PUBLIZIERBARER ENDBERICHT

A) Projektdaten

Kurztitel:	TERIM
Langtitel:	Transition Dynamics in Energy Regions: An Integrated Model for Sustainable Policies
Programm:	ACRP, 3. Ausschreibung
Dauer:	01.04.2011 to 31.03.2014, 36 Monate
KoordinatorIn/ ProjekteinreicherIn:	Institut für Systemwissenschaften, Innovations- und Nachhaltigkeitsforschung (ISIS), Karl-Franzens-Universität Graz
Kontaktperson Name:	Claudia R. Binder
Kontaktperson Adresse:	Ludwig-Maximilians Universität München, Lehrstuhl für Mensch-Umwelt Beziehungen, Luisenstraße 37, 80333 München
Kontaktperson Telefon:	+49 (0) 89 / 289 – 22831
Kontaktperson E-Mail:	Claudia.Binder@geographie.uni-muenchen.de
Projekt- und KooperationspartnerIn (inkl. Bundesland):	P1. Section Energy & Industry, Faculty of Technology, Policy and Management, TU Delft, Niederlande P2. Europäisches Zentrum für Erneuerbare Energie (EEE), Burgenland P3. Energieregion Weiz-Gleisdorf, Steiermark P4. Lehrstuhl für Mensch-Umwelt Beziehungen, Ludwig-Maximilians Universität München, Deutschland
Schlagwörter:	Energieregion, sozio-technische Transformation, Energieflussmodell, Verhaltensmodell, integriertes Simulationsmodell, Multikriterielle Bewertung, Stakeholder-Beteiligung, politische Maßnahmenempfehlungen
Projektgesamtkosten:	277.132 €
Fördersumme:	277.132 €
Klimafonds-Nr:	B068700
Erstellt am:	29.06.2014

Projektübersicht

1 Executive Summary

Einleitung und Zielsetzung

Energieregionen bestehen aus regionalen Initiativen und Organisationen, die Energieautarkie durch die Nutzung von regionalen Energiequellen und dem Aufbau einer dezentralisierten Energieinfrastruktur als Vision haben. Sie werden als wichtige Akteure für den Übergang zu einem auf erneuerbaren Energien beruhenden Energiesystem betrachtet. Zu Energieregionen sind bereits Berichte und verschiedene Leitfäden erstellt worden; erst vor kurzem haben sie auch im wissenschaftlichen Bereich Beachtung gefunden.

Das Hauptziel dieses Projekts ist es, die Übergangsdynamiken zweier österreichischer Energieregionen zu verstehen und zu modellieren. Daraus sollen politische Empfehlungen für die Schaffung von neuen Energieregionen sowie für die Unterstützung bereits bestehender und die Unterstützung von im Übergang befindlicher Regionen abgeleitet werden. Die Forschungsarbeit wurde aufgenommen, um einen ersten Beitrag zu unserem Verständnis von der Dynamik dieses Übergangsprozesses und der Rolle der Stakeholder-Interaktion und Politik, welche diese Dynamiken beeinflussen, zu leisten. Dafür wurden zwei Fälle analysiert: die Energieregionen *öko*Energieland und Weiz-Gleisdorf. Die folgenden Forschungsfragen wurden erörtert:

1. Wie gestaltet sich der Übergang der beiden Regionen in Bezug auf die Bereitstellung erneuerbarer Energieträger, die Produktion erneuerbarer Energie und deren Verbrauch?

2. Welche Schlüsselakteure und Schlüsselparameter (soziale Norm, Kultur, Politik, etc.) haben den Übergang unterstützt oder behindert?

3. Wie kann der Übergang einer Energieregion unter Berücksichtigung der sozialen und technischen Komponenten des Systems, deren Interaktionen und Feedbackmechanismen modelliert werden?

4. Welche Richtlinien können zur Gründung, erfolgreichen Entwicklung und langfristigen Erhaltung (Nachhaltigkeit) von Energieregionen beitragen?

Methoden

Das Projekt wurde transdisziplinär mit jeweils einem Co-Leader der Energieregionen entworfen. Es bestand aus drei Modulen oder Arbeitspaketen: WP1: System Charakterisierung; WP2: Dynamische Modellierung; und WP3: Richtlinienentwicklung. Die Arbeitspakete wurden auf iterative Weise ausgeführt. So wurden während WP1 Informationen in Hinblick auf die Modellierung in WP2 gesammelt; außerdem wurden bereits während des ersten und zweiten Jahres des Projektes Richtlinien entworfen und diskutiert. In jedem Arbeitspaket wurde eine spezifische Reihe an Methoden angewandt.

Für beide Regionen wurde Daten zu den regionalen Energieressourcen, der Energieinfrastruktur und dem Energiebedarf erhoben; insbesondere zum Gebäudebestand, dessen Größe, technischem Standard und Entwicklungsstand. Diese Daten wurden für ein quasi-stationäres und dynamisches Energieflussmodell verwendet, um Energiebedarf und Versorgung in spezifischen Richtlinienszenarien zu simulieren. Durch eine Analyse der Akteure gelang es die Schlüsselfiguren der Region zu identifizieren und die Entwicklung der Netzwerke der beteiligten Akteure zu analysieren. Dies war mit der Analyse der Entwicklung regionaler Institutionen verkoppelt. Da Haushalte eine Schlüsselrolle in den Bereichen Energiebedarf und Energieversorgung einnehmen, wurde eine detaillierte Analyse der Faktoren erstellt, welche die Entscheidungen von Haushalten bezüglich Sanierung und Neubau beeinflussen. Hierbei wurden Experteninterviews mit einer quantitativen Umfrage und einem Simulationsmodell kombiniert. Zuletzt werden

Richtlinienszenarien mit den regionalen Partnern entwickelt und mit dem Simulationsmodell getestet.

Resultate

Im Folgenden werden die Schlüsselergebnisse des Projekts präsentiert:

- Der Übergangsprozess in beiden Energieregionen ist durch visionäre, institutionelle, physikalische (z.B. neue Infrastruktur, Anschlüsse an das Fernwärmenetz) und externe, institutionelle Meilensteine charakterisiert. Die visionären und institutionellen Meilensteine gehen den physikalischen Meilensteinen voraus. Zwischen der Vision, der Gründung eines institutionellen Leitungsorgans und der tatsächlichen Auswirkung auf das physikalische Energiesystem kann eine zeitliche Verzögerung beobachtet werden.
- Der Übergang des Energiesystems wurde vor allem von Führungskräften mit Vision, politischen Akteuren und Experten im Bereich erneuerbare Energien, Bildung, Tourismus, Forschung, Entwicklung und Wirtschaft vorangetrieben. Regionale Entwicklung war der Hauptantrieb für die Stakeholder, die in beiden Energieregionen beteiligt waren. Das Thema Energie und die Strategien für die Entwicklung hin zu einer Energieregion sind aus den regionalen Vorbedingungen, Präferenzen und komparativen Vorteilen hervorgegangen.
- Momentan ist keine der Regionen imstande den Energiebedarf aus regionalen Quellen zu decken. Theoretisch wird es in der Zukunft in beiden Regionen möglich sein, ausreichend Energie bereitzustellen, um den gesamten Energiebedarf (Wärme, Elektrizität und Kraftstoffe) zu decken. Im ökoEnergieland wäre es möglich alle MIDI Szenarien anzuwenden und in der Energieregion Weiz-Gleisdorf alle MAXI Szenarien. Im Falle der MAXI Szenarien würde dies jedoch bedeuten, dass die gesamten vorhandenen Flächen (z.B. Waldflächen, landwirtschaftliche Flächen, Dachflächen und Fassadenflächen) für die Energiegewinnung benötigt werden würde.
- Der Schlüssel zur Transformation des Energiesystems liegt in der Reduktion des Energiebedarfs. Dabei spielt der Wandel des Häuserbestandes eine zentrale Rolle, z.B. durch Sanierung und Umsetzung von Energiestandards. Unsere Simulationsergebnisse zeigen, dass zwischen dem Erhöhen der Sanierungsrate und höheren Energiestandards ein trade-off besteht. Es besteht die Möglichkeit, dass die Durchsetzung höherer Energiestandards die Sanierungsrate verringern könnte.
- Der Entscheidungsfindungsprozess bezüglich der Energiestandards von Sanierungen und Neubauten findet in einer Sequenz von Phasen statt. Während der ersten Phase spielt das soziale Umfeld eine sehr wichtige Rolle. In der zweiten Phase haben Architekten und Planer den größten Einfluss auf die getroffenen Sanierungsentscheidungen.
- Zuletzt hat sich der gewählte transdisziplinäre Ansatz als äußerst wertvoll erwiesen. Wir stellten einerseits fest, dass den Forschern hohe Einsatzbereitschaft und Unterstützung von Seiten der regionalen Führungskräfte entgegengebracht wurde. Andererseits profitierte die Region, durch die Ko-Leitung, von den gesammelten Daten und Modellen. Der Prozess gegenseitiger Inspiration und wechselseitiger Lerneffekte setzt sich weiterhin, auch nach dem offiziellen Abschluss des Projektes, fort.

2 Executive Summary

Introduction and objectives

Energy Regions are regional initiatives, organisations who envision energy self-sufficiency by using regional energy sources and by building a decentralized energy infrastructure. They are seen as important players in the transition towards a renewables-based energy system. Energy Regions have been reported upon and several manuals have been developed; they only have attracted scientific interest recently.

The main objective of this project is to understand and model the transition dynamics of two Austrian Energy Regions and to derive policy recommendations for establishing new, supporting current and maintaining successful transitions of Energy Regions. The research was set up to make a first contribution to our understanding of the dynamics of the transition process, and the role of stakeholder interaction and policy affecting these dynamics. To this end, two cases were analyzed: the Energy Region *öko*Energieland and Weiz-Gleisdorf. The following research questions are addressed:

5. What are the characteristics of the transition in the two regions in terms of renewable energy sources allocation, renewable energy production, and energy consumption?
6. Who were the key agents and which were the key parameters (social norm, culture, policies, etc.) which supported or hindered the transition?
7. How can we model the transition in an Energy Region considering the social and technical components of the system, their interactions and feedback mechanisms?
8. Which policies can support the establishment, successful development, and long-term maintenance (sustainability) of Energy Regions?

