sustainability under all its aspects requires a conscious resource-management.
The definition of sustainable development introduced by the Brundtland Commission in 1987 states that it has to meet *"the needs of the present without compromising the ability of future generations to meet their own needs" [125][72]:* under the point of view of resources it directly leads to resource management issues, resource depletion and renewable resources implementation.
In a sustainable energy network the raw-materials should be used at maximum at the rate as they are regenerated [123], furthermore the social aspects of land-use and competition between energy crop and food have to be taken into account, so the preliminary study about land-use is central if we want to answer to energy demand in a reliable way also for the next generations.
The quantification of available land allows the estimation of the intensity of resource-use for energy supply in the actual and in the proposed networks.
Thus the assessment shows if there is overexploitation or if there is room for further implementation.
The livestock of a region has many influences and interactions with the energy network: as first it influences the availability of land as proper areas for pastry and feed are needed, in second instance it is relevant as output of some wastes that are raw-materials in energy production.
The composition of buildings and heat demand are fundamental in the planning and implementation of heat networks: the BMWFJ and BLMFUW stated that the heat supply is one of the most important sectors for emissions lowering, economic development and implementation of efficiency [12].
Also European statistics show how the residential heat demand is one of the leading sectors in heat-consumption [78][93][94][25][24].
The share of buildings by year of fabrication and the level of insulation directly affect the heat demand.
As the insulation and the materials used for buildings vary with the year of fabrication and the reconditioning degree of a building, there is an indirect dependency relation between fabrication year/reconditioning and heat demand.
In order to avoid competition and to include the existing infrastructure, the user is also asked to insert the already existing network of green energy supply: this is the network that RegiOpt needs to implement and to optimize by adding technologies and covering the energy demand.
The amounts of raw-materials and products produced in the region are fundamental for the PNS as they constitute the material flow and have related energy flows.

As the optimization is done by economical means, the local prices of materials and products have to be known before the PNS can be applied.
After the input phase, some background calculations prepare the data for the PNS: the boundary conditions are posed and the data are normalized by reference to the economical values.
Theoretically the optimization could have be done using other reference units like mass, power or energy content but the economical point of view has shown to be the most reliable and wide-accepted [113].
The required amounts of energy are calculated as they are boundary conditions for the optimization process.
Acting on the input data, it is possible to generate different scenarios [113][112]: different energy consumptions patterns, different technologies networks and different prices evolutions can be investigated.
After PNS the ecological footprint is assessed with the SPI method.
The results of RegiOpt comprises a set of indications about the optimal technologies network.
As first we can visualize the output of PNS: the graph in Figure 18 shows an example of maximal structure in the background with the optimal structure highlighted.

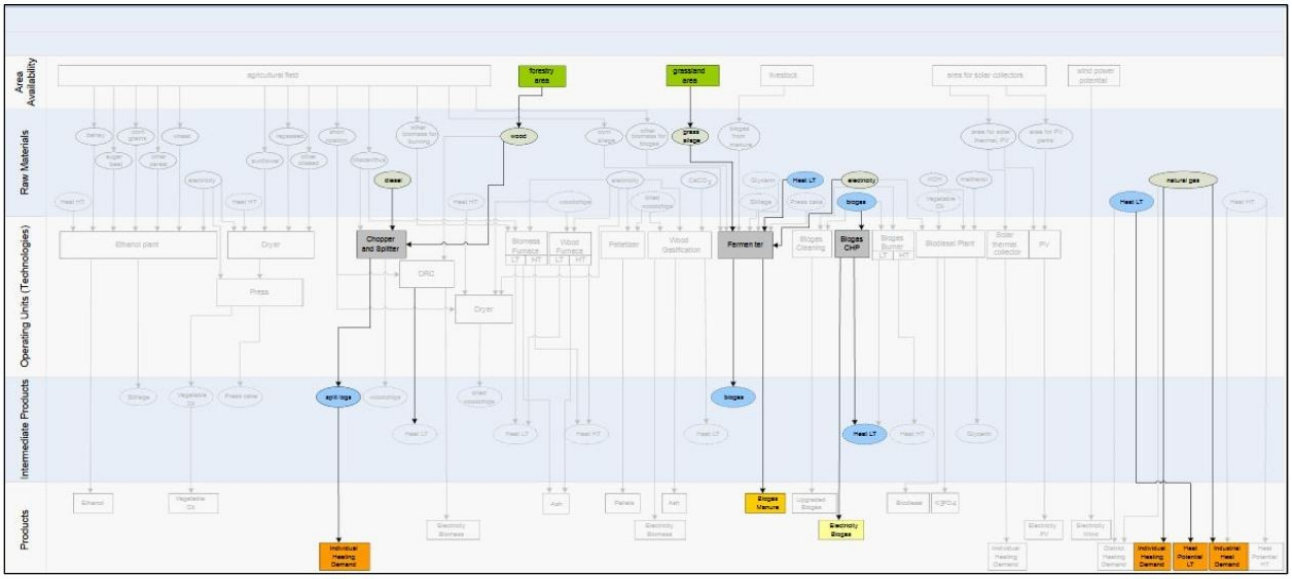
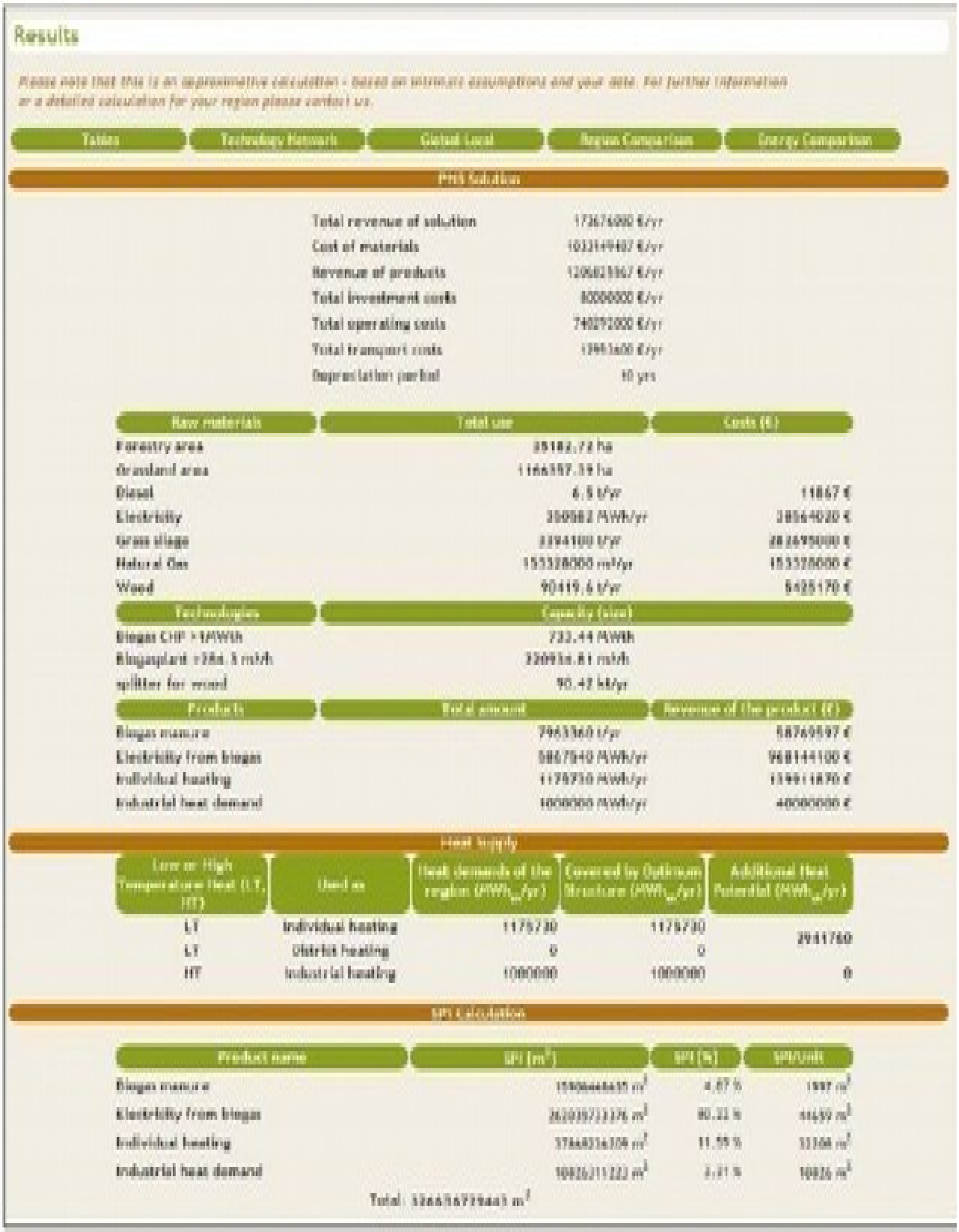


Figure 18: Visualization of the optimal structure. (Source: Maier et al., 2014[112])



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 Datasheets | Global Local | Region Comparison | Energy Comparison

PMS Solution

Total revenue of solution	173676000 €/yr
Cost of materials	103314940 €/yr
Revenue of products	120602967 €/yr
Total investment costs	80000000 €/yr
Total operating costs	74029000 €/yr
Total transport costs	1941600 €/yr
Depreciation period	10 yrs

Raw materials	Total use	Costs (€)
Forestry area	35182.72 ha	
Grassland area	1166397.39 ha	
Diesel	8.5 t/yr	11867 €
Electricity	350982 MWh/yr	38664020 €
Grass silage	2394100 t/yr	28169000 €
Natural Gas	155328000 m³/yr	155328000 €
Wood	90419.6 t/yr	5425170 €

Technologies	Capacity (size)
Biogas CHP >1MWth	722.44 MWth
Biogasplant >286.5 m³/h	320936.81 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	5867940 MWh/yr	968144100 €
Individual heating	1176730 MWh/yr	13961870 €
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	1176730	1176730	3941760
LT	District heating	0	0	
HT	Industrial heating	1000000	1000000	0

SPI Calculation

Product name	SPI (m^2)	SPI (%)	SPI/Unit
Biogas manure	15906446635 m^2	4.87 %	1997 m^2
Electricity from biogas	262093723376 m^2	80.22 %	44639 m^2
Individual heating	37844316306 m^2	11.59 %	32166 m^2
Industrial heat demand	10826211222 m^2	3.31 %	10826 m^2

Total: 326676779663 m^2

Figure 19 Optimal structure table: the results are shown in tabular form with quantification of amounts and economic evaluation.(Maier et al., 2014[112])

The optimal structure is also defined numerically with the structure table (Figure 19), in which we find following data:

1. required amounts of raw-materials
2. costs of raw materials
3. amounts of products
4. revenue of products
5. technologies of the optimal network
6. yearly working hours of every technologies
7. operational and transport costs
8. depreciation period
9. overall investment/revenue evaluation
10. assessment of heat supply structure
11. SPI

As the focus of RegiOpt is on a sustainable energy supply system, a set of graphs show the ecological pressure of the proposed solution: the use of land is outlined by the SPI and comparisons of the optimal network with the BaU quantify the ecological gain in terms of footprint, CO_2 emissions, overall ecological impact.
In conclusion, following characteristics make RegiOpt an innovative software in sustainable energy management:

1. it is user friendly and can be used also by people without expertise, so potentially all stakeholders can be involved
2. it touches all sides of sustainable development: environment, society and economy
3. the users and stakeholders are involved in a knowledge process while constructing the state of the art
4. the output is a set of tables and graphics with the proposed technologies for the network implementation and a clear outline of economic and ecological gains
5. the possibility to generate different scenarios by acting on the input data adds to RegiOpt a time dimension and allows stakeholders to evaluate the feasibility of different networks under different (future) conditions.

3.3 RegiOpt and sustainability

A sustainable energy system can only be achieved if it is accepted by the majority of stakeholders, so a central point is the right formation and information of all interested parties about the possible available technological solutions.
Furthermore, sustainability requires a wide consensus because the deep changes in the supply system have consequences that last with time and will influence also the next generations.
Under this point of view, RegiOpt allows formation and information of all stakeholders and generation of consensus by the evaluation of technical solutions, ecological and economical impacts and the possibility to generate scenarios in order to evaluate the persistence of sustainability of solutions with time.
Furthermore RegiOpt is an innovative tool because it touches almost all aspects of sustainability.
The environmental sustainability is treated under many aspects.
As first, the aspect of resource depletion and competition is treated by the evaluation of local availability of resources and local economic system.
As second, the amount of available raw materials and resources are given as input to PNS and the optimization leads to minimization of dissipations.

Furthermore with the Sustainable Process Index (SPI) the stakeholders are advised on the footprint of the involved processes.
The SPI method uses characteristics that are already known in planning phase to evaluate the sustainability of a process[85].
The method associates to every process an amount of area: as globally the only type of energy incoming is sunlight and all the other energy types can be seen as derived from it through transformations in the biosphere, there is a deep connection between land-use and sustainability of a process.
Thus SPI is based only on known process-data and is independent from social variables and complete knowledge of environment.
Regarding economic sustainability the optimization of resource use and technology choice performed through the PNS ensure that the proposed system is economically accepted.
As stated before, the actual approach is on annual basis and the optimization is performed with yearly means.
Both under the social and economical point of view this approach results weak because it meets only partially the requirements of energy security.

3.4 RegiOpt and Energy Security

One of the most important issues in energy supply and energy policy is energy security: according to the IEA, energy security is "*the uninterrupted availability of energy sources at an affordable price*"[67].
In western countries the energy security is a central issue in energy planning: in the short-term it means to cover successfully the demand also under peak conditions without black-outs, while in the long term it concerns the planning of energy networks, the use of re-sources and socio-economic factors.
The central point is the uninterrupted and affordable energy supply: it is widely known that the absence of energy or the shortage of fuels have deep impacts on society and eco-nomy.
The most important risks connected to energy security are the price spikes and the follow-ing socio-economic impacts.
As a consequence, energy security is a big issue in the implementation of Green Power: many technologies, show characteristic time-dependencies that affect the ability to react promptly to sudden changes in the demand.
This characteristic leads to economic feasibility issues for these technologies.
In addition the re-thinking of the energy network involves long-term energy security issues.
Thus a sustainable energy network must take into account both time scales of energy se-curity and evaluate contemporary resource depletion and time-dependency issues.
Actually RegiOpt deals successfully with long-term issues of resource use, social sustain-ability and economic sustainability.
The tool supports the diversification of energy sources, focusing on renewables, which gives long-term stability to the system.
The exclusion of fossil-fuel based technologies from the analysis is based on the explicit political aim outlined in the "Energy Strategy Austria"[12]: implementation of renewables, Energy Autarky, Energy Transition and energetic independence.
Locally, RegiOpt enhances the long-term availability of resources: the efficient use due to PNS optimization and the footprint evaluations enhance the preservation of the natural capital.
Under the point of view of short-term energy security RegiOpt lacks on assessments about time dependency of energy supply and energy demand.

Exactly this gap has to be filled by the current work: the efficient coverage of energy demand during periods of time in the range of a year need an assessment of the seasonal oscillations of demand and supply.
It is widely known that demand shows characteristic oscillations during day, week and year which we will analyse properly in chapter 5.

4 Sustainable energy production and time dependency in energy supply

Many are the available technologies for Green Energy supply, in this chapter we will introduce the most common and see their main features.
This main features will be the basis on which the time dependencies are individuated and classified.
In addition the functioning of the technologies allows also to integrate the lack of data of proper temporal and/or spatial resolution with simple models.

4.1 Hydro-power

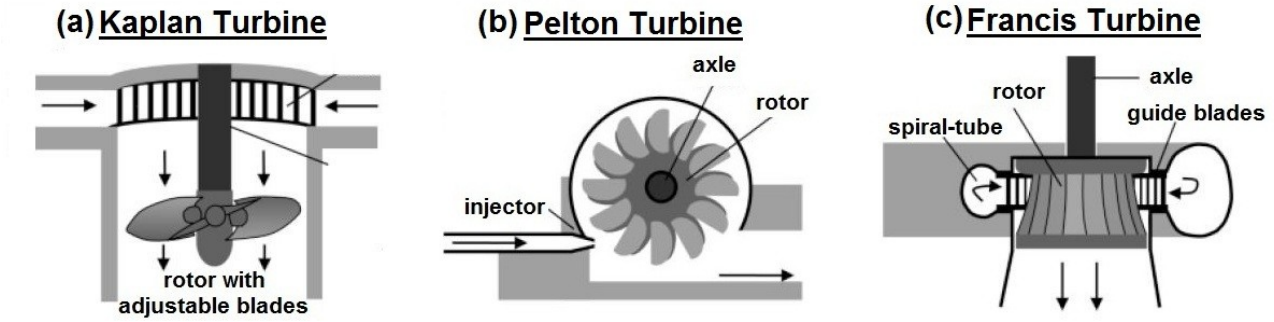


Figure 20: (a) Kaplan turbine: the water-flow is directed on a rotor with adjustable blades; (b)Pelton turbine: the water is injected on the blades of a wheel; (c) Francis turbine: the water is guided to the wheel by a spiral tube in order to use kinetic and pressure for energy generation. (translated from: Diekmann, 2014 [9])

Hydro-power is the most ancient family of technologies used in power generation.
It is based on the conversion of the potential energy from a water flow or waterfall to electric energy.
The most common turbines where patented between 1849 and 1913 from Francis, Pelton and Kaplan (Figure 20)[119][74][9][66].
In the Kaplan turbine the water-flow is directed on a rotor with adjustable blades.
The falling water puts the rotor in motion and the mechanic energy is transmitted to a generator.
The Pelton turbine is based on the injection of water on the concave blades of a wheel.
In the Francis turbine the water-flow is directed to the rotating wheel by a spiral tube.
From the point of view of the motion of the input water-flow the Kaplan turbine is axial, the Pelton one is tangential and the Francis combines radial and axial inflow.

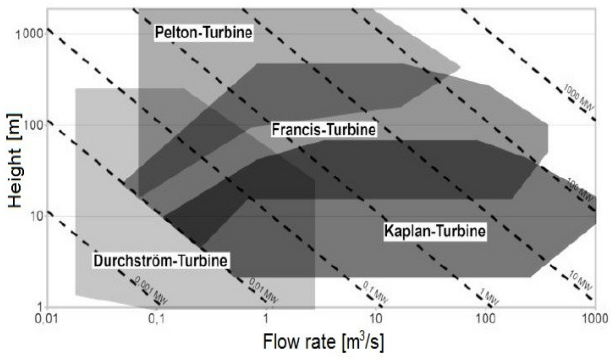


Figure 21: Ranges of application of the turbines. (translated from: Diekmann, 2014 [9])

The former turbines work on falling water: they need an appreciable difference in height to be put in motion.
A further turbine-type, the Cross-flow turbine, is used in water-flows that aren't steep enough: in this case the flowing water is directed on a water wheel and passes through the turbine.

The constructional features of the turbines make them suitable for different ranges of flow-rate and height (Figure 21).
In order to know the energy output of a turbine we should consider how the kinetic energy of the flow is converted to mechanical and then electric energy.
Remembering the second Newtonian Law of motion, every mass is subject to the gravitational force (**G**) and shows an acceleration (**g**):

$$\boldsymbol{G} = m \ \boldsymbol{g}$$

The mass on which the gravitational force is acting at every instant can be expressed using the rate-flow (Q) and the density of water (ρ):

$$m_t = \rho \ Q$$

The work that can be generated by a conservative force field, as the gravitational is, can be expressed as:[6]

$$L = \int \boldsymbol{F} \ d \ \boldsymbol{s}$$

Consequently, as the gravitational force G is acting every instant over a falling mass mt over a space Δh, the generated power can be written as:

$$P = \eta \ \rho \ Q \ \Delta \ h$$

where the constructional features of the device are represented by the overall efficiency factor η.
Thus the power output depends on the flow-rate (Q) and on the features of the turbine (η).
Also the design of the power plant affects the power output, under this point of view we can define three main families of hydroelectric power plants:

- conventional
- run-of-the-river
- pumped-storage

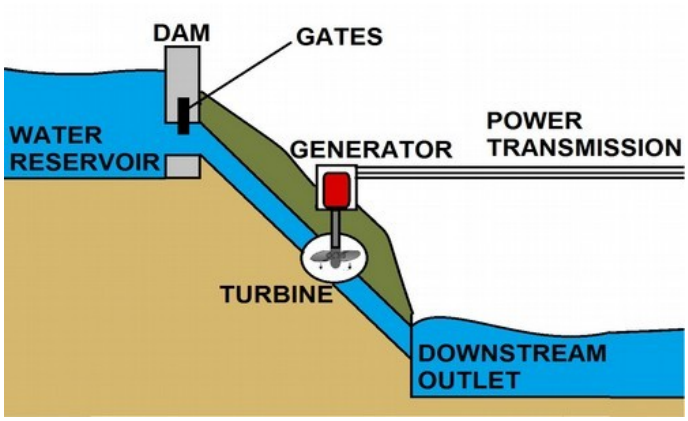


Figure 22: scheme of a hydroelectric power plant.

Conventional hydroelectric power plants comprise an upper water reservoir from which a channel leads the water-flow to the turbine and to the outflow.
On the upper part of the power-plant a dam contains the water coming from a river or a lake.
Gates are built in the lower part of the dam and can be opened or closed in response to energy demand.
From the gates the water is channelized in a waterfall, near the bottom of the waterfall the turbine transforms the motion of the fluid in mechanic energy.
A generator transforms the mechanic energy in electric power that is fed in the grid.
The output water-flow passes the turbine and is let out in a downstream basin.
Contrary to the conventional hydroelectric, the run-of-the-river power plants have little or no storage and depend directly on the flow-rate of the water-flow.
In this case, either the water reservoir is very little, or the power plant is set directly on a river.
The pumped-storage power-plant is a further evolution of the conventional hydroelectric: at the bottom the water is collected in a closed basin and pumped to the top basin when there are energy surpluses.
Pumped storage power-plants usually have reversible turbines that work as seen above but can be reverted and act as pumps during periods of energy surpluses.

[6] For explanation of conservative force fields, work and potential energy consult S. Rosati [115]

In periods of surplus energy production the turbine is reverted and the electric energy converted to potential energy by the upwards pumping.
In times of high demand the energy stored in the mass of water in the upper basin can be converted to electricity.
The pumped storage technology is one of the most important storage technologies: the storage of electrical energy is costly and not-feasible at industrial scale, thus all the actual storage systems convert the surplus electricity in mechanical or potential energy that can be used during peak load conditions.

4.2 Solar energy

The use of the solar radiation for energy supply is one of the most known Green Energy supply technologies.