Methods

The project was designed in a transdisciplinary way with a co-leader from each Energy Region and steering boards supporting the research process in all phases. It consisted of three modules or work-packages: WP1: System Characterization; WP2: Dynamic Modeling; and WP3: Policy Development. In each work-package a specific set of methods was applied.

For both regions detailed data about the regional energy resources, energy infrastructure and energy demand, in particular the building stock, its' size, technical standard, and development were collected. These data were used in a quasi-stationary and dynamic Energy Flow Model to simulate energy demand and supply given specific policy scenarios. An agent analysis allowed us to identify the key players in the region and to analyze the development of the agent networks. The agent analysis was coupled to the analysis of the development of the regional institutions. As household play a key role in energy demand and supply a detailed analysis of the factors affecting households' decisions on renovation and new buildings was made. In doing so, expert interviews were combined with a quantitative survey and simulation modeling. Finally, policy scenarios are being developed with the partners in the regions and tested with the simulation model.

Results

In the following the key results of the project are presented:

- The transition process in both Energy Regions is characterized by visionary, institutional, physical (e.g., new infrastructure, connections to heating grids) and external institutional milestones. The visionary and institutional milestones precede the physical milestones. A time delay between the vision, the establishment of an institutional governance-body and its actual impact on the physical energy system can be observed.
- The energy systems' transition was mostly promoted by visionary leaders, political agents, experts in the field of renewable energy, supported by agents in the societal fields of education, tourism, research and development, and economy. Regional development was the main driver for the stakeholders in both Energy Regions. The topic of energy and the

strategies for becoming a self-sufficient energy region emerged from regional preconditions, preferences and comparative advantages.

- Currently, none of the regions is able to supply its energy demand out of regional sources. In the future, in both regions it would theoretically be possible to supply sufficient energy to cover total energy demand (heat, electricity, and fuels). In the ökoEnergieland it would be possible applying all MIDI (i.e. medium exploitation of energy sources) scenarios, in the Energieregion Weiz-Gleisdorf all MAXI scenarios. In case of the MAXI scenarios this would mean that the entire available area (i.e. forest area, agricultural area, roof area, and façade area) is needed to generation energy.
- Key for transforming the energy system is the reduction of energy demand, whereas the change of the building stock plays a central role, i.e. renovation and energy standards. Our simulation results suggest that there is a trade-off between increasing the renovation rate and higher energy standards. It may be the case that enforcing higher energy standards would decrease the renovation rate.
- The decision-making process regarding the energy standards for renovation and new buildings takes place in a sequence of phases. In the first phase the social environment, people within the social context having built or renovated, is highly relevant. In the second phase the architects and the planners have the highest impact on the renovation decisions made.
- Finally, the transdisciplinary approach chosen proved to be extremely valuable. We found that on the one hand the researchers had a high commitment and support from the leaders in the Energy Region. On the other hand, the region itself benefitted from the collected data and models and the discourse which has been initiated in the course of the transdisciplinary research process by being closely involved. The process of mutual inspiration and mutual learning is still growing even after the official end of the project.

3 Hintergrund und Zielsetzung

Initial situation / motivation for the project

In order to mitigate climate change, climate and energy policies on the international (UNFCCC, 1997), European (EC, 2007) and national level (BMWFJ and BMLFUW, 2010) prescribe reductions of GHG emissions, energy saving, increase in energy efficiency, and increase of renewables in energy consumption. Nevertheless, energy consumption per capita, CO_2 emissions per capita, and fuel import in Austria increased continuously from 1990 until 2007 (EC, 2010). Experts claim that the solution lies in a structural change or transition from the existing conventional centralized and mainly fossil fuel-based energy infrastructure towards a decentralized and renewable-based energy infrastructure (Paula, et al., 2009). Examples for such transitions are energy regions, regional initiatives envisioning energy self-sufficiency by using regional energy sources and building a decentralized energy infrastructure. In Austria, energy regions emerged in the 1990s (Klima- und Energiefonds, 2010) and besides GHG emission reductions, positive effects like increase of regional valued added and creation of new jobs have been found (BMVIT, 2005).

Reports on energy regions and similar initiatives in Austria and other European countries can be found in numerous manuals, workshop reports, and websites (e.g., Koch et al., 2006, Hofbauer, et al., 2006; Bärnthaler and Schauer, 2009; Tischer et al., 2006, CONCERTO, 2010). Attempts to scientifically investigate energy regions have started only recently. Späth (2007) and Späth and Rohracher (2010) investigated the role of guiding visions and stakeholder networks in the transition management in selected energy regions in Austria. Kolbmüller et al., (2010) build on experiences of ongoing projects and developed a manual including a typology and an evaluation system for energy regions. However, studies on energy regions so far have not aimed at understanding the dynamics of the transition process, nor the role of stakeholder interaction or policy affecting these dynamics.

2.2.1. Objectives of the project

The main objective of this project is to understand and model the transition dynamics of two Austrian energy regions and to derive policy recommendations for establishing new, supporting current and maintaining successful transitions of energy regions. The research was set up to make a first contribution to our understanding of the dynamics of the transition process, and the role of stakeholder interaction and policy affecting these dynamics. To this end, two cases were analyzed: the Energy Region *öko*Energieland and WeizGleizdorf. The following research questions are addressed:

- What are the characteristics of the transition in the two regions in terms of renewable energy sources allocation, renewable energy production, and energy consumption?
- Who were the key agents and which were the key parameters (social norm, culture, policies, etc.) which supported or hindered the transition?
- How can we model the transition in an energy region considering the social and technical components of the system, their interactions and feedback mechanisms?
- Which policies can support the establishment, successful development, and long-term maintenance (sustainability) of energy regions?

4 Projektinhalt und Ergebnis(se)

Conceptual framework and module description from proposal

The project was conceptualized as a transdisciplinary project. In each of the regions a co-leader of each of the energy regions was selected. The project was presented in the regional board meetings and a steering group supported the data gathering, reflected on intermediate results and provided a significant input into the modeling and policy development process.

The project itself was designed in three modules or work-packages: WP1: *System Characterization*; WP2: *Dynamic Modeling*; WP3: *Policy Development* (see Proposal Figure 2). The work-packages built on each other and overlapped to some extent. That is, information in WP1 was collected in view of the model to be developed in WP2 and policies were designed and discussed already in the first and second year of the project.

<u>WP 1: System characterization</u>

For characterizing the energy transitions of the two study regions, we based ourselves on existing data sets from the study regions and applied methods from social as well as natural sciences. The characterization included: (i) development of the physical resource base of the region (e.g. agricultural area, forest area, areas covered with photovoltaic cells); (ii) development of energy demand; (iii) industrial development in the region (e.g. new energy-related firms, which located themselves in the region); (iv) socio-economic factors affecting households' investment and consumption decisions; (iv) policies and external boundary conditions; and (v) the development of the stakeholder map and network. The characterization was performed as follows:

Literature data and data from the study regions

For the overall characterization of both energy regions we used regional study reports (EEE, 2011; Energieregion Weiz-Gleisdorf, 2007) and gathered data from statistical institutes (Statistics Austria, 1990-2010, BEV, 2012). For further details see part C.

Energy flow analysis

For both energy regions an energy flow analysis was conducted for the reference years 2000 and 2010. Thereby, the energy regionally produced by renewable energy carriers was compared with the energy regionally consumed resulting in the degree of energy self-sufficiency for each reference year. To calculate the amount of regionally produced energy by large-scale energy plants a more detailed analysis was made (for details see below).

Regional energy potentials

For both study regions the regional energy potential for biomass (forestry and agriculture), solar power, and geothermal energy was calculated. For each of these, 3 scenarios were compiled: (i) the MAXI scenarios represent the respective maximum technical potential assuming that the total available area (e.g. area of land, roof area, façade area, etc.) is entirely used for energy generation not restricted through any other energy technology. The MIDI scenarios reflect the potentials assumed to be realizable within the observation period (2030). The MINI scenarios represent the minimum potential oriented towards the status quo.

Regional energy demand from buildings

For analyzing the regional energy demand a building stock model was developed, based on statistical data about different building types and their energy demand. Since this data is only partially available on the regional scale several buildings' and technologies' attributes have been calculated referring to data sources on national or district level. Four data sets were collected to initialize the model: (i) building stock data including number of buildings of a certain type, construction period, and energy carrier (study regions specific), (ii) average gross floor area per building type and construction period (district level), (iii) heating, hot water, and electricity demand data (national level), and (iv) heating technology specific data such as current efficiencies and expected efficiency increases (national level). In the following we briefly address the calculation and data sources for each of these in turn.

Stakeholder interviews – Agent and policy analysis

We performed and agent and policy analysis which was conducted in close cooperation with the steering boards of the energy regions. It consisted of three steps: In the first step, the key agents directly and indirectly influencing the transition of the energy region were identified in interviews (see Hecher et al., 2014). First, the steering board members were interviewed and relevant actors as well as their role in the different phases of the transition process of the energy region were identified. Results of these interviews have been jointly analysed in the steering boards. Subsequently, further interview partners have been selected and the interviews extended. In a snowball system, further actors have been identified. In a second step the role of the agents and their resources were analyzed with respect to institution building in the region. We differentiated between (i) visionary leaders, who play a crucial role in the initiation of the transition process; and (ii) political representatives of municipalities who hold a substantial role as they are legitimized to realize agreements on the inter-municipality level (Hauber and Ruppert-Winkel, 2012; Rohracher, 2008; Späth and Rohracher, 2011). In the third step, milestones of the transition process were derived from both literature research and the interviews and were validated by the representatives of the energy regions' institutional body (Hecher et al., submitted). The milestones were categorized into visionary, institutional, physical, and external institutional milestones. Visionary milestones were defined as densifications of guiding ideas, institutional milestones as permanent and binding agreements, physical milestones as infrastructural measures in the energy sector and external institutional milestones as events affecting the Energy Regions' development from outside (see Hecher et al., submitted)

Standardized survey

The goal of the in-depth household survey was to analyse the social, economic, and political factors affecting the investment and consumption decisions of households related to their energy consumption. Because 87% of total household energy demand accounts for heating and hot water supply (Bohunovsky, 2008), we decided to focus on decision-making related to the energy performance of dwellings, which is affected by policies, personal factors, as well as experts in the building sector. In order to exclude the landlord-tenant problem from our study, we interviewed only owners of single-family houses, which cover 80% and 88% of all buildings in the two study regions Energieregion Weiz-Gleisdorf (Styria) and ökoEnergieland (Burgenland), respectively.