4.2.1 The source: radiation income and geometry

While the incoming energy from other stars is negligible, the incoming radiation from the sun can be used for energy supply.
The inner nuclear reactions transform hydrogen atoms in helium with energy output.
The energy emission of the sun can be fairly represented by the emission spectrum of a black body, thus we can apply Planck's Law:

$$B_\nu(\nu, T) = \frac{2\pi\nu^3}{c^2}\frac{1}{e^{h\frac{\nu}{k_B}T} - 1}$$

Once the temperature T of the black body and the frequency of interest v are known, also the radiance B_ν can be calculated. We remember that c is the speed of light, k_B Boltzmann's constant and h Planck's constant.
The frequency at which the radiance has its maximum is given by Wien's displacement law:

$$\lambda_{max} = \frac{c}{\nu_{max}} = \frac{h\,c}{4{,}965\,k_B\,T}$$

and the emitted by the Stefan-Boltzmann law:

$$P_T = \sigma\,T^4$$

The Sun has a surface temperature of 5800 K, thus the maximum of the irradiance is at a wavelength of λ_{max} = 498 nm [100].
To evaluate the power incident in our planet the geometry of the sun and the distance of the Earth have to be introduced.
Due to the big distance, the Sun can be considered as a punctual source and the power incident on a point at distance d is:

$$P_{sun} = \frac{P_T}{4\pi d^2}$$

For the Earth, which is on a mean distance d_{earth} =1,496·10^{11} m the incident power is 1367 W/m^2.
In Figure 23 we see that there is good accordance between the above predicted values and the real spectrum at the top of the atmosphere.

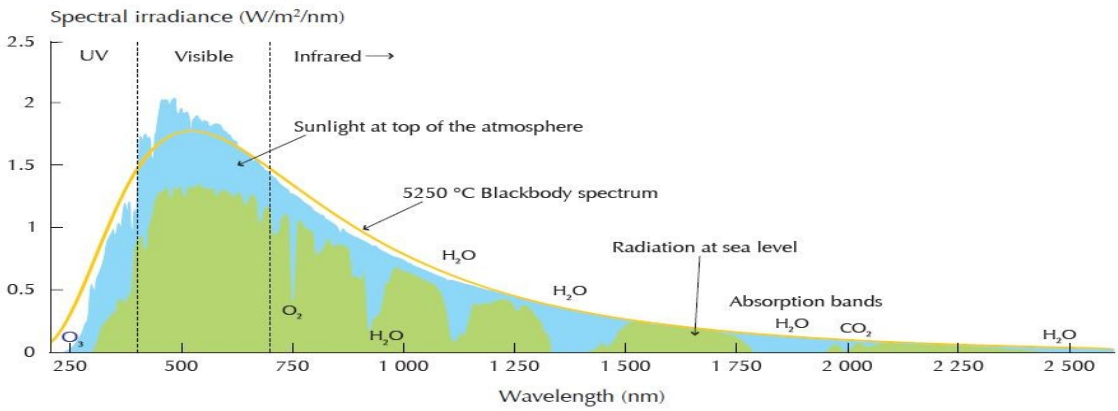


Figure 23: Spectral irradiance of the sun. Source: IEA, 2011[65]

As the energy output of a solar device is influenced by the duration of daylight, further geometric consideration have to be done about daylight duration and position of the sun in the sky.

The orbital plane of the Earth is posed at a degree of ε = 23,44° to the Equatorial plane, causing a different duration of the day in the two hemispheres during the year[16].

This angle ε, called obliquity affects the duration of the day: in Figure 24 we can notice that in winter the North Pole is always in the irradiated part of the globe and the South Pole completely in the shadow-side while in summer we have inverted conditions.

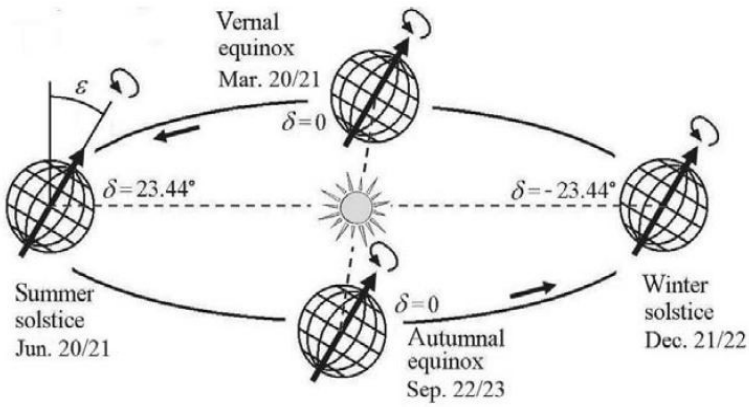


Figure 24: Obliquity: the orbital plane of Earth and the Equatorial plane stand at 23,44°. (Source: C.J. Chen,2014[16])

Thus we have a constant duration of day at the Equator (always 12 hours) and a variable duration of day at the other latitudes.

The sun has a different position in the sky during the year: the height of the sun from the horizon at a certain latitude is defined declination δ.

The declination δ in a certain day of the year N can be described making simplified geometric considerations.

The apparent motion of the sun above and under the Equator completes a cycle during a year and can thus be described by a sinusoidal function of the mean longitude l.

The maximum amplitude of the sinusoidal function is the obliquity ε, thus:

$$\delta = \epsilon \cdot \sin\ l \simeq \epsilon\ \sin\left(\frac{2\ \pi\ (N - 80)}{365{,}2422}\right)$$

In the formula above a linear dependence of the mean longitude l with the day of the year was assumed [16].

Depending on the position of the Sun in the sky the incidence angle on a surface varies and also the collected radiation, this situation is known as the cosine effect.

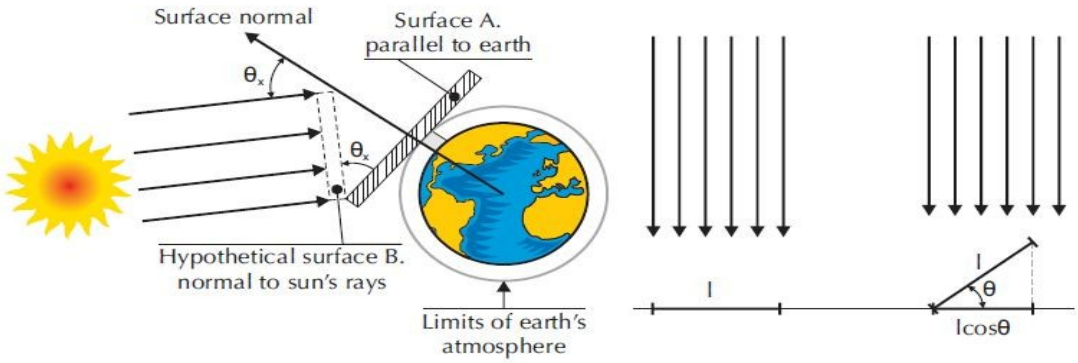


Figure 25: The cosine effect: when the incoming solar radiation hits an inclined surface the radiation is spread in function of the inclination. (Source: IEA, 2011[64])

In Figure 25 we see that a surface posed normally to the radiation collects more beams than an inclined surface: defining the incoming intensity with the vector **I** and the surface through its normal versor N, we obtain the incident intensity **I:**

$$I = \vec{I} \cdot \vec{N} = I \cos \theta$$

The angle θ is a function of:

- the declination δ = angle between the ecliptic and the equatorial plane
- the latitude Φ = angle between the equator and the position of the observer
- the hour angle ω = angle between the position of the sun at noon and the position of the sun at the given time
- the polar angle β = inclination of the surface with respect of the plane tangent to the Earth surface in that point (horizontal surface)
- the azimuth angle γ = angle between the south point of the horizon and the surface

$$\cos \theta = \sin \delta \left(\sin \phi \cos \beta - \cos \phi \sin \beta \cos \gamma\right) + \\ + \cos \delta \left(\cos \phi \cos \beta \cos \omega + \sin \phi \sin \beta \cos \gamma \cos \omega + \sin \beta \sin \gamma \sin \omega\right)$$

Four cases are of main interest:

1. horizontal surface (β=0)
2. latitude tilt condition (β=ϕ)
3. solar tracking surface (θ = 0)

vertical surface facing south (β=π/2; γ=0)

For a horizontal surface cosθ can be written as:

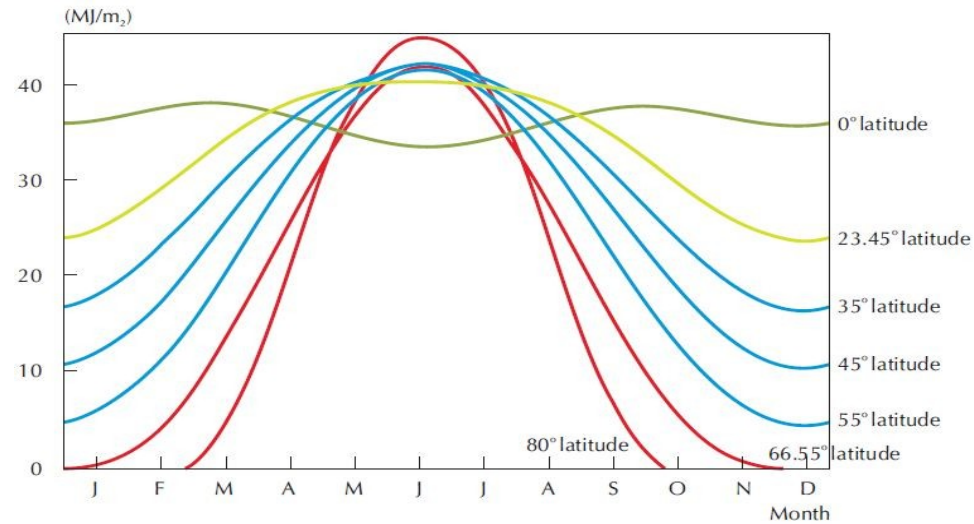


Figure 26: Daily incident power on a horizontal surface on Earth for different latitudes (Source: IEA, 2011 [65])

$$\cos\theta = \sin\phi \sin\delta + \cos\delta \cos\phi \cos\omega$$

Thus the power income in a day can be expressed as a function of the mean incident power:

$$I_{day} = I_{mean} \left(\frac{24}{\pi} \sin\phi \sin\delta + \right.$$
$$\left. + \frac{12}{\pi} \cos\delta \cos\phi \int_{-\omega_s}^{+\omega_s} \cos\omega \, d\omega \right)$$

In this equation the declination, the sunset and the sunrise depend on the day of the year, thus the daily income power varies over a year.

Figure 27 shows the daily income power over a year for different latitudes.

It can be demonstrated that the most profitable static positioning for a solar device is the latitude tilt: when β=ϕ the surface enjoys maximum power income almost all the year.

The cosθ is reduced to

$$\cos\theta = \cos\delta \cos\omega$$

and the incident power can be written as

$$I_{day} = \begin{cases} I_{mean} \frac{24}{\pi} \cos\delta & spring, summer \\ I_{mean} \frac{12}{\pi} \cos\delta \sin\omega_s & autumn, winter \end{cases}$$

Obviously the maximum energy input is obtained with solar tracking: if the surface follows the motion of the sun the angle of incidence can be fixed at θ=0.

Consequently cosθ=1 and

$$I_{day} = \frac{12}{\pi} \cos\delta \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos\omega \, d\omega = ¿$$

$$¿ \frac{24}{\pi} \cos\delta$$

In some cases, further variables affect the time-span of the incoming radiation: the surface itself can be positioned to be in shadow under certain conditions and obstacles can hide the sun.

For example the daily irradiation on a vertical surface facing south is limited to the timespan when the sun is in the southern half of the sky.

The cosine of the incidence angle can be written as

$$\cos\theta = \cos\delta \cos\omega \sin\phi$$
$$- \sin\delta \cos\phi$$

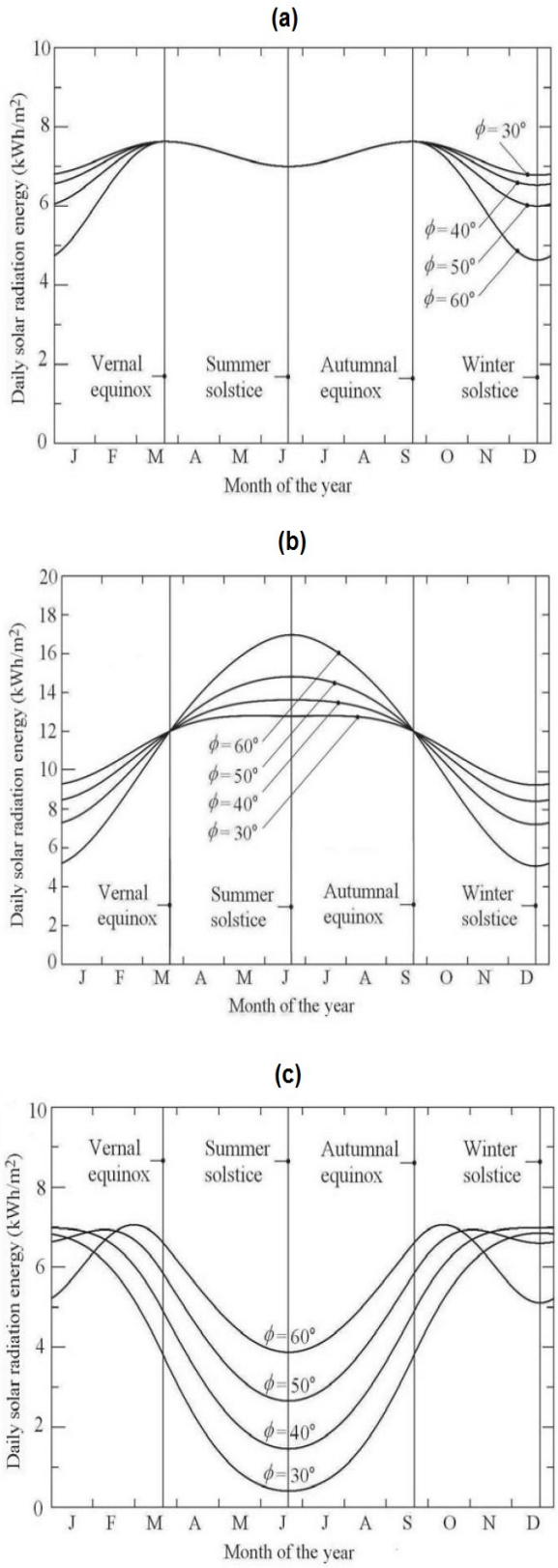


Figure 27: Daily irradiation curve for different expositions: (a) latitude tilt; (b) sun-tracking; (c) vertical surface facing south.(Source: C.J. Chen, 2014, [16])

In autumn and winter the sun is always in the southern half of the sky and we have:

$$I_{day} = \frac{12}{\pi} \cos\delta \sin\phi \int_{-\omega_s}^{\omega_s} \cos\omega \, d\omega - \frac{24}{\pi} \omega_s \sin\delta \cos\phi$$

$$= \frac{24}{\pi} \cos\delta \sin\phi \sin\omega_s - \frac{24}{\pi} \omega_s \sin\delta \cos\phi$$

In spring and summer we have to substitute the integration limits of sunrise and sunset (+/- ω_s) with the angle at which the sun passes to the northern half of the sky, ω_{ew}: $\cos\omega_{ew} = \tan\delta \cot\phi$

So for spring and summer the daily incident radiation is:

$$I_{day} = \frac{12}{\pi} \cos\delta \sin\phi \int_{-\omega_{ew}}^{\omega_{ew}} \cos\omega \, d\omega - \frac{24}{pi} \omega_{ew} \sin\delta \cos\phi$$

The upper examples show how the positioning of a solar panel affects the harvesting of solar energy, the daily radiation incomes are shown in Figure 27.

In practice the positioning of the surface depends on outer conditions.

On one hand higher costs and technical feasibility prevents the diffusion of solar tracking devices especially for private installations, on the other hand the availability of proper installation places affects the orientation of the devices.

While in industrial applications it is likely that the devices are installed in locations chosen on purpose, in private applications the available surfaces have already boundary conditions such as:

- inclination
- orientation
- shadowing

A simple example of these conditions is the positioning on a roof or a wall: the inclination and the orientation angles are usually those of the roof or wall.

Shadowing conditions can occur when big objects hide the sun: in presence of big buildings, mountains and vegetation the solar radiation can be blocked for certain time-spans.

To evaluate if there are shadowing conditions the location is usually analysed and the radiation income can be evaluated by the upper equations introducing the shadowing time-span.

Also the atmosphere plays an important role affecting the radiation income at ground level: both meteorological conditions and interaction with the gases of the atmosphere have an attenuation effect.

The interaction of the radiation with the atmosphere is schematically shown in Figure 28, the main effects are the characteristic absorption bands of the main atmospheric gases (oxygen, ozone, water-vapour) and an overall attenuation (Figure 23).

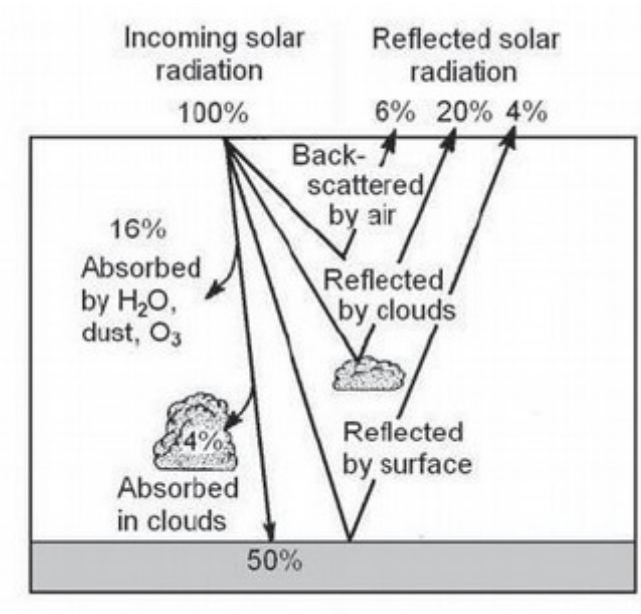


Figure 28: Interaction of incoming radiation with the atmosphere. (Source: C.J. Chen, 2014 [16])

In order to evaluate the incoming radiation at the ground, the best method is to analyse time-series of measured values: unfortunately the measurements need to be done with proper devices called pyranometers and are consequently punctual.
In presence of measured data from a meteorological network the evaluation of the incoming radiance can be done by statistical study of the time-series and spatial interpolation.
In conclusion, to know the incoming radiation on a surface following variables have to be taken into account:

- geometry of the surface
- geographical positioning
- measured/interpolated incoming radiation at the chosen location
- shadowing effects (obstacles)

To evaluate the incident radiation the Renewable Energy Unit a department of the European Commission Joint Research Centre has developed the Photovoltaic Geographical Information System (PVGIS): a map based inventory that allows the calculation of monthly incident radiance for Europe, Africa, and South-West Asia[36].
PVGIS evaluates following information from databases:

1. monthly averages (period: 1981-1990) of daily sums of global and diffuse irradiation, measured or calculated for 566 ground meteorological stations
2. Linke turbidity
3. digital elevation model with a grid resolution 1×1 km; derived from the USGS data
4. land cover
5. satellite data
6. geographical data

Now that we know how the source behaves, we should consider the functioning of the devices.

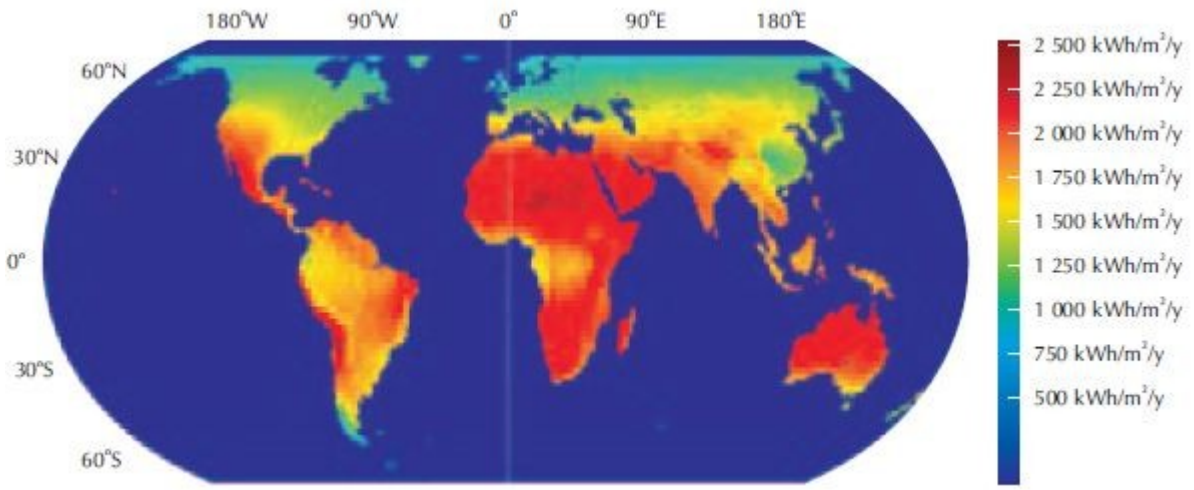


Figure 29: Yearly global solar irradiance flux at the Earth's surface (in [kWh/m²y]). Source: IEA, 2011 [64]

4.2.2 Solar energy technologies: photovoltaics

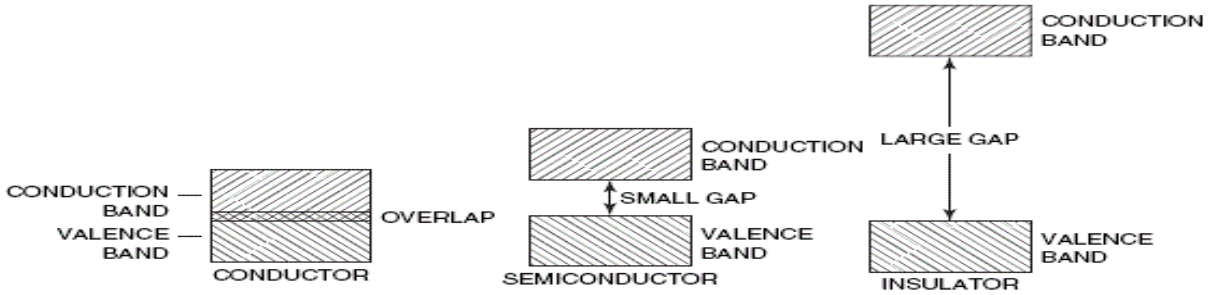


Figure 30: Scheme of the positioning of valence and conduction band in conductors, semiconductors and dielectric materials.(Source: Kittel, 2005 [17])

Two are the main families of solar-based technologies: photovoltaics and solar thermal.
The photovoltaic technologies are based on the photoelectric effect in semiconductors.
The photoelectric effect occurs when incident photons have enough energy to excite the electrons of the valence band to the conduction band.
The valence band of a material is defined as the outer non-empty group of energy levels at a temperature of 0 K.
The conduction band is the group of energy levels right above the valence band.
Depending on the relative position of the two bands the materials are classified in conductors, semiconductors and dielectric: the dielectric materials are those in which the energy gap between the two bands is high, the semiconductors have a little energy gap and conductors have superposition of valence and conduction band (Figure 30).
In semiconductors the energy gap E_g between the valence and conduction bands is such that at room temperature electrons can be excited from the valence to the conduction band.
To enhance semiconductor properties in crystalline materials they can be engineered with a technique called doping: the deliberate addition of impurities in a material enhances conductivity.
Two are the types of doping: in n-doped materials the impurities have one valence electron more than the base material (group V materials doped with group IV materials), thus the remaining electron is available for conduction; in p-doped material the impurities have one valence electron less than the base material (group IV materials doped with group III materials), thus a positive charged gap is formed. This positive gap is likely to be filled by adjacent electrons and so it moves creating conduction.
As a consequence in n-semiconductors the charge carriers are negative (electrons) and in p-semiconductors the carriers are positive (holes).

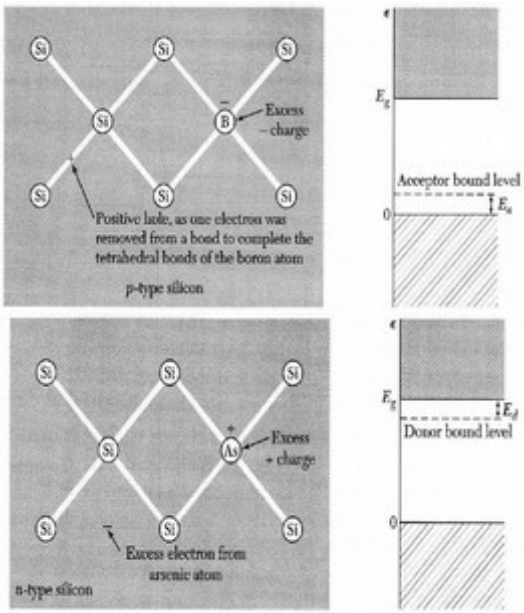


Figure 31: Upper: n-type silicon. Lower: p-type silicon(Source: Kittel, 2005 [17])

The effect of doping is shown in Figure 31: in the n-type the impurity is an electron donor and its presence lowers the conduction band-edge while in the p-type the impurity is an electron acceptor and heightens the valence band-edge.

In both cases the doping reduces the energy gap E_g: the magnitude of the energy gap is such that proper radiation can excite the electrons of the valence band to the conduction band.

The energy required for conduction can be delivered by incoming radiation of the proper frequency:

$$E_g = h\ \nu$$

The conduction induced in a material by incoming radiation of proper frequency is defined as photoelectric effect.

To generate electric power from the photoelectric effect in a semiconductor an asymmetry has to be introduced in the material: such a device is called p-n junction.

In a p-n junction a n-semiconductor is in contact with a p-semiconductor.

When conduction conditions occur in the n-material electrons are free to move, while in the p-materials we have moving holes, at the interface of the two materials the holes will diffuse to the n-material and the electrons to the p-material until a dynamic electric equilibrium is reached.

Thus, at the junction surface a positive charged layer and a negative charged layer form with the generation of an electric potential V.

In a photovoltaic device many p-n junctions are connected in parallel to generate power.

The efficiency of photovoltaic cells depend on the material used and on the constructional characteristics.

In Figure 32 we see a comparison of efficiency of different photovoltaic cells.

Actually the most diffuse photovoltaic cells on the market are the crystalline silicon cells.

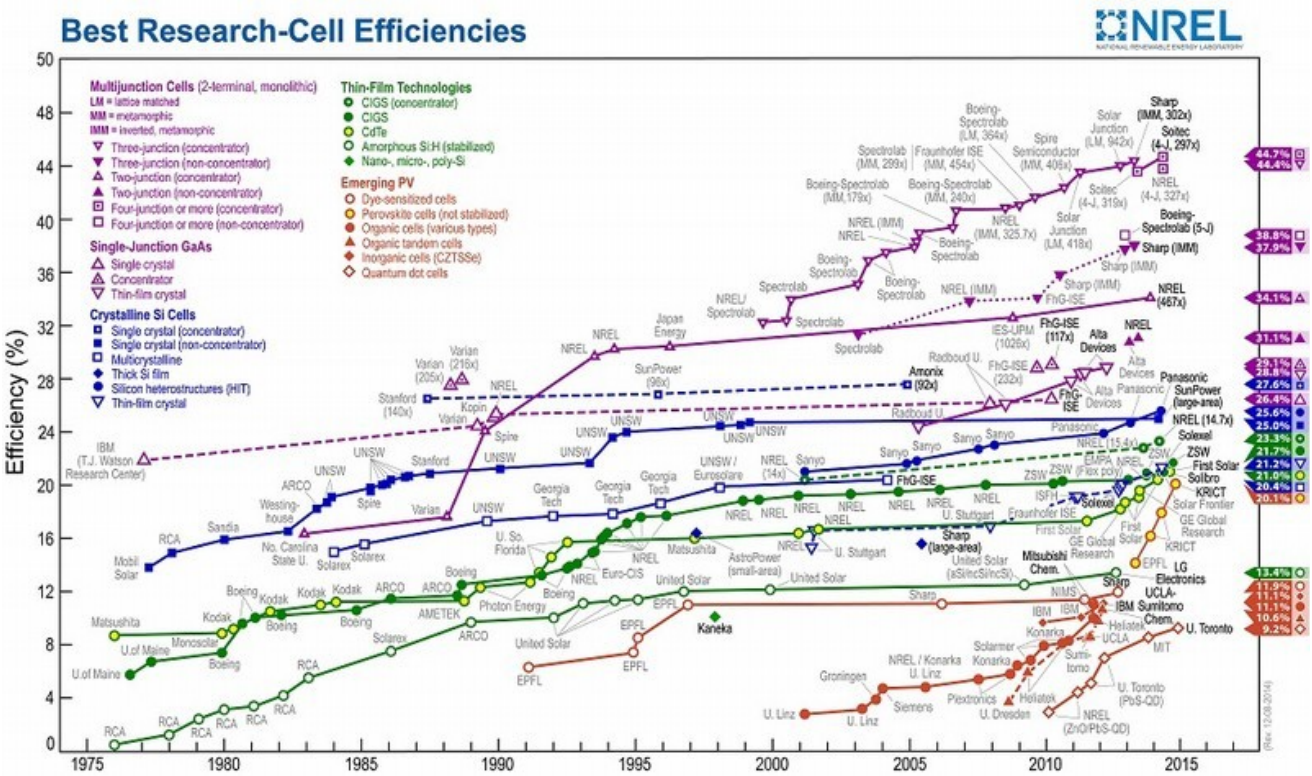


Figure 32: Efficiency of photovoltaic cells. (Source: NREL [89])

4.2.3 Solar energy technologies: solar thermal collectors

The solar thermal technologies are based on the conversion of incoming solar radiation into heat.
There are different types of solar collectors:

1. flat-plate collectors
2. evacuated-tube collectors
3. compound parabolic collectors

Figure 33 shows a typical flat-plate collector: pipe is posed in an outer casing, behind a tempered solar glass.
To optimize the energy uptake and the conversion in heat the panel is insulated at the back and the pipe lies on a heat-absorbing layer.
The cold water is let in at the bottom and flows upwards when heated due to convection.
The most important factors that influence the efficiency of flat-plate panels are related to the materials used: optimal insulation, highly transparent glass, proper absorber and coatings.
The losses of a flat-plate collector are schematically shown in Figure 34.
Thus the efficiency of a thermal solar panel depends on the thermal losses and on the outer temperature.

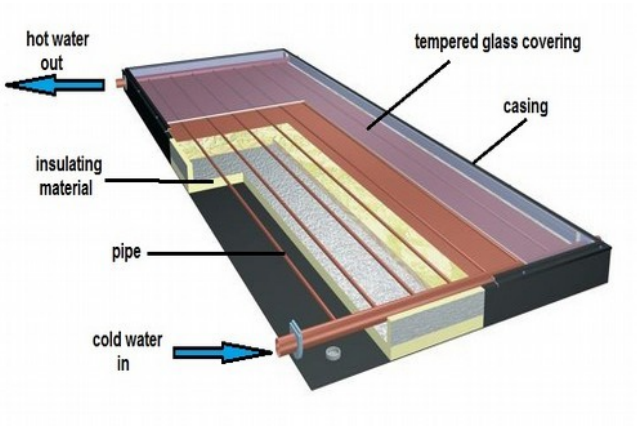


Figure 33: Solar flat-plate collector. (Modified from: SunEarth Inc.[124])

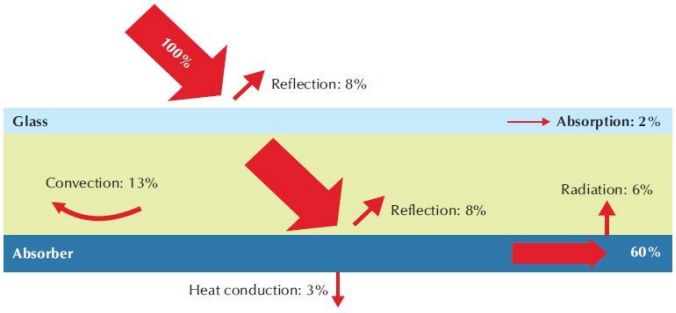


Figure 34: Losses of a flat-plate collector. (Source: IEA, 2011 [64])

Different constructional types of collectors show different behaviours: in Figure 35 three types of collectors are compared and their efficiency outlined.

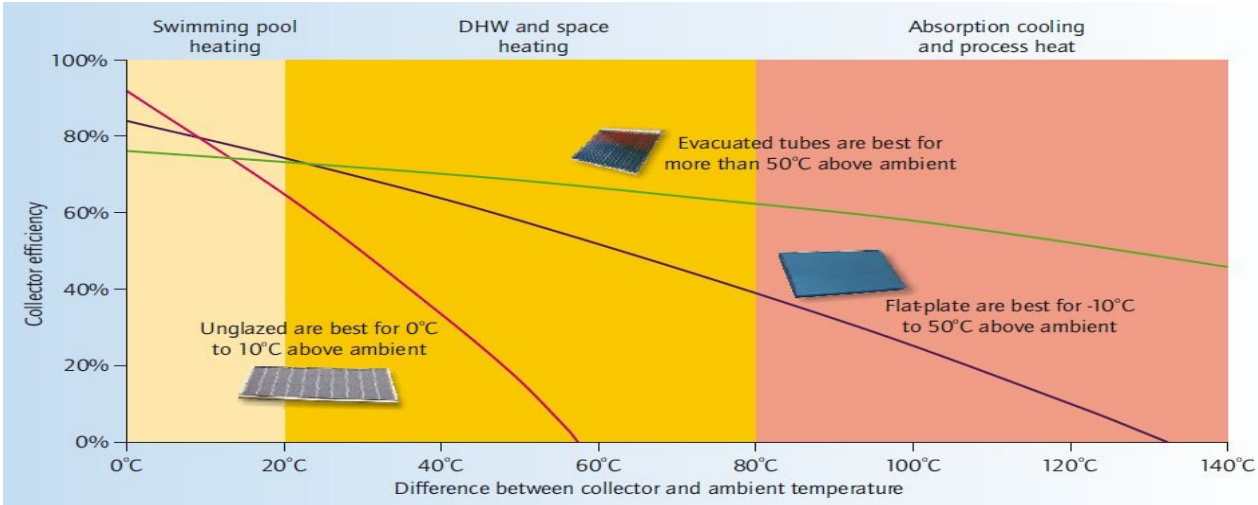


Figure 35: Efficiency of different types of solar collectors in function of the temperature difference between collector and ambient. (Source: IEA, 2014 [61])

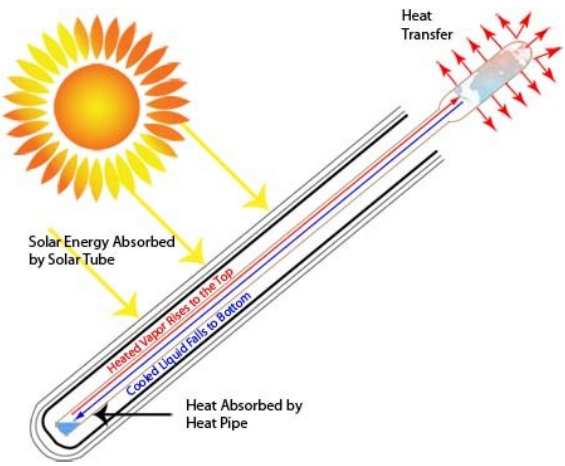


Figure 36: Evacuated tube functioning principle. (Source:[75])

Flat-plate collectors show good efficiency in achieving low to middle temperature differences (-10° to 50 ° C) while evacuated tube collectors have good efficiency in the whole interval.
As a consequence evacuated tube collectors have better performance at higher latitudes (temperate and above) and are also suitable for industrial applications.
The better efficiency of the evacuated tube technology comes from high insulation of the heat-pipes: in this kind of collectors the heat-absorbing pipes are posed singularly in a battery of tubes under vacuum.
It is well known that vacuum has high thermal insulating properties: conduction and convection are precluded and only the radiative component of thermal transmission is allowed.
Contrary to the flat-plate, the pipes in the vacuum-tube are closed at the top (Figure 36).
Proper coatings of the pipe allow the transformation of radiation into heat.
The heat absorbed at the surface of the pipe is transmitted to an inner fluid, usually water, that increases its temperature and moves to the top of the pipe due to convection.
At the closed top of the pipe a heat-exchanger transmits the collected heat from the pipe to the warm-water system of the building: the warm fluid cools down and gets back to the bottom of the pipe where the heating and convection cycle begins again.
Due to constructional properties, evacuated tube systems have shown to be suitable for low environmental temperature and high output temperature applications.

4.2.4 Solar concentration

Solar concentration technologies are based on the concentration of incoming radiation: the incoming beams are focused on pipes or devices and heat a fluid.
The heated fluid is then transported to electrical power generation, usually a conventional steam cycle.
The geometries of the system are principally four:

1. line focus, fixed receiver
2. line focus, mobile receiver
3. point focus, fixed receiver
4. point focus, mobile receiver.

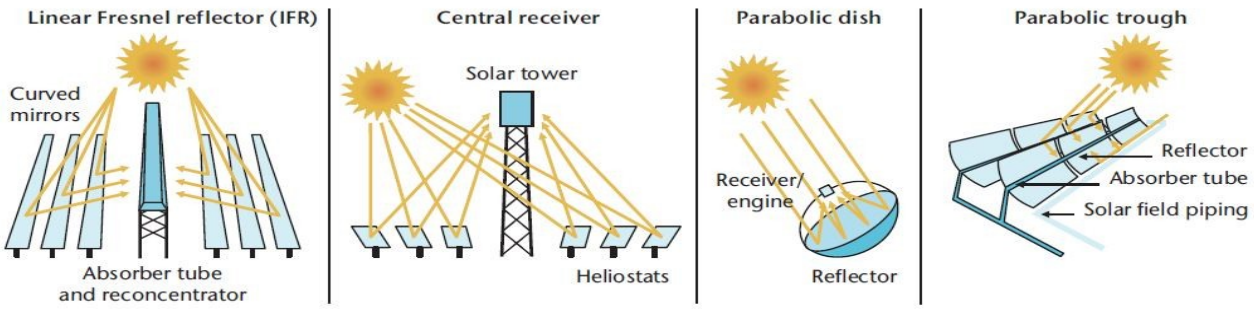


Figure 37: Concentrating Solar Power: scheme of technologies. (Source: IEA, 2011 [65])

From the point of view of the focus while in the line focus technologies curved mirrors or parabolic troughs focus the incoming beams on a line, in the point focus the incoming beams are concentrated to a point.
If the receiver is fixed the collecting of heat is easier but, as shown in section 4.2.1. mobile receivers with sun-tracking harvest more energy.
Linear Fresnel Reflectors are used in line focusing in combination with mirrors: the incident radiation is reflected by the mirrors and collected by a line of Fresnel lenses.
The Fresnel lenses are specific optical devices that concentrate a set of parallel incoming beams to a point (the focal point) [18].
A line of Fresnel lenses allow to concentrate the incoming beams on a pipe where a proper fluid (water or diathermic oil) is heated.
The heated fluid is then sent to a conventional steam cycle for electric power generation. Similarly, the line focusing of parabolic troughs is pointed at a pipe.
In this case the focusing device is the mirror parabolic through itself and the beam is concentrated on the pipe.
The main difference between parabolic troughs and linear Fresnel reflector is the sun-tracking: while the linear Fresnel system has a fixed receiver, the parabolic troughs and their receiver follow the motion of the sun.
The two types of point-focusing devices are shown in Figure 38 (a) and (d): while in the central tower technology a field of heliostats concentrates the incoming radiation to a central receiver in a tower, in parabolic dishes the receiver is mounted at the focus point of the parable and the whole device follows the motion of the sun. The upper technologies are industrial applications and require the availability of big areas, thus the application should be restricted to unproductive land.

Figure 38: (a)Solar Tower: point focus, fixed receiver. (b) Mirrors and Fresnel lens receiver: linear focus, fixed receiver. (c) Parabolic through: linear focus, mobile reciver (d) Parabolic dish: point focus, mobile receiver (Sources: DLR and Spartansaving [48][117])

4.3 Wind energy

Figure 39: Wind power plant. (Source: [114])

Among the green Power technologies the wind power generation is the most discussed one.
The main problems about wind power generation are:

- landscape and artistic protection
- use of land
- location and availability of proper wind-system

Under the point of view of landscape big discussions rise every time a wind-power plant is planned: especially in lands with high artistic value and a deep consciousness about landscape aesthetics a big point in power plants development is the induced landscape change.
Possible negative effects on local economy, especially on tourism, often stop the development of wind power plants.
Further problems arise in the use of land: a wind-power plant needs open areas to be installed and disturbs some agricultural activities.
Furthermore, to achieve an economic profitable power generation also the geographic location has to be chosen properly: the existence of proper wind-systems with a high presence of wind in a good speed-range is the first requirement for a wind power plant installation.
The technical key-points in location choice can be understood by comprehending the technical features of aeolian devices.
Wind is caused by variations in pressure and temperature in the air: it is basically a movement of masses of air.
From the ideal gas law we know that pressure and temperature are proportional to the volume of a gas.
Thus a variation in temperature induces a variation in density and the mass of air will tend to move upwards.
As the density of a fluid ρ is defined as the ratio between the mass m and the occupied volume V, the force of the moving air mass can be written as:

$$F = m \cdot \vec{a} = \Delta \rho \cdot V \cdot \vec{g}$$

The kinetic energy of the wind is:

$$E = \frac{1}{2} m \cdot v^2$$

Where v is the velocity of wind and m the mass in movement.
The mass of air that passes through the surface area A of the rotor of the device is m=Av.
Now, considering the overall efficiency of the device c_p, the output power can be written in function of the wind-speed:

$$P = \frac{1}{2} A v^3 c_p (v)$$

Also the efficiency of the device c_p is a function of the wind-speed[74][9][119].
From this equation we see that the power generation from wind depends on:

1. wind-speed
2. surface exposed to the flow
3. constructional characteristics

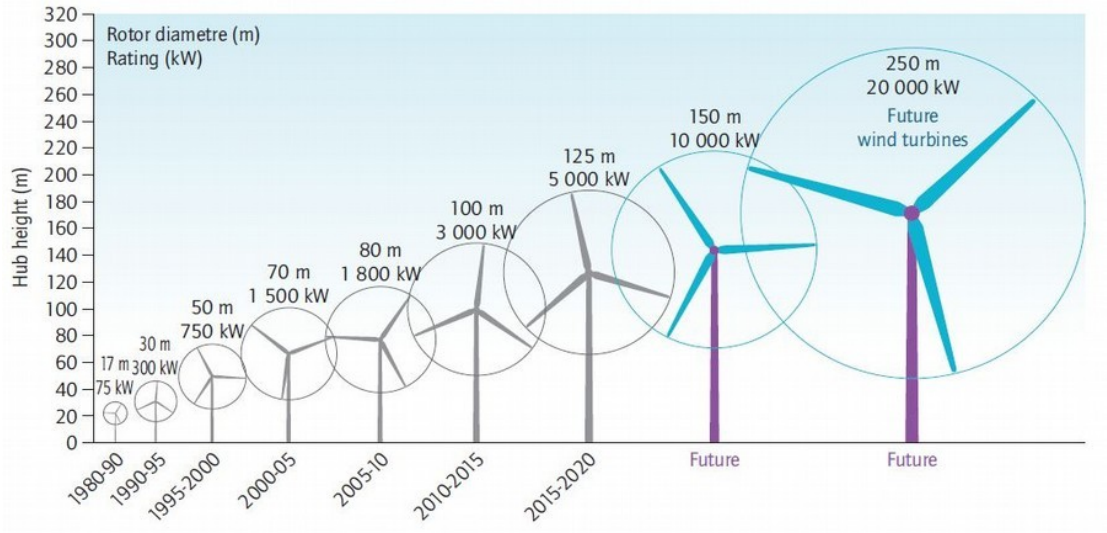


Figure 40: Growth of the size of wind turbines. (Source:IEA,2013 [63])

The wind speed is the main variable affecting the power output, thus it is the most important point in the location choice.
Furthermore, it is well known that wind-speed increases with height, thus the height of the tower indirectly influences the efficiency.
Also the size of the turbine affects the output power, but the increasing height, weight and needed space lead to higher constructional costs.
The bigger the rotor the more proper technical solutions for the tower, the nacelle and the foundations or anchorage are needed.
In Figure 40 we see that the size of the turbines is constantly growing.
Also the design of the rotor affects the efficiency of the device.
A first classification can be done on hand of the rotation axis: in Figure 41 we can see different design for horizontal and vertical axis rotors.
The best efficiencies are achieved by horizontal axis rotors, especially in the windward type (c_p=0,5)[74].
The power generation of wind-turbines depends also on mechanical boundaries: too low wind-speeds are insufficient to put the turbine in motion, while too high wind speeds generate mechanical stress and the turbine has to be stopped.
Thus every turbine has an operational range.