Policies and external boundary conditions

Relevant policies and external boundary conditions related to the behavioural analysis were identified through a literature review and the evaluation of 6 expert interviews and 10 explorative interviews with households. The firstly identified relevant factors (policies, fuel prices and prices of different technologies) were, after a further evaluation of interviews, narrowed down to zoning law regulations and subsidies on state, department and municipality level.

<u>Module 2: Dynamic modeling</u>

In Module 2 the energy transition for both study regions were modeled and simulated. The model integrates the regional energy demand in a dynamic buildings energy demand model, which is then linked with the behavioral model (see below).

Dynamic buildings' energy demand model

The model aims to portray the building stock's energy demand and heating systems transition in the energy regions. Furthermore, it is designed to test the effectiveness of different policy measures on overall energy demand, cumulative energy savings and energy source used. It is based on statistical data from regional energy demand as outlined above.

Behavioral Modeling (ABM)

We developed the behavioural model based on data about external factors and empirical data collected in interviews and the household survey. The purpose of the model is to examine the decision-making of households, using the quantified factors (see below). The focus is the actual energy efficiency standard of dwellings, which is selected in a stepwise process influenced by different factors. The following methods were applied: Structural Equation Modelling (SEM), a standard technique for hypothesis testing, and Agent-Based Modelling (ABM), which allows simulating individual based decisions of agents in a system (Nikolic, 2009; Chappin and Dijkema, 2009).

<u>Module 3: Policy development</u>

The goal of Module 3 is to develop and assess a set of policies, which should be able to support the development, the establishment, and the long-term maintenance of energy regions. We developed potential policies during the whole research process, in particular during the expert interviews. In a final workshop at Weiz-Gleisdorf (25.09.2013) specific policies were elicited regarding energy supply and energy demand.

Simulation and assessment of policies

The dynamic building model allows for simulating different scenarios and their impact on the regional energy demand, and energy carrier distribution. Renovation rates and building standard regulations were the key parameters varied in the scenarios. As randomization had little impact on the results with the top-down fixed behaviours (i.e. new construction, demolition, renovation,

energy standards, and heating systems) a fixed random seed was used to show reproducible results.
The prototype integrated model implemented in NetLogo allows simulation experiments for both energy regions with switches and sliders (on the left in Figure 1). The output of the model is presented as plots and monitors (on the right in Figure 1) for demographics, social parameters, energy efficiency standards portfolio and heating systems. For data generation an experiment was executed with 250 runs per region.

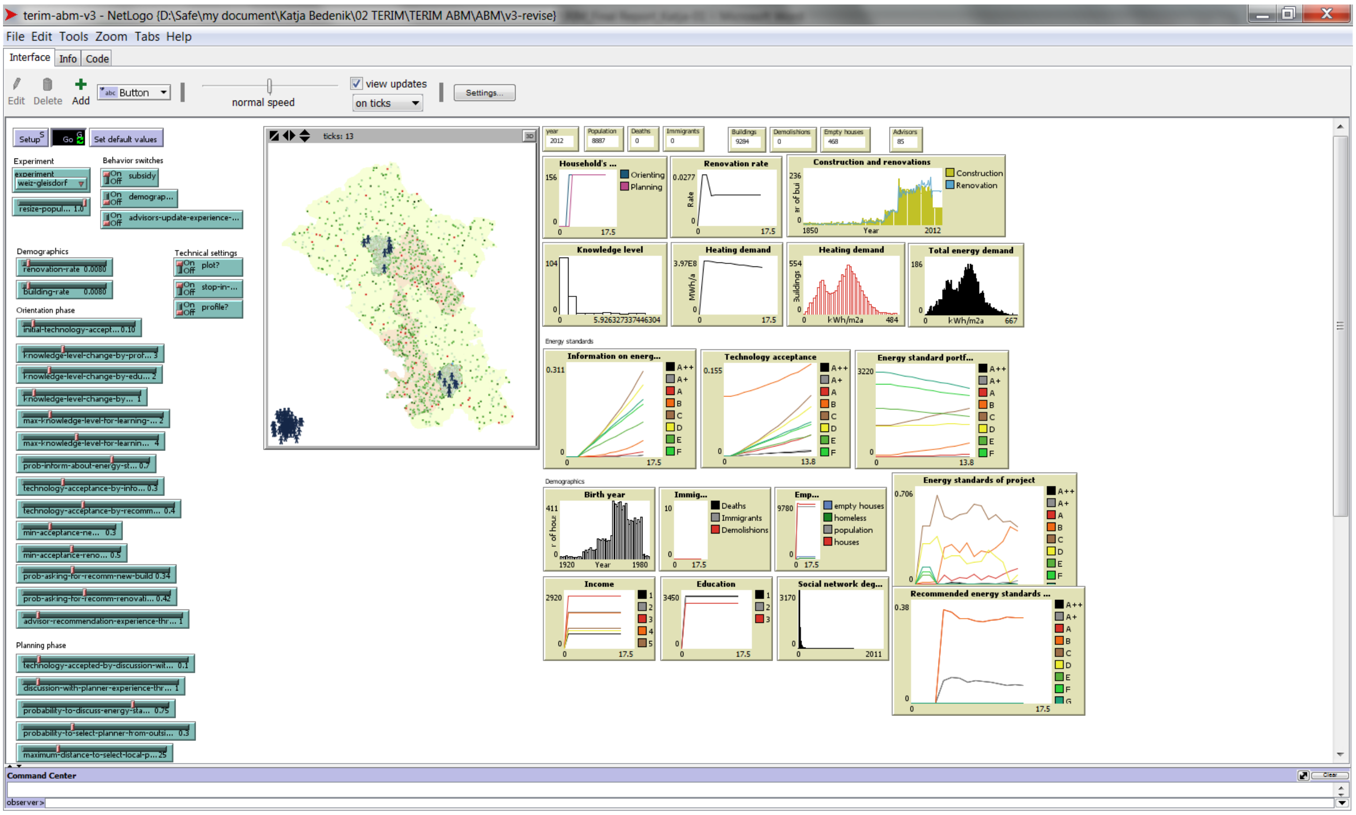


Figure 1: Interface of integrated model: Simulation for Energieregion Weiz-Gleisdorf

Results

Description of the results and project milestones

<u>Module 1: System characterization</u>

Overall comparison of the development in the two study regions

The study region ökoEnergieland is located in the southeast of Austria on the border to Hungary and has neither a direct railway nor a highway connection. It covers an area of 317 km², from which 48% is used as agricultural land and 42% as forest area. Due to its peripheral location, the substantial capital outflow for energy imports, and the untapped potential of renewable energy sources, experts developed a model to primarily supply the town of Güssing with regional energy carriers. In a first step, the municipality council of Güssing decided to withdraw from fossil fuels in 1990. In 2005 the association ökoEnergieland emerged including 10 member municipalities, in 2010 already 14 member municipalities were involved in this process (BMVIT, 2007). In 1990, the region had a population of 14.430 inhabitants with a population density of 46 inhabitants per km² (see Table 1). Between 1990 and 2010, the region's population even decreased by 9%, and the population density shrank to 41 inhabitants per km². In 1990, 10% of the study regions' working population worked in the first sector (-3% in 2010), 39% in the second sector (-14%), and 47% in the third sector (+16%), whereby 4% of the workforce was unemployed (+1%). In 2001, the region already provided 606 workplaces (+17% compared to 1990) for 4.035 employees (+20%), although the forestry and agricultural enterprises (-61%) and its employees (-49%) decreased between 1990 and 2010.

The energy region Energieregion Weiz-Gleisdorf established in 1996 and includes 18 member municipalities in Styria. It covers an area of 264 km², whereby 44% of this area serves for agricultural purposes and 42% is used as forest area. The region records a number of concluded energy projects, innovations in passive house building methods, high-quality energy renovation of buildings, and major applications of solar technologies. Besides the concentration on 'renewable energy' and 'energy efficiency', the region set its focus on 'e-mobility'. Compared to ökoEnergieland*,* the Energieregion Weiz-Gleisdorf is an industrial region with a high proportion of large scale as well as medium and small scale enterprises (Energieregion Weiz-Gleisdorf, 2007). In 2001 the region provided 1.720 workplaces (+37% compared to 1990) for 19.178 employees (+41%). In 1990, 10% of the study regions' working population worked in the first sector (-4% in 2010), 38% in the second sector (-7%), and 47% in the third sector (+13%), whereby 5% of the workforce was unemployed (-2%). Furthermore, the region is characterized by an increasing population. Between 1990 and 2010 the population increased by 11% from 16.361 to 21.931 inhabitants and represents a population density of 158 inhabitants per km² in 2010.