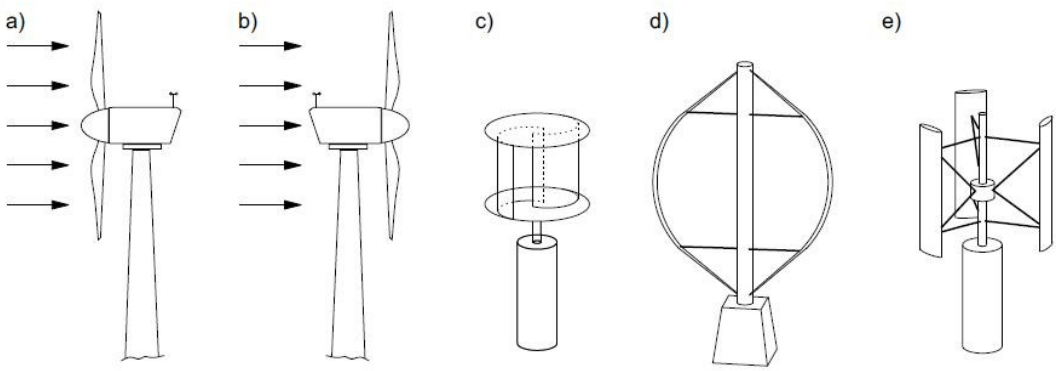


Figure 41: Different designed turbines, classification with regard to the rotation axis and direction of incident wind-flow: (a) horizontal axis, luvward; (b) horizontal axis leeward; (c) vertical axis, Savonius type; (d) vertical axis, Darrenius type; (e) vertical axis, H-type. (Source: Heuk 2013 [74])

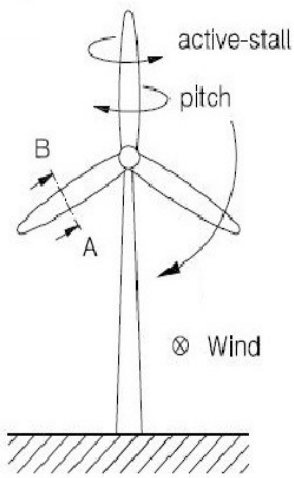


Figure 42: Rotor blades regulation: rotating the blades the exposed surface varies and the rotation speed is regulated. (modified from: Heuk, 2013[74])

To enhance the productivity of a wind turbine also the aerodynamics of the rotor blades has to be considered: when the wind hits the blades it acts a force on the surface ad puts the rotor in motion.
To control the speed of the rotor the blades can be designed to rotate also around their axis: with proper rotation the exposed surface can be varied in response to wind speed with optimization of the motion of the rotor.
The first type of motion control is the aerodynamic braking of the rotor: the shape of the blades is designed in a way that over a certain threshold wind-speed the blade has a self-stalling action.
This control is called stall.
The other two types of control consist in the rotation of the blades in order to reduce the wind exposed surface.
In pitch control the blades are rotated around their own axis.
The rotation of the blades gradually brings the active surface parallel to wind direction and the rotation stops when no active surface is exposed.
The active-stall regulation is a composition of pitch and stall: at a certain threshold the blades begin to rotate around their axis until the upper operational limit is reached.
The surface of the blades is designed in such a way that at the upper operational limit it has an aero-dynamic braking effect like in the stall controlling.
The power output is affected by the regulation type: while the stall regulation allows a higher efficiency peak, it has a decreasing efficiency in the nominal range; the active-stall and the pitch regulations have a constant power output in the nominal range but the pitch regulation reaches the nominal range earlier.
On contrary the active-stall type reaches the nominal range at higher wind-speeds but the aerodynamic braking effect of the blades gives more stability of the output in response to quick wind-speed oscillations.

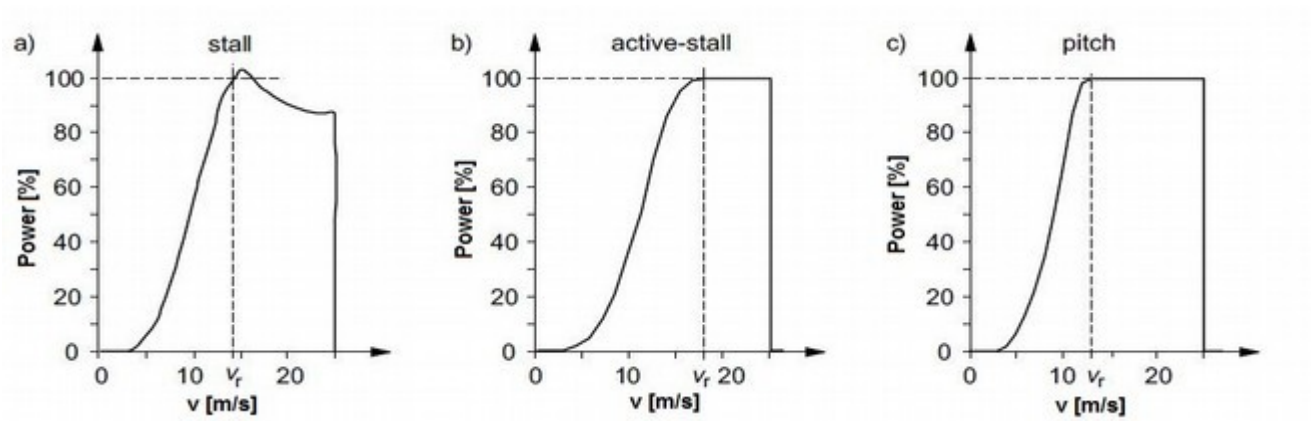


Figure 43: Power output in regulated turbines. (a) stall; (b) active-stall; (c) pitch. (Source:Heuk, 2013[74])

4.4 Biomass

The term biomass is used to indicate all the materials of biologic origin.
This definition comprises a big number of different materials with different properties.
To obtain energy from these different products different processes are applied.
There is not a unique classification of biomass and the processes involved and also in the existing classifications borders between classes are not univocally defined: more than borders there are ranges of application that can intersect.
A first classification can be done on hand of the biomass type:

1. woody biomass
2. energy crops
3. liquid biomass
4. agricultural residues

Figure 44: Energy crops. Source: [136]

Woody biomass is characterized by high presence of lignine and cellulose that, under proper conditions, are capable to be oxidized directly by burning.
Energy crops are plants that can be cultivated and destined to power supply and fuels productions.
Liquid biomass is represented by all the substances and oils of biologic origin that are fluid.
Agricultural residues are by-products and wastes coming from agricultural activities.
A classification that has a more important social and ethical meaning divides the biomass in energy crop, woody biomass and wastes.
This classification allows to threat ethic and social impacts such as land-use and destination of crops: actual policies try to avoid the use of food-crops for energy production, furthermore the use of land for energy production has to be planned and hold into certain boundaries in order to avoid resource and soil depletion.
The actual trend is to shift the energy production from energy crops to by-products and wastes.
The use of by-products and wastes improves the overall efficiency and avoids resource depletion: the content of energy and mass is no more thrown away but used to produce fuels, chemicals and heat/power.
This further exploitation of wastes leads to diminution of residual waste and disposal costs.
The variety of materials leads also to a variety of techniques and processes.
A general classification of the processes comprises:

1. burning
2. physical processes
3. thermo-chemical processes
4. bio-chemical processes

All these processes have in common the final oxidation of the material: the energy is finally obtained from the oxidation of the chemical bounds.
The following formula (in which the stoichiometry is neglected) shows the complete oxidation of an organic compound.

$$C_n H_m + O_2 \rightarrow C O_2 + H_2 O$$

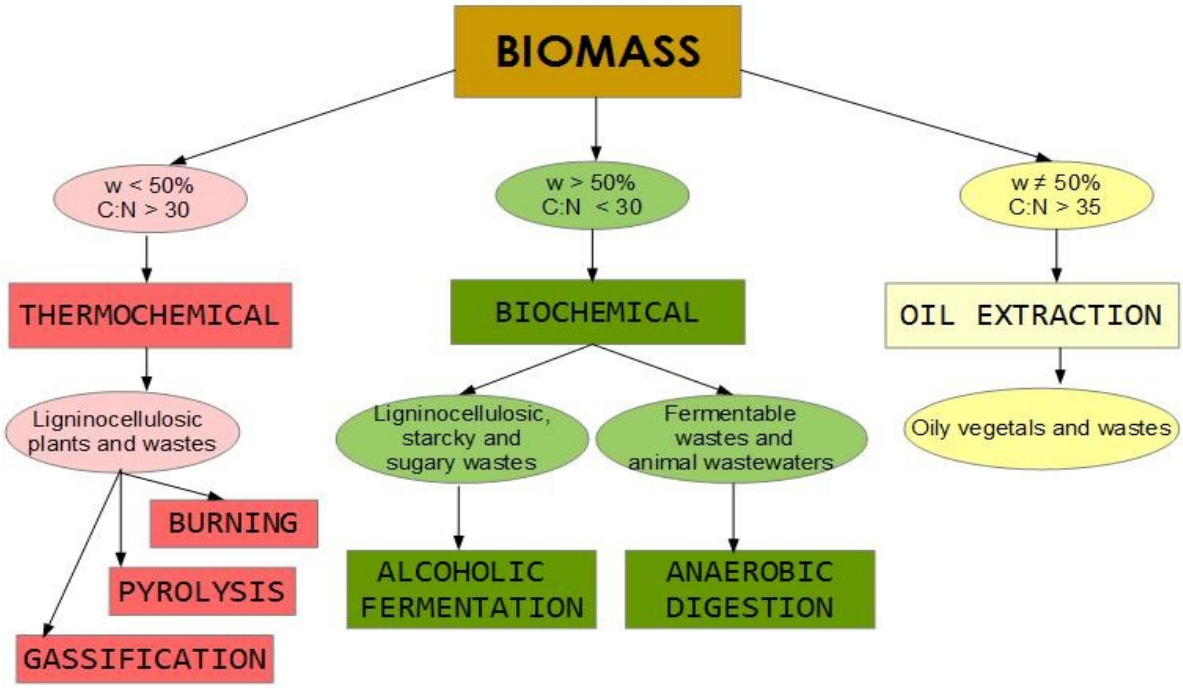


Figure 45: overall classification of processes in energy production from biomass.(Translated from: Lazzarin, 2005 [103]).

In practice biomass is not only composed by carbon (C) and hydrogen (H) but contains also amounts of nitrogen (N), phosphor (P), potassium (K), calcium (Ca), magnesium (Mg) and other minor compounds that affect the processes involved in energy generation.
The upper reaction can be achieved completely in one process (for example by burning) or in a composition of processes that can also take place at different moment and places.
As first the raw biomass has to be harvested, transported and treated (mechanically or thermally).
Depending on its chemical and physical properties the treated biomass undergoes different processes:

- dry biomass (water content < 50%) with high content of lignine and cellulose and low content of Nitrogen (C:N > 30) is suitable for thermochemical processes like burning, pyrolysis and gassification
- wet biomass (water content < 50%) with high content of Nitrogen (C:N < 30) can undergo two types of biochemical processes. Biomass with high content of lignine, cellulose, stark and sugar is suitable for alcoholic fermentation, while fermentable wastes and animal sludge can be anaerobic digested.
- Oily biomass can undergo oil extraction

Figure 45 [103]
Three are the possible thermochemical processes:

- pyrolysis
- gassification
- burning

They have different reaction conditions: the main variables used to distinguish these three processes are the temperature and the furnished air.
To assess the type of process a common parameter is the excess air ratio λ.
λ is the quotient between the furnished air and the minimum necessary to complete the oxidation:

$$\lambda = \frac{m_{fournished}}{m_{min}}$$

It is an index of the capacity of the system to complete the oxidation, thus the higher λ is, the higher is the oxidation degree.

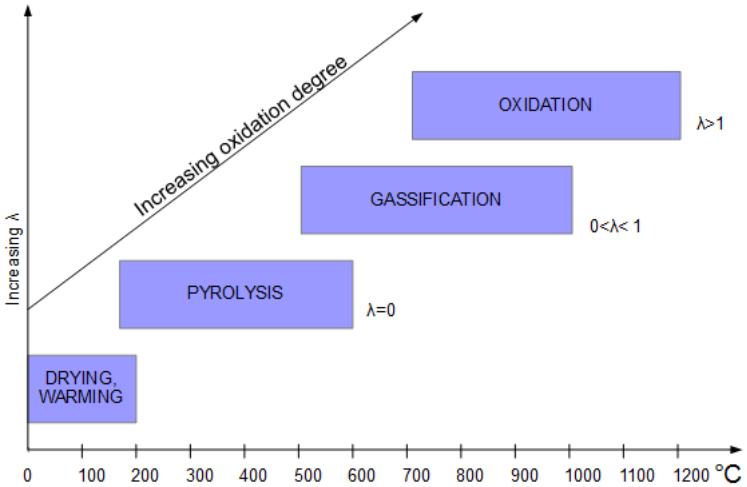


Figure 46: Overview of thermochemical processes. Adapted from: Kaltschmitt, 2009[84]

In pyrolysis and gassification λ is low and the biomass is not completely oxidized: we have the production of intermediate substances that can be used as fuels.
The only partial oxidation of the products means that they have left a certain amount of energy in their chemical bounds.
The products of pyrolysis and gassification can be liquid, solid or gaseous substances capable to be stored, transported and used when needed.
The complete oxidation is wanted and carried out in the burning processes.
The functioning principle of the burning technologies is to obtain all the energy stored as chemical bounds from the biomass in form of heat and transmit it to the end-user.
A first classification can be done by the type of device: home systems usually have less installed power and less control systems while industrial burners have higher power output and more control systems.
The home fireplaces, ovens and boilers can usually be turned on and shut down in response to the energy demand.
They can be manually driven or have automatic control systems with proper sensors and electronics.
Industrial burning systems have combustion chambers of different sizes and different designs.
The biomass is charged automatically and the burning conditions are controlled by sensors.
The control of the combustion conditions allows to maximize the efficiency and reduce dangerous emissions.

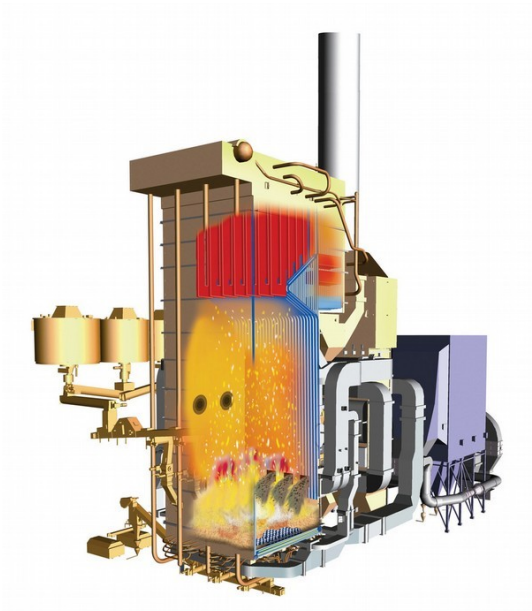


Figure 47: Industrial burner. Source: biomassmagazine.com [76]

Furthermore, the control of the combustion allows the regulation of the heat output in the operational range (usually from 30 to 100 %)[84].

The heat produced in industrial burners has four main destination possibilities:

1. Process heat
2. District heat
3. Electrical power generation
4. Combined heat and power (CHP) generation

In process heat and district heat generation the energy generated by combustion is transmitted through a fluid, usually water, to the delivery network.
In the electric power generation the energy from combustion heats the water that is then sent to a steam cycle.
The efficiency of electrical power production from biomass is usually low, a solution to improve the overall efficiency and consequently the profit, is a CHP: the efficiency of electric power generation from biomass is of about 65 to 75 %, in CHP the efficiency can be driven up to 85-90%, from which about 40-45% is electrical power and the remaining is heat[84] [9].
This high efficiency of CHP makes it preferable and economically more profitable than the simple electric production.
Actually the main problems in CHP is the coupling of heat and power generation: most plants are designed in order to respond primary to heat demand, thus electricity generation follows the heat demand.
There are systems that decouple the two energy generations by excluding the heat transmission to the network, but they are more expensive and technically complicated.
Gassification and pyrolysis are the other two thermochemical methods for energy production from biomass: in these methods the biomass is oxidized only partially leading to the production of solid, liquid or gaseous fuels.
In presence of biomass with high content of water (w>50%) and higher content of Nitrogen the biochemical methodologies offer the best way to transform the biomass in fuels.
In both anaerobic digestion and alcoholic fermentation the constituents of biomass are processed by microbial colonies and transformed in fuels and chemicals.
The alcoholic fermentation transforms the glucose contained in cellulose, lignine, stark and sugars in ethanol: this transformation is carried out by consortia of micro-organisms that use the glucose as energy source and oxidise it to ethanol.
The anaerobic digestion is also carried out by consortia of micro-organisms and leads mainly to the production of methane.
The reaction conditions have to be strictly controlled due to competition of different chemical reactions.
Furthermore the environmental conditions in the reactors affect the composition of the microbial consortia from which depends the composition of the product.
The transformation of biomass into fuels has strict time dependency: every reactor has a maximum load and a residence time during which the biomass is transformed.
Due to storage capacity of the products, these methodologies finally result time-independent from the point of view of energy production.
When the biomass is oily it can undergo oil extraction: both mechanic and chemical methods can be used to extract the oils from biomass.
The products of the extraction are used as chemicals and fuels.
Also in this case the overall process results time-independent.

4.5 Time dependency in energy supply

The technical features discussed in the former sections influence the ability of supply technologies to promptly respond to variations in energy demand.
In order to insert the time dependencies in RegiOpt software a classification is needed.
The technologies can be divided in:

- technologies with constant time dependency
- controllable technologies
- time-dependent non-controllable technologies

4.5.1 Technologies with constant time dependency

This category comprises all technologies that have a constant power output over a year.
This is a virtual category because almost all energy supply technologies have a certain manageability but there are outer conditions that lead to stiffness.
The most important cases of constant time dependency are thermoelectric power plants: in such power-plants the thermal properties of materials allow only very slow oscillations in power output because the junctions and the pipes are susceptible to thermal shock.
This leads to stiffness in manageability and the power output will follow only very roughly oscillations in energy demand.
An example of this type of technology can be a nuclear power plant: the starting times can vary from a couple of hours to days and the variation of the output is avoided due to technical and economical requirements.
Classic fossil-fuel based electric power plants have different degrees of stiffness: starting times can vary between minutes (i.e. gas turbines) and hours (i.e. coal thermoelectric).
Concerning renewable-based power plants the following cases should be considered:

- hydroelectric on-flow power-plants in a river with constant water-flow (Q=cost.)
- dam power plants in which the storage allows a constant flow to the turbine

In the first case the constant power output comes from the proper location of the power-plant.
In the second case the proper dimensioning of the storage leads to the constant power output.
Other power plants that can be managed to have a constant output or for which a constant output is a good approximation are the biomass based electric power plants: this are particular cases that depend on the management and planning of the plant.

4.5.2 Controllable technologies

We define as controllable all those power generation technologies that can be managed in order to respond promptly to changes in energy demand.
Under these type we can list:

- pumped storage hydro-power
- energy from bio-fuels
- heat-only generation from biomass

In the first case the ability to react to changes in energy demand come from the proper planning and management of the power plants: proper dimensioning and adequate use affect the level of the water in the dam and thus the ability to produce power at the right moment.
In the second case, the storage possibility of bio-fuels allows to use them in rapidly governable processes suitable for energy peak response: for example gas turbines can be fired with bio-fuels and brought from 0 to 100% power output within minutes [9][74][119].

In all cases the storage possibility and transportability of bio-fuels allow the classification of all related power generation processes under the governable ones.
Actually, beside hydro-power, gas turbines are used in peak-load covering and many authors suggest that they will hold this role also in future: the use of bio-fuels to fire the turbines has been proven to be a valid alternative to fossil fuels.
The heat-only generation from biomass can be considered completely governable due to proper planning, heat-storage possibilities and biomass storage capacity: the proper planning and storing allow to respond quickly to demand changes.
As a consequence the main problems in biomass use are the proper dimensioning and the resource depletion.
Also in conventional and pumped storage hydro-power the central point to solve the time-dependencies is the proper dimensioning, planning and management of the plants.

4.5.3 Time dependent technologies

The category of most interest in studying time dependencies of energy supply is that of time dependent technologies.
Under this category we classify all the technologies that have strong time dependencies and are stiff in manageability: the output power is determined by outer conditions that can't be changed by man.
Solar-based energy production and wind-power are the two main technologies in this category: in chapter 4 we saw how the devices respond to the input energy from the source.
In solar technologies the output depends on the incident radiation thus variables that have to be considered are:

- motion of the sun
- geometry of the system sun-device
- weather/cloudiness
- efficiency of the device

Combining the information about these variables yearly power generation curves can be assessed (for example see PVGIS[36]).
When considering wind-power and assessing the power output the key-points are:

- efficiency of the device
- type of the rotor
- windiness of the location
- yearly wind patterns

We see that in this category we consider the supply technologies for which the discontinuity of the source causes a discontinuity in energy generation: this is a key issue for these technologies.
The two main problems in the development of Green Power networks are exactly resource depletion and energy security.
Now it can be outlined that while the PNS evaluates the first point successfully, it does not account the central problem for wind-power and solar energy: the economical feasibility and the success of these two energy supply families depends strongly on the possibility to integrate the periods of low production with other technologies.
Many authors suggest the development of biomass-based technologies and storage systems to implement solar and wind energy supply: while biomass and heat storage have proven to be good solutions, electrical storage systems are still very costly.
The actual trend in electrical storage systems is to convert the energy to mechanical/potential energy that can be stored.

Two main examples can be the pumped storage hydro-power and the compressed air energy storage: these two solutions require proper spaces and are intensive in costs and construction.

4.6 Classification of technologies

As a result of the evaluation of technical features of energy supply technologies and the considerations done in the previous chapters a classification of the technologies was achieved and the relevant ones were identified.
In the following table an overview of the relevant technologies and the main variables that cause their strong time-dependency is shown.

Table 3: Classification of relevant supply technologies on hand of the time dependency

	ENERGY	TYPE OF TIME DEPENDENCY	MAIN VARIABLES
ON-FLOW HYDROPOWER	electricity	non-controllable	water flow rate (Q)
CONVENTIONAL HYDROPOWER	electricity	controllable	-
PUMPED STORAGE	electricity	controllable	-
PHOTOVOLTAICS	electricity	non-controllable	sun motion position weather
THERMAL SOLAR	heat	non-controllable	sun motion position weather
WIND-POWER	electricity	non-controllable	wind-speed
CHP	electricity	controllable	-
	heat	controllable	-
BIOMASS (without CHP)	heat	controllable	-
	electricity	controllable	-

5. Time dependency of energy demand

The study of energy demand is always required in energy network planning.
The energy companies need to know and predict precisely the loads to act properly in the national markets and to avoid grid overload and power losses.
Professional software for energy companies allow simulations with different resolutions: from days to minutes.
For example HOMER has an output resolution up to a quarter of hour[88].
In general the main actors in electric power supply are the power grid authority which controls the national transmission network, the electric energy market authority in which the power is traded, regional power grids and energy suppliers.
Responding on energy demand variations the suppliers sell or buy energy on the national market to cover the demand of their customers.
Depending on projections and statistics the suppliers plan the energy production in two main time-scales:

- on yearly scale the analysis focuses on seasonal oscillations and on the trends in energy consumption
- on daily scale the projections are needed to operate in the market and manage the hourly production responding on daily consumption patterns

The network has to be planned as a composition of technologies that allow coverage of basal energy demand (base-load) and technologies that respond on quick changes in demand (peak-load).
Fundamentally the network is planned to cover the base-load with proper technologies, day-by-day the energy companies trade electric energy on the market for the next day[49][51][120][26][7].
In addition also in-day market trade allows the integration of energy quantities to adjust the supply on hand of the demand.
The power grid authority (TERNA in Italy and Austria Power Grid in Austria) controls the loads and sets the maximum amounts of energy that can be transmitted[120][7].
When there is a sudden change in the demand three actions take place:

1. within seconds the demand is covered by energy stored in proper capacitors
2. the power grid authority sends a call to suppliers to produce more electricity
3. within minutes peak-load technologies are started

The traditional definition of base load sees it as the minimum power demand of the day, while peak-load is the maximum: this definition is a bit out of scope if we treat renewables and if we look how the energy market works.
In the actual system a third dimension has to be introduced: the network has to respond not only on changes in demand, but also to changes in supply.
On the thermal side of energy supply a division in peak and base load is out of scope: the structure of markets related to heat energy is different.
When we are talking about heat two are the markets of interests: the fuels trading market and the district heating networks.
While the fuels markets are almost completely de-coupled from sudden changes in energy demand, district heating networks have high degree of manageability and are already developed to respond to peak conditions.
In the following sections the main variables that affect the yearly patterns in local energy demand are discussed.
An insight of critical points about spatial and temporal scales is given by examples and development possibilities are outlined.

5.1 Thermal load

The thermal load is the amount of heat consumed during a period of time.
The industrial thermal load depends on the process type, thus has different characteristics depending on the industry type.
As a consequence, the daily, weekly and yearly load-curves strongly vary in magnitude and periodicity depending on the required process temperatures, the size of the industrial site and the production management.
Thus the thermal load for industrial use has to be studied case to case, possibly using real data from the industry involved[112].

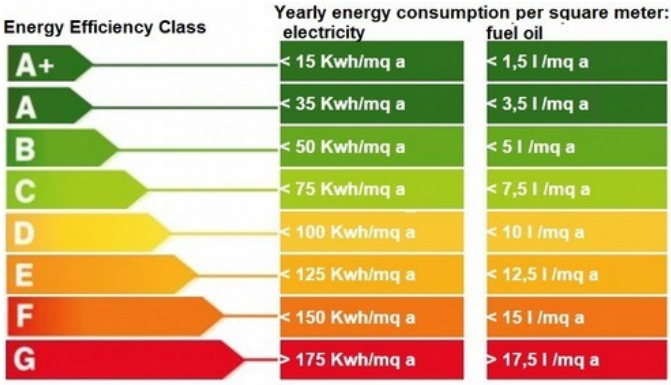


Figure 48: Efficiency class of a building and yearly energy consumption. Modified from: corriereimmobiliare.com [43]

In this study we shall focus on the thermal loads in the residential and tertiary sectors: in this cases the temperature ranges are known as we are talking exclusively about room and water heating.
The amount of warm water needed in a household depends mainly on the amount of occupants and their behaviour.
The energy needed for room-heating is strongly dependent on the climatic conditions, the dimensions and the energy efficiency of the building itself.
A bottom up approach is to evaluate the composition of the buildings heritage by energy efficiency and dimensions, this is possible only if there is a building energy efficiency database for the region under study.
In Italy such databases are under construction: for example the Regions Friuli-Venezia Giulia (FVG), Abruzzo and Piemonte allow the direct transmission of the efficiency performance certification (EPC) to the online database [111][21][5].
The European DIRECTIVE 2010/31/EU introduces the framework for the energy performance certification for buildings (APE-EPC) which is mandatory to sell, rent-out or obtain funds to upgrade a building, a house or a flat.
This certification allows to know the energy needed for that building or flat on yearly base, both electric energy consumption and heat load are estimated by in-deep analysis of:

- climate of the location
- type of building
- year of construction
- insulating properties of the walls
- materials used in the building
- type of roof
- type of pavement
- insulation degree of doors and windows

Thus the electric and heat energy needed are estimated with high precision.

The high precision of the EPC-APE allows the construction of databases that will be a reference for energy planning in the future, for now the databases are incomplete or not-accessible and the heat consumption estimation has to be based on the statistical data available:

- yearly pro-capita energy consumption
- share of energy for room heating
- share of buildings by year of construction
- type of buildings
- monthly heating-degree days

The yearly pro-capita energy consumption and the share of energy for room heating allow the quantification of the yearly amounts but do not help in determining the periodicity and the oscillations during the day, the week and the year.
The share of building by year of construction and type can be used for a rough estimation of the heat needed for heating: every constructional period has characteristic materials and constructional features with different degree of insulation.
If we know the average thermal losses and the dimensions of the buildings we can estimate the heat need by calculating a heat balance using meteorological data series.
Let's take Austria and Italy as examples and show some critical points in heat demand evaluation.
In many European lands, daily heat demand assessment through meteorological data is possible, for example in Italy we can get local meteorological data series without charge[7] either requesting them to the regional environmental protection agencies (ARPA -Agenzia Regionale per la Protezione dell'Ambiente) or from on-line databases, as it is the case of the Region FVG ([92]).
Unfortunately the Austrian data from the Austrian Central Institution for Meteorology and Geodynamics ZAMG (Zentralanstalt für Meteorologie und Geodynamik) are not completely available for free ([130]).
Series of monthly national and regional heat-degree days are made available by the European Commission in the Eurostat databases ([32]).
A common used method for heat demand evaluation is the degree-day method: the heating demand of a building is calculated as

$$H_{demand} = \frac{h_{loss} \cdot 24 \cdot HDD_{day}}{1000} \; [KWh]$$

The heating-degree days are a quantification of heat needed for heating as they comprises the difference between the inner temperature (conventionally posed from Eurostat at 18°C) and the outer mean temperature T_{mean}.
The heating threshold was chosen as 15°C, under this outer temperature the heating degree days are defined as the difference between the inner temperature and the mean temperature:

$$HDD = d \cdot (18\ ^\circ C - T_{mean})$$

For mean temperatures over 15°C the heating degree day equals zero([32]).
Other definitions can be applied to the heating-degree days in function of the heating threshold and the inner temperature.
The thermal losses of a building are principally due to heat transmission of walls, roof, windows, doors and floors and to circulation of air.
As these variables depend on the building type, the heat loss coefficient varies in every building due to constructional features and materials involved.
In the TABULA report *"Average EU building heat load for HVAC equipment"* [57][102] the heat loss is defined as:

[7] The author advices that the data has to be free of charge to reach all the stakeholders

$$h_{loss} = U\ S + V\ q\ (1 - rec)\ c_{air}$$

Where U=0.93 [W/K. m²] is the mean insulation value of the Shell (S) of the building, V is the heated volume, q is the hourly air exchange , rec is the ventilation recovery rate and c_{air} is the specific heat of air (c_{air}=0.343 [Wh/ m³.K]).

The volume can be estimated by using the floor area (A_{floor}) and the minimum height (H_{min}) of the rooms set by law, thus we can write:

$$V = A_{floor} \cdot H_{min}$$

The shell surface can be evaluated by using the given S/V ratio of 0.43 m^{-1}.

$$S = (S / V) * V$$

Also the ventilation air exchange is given:

$$q\ (1 - rec) = 0.82\ [h^{-1}]$$

So we can write:

$$h_{loss} = 0.93 \cdot 0.43 \cdot A_{floor}\ H_{min} + A_{floor}\ H_{min} \cdot 0.82 \cdot 0.343 \approx 0.68 \cdot A_{floor}\ H_{min}$$

Thus the heat demand can be estimated in function of the heating-degree days and the known parameters of floor area and minimum height of the rooms

$$H_{demand}\ [KWh] = 0.68 \cdot 24 \cdot 10^{(-3)}\ A_{floor}\ H_{min} \cdot HDD_{day}$$

where the heat demand (H_{demand}) can be calculated over a day (24h), over a month or over a year.

To estimate the residential energy demand for room heating we can thus use the monthly data and construct the monthly sums of needed energy for room heating.

The monthly heating degree days are shown in Figure 49: we can notice that the far higher difference between the national data and the regional case in Italy is due to the far higher climatic complexity of Italy.

While Austria is posed almost completely in the Alpine region, the Italian climatic regions vary from Mediterranean to Alpine.

Even in the region FVG itself we can notice a littoral region, a plain and the Alps, thus the Italian mean values can differ strongly from local data.

As an example, using the formulas above the heat demand for two chosen locations (Tarvisio in the region FVG, Italy and Villach in Carinthia, Austria) can be roughly assessed.

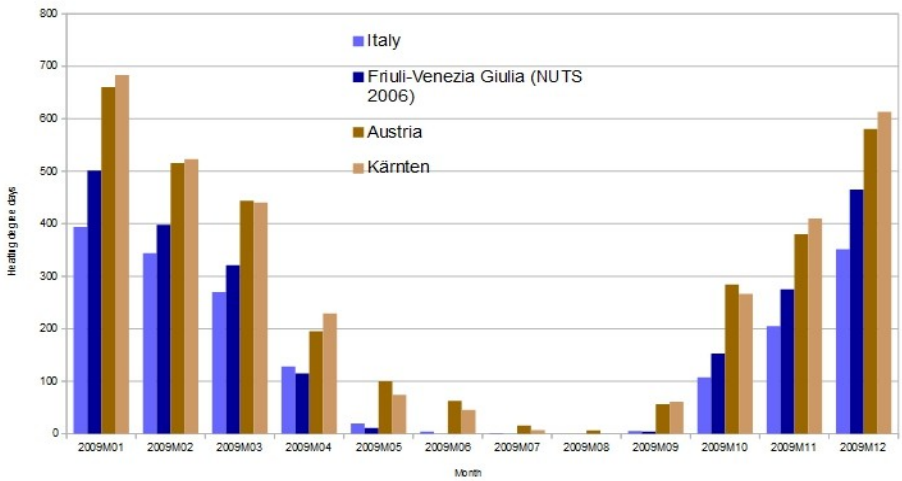


Figure 49: Heating degree days in 2009 in Austria, Carinthia, Italy and FVG. Data: Eurostat [32]

The floor surface in Tarvisio is 197601 m^2 and the minimum height of rooms is 2,4 m[70][69][110].
Villach counts 4736560 m^2 and the minimum height of rooms is also 2,4 m [116] [118].
In presence of meteorological data of the location or region under study a higher temporal resolution can by achieved by using the daily temperatures.
By comparing the Figure 51, Figure 50 and Figure 52 we notice the effect of heated area and of local data.
The plots of Villach and Tarvisio from Eurostat data show a difference of the energy scale from 10^7 for Villach to 10^6 of Tarvisio, due to higher heated area.
The comparison between Figure 51 and Figure 52 shows that the use of data on regional spatial scale is a bit misleading when applied to sub-regional scales, especially in presence of appreciable climatic inhomogeneities: as expected the estimate with local meteorological data from OSMER-FVG (Osservatorio Meteorologico Regionale) is about 3 times higher of the estimate done with the regional data from Eurostat.
As the climatic conditions are the first variables that influence the heat demand, a good assessment of the energy needs should use local data or data of homogeneous climatic regions.
A further implementation of the energetic assessment can be done by evaluating the construction year of the buildings.
The projects TABULA-EPISCOPE and ENTRANZE try to construct a database of building stocks and energy consumptions[57][25].
The Reports of ENTRANZE Projects [93][78][94] outline specific heating energy loads in relation to the construction year of the buildings: this type of approach, combined with the statistics of buildings (construction year and useful floor space) allows to introduce a regional specific estimate of the residential heat demand that comprises efficiency improvements.
As shown in Error: Reference source not found and Figure 81 the specific heating demand varies with the constructional period due to improvements in the materials and the insulating properties.
In case of Austria specific local data on the building stock exist and can be purchased from Statistik Austria.

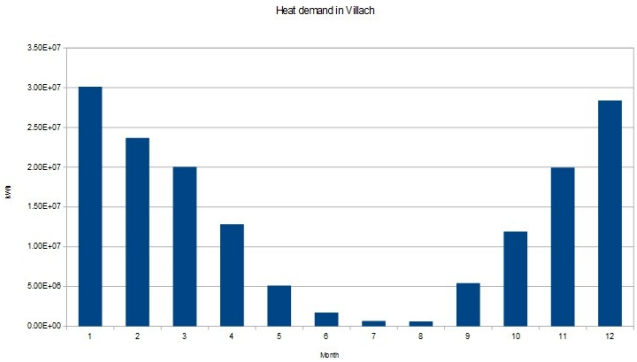


Figure 50: Heat demand in Villach. Based on monthly heat degree days of Carinthia from Eurostat.

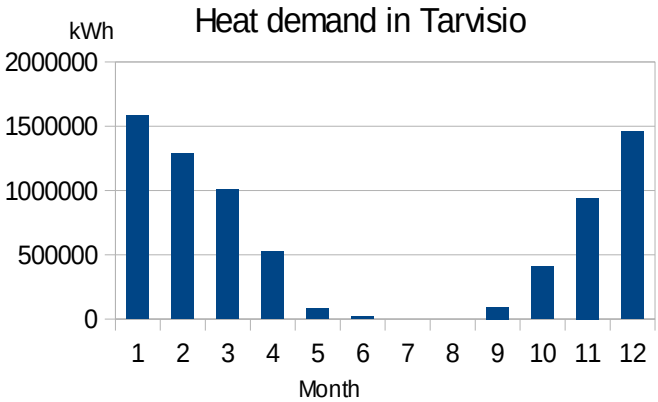


Figure 51: Heat demand in Tarvisio. Based on monthly heat degree days of FVG from Eurostat.

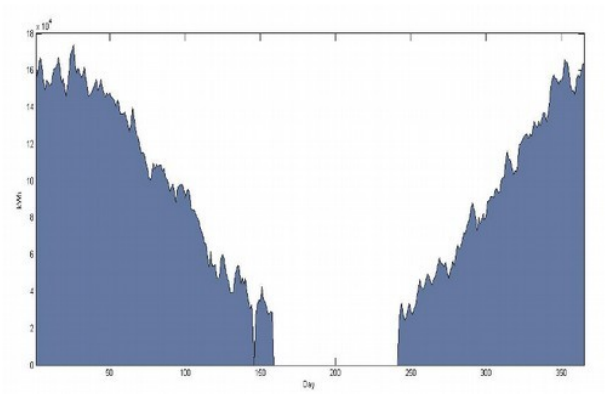


Figure 52: Heat demand in Tarvisio. Based on daily temperature data of the OSMER-FVG meteorological station of Tarvisio.

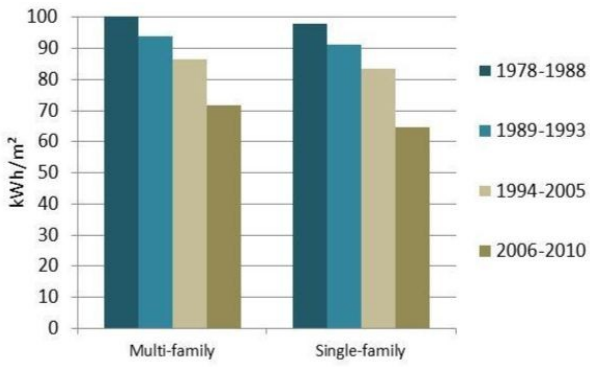


Figure 53: Specific heat demand for Italian dwellings by age of construction and type. Source: [93]

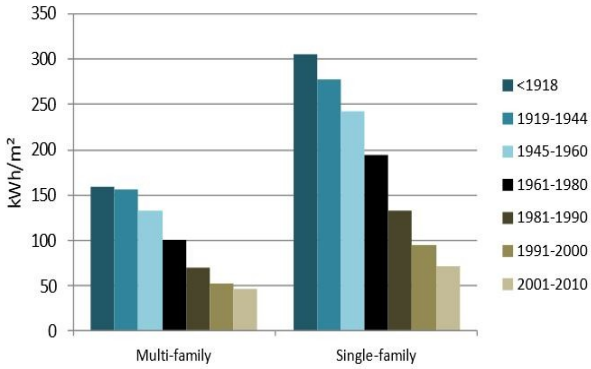


Figure 54: Specific heat demand for Austrian dwellings by age of construction and type. Source:

In Italy the statistical database of ISTAT has data on the number of dwellings by construction year, but the floor area is not available and the construction years are not conform to the data from ENTRANZE.
Thus a splitting of the thermal efficiencies of the buildings in the current work was not possible and the refining of the estimate was not done.

5.2 Electrical load

Figure 55 and Figure 56 show that the electrical energy demand is not strongly dependent on climate: there is a low oscillation during the seasons but far higher oscillations during weeks and holidays can be seen.
A lowering of the demand can be noticed in Austria and in Northern Italy during the winter holidays around Christmas and only for Northern Italy also in August, during the Feast of Assumption.

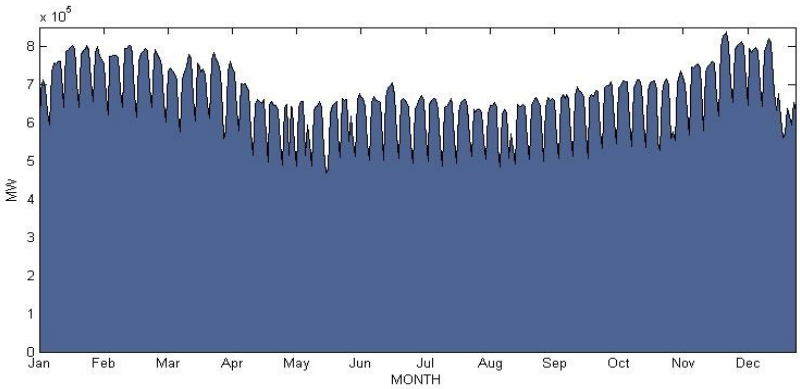


Figure 55: Daily electrical loads in Austria in 2013. Data source: e-control.at[26]

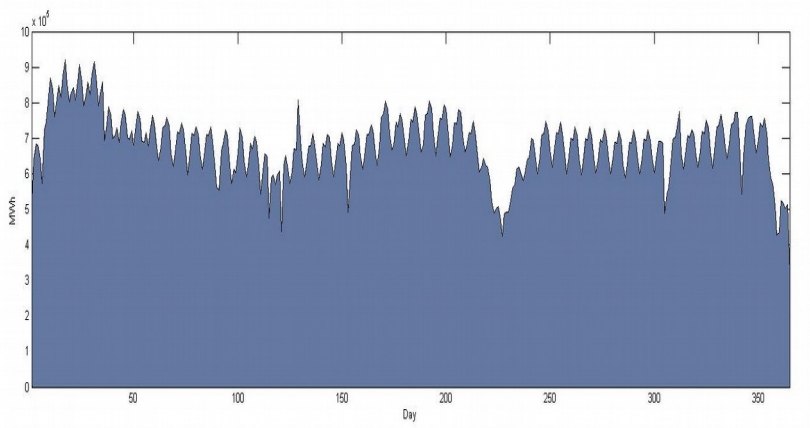


Figure 56: Daily electrical loads in Northern Italy, daily means of 2011 to 2014. Data source: TERNA[121]

According to IEA in 2009, heat represented 47% of final energy consumption of all sectors, while electricity was only 17%[62].
While the heat demand is mostly lead by the residential sector and the services, the electricity demand is lead by industry and services ([24][94]).
An in-deep analysis of local electricity demand should comprehend socio-economic considerations that are far from the scope of this work.
In this work a simple downscaling using the pro-capita energy demand is sufficient to have a gross estimation of the electricity demand in the analysed region.

6. Study of supply and load curves

In the former chapter we saw how suitable data on energy demand can be retrieved or generated in order to be inserted in an energy planning process.
In chapter 4 we saw the main features of energy supply and determined the main variables that imprint time-dependencies in supply, thus, in absence of real measurements we can use the described laws to assess the energy outputs.
Also regarding energy demand, in chapter 5 we identified the main variables related to time dependencies, thus these considerations shall now be applied.
To analyse and compare different curves as first data of proper resolution are needed: the data input is task of the user of RegiOpt, but a good interface is prepared to assign proper default values.
Usually there are 4 main cases:

1. the user has own data with high resolution
2. the user doesn't have any data and the available data/simulations have low resolution
3. the user doesn't have any data and the available data/simulations have proper resolution
4. the user doesn't have any data and the resolutions are variable

As RegiOpt is a preliminary study software, unless the user is a stakeholder that owns or has access to local data with high resolution, the average user will not be willingly to pay for good data and simulation will be used.
Let's consider the case of a little municipality in Italy, Tarvisio, and make an example.
In Tarvisio there are following installed supply technologies:

- photovoltaic panels
- solar panels

and following demands:

- electricity
- residential heat demand

In the whole community of Tarvisio there are 28 installed PV systems with an installed power of 221 kWp [50].
An electricity output profile for the installed photovoltaic panels can be obtained using the global radiation data from OSMER-FVG.
The installed power is the output power obtained by a system of PV cells with an incident radiation of 1 kWh:

$$W_p\,[kWp] = \eta\ 1000\ [W/m^2]$$

Thus the efficiency factor is

$$\eta = 221$$

which comprises all installed systems (and their surface area).
The electrical energy demand can be downscaled by using the data for Northern Italy and dividing the amounts for the population: the obtained curve is an estimation of the daily load curve for Tarvisio.
To evaluate the thermal solar power output the number of installed devices was retrieved from ENEA [86].
To estimate the thermal output for the community a simplified method is proposed by Nielsen[71]: the output heat can be written as

$$Q = 0{,}42 \cdot I_{horizontal} \cdot A$$

where Q is the output heat, $I_{horizontal}$ is the horizontal incoming radiation and A is the area of the collectors.