Table 1. Comparison and development of socio-economic characteristics in both study regions

Energy region	**ökoEnergieland**			**Energieregion Weiz-Gleisdorf**		
	1990	**2010**	**Δ 1990/2010**	**1990**	**2010**	**Δ 1990/2010**
Inhabitants	14.428	13.151	-9%	37.658	41.800	11%
Population densitiy [inhabitant/km²]	46	41	-9%	142	158	11%
Working population	6.296	6.325	-0,2%	17.161	22.594	34%
- Agricultural sector	653	464	-29%	1.766	1.433	-19%
- Production sector	2.450	1.601	-35%	6.546	7.021	7%
- Service sector	2.939	3.967	35%	8.049	13.477	67%
Employment participation rate	44%	48%	4%	46%	54%	6%
Unemployment rate	4%	5%	1%	5%	3%	-2%
Workplaces *	516	606	17%	1.252	1.720	37%
Employees *	3.365	4.035	20%	13.591	19.178	41%
Forestry and agricultural enterprises	2.114	823	-61%	2.251	1.504	-33%
Employees in forestry and agricultural enterprises	3.106	1.598	-49%	4.246	5.508	30%

** as data is not yet available for 2010, the comparison is made between 1990 and 2001*

Energy flow analysis

Development of large-scale renewable energy production technologies in both study regions: Between 1990 and 2010, 13 district heating plants and 4 cogeneration plants were installed in the energy region ökoEnergieland with a total installed capacity of 36 MW. In the region a district heating network was built up with a total length of 77,053 m. With the use of forestry and agricultural products (i.e. wood chips, sawdust, splinter, corn, and grass) a total energy output of 119 GWh could be reached in 2010. Furthermore, 3 small hydropower plants with a total installed capacity of 240 kW annually produce 1 GWh of electricity. Besides biomass and hydropower plants, 4 large-scale solar thermal installations (1,155 m²) and 2 large-scale photovoltaic systems (38 kW_{peak}) were installed, producing 1 GWh of energy per year. In total, the regional energy production from large-scale renewable energy technologies increased from 1 GWh in 1990 to 28 GWh in 2000 and to 121 GWh in 2010. At that time, 30 district heating plants and 4 cogeneration plants were installed in the Energieregion Weiz-Gleisdorf. The biomass plants have a total installed capacity of 32 MW and annually produce 148 GWh of energy in 2010. The district heating network in the region accounts for 43,753 m. Additionally, 11 water power plants (3.5 MW) were installed in the region producing 26 GWh of electricity per year. In sum, 174 GWh of energy is produced in the energy region in 2010, compared to 59 GWh in 2000 and 28 GWh in 1990. In Figure 2 the development of the respective regional end energy production with large-scale energy technologies between 1990 and 2010 is illustrated.

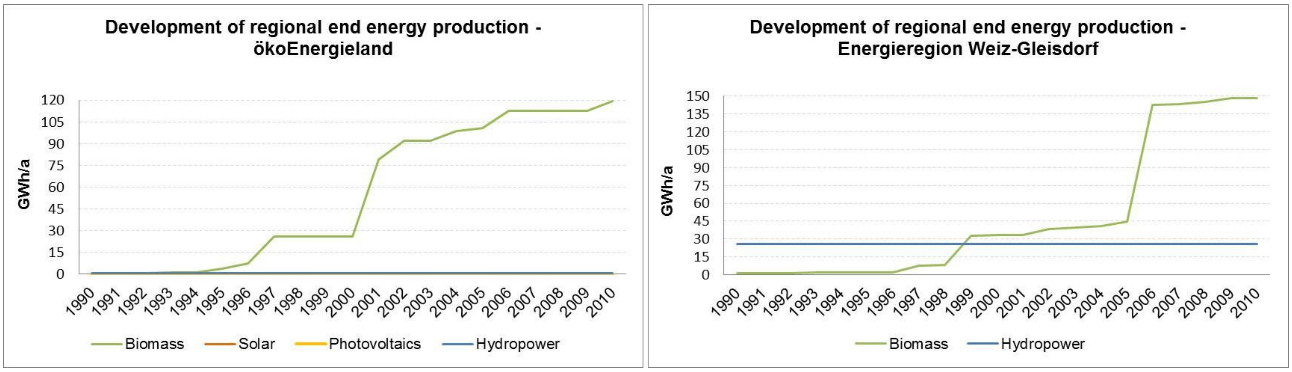


Figure 2: Development of regional end energy production from large-scale energy plants between 1990 and 2010 [GWh/a]

Regional energy flows in both study regions and their changes between 2000 and 2010: Table 2 summarizes the energy flows and its most significant changes between 2000 and 2010 in terms of the regional energy supply, the regional energy demand, and the degree of self-sufficiency. In ökoEnergieland, besides large-scale energy technologies, individual heating systems based on renewable energy such as small-scale heating (+68%), heating pumps (+83%), solar thermal installations (+83%), and photovoltaic panels (+89%) gained importance. In 2010, small-scale renewable energy technologies produced 111 GWh of energy (compared to 66 GWh in 2000). The total regional energy demand accounts for 359 GWh in 2000 and increased to 438 GWh in 2010 (+22%). Thereby, the energy demand of the industry sector increased the most (+91%), while the energy demand of private households remained relatively stable (-0.2%). In 2000, the energy demand from regional renewable energy carriers accounts for 26%, the fossil fuel demand for 59%, and the electricity demand for 15%. Between 2000 and 2010, the energy provided from renewable energy carriers increased by 148%.

In the case of fossil fuels a decrease of 18% could be reached, whereby electricity imports decreased by 39%. In ökoEnergieland, the degree of energy self-sufficiency between 2000 and 2010 increased from 26% to 53%. Compared to ökoEnergieland, also in the Energieregion Weiz-Gleisdorf an increase of small-scale renewable energy technologies can be observed between 2000 and 2010. In 2010, 290 GWh of energy is produced with these technologies (+48% compared to 2000). By adding up small-scale and large-scale energy technologies, the total regional energy supply accounts for 464 GWh in 2010, compared to an energy demand of 1,771 GWh. From the energy demand, 54% is consumed by the industry and transport sector, 22% by private households, 21% by public and private services, and 4% by the agricultural sector. Between 2000 and 2010, the energy demand from renewable energy carriers increased by 82%. However, also the demand for fossils fuels (+8%) and electricity (27%) increased. The level of energy self-sufficiency in the Energieregion Weiz-Gleisdorf increased from 18% in 2000 to 26% in 2010.

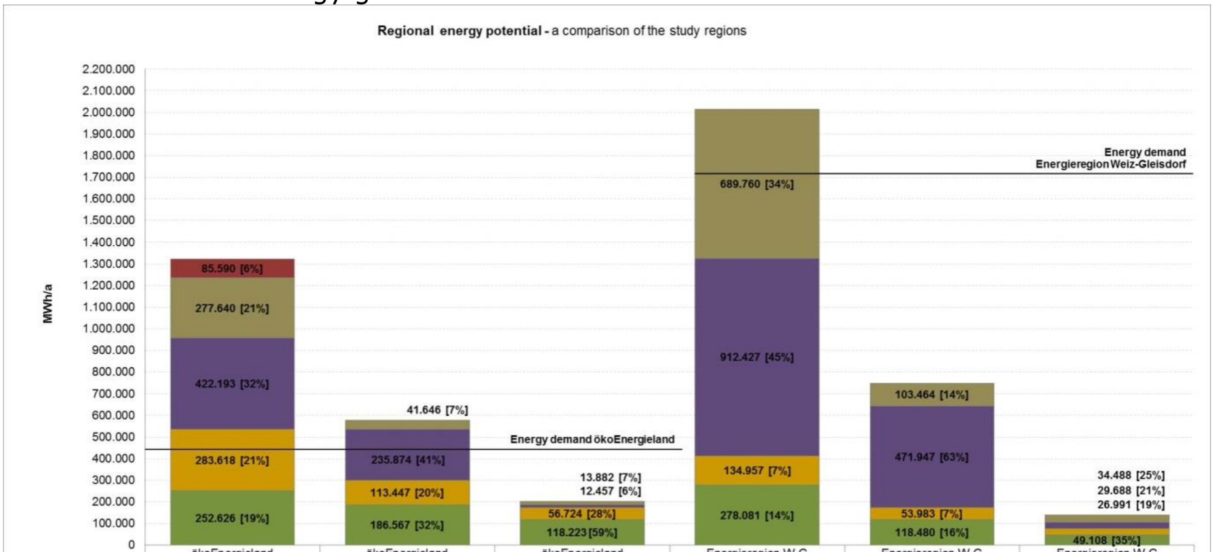
Table 2. Energy flows in both energy regions and its changes between 2000 and 2010 [MWh/a]

Energy flow analysis	ökoEnergieland			Energieregion Weiz-Gleisdorf		
	2000 MWh	2010 MWh	∆ 2000/2010 %	2000 MWh	2010 MWh	∆ 2000/2010 %
Energy supply (large-scale)	**27,989**	**121,222**	**333%**	**59,139**	**173,903**	**194%**
Biomass plants*	26,115	119,298	357%	33,227	147,991	345%
Hydropower plants	975	975	0%	25,912	25,912	0%
Solar thermal installations	899	913	2%	0	0	-
Photovoltaic panels	0	36	-	0	0	-
Energy supply (small-scale)	**65,555**	**110,875**	**69%**	**195,901**	**289,779**	**48%**
Small-scale heating*	61,998	104,370	68%	188,584	273,731	45%
Heating pumps	1,934	3,536	83%	3,082	6,715	118%
Solar thermal installations	1,596	2,918	83%	4,201	9,154	118%
Photovoltaic panels	27	51	89%	34	179	426%
Energy demand	**359,200**	**437,659**	**22%**	**1,414,830**	**1,770,878**	**25%**
Private households	193,349	192,987	-0,2%	329,606	383,478	16%
Industries & transport	71,506	136,482	91%	772,973	949,487	23%
Public & private services	70,284	81,868	16%	270,802	372,962	38%
Agriculture	24,061	26,322	9%	41,449	64,951	57%
Energy carriers	**359,200**	**437,659**	**22%**	**1,414,830**	**1,770,878**	**25%**
Regional renewable energy	93,544	232,096	148%	255,040	463,682	82%
Fossil fuels	210,421	171,781	-18%	888,110	961,888	8%
Electricity	55,235	33,782	-39%	271,680	345,308	27%
Level of self-sufficiency	**26%**	**53%**	**27%**	**18%**	**26%**	**8%**

* It is assumed that biomass plants and small-scale heating systems are supplied by regional biomass resources, although exact numbers are not known.