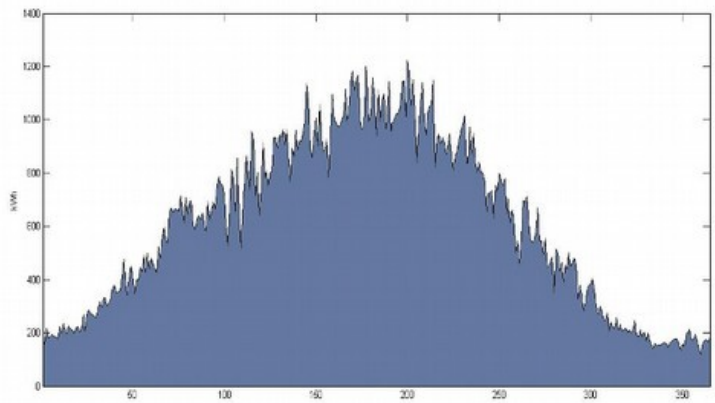


Figure 57: Electrical energy output simulation for 221 kW installed in Tarvisio. Based on radiation data from OSMER-FVG

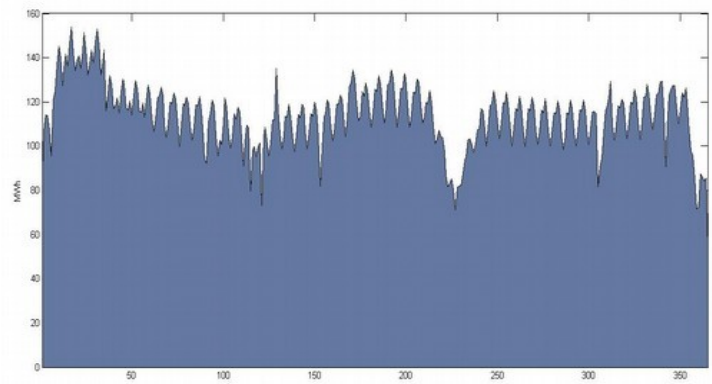


Figure 58: Estimation of electrical load in Tarvisio.

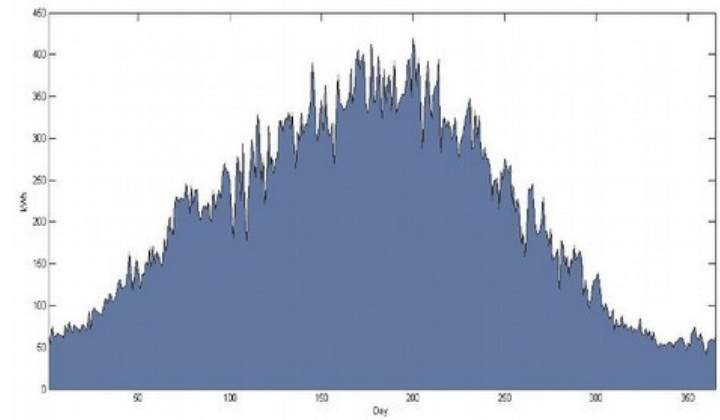


Figure 59: Theoretical heat output from solar panels in Tarvisio. Based on radiation data from OSMER-FVG

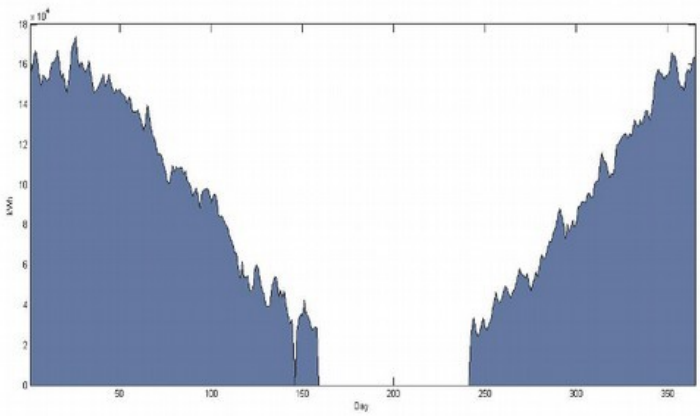


Figure 60: Heat demand in Tarvisio. Based on daily temperature data of the OSMER-FVG meteorological station of Tarvisio.

Applying this formula to an area of 230 m^2 and using radiance data from the OSMER-FVG meteorological station in Tarvisio the daily heat output curve is obtained.
Using the heating-degree days method the daily heat demand for the community is estimated (Figure 60).
To properly plan the implementation of a sustainable energy network the individuation of the amounts of energy demand not already covered by green technologies in the region is central.
This amounts can be evaluated as the energy demands minus the already existing Green energy supply:

$$Q_{required} = Q_{demand} - Q_{solar}$$

and

$$E_{required} = E_{demand} - E_{PV} - E_{wind}$$

The heat demand to cover $Q_{required}$ has to be evaluated by considering the demand and the already existing Green-supply technologies such as solar panels (Q_{solar}).
In the same way the electricity demand to be covered $E_{required}$ is evaluated as the existing demand E_{demand} minus the supply from Green-power technologies in the region(E_{PV}, E_{wind}).
In the case of Tarvisio the evaluated components are:

$$Q_{required} = Q_{demand} - Q_{solar}$$

and

$$E_{demand} = E_{demand} - E_{PV}$$

6.1 Generation of approximation curves

The raw data have oscillations and background noise unsuitable for further modelling, thus a data smoothing is processed in order to

1. clean up the background noise and the weekly/daily oscillations
2. have a mathematical formulation of the curves to handle

A common method to approximate data is to use polynomials or Fourier series.
In this study Fourier series were chosen for the following reasons:

- simple mathematical handling
- simple programming
- proper data smoothing
- filtering of high frequencies
- good interpolation possibility
- suitable for periods[8] identification

The technical suitability of this approach will be properly understood in the next chapters.
For every data-set a filtering of the high frequencies was done in order to smooth data and to discard the short-time variability of the data.
The short-term oscillations are not of interest because this work deals with the overall planning of the energy network on yearly scale and does not deal with the short-term peak load covering.
As a consequence the information that is relevant for the division in periods is some-kind of seasonal trend: the oscillations of interest are those of periods higher of 20 days.
Once the Fourier series is written, we can evaluate the residual sum of squares (RSS), which is a measure of the introduced error between the real value x_{real} and the approximated value x_{series}:

$$RSS = \sum (x_{real} - x_{series})^2$$

RSS can be evaluated in every point of the data and the generated series.
Generally the representation is of the form:

[8] For "periods" we mean time-intervals and not oscillation periods.

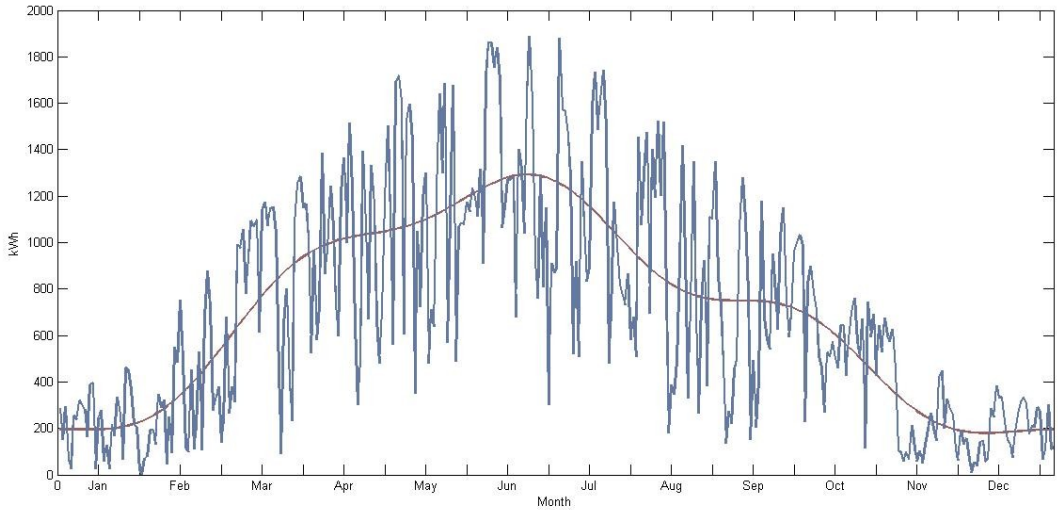


Figure 61: Data (blue) and Fourier series (blue) for a Photovoltaic device, based on radiation data.

$$f\ (x) = \sum_{i=0}^{n} a_i \cos\ (2\ \pi\ t\ \omega_i) + \sum_{i=0}^{n} b_i\ sen\ (2\ \pi\ t\ \omega_i)$$

The frequencies ω_i are the fundamental frequencies (j/n)[9] where n is the sample size.
The corresponding coefficients can be calculated as:

$$a_i = \frac{2}{n} \sum_{t=1}^{n} x_t \cos(2\pi\omega_i)$$

$$b_i = \frac{2}{n} \sum_{t=1}^{n} x_t\, sen(2\pi\omega_i)$$

Then frequencies lower than 1/20 are filtered out and the result is an approximation curve that shows the overall trend of the data.
In order to evaluate if it is possible to cut-off the series the Schwarz's Information Criterion (SIC) method was applied.
Schwarz proposed a method to weight the number of components of a series through the increment of precision and defined the SIC as:

$$SIC = \log(RSS_k) + \frac{k \log(n)}{n}$$

The SIC is evaluated for every number of parameters k in the model, and
n is the sample size.
If we plot the SIC against the number of parameters k, we obtain a curve that has a minimum: this minimum shows the k-threshold for which an increment in the number of parameters leads to a negligible decrement of error (RSS), thus this minimum identifies the cut-off.

[9] For in-deep explanation see *Time Series Analysis and Its Applications, Springer[101]*

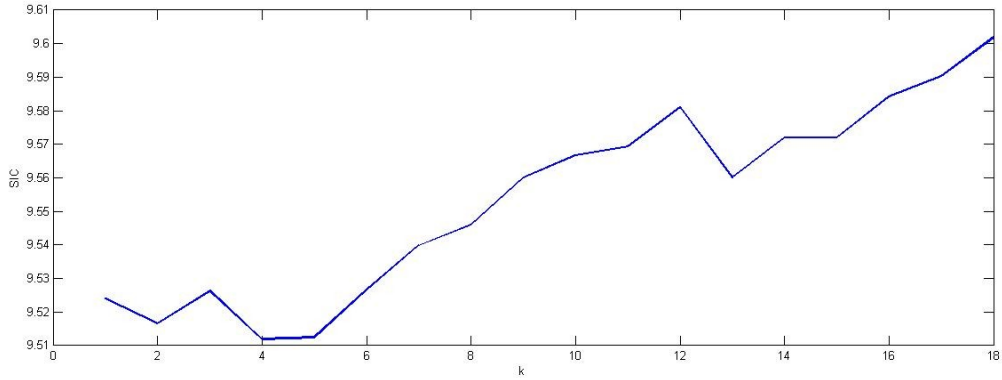


Figure 62: BIC for the data in Figure 59.

In our case the SIC criterion is not always applicable: the filtering of the higher frequencies already took out a certain number of components of the Fourier series, thus it can happen that the SIC has no minima: this is the case shown in Figure 61 and Figure 62.

In this case it was choosen to keep all the remaining components after the filtering.

So, when the SIC shows a minimum the series was cut-off at the corresponding k component, if else the filtered series was left without any cutting-off.

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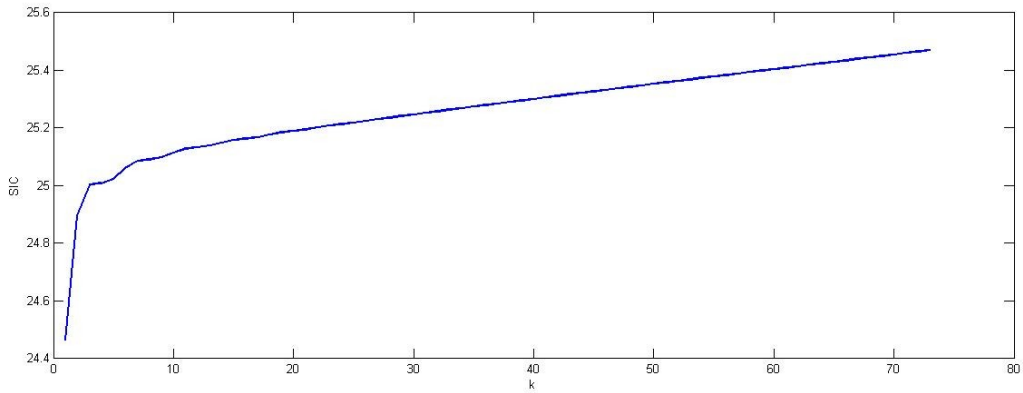

Figure 63: SIC for the data in Figure 61.

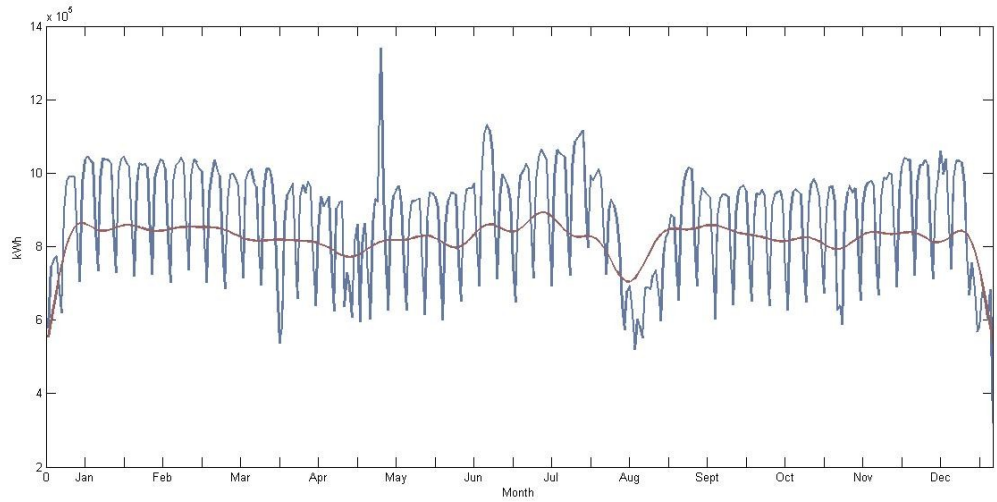

Figure 64: Approximation and filtering of the data with Fourier series. The data are shown in blue and the obtained Fourier series in red.

6.2 Overall assessment curve and periods

The energy needed to cover the local demand can now be assessed as:

$$E_{required} = E_{demand} - E_{PV} - E_{wind}$$

and

$$Q_{required} = Q_{demand} - Q_{solar}$$

In Figure 62 we see an example of Fourier series of electric demand, PV generation and wind-power generation.

These curves are summed as above and an electric assessment curve is generated (Figure 64).

Every Fourier series has an associated RSS, as a consequence the overall error introduced in the assessment curve is the sum of the squared errors:

$$RSS_{curve} = RSS_{demand} + RSS_{PV} + RSS_{wind}$$

In the same way, the thermal assessment curve and its RSS can be assessed

The results of this process are two overall assessment curves that represent the uncovered heat and electrical demands of the given region.

Also the error between this representation of the market share and the real oscillating values is assessed (RSS).

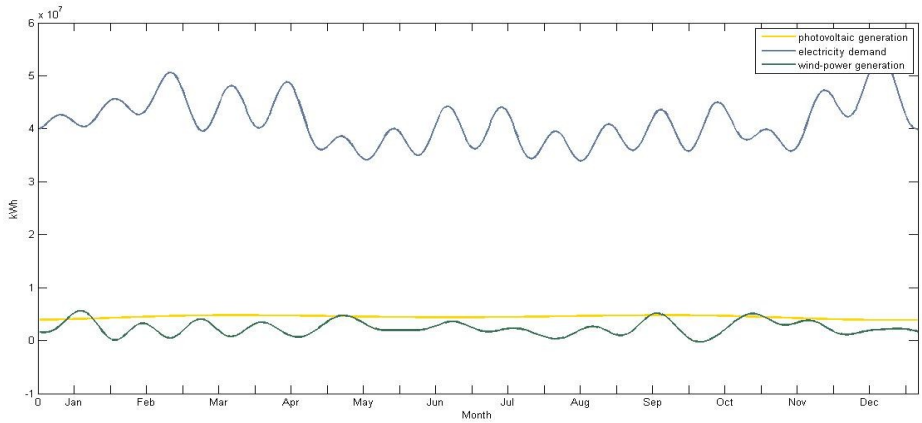

Figure 66: Electric demand (blue), PV electric generation (yellow) and wind-power generation (green) in Austria

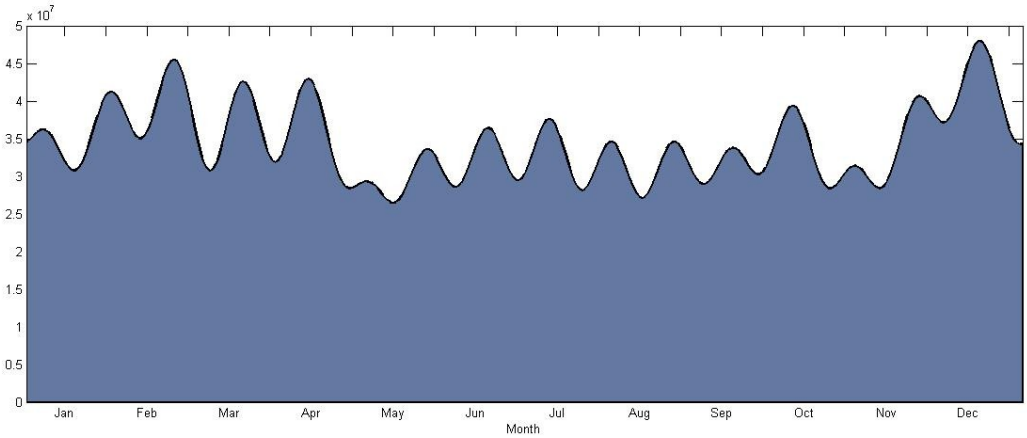

Figure 65: Electric assessment curve for Austria

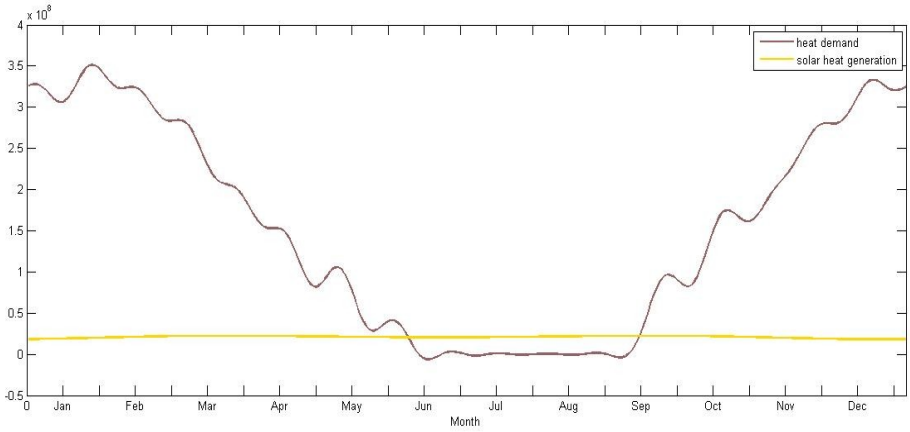

Figure 67: Heat demand (red) and Solar heat production (yellow) for Austria

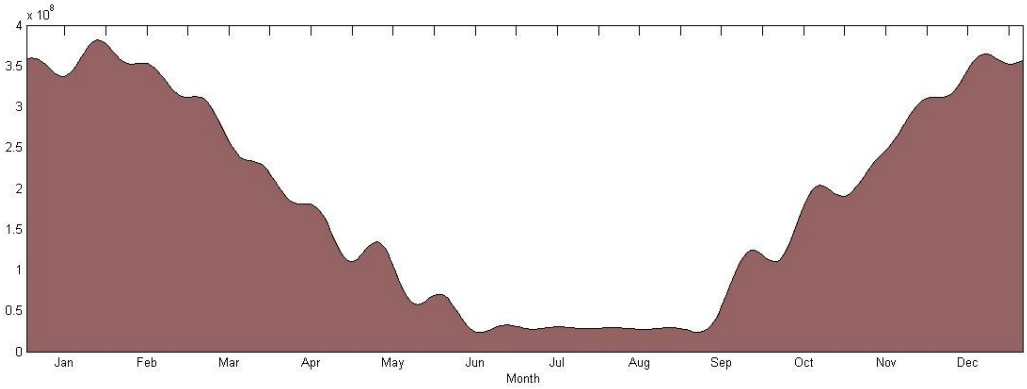

Figure 68: Thermal assessment curve for Austria

7. Case studies

Now that the study of supply and load curves was described with the help of an example let's apply the developed methodology to two case studies: the local case study (Tarvisio) will show how the methodology works on local scale with good availability of meteorological data, while the national scale (Austria) will show the application on large scale with critical situations about spatial distribution of data.
The author recalls that the main issue of this work is the insertion of time-dependencies in the RegiOpt software, thus has to remain of general character and open to every type of data and data resolutions on spatial and temporal scales.

7.1 Case study 1: Tarvisio

Table 4: Case study 1: Tarvisio, data table.