Regional energy potentials

Figure 3 illustrates the results of the regional energy potentials in terms of (i) forestry, (ii) agriculture (II indicates the approach that the total agricultural area is cultivated with the most common crops, compared to energy crops in I), (iii) solar energy (MIX indicates that the total suitable area is used for solar thermal installations and photovoltaics, 50% respectively), (iv) heat pumps, and (v) geothermal energy. For both energy regions the MAXI, MIDI, and MINI scenarios are demonstrated respectively and compared with the regional energy demand in both study regions (total energy demand in 2010 derived from energy flow analysis). The forestry potentials in the ökoEnergieland are higher than in the Energieregion Weiz-Gleisdorf (MIDI and MINI scenario) due to both a larger forest area and a higher share of the wood increments' energy use. In the MAXI scenario this is not the case as the annual wood increment in the Styrian region exceeds that of the Burgenland and in both regions it is assumed that 100% of the wood increment is used for energy generation. The figure also shows that the agricultural potentials in the ökoEnergieland are higher than in the Energieregion Weiz-Gleisdorf. This is explained by the larger agricultural area available in the ökoEnergieland and the varying composition of the crops in both regions leading to higher end energy outputs in the ökoEnergieland. In the case of the solar energy potentials it is different. Due to the fact that the number of buildings in the Energieregion Weiz-Gleisdorf is more than twice as high as in the ökoEnergieland, also the suitable roof and façade area is higher leading to higher energy potentials in all scenarios. The higher number of buildings in the Energieregion Weiz-Gleisdorf is also reflected in the regional energy potentials for heat pumps. In all scenarios the energy potential for heat pumps is higher in the Energieregion Weiz-Gleisdorf than in the ökoEnergieland. And finally we calculated the geothermal energy potential for the ökoEnergieland (MAXI scenario only) as it is located in one of Austria's most promising regions for hydro-geothermal energy. In the Energieregion Weiz-Gleisdorf it is assumed that geothermal energy is not an option. The figure also illustrates that the regional energy demand in the ökoEnergieland can only be provided from renewable energy sources in case all MAXI or MIDI scenarios would be realized. In the Energieregion Weiz-Gleisdorf the regional energy demand is relatively high compared to the regional energy potentials and energy self-sufficiency can only be achieved if all MAXI scenarios would be applied However, in case of the MAXI scenarios this would mean that the entire available area (i.e. forest area, agricultural area, roof area, and façade area) would be used for energy generation.



	ökoEnergieland MAXI	ökoEnergieland MIDI	ökoEnergieland MINI	Energieregion W-G MAXI	Energieregion W-G MIDI	Energieregion W-G MINI
Geothermal energy	85.590	0	0	0	0	0
Heat pumps	277.640	41.646	13.882	689.760	103.464	34.488
Solar energy MIX	422.193	235.874	12.457	912.427	471.947	29.688
Agriculture II	283.618	113.447	56.724	134.957	53.983	26.991
Forestry	252.626	186.567	118.223	278.081	118.480	49.108

Figure 3: Regional energy potentials in both study regions

Regional energy demand from building

In the following we present the distribution of the key characteristics (i.e. type of buildings, heating systems, and energy carriers) of the regional energy demand model from buildings.

Type of buildings: Single-family houses present the majority of building types within both energy regions (Weiz-Gleisdorf 80%, ökoEnergieland 88%), followed by the non-residential buildings (Weiz-Gleisdorf 15%, ökoEnergieland 11%). The age distribution of single-family is similar in both energy regions. One third of the building stock was constructed in the period between 1961 and 1980 (see Figure 4), a period characterized by fast construction without spending too much attention on energy saving measures. A similar image can be drawn of the non-residential building stock but with a less severe peak in the 60iess and a more dominant representation of buildings constructed before 1919 and after 1991. Multi-family houses (1,4% ökoEnergieland; 6,2% Weiz-Gleisdorf) are rather underrepresented in both regions compared to national share in Austria.

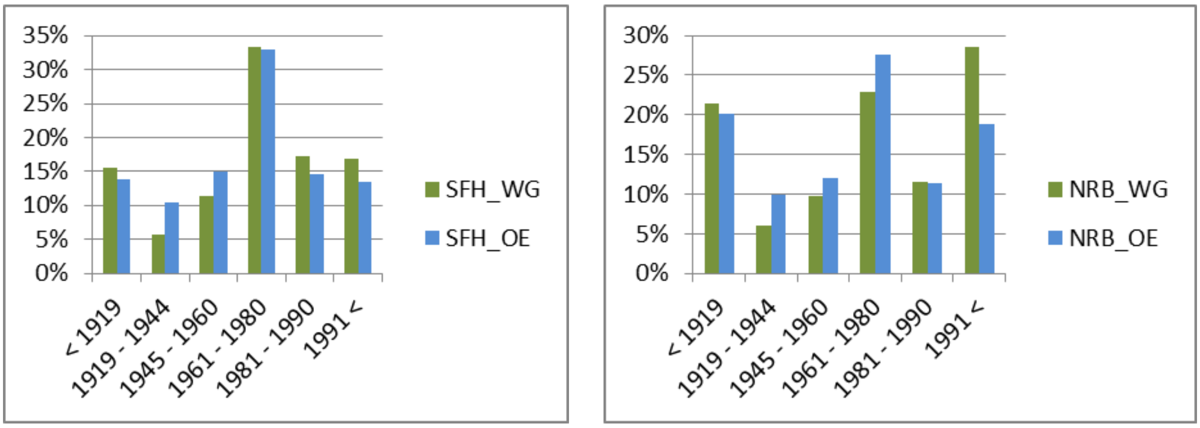


Figure 4: Age distribution of single-family houses and non-residential buildings within the energy regions

Heating Systems: The majority of buildings are supplied by central heating systems (Table 3). In Weiz-Gleisdorf central heating systems are more dominant (81%) while in ökoEnergieland individual heating systems still account for 28%. However, a comparison of heating systems installed in 1991 and 2001 [7] shows a clear shift from individual heating systems to central heating systems in both regions.

Table 3: Share of Heating Systems within the two Energy Regions

	Share of Heating Systems 2001 (1991) in %		
Heating System	District Heating	Central Heating	Individual Heating
Weiz-Gleisdorf	5 (2)	81 (68)	14(29)
ökoEnergieland	11 (1)	61 (54)	28 (45)

Energy Carriers: Comparing the share of energy carriers in total the dominant ones are oil (ökoEnergieland 31%, Weiz-Gleidsdorf 39%) and wood (ökoEnergieland 43 %, Weiz-Gleisdorf 33%), followed by gas in Weiz-Gleisdorf (14%) and power (11%) as well as woodchips (8%) in ökoEnergieland. Energy carriers for alternative heating systems such as thermo solar and heat pumps, account for less than 1% of all installed systems.

Total heating demand comparison of both regions: The total energy demand of Weiz-Gleisdorf is about 950 GWh/a, the one of ökoEnergieland 394 GWh/a. The results of the end energy demand by type of building and demand are presented in Figure 5. Although non-residential buildings account only for 11-15% of the buildings in the regions they are responsible for almost 50% of the energy demand due to their large average floor areas and high power demand. Single-family homes demand only up to 50% of the energy demand from buildings in the regions despite the share of 80-90% of all buildings. Expectedly, from the number of buildings multi-family homes play a minor role regarding the regional energy demand, they cover 10% more in Weiz-Gleisdorf compared to ökoEnergieland, though. In all three building types, heating demand (HD) takes the biggest share, usually followed by the technical energy demand (TED) and power demand (PD). From a policy making perspective this is important as HD and TED are reduced through envelope and heating renovations and are expected to decrease in the future, PD seem to be rather stable.

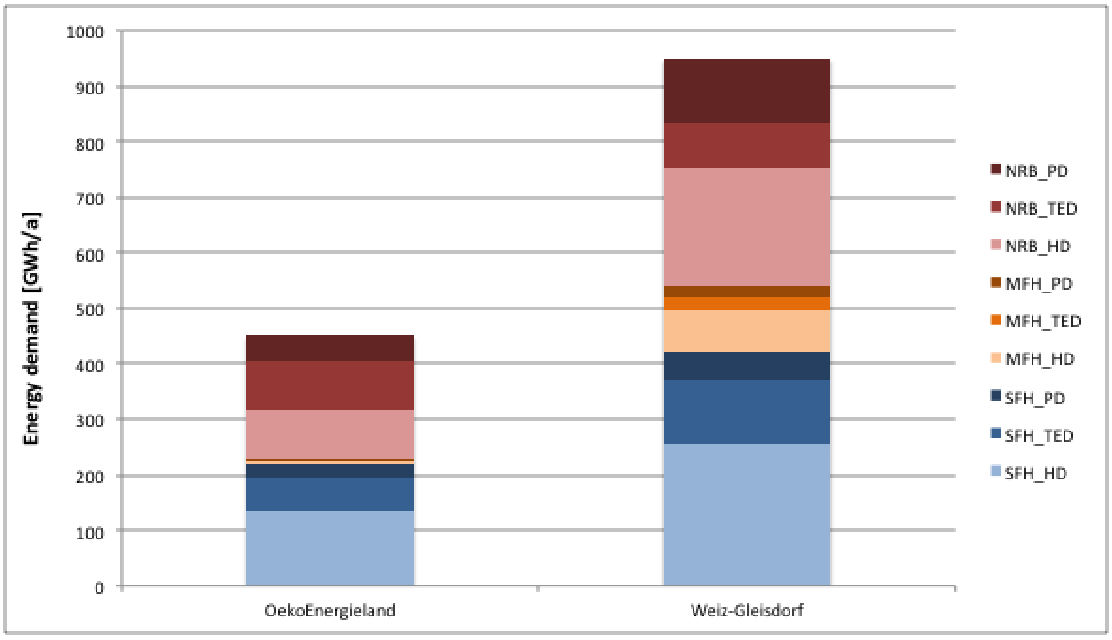


Figure 5: Energy demand from different building categories by type of demand (Heating demand (HD), technical energy demand (TED), power demand (PW)).

Agent and policy analysis

In both energy regions we identified visionaries from different societal fields who paved the way for developing the energy region. In both study regions, the initiation phase was dominated by the motivation to foster regional development and accordingly actors from politics together with visionary leaders from engineering and economy played an outstanding role. The power for transition was unfold by the combination of visions, expertise, political power, and financial resources, through collaboration between experts and engineers in the field of renewable energy as well as visionary leaders with political power and financial resources. Beyond political agents and agents directly affecting the energy system (resource owners: forest holders and farmers owning biomass resources from forests or agricultural land but also companies providing resource residues) agents from the fields of education, tourism, research and development, economy, and relevant special interest groups played a significant role in the development of the energy regions. Activities within these fields contributed to spreading visions in different contexts and forms, to awareness building and overall to foster acceptance of joint targets and actions towards the transition process (see Hecher et al., submitted).