Input Data	Value	Simulation/Estimation	Resolution	Data Source
Population	Number	No	-	ISTAT
PV	Installed Power	No	-	GSE
	Daily output	Yes	day	OSMER-FVG GSE
Solar panels	Surface area	Yes	-	ENEA
	Daily output	Yes	day	OSMER-FVG ENEA
Heat demand	Daily need	Yes	day	OSMER-FVG TABULA-EPISCOPE ISTAT
Electricity demand	Daily load	Yes	day	TERNA ISTAT

1. First step
   the input data are processed as seen in the previous chapters to obtain yearly input curves with daily resolution

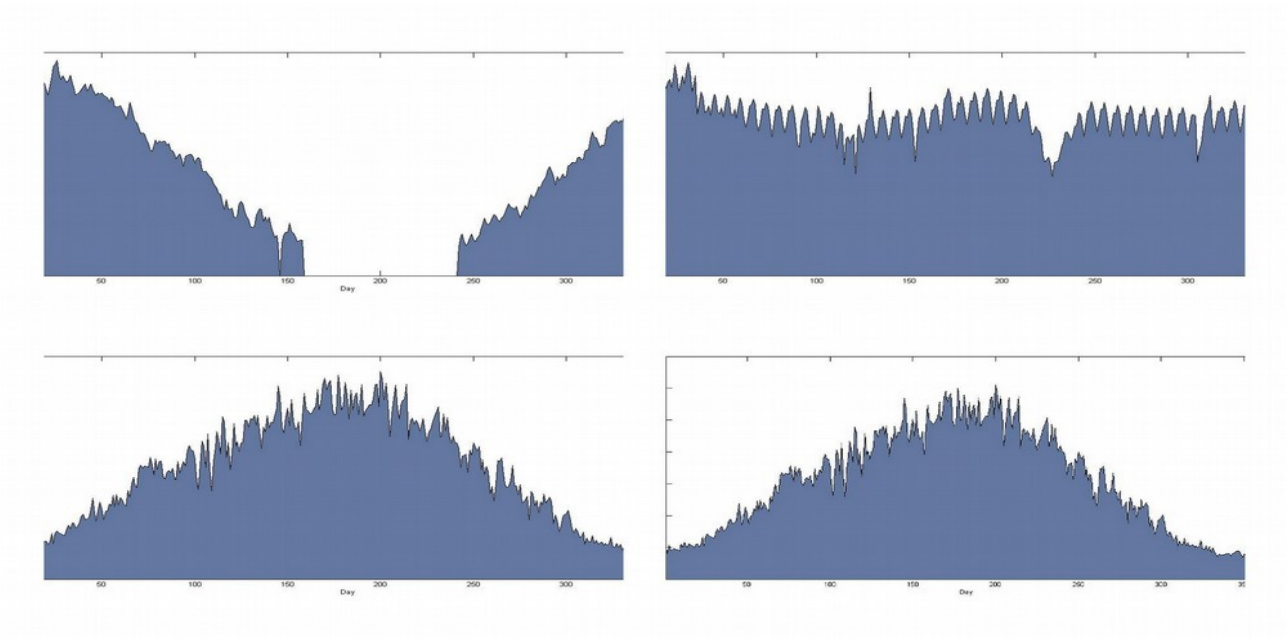

Figure 69: Input data for Tarvisio

2. Second step
   the processed data are approximated by Fourier series and evaluation of RSS

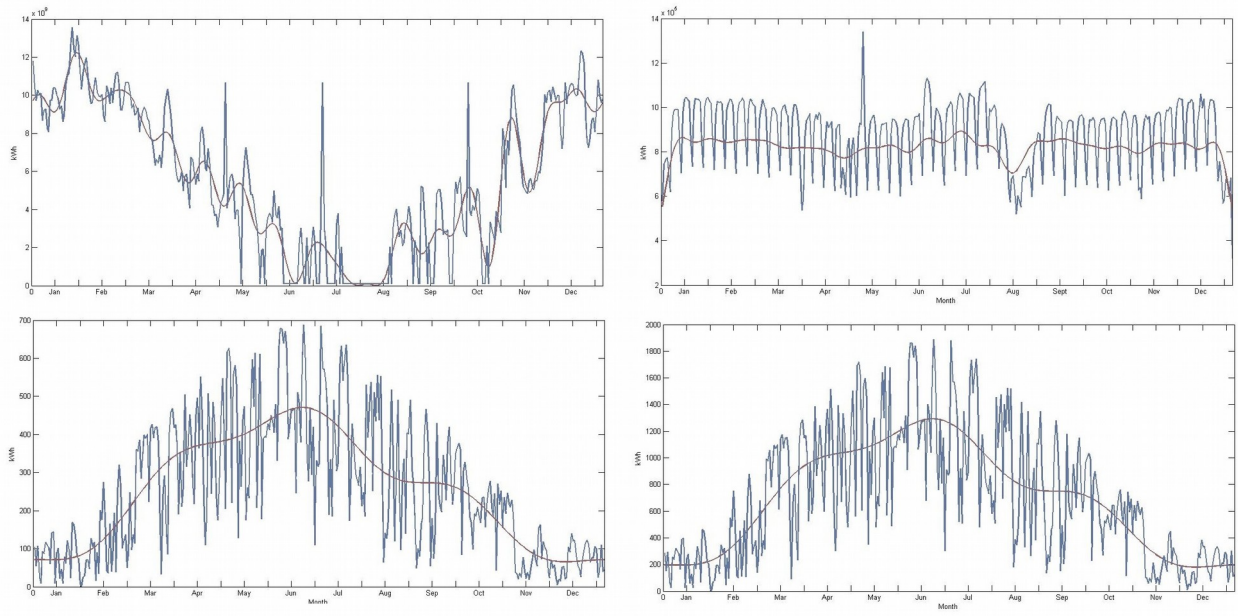

Figure 70: Approximation of data with Fourier series

The RSS of every series is calculated:
$RSS_{heatdemand}$=1.6009^{22} kWh^2;
$RSS_{heatsolar}$=7.9546^{07} kWh^2;
$RSS_{electricitydemand}$=8.3272^{15} kWh^2;
RSS_{PV}=5.9953^{08} kWh^2;

3. Third step
   the assessment curves are generated

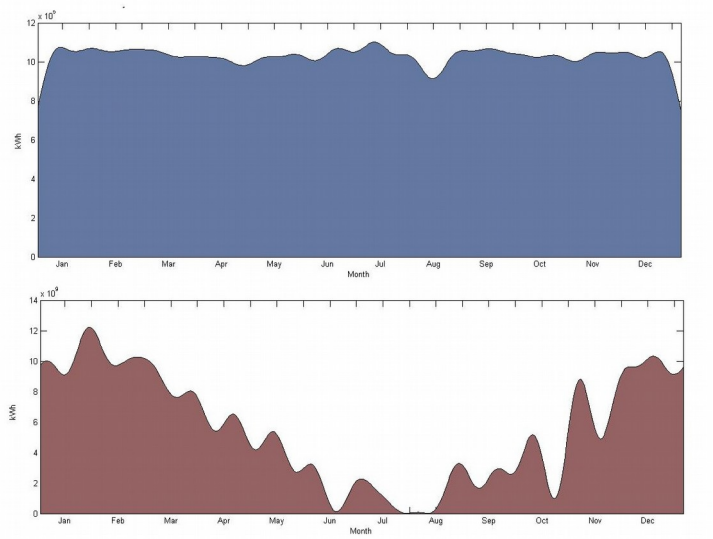

Figure 71: assesment curves for Tarvisio: electrical assesment curve (up) and thermal assesment curve (bottom)

The corresponding errors are calculated as:

$$E_{term} = \sqrt{RSS_{heatdemand}} + \sqrt{RSS_{heatsolar}} = 1.2653\, e^{11}\, kWh$$

$$E_{el} = \sqrt{RSS_{electricitydemand}} + \sqrt{RSS_{PV}} = 9.1278\, e^{07}\, kWh$$

4. Fourth step
   Division of the year in periods

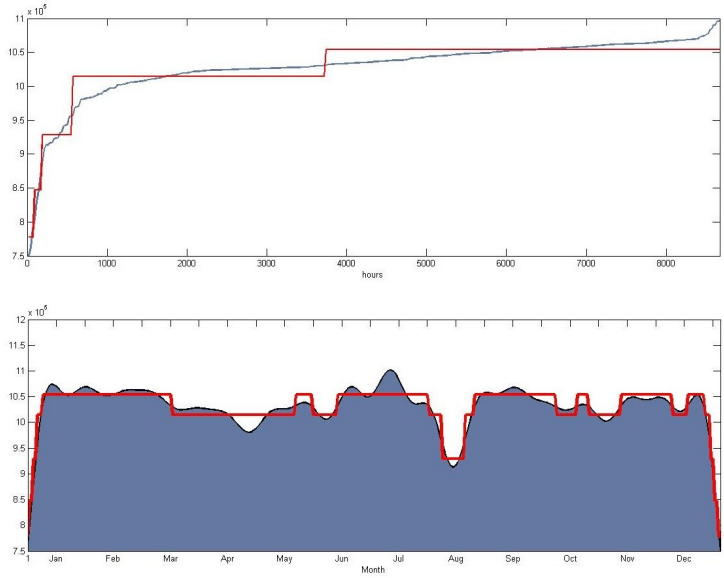

Figure 72: Electric periods: the division of the year in periods in the space operating hours vs. amounts (up) and the representation of the periods in the date-sorted space(bottom).

The periods that a re fed in the PNS are shown in the top, while the obtained representation of the year is at the bottom.

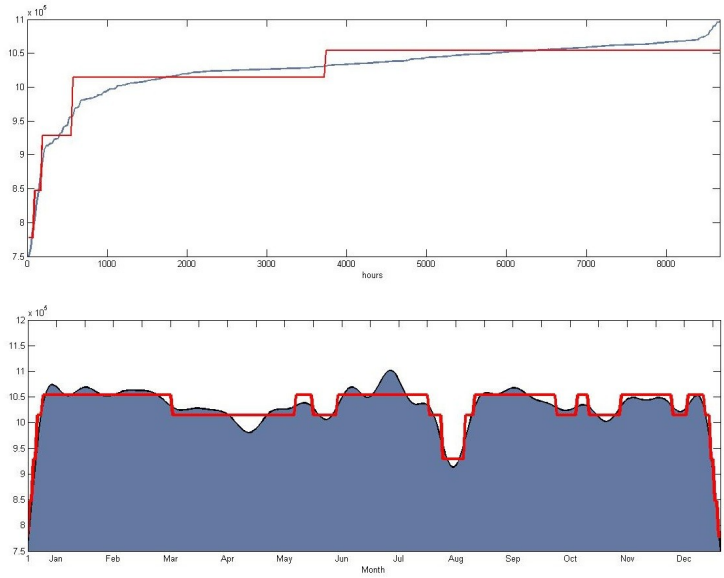

Figure 73: Thermal periods: the division of the year in periods in the space operating hours vs. amounts (up) and the representation of the periods in the date-sorted space(bottom).

The periods that a re fed in the PNS are shown in the top, while the obtained representation of the year is at the bottom.

Also over the defined periods the error between the assessment curve (blue area in Figure 72 and Figure 73) and the representation in periods of the year (red line in Figures 70 and 71) can be calculated as the difference between the two curves:

$$E=\sum_{n=1}^{365}\left|y_{period}(n)-y_{assesscurve}(n)\right|$$

E_{el}=4.4390e^{06} kWh=1,18%

E_{term}=2.3483e^{11} kWh=6,27%

7.2 Case study 2: Austria

Table 5: Case study 2: Austria, data table

Input Data	Value	Simulation/Estimation	Resolution	Data Source
Population	Number	No	-	Statistik Austria
PV	Installed Power	No	-	IEA/Austria, ww.pvaustria.at
	Daily output	Yes	day	C.J. Chen [16] , ww.pvaustria.at
Solar panels	Installed power	No	-	ESTIF
	Daily output	Yes	day	C.J. Chen [16], ESTIF
Wind power	Daily output	No	day	http://www.oem-ag.at
Heat demand	Daily need	Yes	day	ZAMG, TABULA-EPISCOPE
Electricity demand	Daily load	Yes	day	www.e-control.at

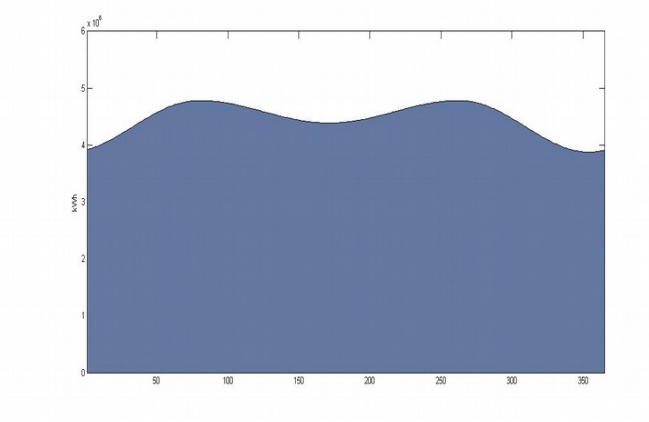

Figure 74: Simulation of the output of the installed PV in Austria, for latitude tilt positioning.

PV

The total installed power of PV panels in Austria is 626 Mwp[95].

To assess the daily output, in absence of global radiation data, a simple model of the incoming radiation from Chen [16] can be used (Section 4.2.1)

Using an incident power of 1 kW/m^2 the theoretical output of the installed PV devices is obtained.

To make this assessment the positioning chosen is latitude tilt (Figure 74).

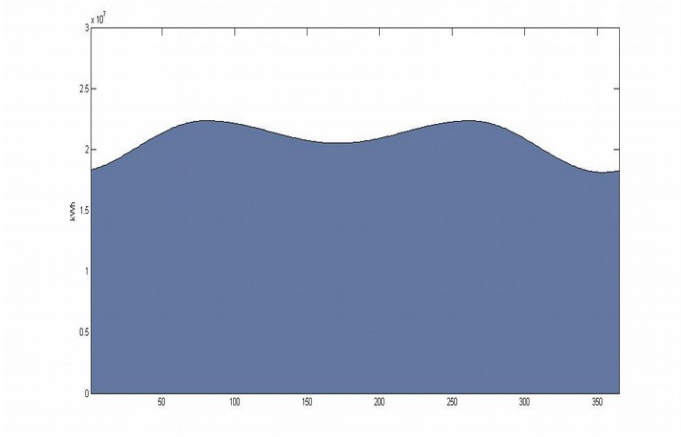

Figure 75: Simulation of the output of the solar thermal panels installed in Austria, for latitude tilt positioning.

Solar thermal

In Austria there are 2926 MW of installed power of thermal solar devices[38].

As done above for the PV panels, the thermal output of the installed solar thermal panels is done assuming a latitude tilt positioning (Figure 75).

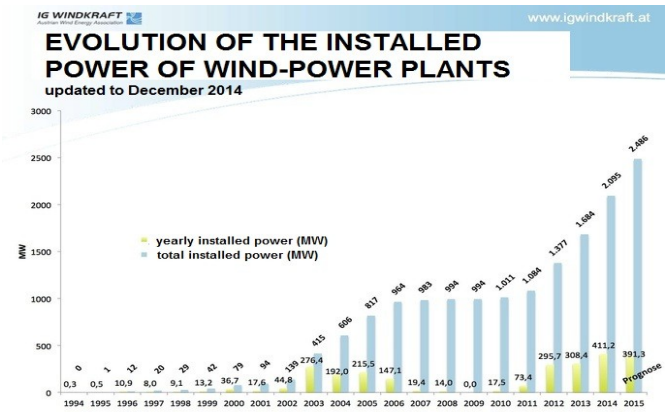

*Figure 76: Installed power of wind-power plants in Austria. Translated from:IGWindkraft**[58]***

Wind power

The output of wind-power plants is strictly dependent on wind conditions, thus is locally variable.

The installed power of wind-power plants in Austria is still increasing (Figure 76), only in 2013 the installed power increased of about 20%, thus a statistical study of historical data series should consider this trend[58].

The power plants are mostly positioned in the eastern of Austria (Niederösterreich and Burgenland).

In the OeMAG (Abwicklungsstelle für Ökostrom AG) website data-series for the years 2003 to 2014 can be found, but to proper analyse the series, in addition to the installed power and the location of the plants, the associated meteorological datasets are needed.

Unless there is no data about windiness a simulation of the behaviour of the plants is not possible and a standard statistical treatment of the data would be misleading: the increasing installed power is not enough to assess the daily behaviour of the installed plants as a whole.
Thus year 2013 was chosen as reference year, as it is the last dataset and is representing the actual composition of power-plants and locations.

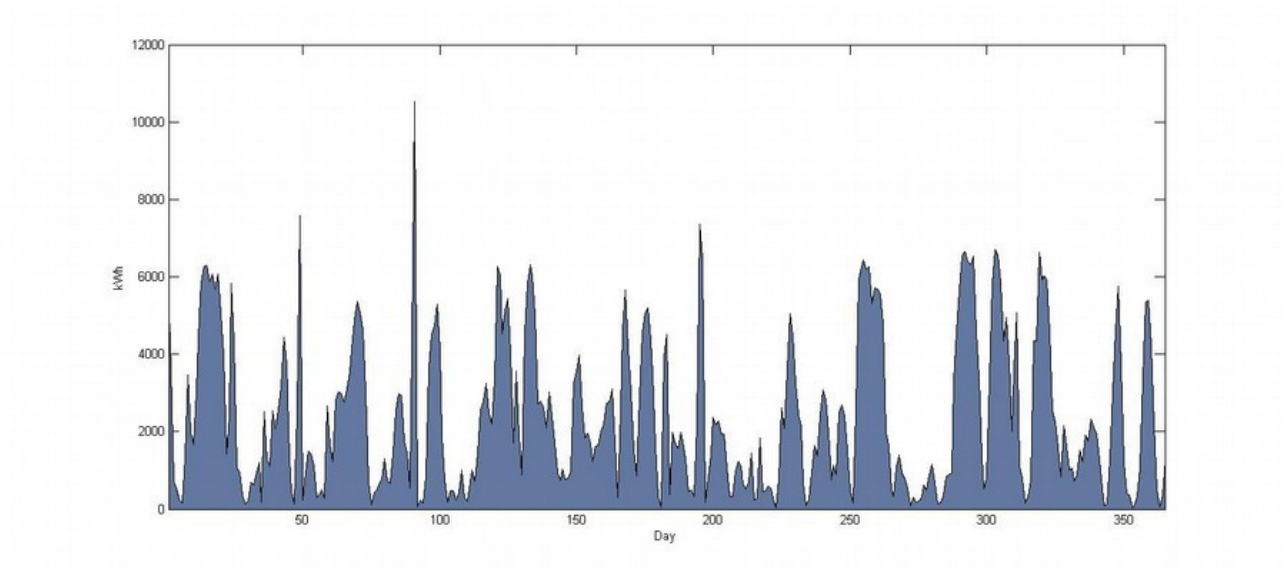

Figure 77: Energy produced in Austrian wind-power plants in 2013. Data: OeMAG
The energy output of Austrian wind power plants in 2013 is shown in Figure 77.

ELECTRICITY DEMAND

The electricity consumption of Austria shows characteristic oscillations with higher consumption during Winter and a lower demand in Summer.
Analysis from e-control shows that there is a trend but that the yearly oscillations linger: a comparison of the weighted monthly loads show divergence lower than 1%.
This allows to take one year as reference for the construction of periods.
As the electricity demand is increasing[62] the best reference year is the last year for which there is a complete dataset: 2013.
The electricity demand for Austria in 2013 is shown inFigure 79 and the comparison of the weighted amounts for the years from 2005 to 2013 is shown in Figure 78.

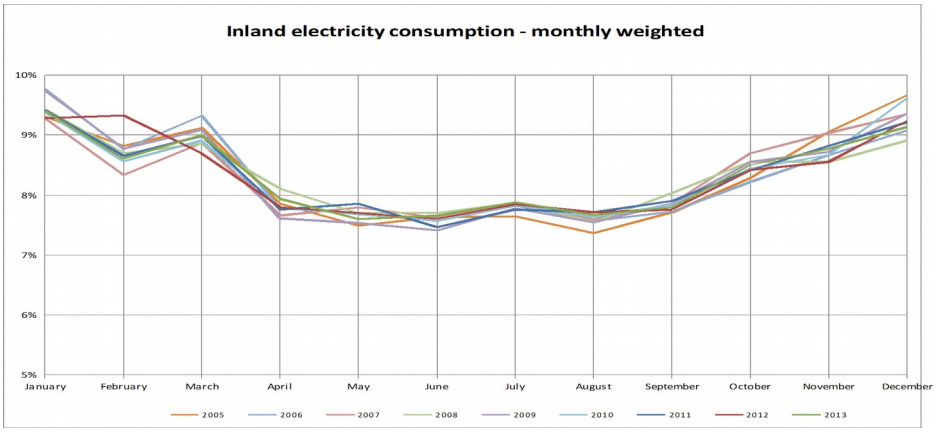

Figure 78: Comparison of the loads 2005-2013, weighted. Translated from: e-control.at

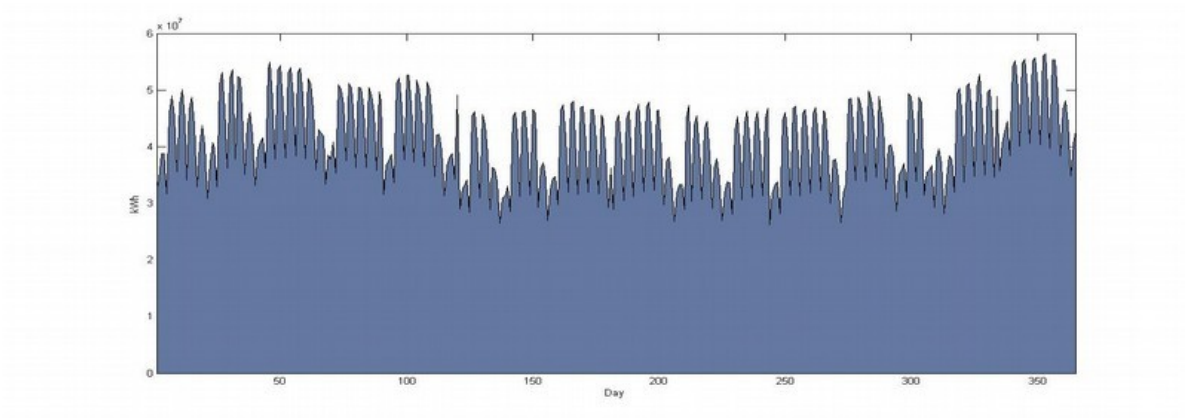

Figure 79: Daily load in Austria in 2013. Data: e-control.at

HEAT DEMAND

The consumption of energy of the residential sector in Austria is about 30% of the total. While the transport sector holds a share of 33%, the remaining share comprehends industrial energy use, electricity and lighting[13].
Thus the most important sector in the heat demand analysis is the residential one, followed by industrial applications.
As seen in section 5.1 the residential heat demand has two main components: the water heating and the space heating.
While the energy used for water heating is nearly constant over the year the space heating is proportional to the heating degree days.

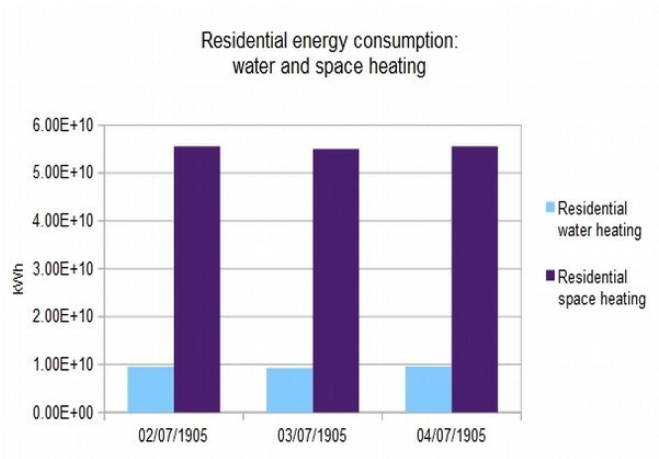

Figure 80: Energy consumption for residential space and water heating in austria. Data from: Enerdata

The daily consumption for water heating can be fairly approximated by the average daily consumption.
Even if the energy needed for water-heating depends on the environmental temperature and on the initial temperature of water and is consequently more energy intensive in winter than in summer, the deviations are low and the daily mean is a good representation of the real situation.
Furthermore the water-heating represents only 11% of the residential consumption in Austria and 9% in Italy, while the space heating is respectively 65% and 60 % (Figure 80).
As seen in section 5.1, the heat demand depends on the outer temperatures.
Thus to assess the heat demand for Austria two data are needed: the daily temperatures and the proportionality constant.
In this case the scale of the assessment is big, thus the errors introduced by an up-scaling on hand of the European means of insulation values from TABULA would be misleading.
A better choice is to distribute the yearly heat demand for space heating (from Statistik Austria) over the heating degree days.

As the daily temperatures are not available for Austria as a whole, the author constructed a mean on hand of the available data from ZAMG[130].
The dataset contains data from 9 meteorological stations, that are representative of the Austrian climate.
A precise evaluation should be done on more complete datasets, a spatial interpolation of the punctual data with construction of a model on hand of a Digital Terrain Model (DTM) and a subsequent weighting of the temperatures with the local buildings stock would lead to a high precision assessment.
For the purposes of this work, as Austria is climatic homogeneous and the superficial area is little (83879 km^2)[118], a simple mean of the available data is precise enough.
For Austria we obtain a distribution of heating degree days similar to the one seen for Tarvisio.
To evaluate the heat needed the yearly energy used for space heating in Austria is distributed over the heating degree days:

$$\int_{day=1}^{365} hdd_{day} \cdot coeff \; d\,(day) = \sum_{day=1}^{365} hdd_{day} \cdot coeff = 555{,}4 \cdot 10^8 \; [kWh]$$

As the coefficient does not depend on the day it can be calculated:

$$coeff = \frac{555{,}4 \cdot 10^8}{\sum_{day=1}^{365} hdd_{day}}$$

The heat demand of Austria is shown in Figure 81

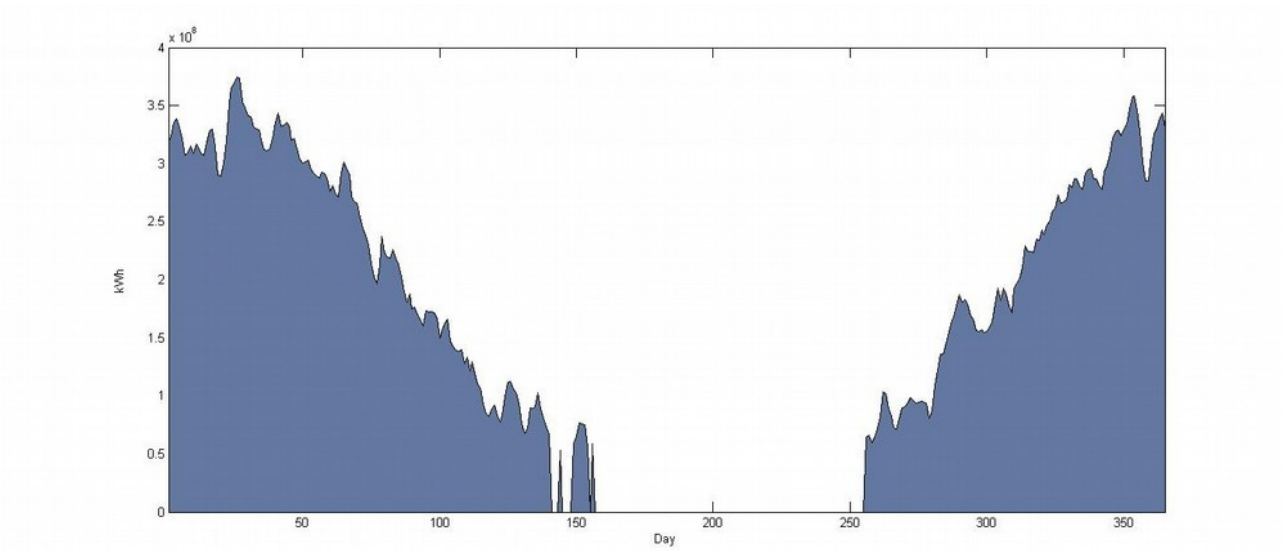

Figure 81: Heat demand in Austria. (Data: ZAMG and Enerdata)

As done for the data of Tarvisio, with exception of the solar models, the Austrian dataset is smoothed and approximated by Fourier series.
The data were filtered for λ<20 and a cut-off executed by assessing the SIC.

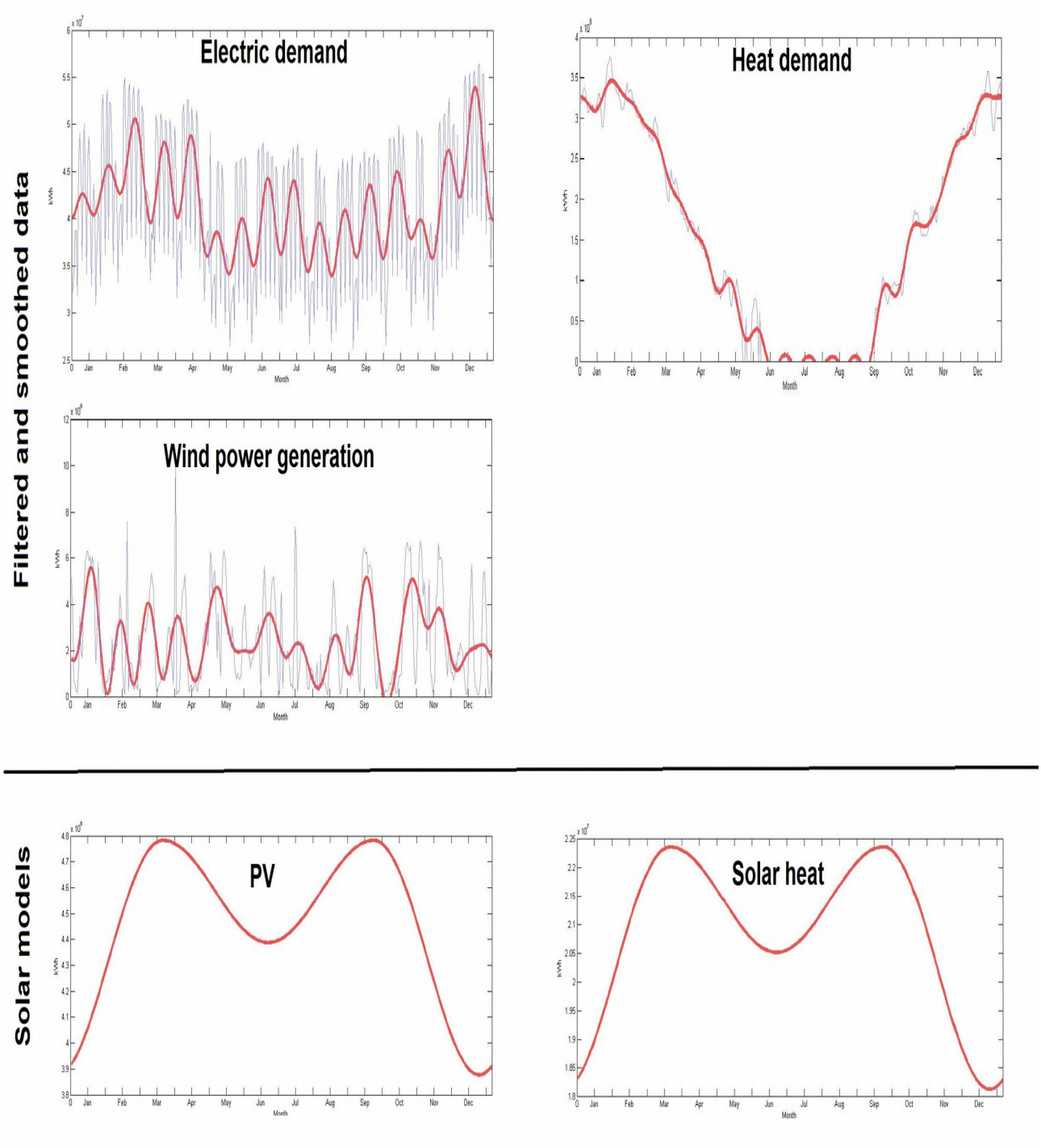

Figure 82: Approximation and filtering of data with Fourier series and solar models.

For the series shown in Figure 82 we can calculate the RSS:
$RSS_{heatdemand}$=1.7391^{18} kWh^2;
RSS_{wind}= 2.0305^{16}kWh^2;
$RSS_{electricitydemand}$= 2.8616^{17}kWh^2;
For the two models the error can't be defined as there are no reference radiation data.
Then the assessment curves are generated and the periods found.

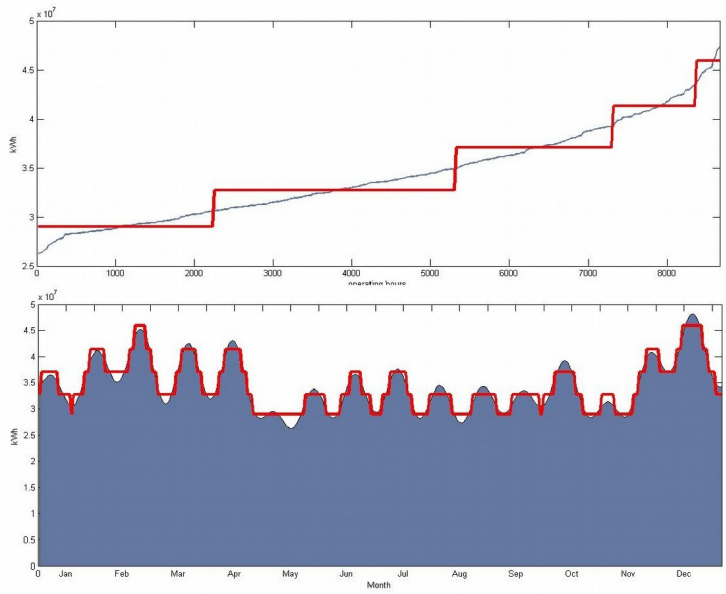

Figure 83: Electrical load periods for Austria

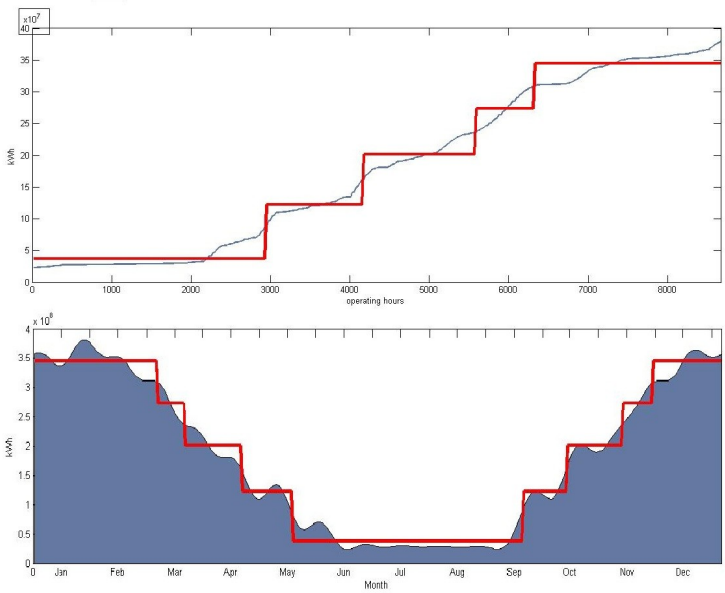

Figure 84: Thermal load periods for Austria

As done for the Case study 1 the error between the generated representation of the year in periods ant the assessment curve can be calculated as:

$$E=\sum_{n=1}^{365}\left|y_{period}(n)-y_{assesscurve}(n)\right|$$

E_{el}= 5.5586^{09} kWh=8,4%

E_{term}= 3.7291^{08}kWh=3,0%

8. Conclusions and further developments

The aim of this work is to answer on this big central issue about Green Energy systems:

Is it possible to integrate energy security issues of time dependency and resource depletion in energy network planning?

In order to answer this question, starting from an implementation of the optimization process in the RegiOpt software, the following questions had to be answered:

1. How does electricity and heat demand vary over time?
2. Which technologies are able to respond promptly to demand variations and how?
3. Which technologies strongly depend on outer non-controllable factors?
4. How do these technologies behave?
5. How could these behaviours be integrated in RegiOpt and at which point?
6. Is it possible to insert some degree of time-dependency without complete reprogramming the optimization software?

The main objective of the work, the integration of energy supply and energy demand curves in the PNS was achieved.
The integration of these curves in RegiOpt allows to propose a complete renewable-based regional energy network that is economically optimized and is able to respond in changes in energy demand.
The short term energy security issue was added to the software (RegiOpt): now the planning of regional renewable-based energy networks by operating an economical optimization, a resource-use optimization (PNS) and assessing the sustainability of the involved processes (SPI) is implemented with time flexibility.
The main goal of integration of the two most important problems regarding energy network planning was achieved: after this work, RegiOpt evaluates both the problem of resource management and the problem of time dependencies for the complete proposed network.
Regarding the secondary research questions that derive from the main problem, the technologies were divided on hand of their time dependencies and their ability to respond to changes in energy demand.
The technologies were divided in:

- constant-time dependent
- controllable
- with strong time-dependencies

Table6: Relevant strong-time dependent technologies

	ENERGY	TYPE OF TIME DEPENDENCY	MAIN VARIABLES
PHOTOVOLTAICS	electricity	non-controllable	sun motion position weather
THERMAL SOLAR	heat	non-controllable	sun motion position weather
WIND-POWER	electricity	non-controllable	wind-speed

Solar heat, PV and wind-power were identified as those technologies with most relevant time dependencies: the strict relation between the output of these devices and the presence of the source (wind, sun) leads to yearly production patterns that are characteristic for every device, thus the time-dependency of these devices is classified as strong.
As a consequence the output of these devices is not controllable and the production patterns have to be considered in the planning process.
The study of Green Energy supply technologies allowed this classification and the description of the behaviour of the solar and wind energy generation.
The main variables that affect the output patterns of the devices during the year were identified and shown in Table 3 and Table6.
Knowing the main variables on which the outputs depend, a description of the yearly output patterns was possible.
Data of proper temporal resolution was retrieved and properly prepared by statistical study:

- data of improper spatial scale was up- or down- scaled
- Fourier series were generated to represent the data
- unwanted frequencies were filtered out
- the SIC criterion was applied to reduce the models

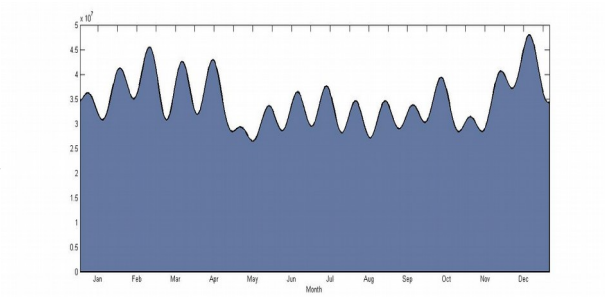

Figure 85: Electric overall assessment curve (Case study 2, Austria)

This statistical study allowed the description of the time variability of energy demand and energy supply with the generation of models, one for the heat demand and one for the electricity demand.
The modelled overall assessment curves (Figure 85 and Figure 86) show the energy amounts yet to be covered by the implementation of the energy supply network.

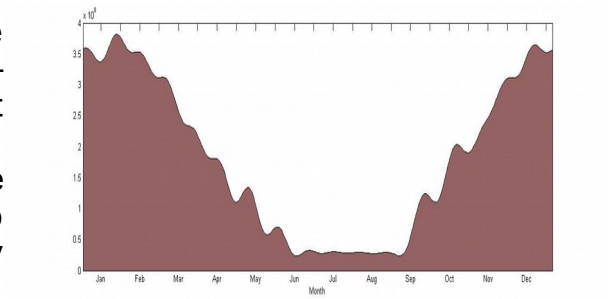

Figure 86: Thermal overall assessment curve (Case study 2, Austria)

These models describe the time-dependence of the energy demand with special focus on long oscillation periods (λ>20 days) within a year, this is congruent with the aim of planning the energy network without dealing with the issue of peak-response.
Furthermore the restricted number of intervals in which the year had to be divided into allows only an assessment of oscillations on scales bigger than 15 days: the short term oscillations have to be neglected.
As preliminary tests show that 5 is the higher number of periods PNS supports without going in overload, the year had to be divided into a maximum of 5 periods.
After the statistical study of the data the overall assessment curves were generated:
this curves represent the market share that has to be covered by the implementation of the existing network.
The overall assessment curves are of general relevance and describe the situation of the market at a local scale and are used to assess the energy amounts that have to be covered from controllable renewable-based technologies in order to reach complete complementarity of renewables (compensation of solar and wind based technologies with other renewable-based ones).
The passage from a date-sorted space to the space of operating hours sorted by increasing amounts of required energy allowed to leave the concept of time periods as classically understood and to generate a division of the year based on the amounts to be produced: the couple amounts/operating hours was then fed into PNS, top of Figure 87.

To visualize the result of this representation of the year, the operating hours were re-associated to the corresponding date and we can see that the precision of the assessment was increased, bottom of Figure 87.

As a result the year was not more divided in the 5 periods along the x-axis of date-time, but into 5 intervals of amounts of energy to be produced, to which far more than 5 date-time intervals correspond: we passed from a very low time resolution (5) to a far higher resolution that can't be assessed in advance.

The objective of dividing the year into 5 periods was not only met, but passed: the found solution enhances the temporal resolution and maintains the number of input parameters for PNS low (5).

At the same time software overload was avoided and the parametrization improved.

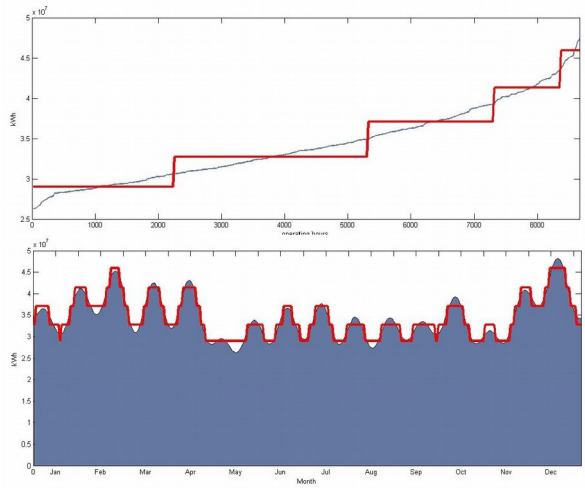

Figure 87: Division of the year in time intervals: passage from a date-sorted space to an amount-sorted space and division of the year (up), resultin representation of theyear in the date-sorted space: the periods are far more than 5 (Case study 2, Austria, electric assessment)

The energy security of the output of PNS is visibly enhanced: the parametric insertion of the time variability in the PNS allows an optimization run over seasonal/sub-seasonal changing conditions and the output is more stable with regard to changes in energy demand.

In conclusion the result of this work is a freely accessible software module that takes as input yearly load and supply curves with daily time-resolution and assesses the market share yet to be covered.

After the quantification of the available market share, the year is divided in finite intervals and fed to PNS: as a consequence the insertion of time-dependent energy supply and energy load curves was achieved parametrically.

The general effect of the developed software module is to insert short-term energy security issues in the RegiOpt software: now we have an innovative software that supports stakeholders in the development of high sustainable energy networks.

The integration of resource management issues, ecological footprint evaluation, economic optimization and time-dependencies of not manageable solar and wind energy generation allows the planning of a full integrated network that is economically feasible, environmentally sustainable and enhances the complementarity of renewable-based energy supply.

The variation of energy demand and supply was studied, the factors on which the output energy depends was outlined and described.

The behaviour of the devices was described in mathematical functions representing the output energy.

The insertion point was individuated right before the PNS module and in the PNS module by operating on the material flows.

Thus a proper handling of the input has been used to imprint to PNS a certain degree of time-flexibilization.

The time flexibilization was achieved by the division of the year into discrete intervals for which the required energy amounts fairly represent the continuous oscillations.
The found methodology has a general character and can be applied to different types of data and different scales.
On the spatial scale the methodology has proven to work properly both at local and at national scale.
On the bigger spatial scale proper interpolation of meteorological data is needed and could be misleading when applied locally.
In the local heat demand assessment, the development of energy efficiency policies and the local insulation degree of buildings affect the procedure: with proper data on the local building stock and its efficiency a higher precision can be achieved.
Furthermore, the insertion of efficiency parameters can be used to produce projections.
The major further development of this work is the re-programming of the PNS algorithms with the insertion of time-dependencies in the algorithms.
The ongoing changes in the energy supply networks make the steady-state assumption weak: assuming that the network can be represented by yearly means is misleading when applied to energy supply.
Furthermore daily and hourly changes in energy demand require an assessment with higher temporal resolution.
The data used to show the developed procedure and the software could be improved.
On the spatial scale local data on building stocks and real heat demand curves would lead to a better assessment: the behavioural components and the local building stock, with thermal efficiencies and daily patterns in the consumption would increase the confidence.
For regions in which there is a good coverage with district heating these data exist and the assessment would we very precise.
In regions in which gas is the leading fuel used in heating, the use of natural gas data could lead to an improvement.
On the solar heat generation the improvement possibility depends in first instance on the availability on daily meteorological data to fit in the models.
The photovoltaic output models could be substituted by real measures if the local energy companies would allow the access on data: the grid-connected devices feed the produced energy surpluses to the grid and these quantities would allow a better assessment of the output of installed devices.
The problems of positioning and shadowing of solar devices were neglected.
The dependence of the efficiency of devices with the input in solar and wind devices was not considered.
In the Case study 2, the bigger spatial scale led to many approximations.
As first the representation of the heat demand was based on a climatologically representative[10] data set for Austria that has very low spatial resolution that can be improved with proper datasets and modelling.
Also the regional and local variabilities of building stock and behavioural components could not be considered.

[10]according to ZAMG

To insert all the particular aspects that locally affect the energy supply from solar and wind devices proper databases are needed.
The most important missing database (under construction in some areas) is the energy efficiency database of building stock.
In conclusion the precision of the assessment can be improved slightly improved by the use of good data with high spatial resolution.
The improvement of the confidence of the assessment has to be weighted towards its application range: the effort in retrieving better data, making measures and develop better models has to be weighted towards the scope of being a preliminary assessment.
In conclusion the objectives of this work were successfully achieved and a scheme of the above explained results is shown in Table 7.
The developed methodology is generally applicable, as required by an online-tool.
The scheme of the developed methodology was shown in Figure 15 at page 28.

Table 7: Main results of this work

MAIN RESULTS TABLE		
RESEARCH ISSUES	INTERMEDIATE RESULTS	MAIN RESULTS
Integration of time dependency and resource depletion		RegiOpt proposes optimized networks with regards to temporal dependencies of energy demand and supply
Description of energy damand variations over a year	Overall description of the behaviour of energy demand	
	identification of the main variables affecting the patterns	
	Statistical study and generation of models	
	Assessment of the seasonal patterns	
Assessment and description of time-dependecnies in supply	Description of the behaviour of energy supply technologies	
	classification on hand of the time dependecies (Table 3 and Table6)	
Description of the behaviour of relevant technologies	Statistical study of data	
	Integration of statistical data and models	
	Generation and use of models	
	Assessment of the seasonal patterns	
Integration in RegiOpt	Evaluation of the required energy production with the overall assessment curves	Software module that integrates energy demand and energy supply curves in the PNS
	Division of the year in finite time intervals	

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