Milestones

The milestones which have been identified through interviews and document analysis serve the characterization of the transformation process of the Energy Regions.

Table 4 shows the visionary and institutional milestones and physical milestones as well as their interrelation within the observation period from 1990 until 2010 for the ökoEnergieland. Generally, it can be observed that visionary milestones precede institutional ones and these precede physical ones. The institutional milestones build the basis for the transition of the physical energy system due to political legitimation and the concentration of relevant resources (i.e. visions, expertise, political power, and financial resources). They result in physical milestones, which represent the implementation of energy infrastructure projects and cause actual changes in regional energy processes and flows (for further details please see Hecher et al. 2014).

Table 4: Milestones of the energy regions' transition process within the observation period *[number of namings in the interviews]* (Hecher et al., in preparation)

Institutional and *visionary* milestones	**Physical milestones**
1989 | **External institutional milestone:** Fall of the Iron Curtain *[1]*	
1990 | *Vision of energy self-sufficiency in the town*	
	1992 | District heating plant in Glasing *[3]*
1995 | **External institutional milestone:** Austria’s accession to the European Union *[2]*	
1996 | Establishment of the European Center for Renewable Energy (EEE) *[2]*	
1996 | Resolution of business location policy in the town Güssing *[5]*	
	1997 | District heating plant in Güssing *[6]*
	2001 | Cogeneration plant in Güssing *[6]*
	2001/2002 | Establishment of parquet industry in
	2002 | Technology Center Güssing *[2]*
2003 | Güssing Energy Technologies GmbH (GET) *[5]*	
	2004 | Biogas plant in Strem *[2]*
2005 | Establishment of the association *ökoEnergieland [5]*	
	2008 | Establishment of photovoltaic company in Güssing *[2]*
	2009 | Technikum Güssing *[4]*
2010 | *ökoEnergieland* becomes a Climate and Energy Model Region *[1]*	
2010 | Expansion of the association *ökoEnergieland [1]*	

Interrelation between energy infrastructure and institution building

Figure 6 demonstrates the comparison of the milestones with results of the EFA in the ökoEnergieland. It shows a time delay between the vision to withdraw from fossil fuels and its implementation. In the study region almost ten years passed between the decision to take advantage of regional resource potentials in 1990 and significant changes in regional energy production flows. Only in 2001, the use of biomass resources and the regional energy production significantly increased due to the initial operation of the cogeneration plant in Güssing. In terms of the regional district heating network, the largest changes occurred in 1997, when the district heating plant in Güssing was built (For more details please see Hecher et al, submitted).

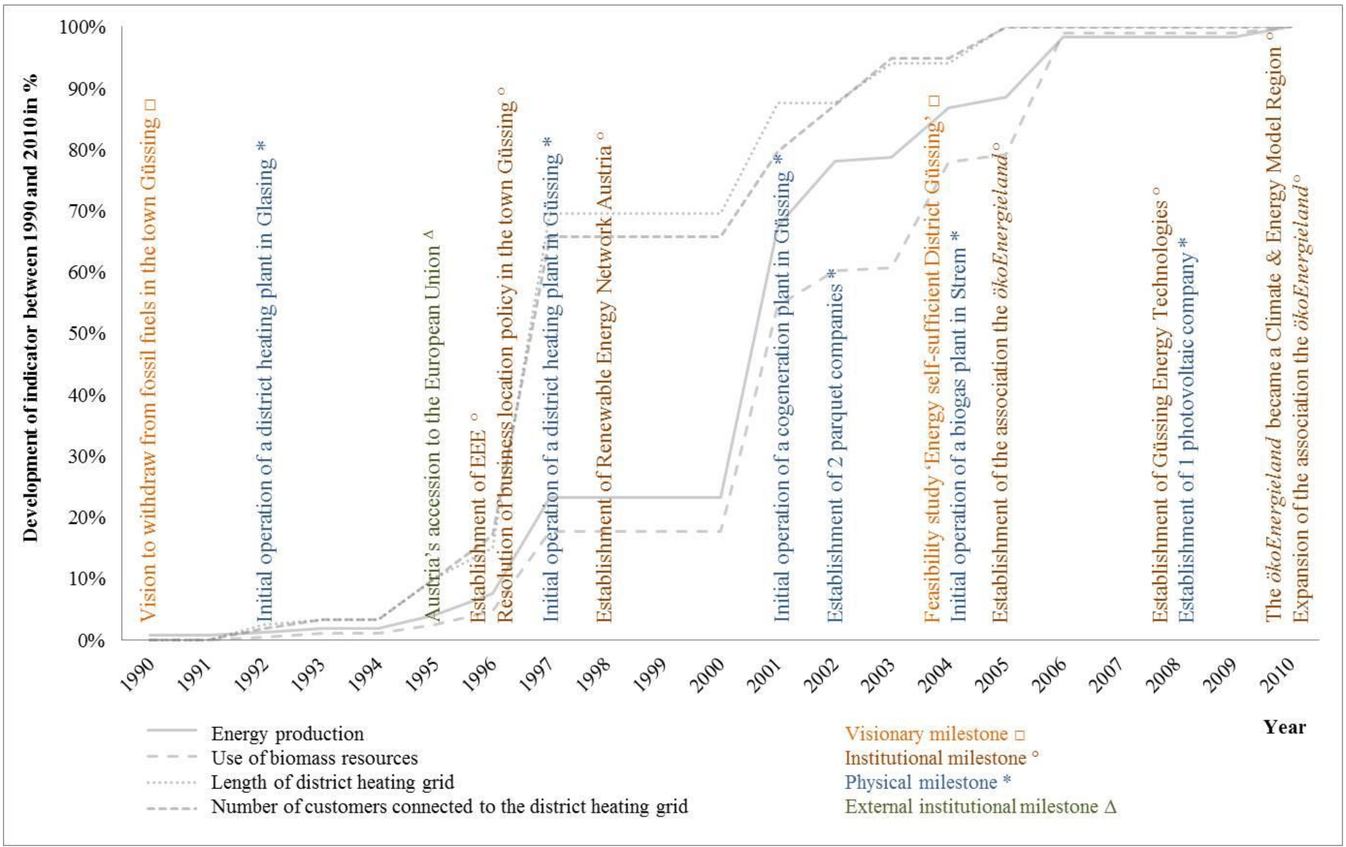


Figure 6: Interrelation between milestones of the transition process and results of EFA (Hecher et al., submitted)

Standardized survey

The main results of the survey are presented in the following paragraphs. The frequencies of selected energy efficiency standards for single-family houses for the period from 2005 until 2013 are summarized in Table 5.

Table 5: Chosen energy standards in new building and renovation projects in the two study regions (Bedenik et al., in preparation)

	A^{++}	A^{+}	A	B	C	Sample size
New building projects	**3 (3%)**	**1 (1%)**	**6 (6%)**	**60 (58%)**	**34 (33%)**	**104**
Energieregion Weiz-Gleisdorf	2 (3%)	1 (1%)	2 (3%)	47 (60%)	26 (33%)	78
ökoEnergieland	1 (4%)	0 (0%)	4 (15%)	13 (50%)	18 (31%)	26
Renovation projects	**0 (0%)**	**0 (0%)**	**0 (0%)**	**13 (33%)**	**26 (67%)**	**39**
Energieregion Weiz-Gleisdorf	0 (0%)	0 (0%)	0 (0%)	5 (28%)	13 (72%)	18
ökoEnergieland	0 (0%)	0 (0%)	0 (0%)	8 (38%)	13 (62%)	21
All projects	**3 (2%)**	**1 (1%)**	**6 (4%)**	**73 (51%)**	**60 (42%)**	**143**

As the decision-making process is stepwise, see Figure 7, we measured the preferences for the different energy efficiency standards in every stage of the process, see Figure 7.

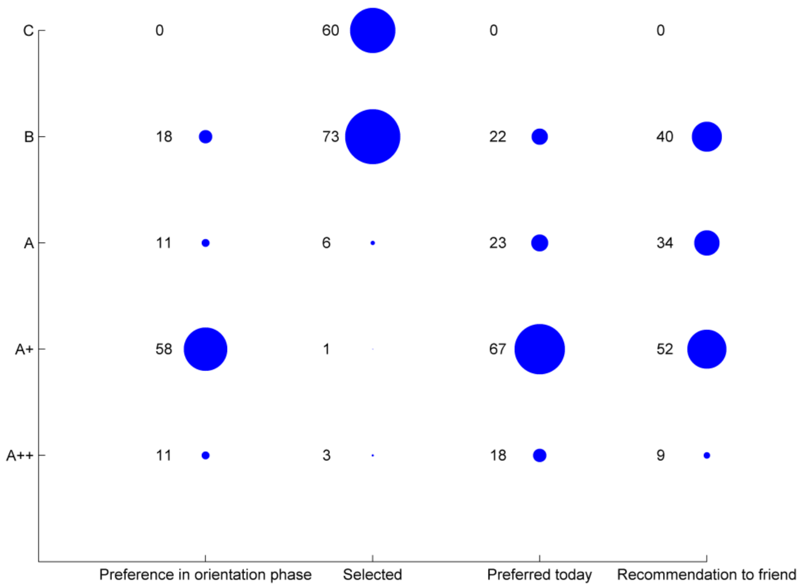


Figure 7. Energy efficiency standards in different stages of the decision-making process; adapted from Bedenik et al. (in preparation).

If we compare households that chose an A++, A+ or A house to households that chose an B or C house, we find that the three groups can be significantly discriminated by the following factors: the attitude, technology acceptance, knowledge about construction and renovation issues, knowledge about energy efficiency standards, and economic aspects, see Table 5. Furthermore, the analysis showed that households´ attitude, their technology acceptance and experts´ recommendations about energy standards showed the largest contribution to group separation. Therefore, they may be key factors for interventions (Bedenik et al., in preparation).

Asking about the main heating system, 41% of households implemented heat pumps, 30% use wood, wood chips or pellets for heating, and only 14% chose a fossil fuel fired boiler (5% oil, 9% gas), the remaining are connected to the district heating (13%) or use solar energy (1%). 10% of households installed photovoltaics, and 41% solar thermal panels.

Households´ identification with the energy regions is quite good: 18% know their region very well, 48% well, and 31% agree fully and 48% agree that the energy region is a meaningful initiative.

Policies and external boundary conditions

The examined external factors legislation and subsidy schemes in Styria and Burgenland are important factors, which might induce differences in selected energy efficiency standards in the two regions. In Burgenland the maximal prescribed heating demand for buildings is lower than in Styria. Examining the selected energy standards in new building projects we observe that the resulting energy efficiency of dwellings in the Energieregion Weiz-Gleisdorf (Styria) is not improving, even more C buildings are built again between 2010 and 2012. On the other hand, in the ökoEnergieland we can observe a slight shift towards A buildings, C buildings were not built anymore. Comparing the two regions, we assume that the differences are attributed to differences in legislation.

Moreover, the differences between the regions might be a consequence of differences in subsidy schemes and differences in their utilization. The survey data show that 40% of households utilized subsidies for energy efficiency measures in new building projects, whereas 77% of those households are from the ökoEnergieland, and only 28% from the Energieregion Weiz-Gleisdorf. In renovation projects 71% of households utilized these subsidies, 81% from the ökoEnergieland, and 59% from the Energieregion Weiz-Gleisdorf. Additionally to those subsidies the department of Styria and the municipalities of the Energieregion Weiz-Gleisdorf offer subsidies for solar thermal panels, modern wood boilers and photovoltaic systems, which are very popular, on the other hand Burgenland offers less in these field; however, such subsidies do not foster the more efficient energy standards.

<u>Module 2: Dynamic modeling / Module 3: Policy development</u>

Simulation and assessment of policies

The two sub-models, the dynamic buildings' energy demand model and the behavioural sub-model are presented in detail in the appendix and the related publications. Here we will only show selected simulation results and the effect of selected policies.

During the simulation the following key aspects regarding energy demand emerged: (i) renovation rate vs. increased energy standards; (ii) simulation of scenarios varying the factors affecting the choice of energy standards.

To model the first case, in our scenarios we analysed the following parameters: (i) the energy consumption in the year 2050, (ii) the distribution of buildings with different energy standards, (iii) and the cumulative energy consumption for four scenarios: current and doubled renovation rate with current legislation and current and doubled renovation rate with increasing legislation standards. Figure 8 shows simulation of policy measures in the area of building renovation shows for the case of Weiz-Gleisdorf.

- Maintaining the current renovation rate of 0,8% would lead to a decrease in heating energy demand of about 42% to 0.5 TWh/year in the year 2050 and cumulatively 34 TWh until 2050.

- Maintaining the current renovation rate of 0,8% but increasing the energy standards would not lead to much additional decrease the energy demand (0.45 TWh/year, cumulatively 33 TWh), but it would change the distribution of the energy standards in the housing sector.

- Increasing the current renovation rate to e.g. 1,6% would cumulatively have a higher impact and reduce the demand to 31 TWh over the years. However the situation in 2050 would be similar to the increased energy standards with an energy demand of 0.46 TWh/year.

- In a combined scenario when increased energy standards and renovation rates, energy demand would decrease down to 0.37 TWh/year, but again with little cumulative impact.

In conclusion, increased energy efficiency standards save about 1TWh until 2050 while a doubled renovation rate would save about three times as much compared to the standard scenario. With a relatively small additional effect of the 2050 energy demand due to increased standards (i.e. 0.05 – 0.09 TWh) the cumulatively higher savings through a doubled renovation rate would require another 45 years to break even. Nevertheless it is important to mention that the highest savings are achieved in a combined scenario. However, efficiency standards are more accessible policy levers than renovations rates. Additional effort to address renovation rates is therefore recommended in future research.

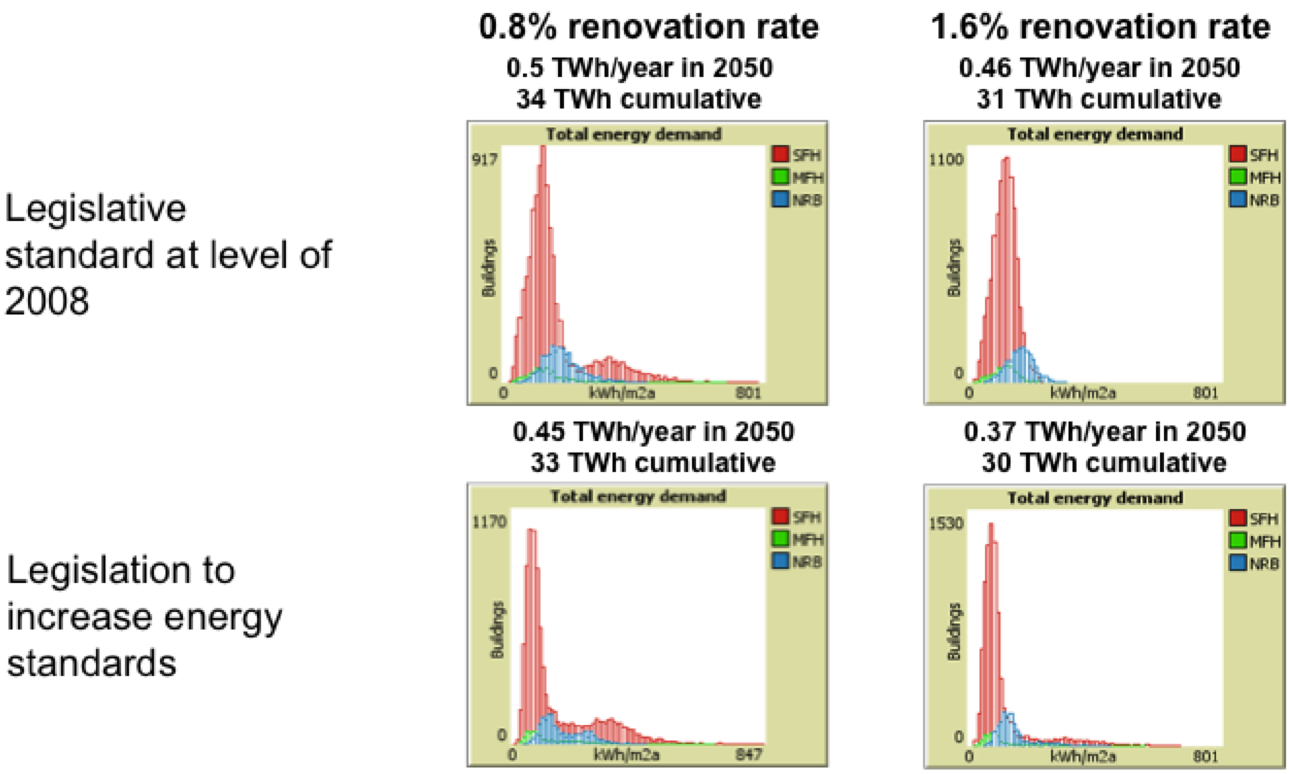


Figure 8: Simulation of renovation rates and different policy scenarios for Weiz-Gleisdorf (Knoeri et al., in prep)

Another interesting aspect is the change of energy carriers over time. Figure 12 shows the development of energy carriers for Weiz-Gleisdorf in the standard scenario (i.e. 0.8% renovation rates and current legislation standards). New buildings and heating renovations were done according to the frequencies observed between 2000 and 2010. Although initially oil and wood dominate, they quickly decrease and have minor importance in the second quarter of the century. While gas has a fairly stable contribution, demand for woodchips and alternative energy carriers (i.e. solar and heat pump) increases drastically in the first quarter and then levels off. Power demand is only slightly decreasing due to the phase out of electric heaters, which is somehow compensated by the electricity demand from heat pumps. It thus quickly becomes the most important energy carrier in the region. This strong dependence on electricity can only be mitigated through the adoption of photovoltaic (PV) in the region. Based on the previous adoption numbers in the region and a logistic growth with conservative potential assumption was implemented. This additional PV power generation kicks in really in the second quarter of the century, reducing the power demand from the grid.

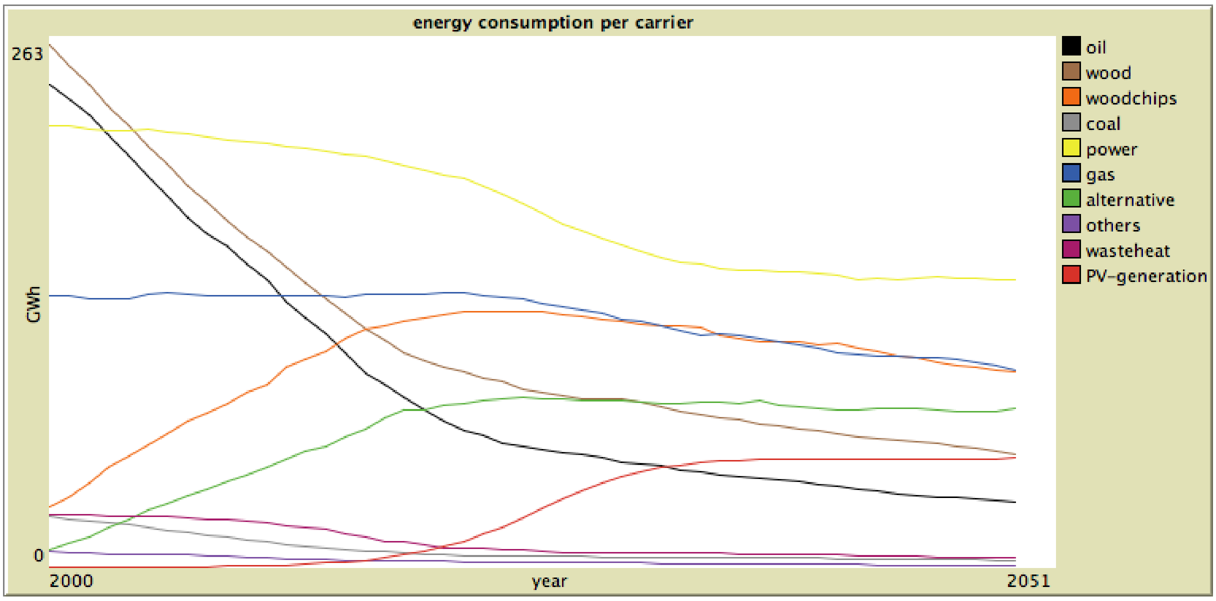


Figure 9: Energy consumption per carrier over time for Weiz-Gleisdorf and the standard scenario (0.8% renovation rates and current legislation standards).

Regarding the choice for the energy standards, the following scenarios selected based on the four areas for interventions developed in the final Workshop in Energieregion Weiz-Gleisdorf:

1. Households: Strengthen their knowledge about energy efficiency measures and the different energy efficiency standards; Raise the technology acceptance of households about passive houses and passive house technologies; Improve the project budget through targeted funding for e.g. A++ and A+ houses in new building projects and A and B houses for renovations
2. Interactions between households: Promote exchange of experiences (positive experiences with A++, A+, and A houses
3. Interactions between households and experts: Energy efficiency should have a higher priority in the planning process.
4. Experts should recommend preeminently the most energy efficient technologies (A++, A+ and A houses).

Regarding the energy efficiency of the buildings the following results were found (Figure 10). The plots show the mean, the maximal and minimum values of all runs for four groups for 50 time steps (from 2000 until the year 2050). In both regions, the houses with energy efficiency D, E, and F decrease within 50 years by about 2/3. The C standard buildings stay in the same order of magnitude. The B standard buildings increase earlier than the A++, A+ and A buildings. At the end of the simulation period, the total number of buildings allocated to the three groups (D, E, F), (A++, A+ and A) and (B) building have the same share of the total building park.

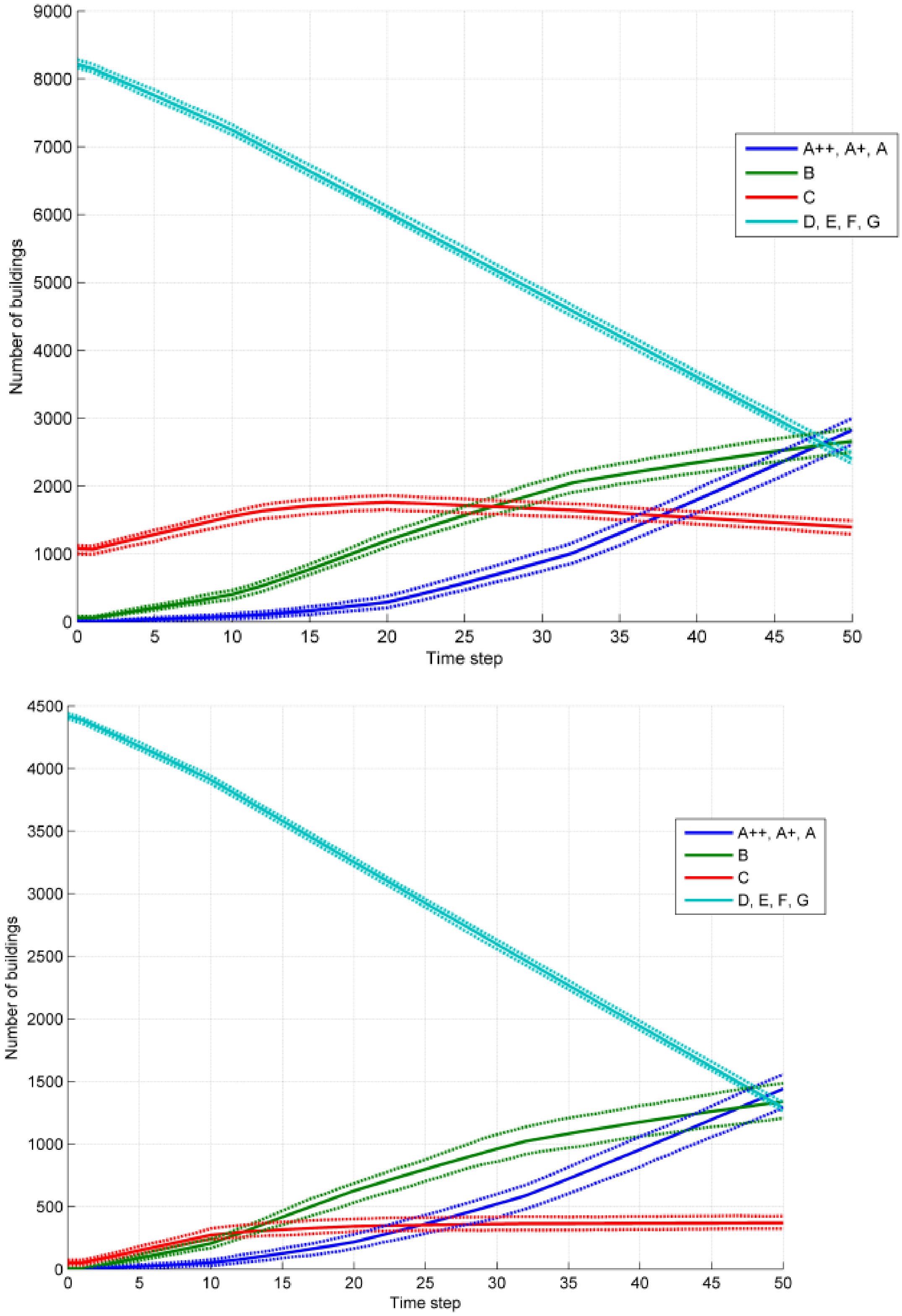


Figure 10. Simulations of development of housing stock in 50 time steps (time period from 2000-2050) showing the portfolio of energy efficiency standards of houses for Energieregion Weiz-Gleisdorf (above) and the ökoEnergieland (below). Full line: average of 250 runs; dotted line: minimum and maximum of 250 runs.

5 Schlussfolgerungen und Empfehlungen

Conclusions

- The transition process in both energy regions is characterized by visionary, institutional, physical (e.g., new infrastructure, connections to heating grids) and external institutional milestones. The visionary and institutional milestones precede the physical milestones. A time delay between the vision, the establishment of an institutional governance-body and its actual impact on the physical energy system can be observed.

- The energy systems' transition was mostly promoted by visionary leaders, political agents, experts in the field of renewable energy, supported by agents in the societal fields of education, tourism, research and development, and economy. Regional development was the main driver for the stakeholders involved in both energy regions. The topic of energy and the strategies for development into an energy region emerged from the regional preconditions, preferences and comparative advantages.

- Currently, none of the regions is able to supply its energy demand out of regional sources. In the future, in both regions it would theoretically be possible to supply sufficient energy to cover total energy demand (heat, electricity, and fuels). In the ökoEnergieland it would be possible applying all MIDI scenarios (potentials assumed to be realizable within the observation period (2030)), in the Energieregion Weiz-Gleisdorf all MAXI scenarios. In case of the MAXI scenarios this would mean that the entire available area (i.e. forest area, agricultural area, roof area, and façade area) is required to generate energy.

- Key for transforming the energy system is the reduction of energy demand, whereas the change of the building stock plays a central role, i.e. renovation and energy standards. Our simulation results show that there is a trade-off between increasing the renovation rate and higher energy standards. It may be the case that enforcing higher energy standards would decrease the renovation rate.

- The decision-making process regarding the energy standards for renovation and new buildings takes place in a sequence of phases. In the first phase the social environment, people within the social context having built or renovated, is highly relevant. In the second phase the architects and the planners have the highest impact on the renovation decisions made.

- Finally, the transdisciplinary approach chosen proved to be extremely valuable. We found that on the one hand the researchers had a high commitment and support from the leaders in the energy region. On the other hand, the region itself benefitted from the collected data and models and the discourse which has been initiated in the course of the transdisciplinary research process by being closely involved. The process of mutual inspiration and mutual learning is still growing even after the official end of the project.

Recommendations

Based on our analysis several policies and measures were developed. Below we present key ideas the stakeholders developed during the workshop in Weiz-Gleisdorf.

Regarding the *optimal use of biomass*, the measures discussed related to (i) increase information measures and support to optimally use forest areas; (ii) stronger mobilization of interest groups; (iii) cooperation with the Almenland (which actually has already been carried out); and (iv) a 50% investment subsidies for wood heating systems.

To *increase the installation of heat pumps, solar heat, and photovoltaics* a large responsibility was attributed to the communities. Thereby they were (i) given the role of multiplicators; (ii) subsidizer by allocating a certain amount of funds to support renewable energies and provide additional financial incentives.

The largest set of measures was developed to *increase the renovation rate* (from 0.8% to 1.6 % per annum) and *improve the energy standards* of the houses. They relate by and large to measures for improving the motivation and identification of population with the region and increase their energy awareness. The first set of measures include: (i) development of pilot projects and best-practice objects as learning objects for practitioners and the public; (ii) creation of a "knowledge platform"; (iii) strengthen the role model function of the municipalities; i.e. buildings of the municipality as showcases; (iv) use neighbouring effects (pilot projects) for developing social capital and pressure; develop a concept for prices, and competitions for energy efficiency.

A second set of measures relate to the financial perspective and include: (v) development of a concept for prizes for energy efficient housing; (ii) development of an "energy–saving contracting model"; (iii) development of a concept for "borrowing" or "leasing" areas for constructing PV cells.

A third set of measures relate to the development of rules and norms, e.g. energy standards, parking, construction. That is norms at regional level should be unified and made consistent with each other.

Furthermore, in order to foster the most efficient energy efficiency standards for residential buildings, we identified four areas for interventions (also see pages 26/27): (i) households (knowledge and technology acceptance); (ii) interactions between households (exchange of experiences); (i) interactions between households and experts (energy efficiency as priority in the planning process); (iv) and experts (should recommend preeminently the most energy efficient technologies (A++, A+ and A houses).

At the level of organisation and institutions, the following measures were proposed: (i) involve representatives of diverse societal fields in the board of an energy region to foster the involvement of and activities in all relevant fields of action and, subsequently, the identity with the energy region of inhabitants and stakeholders; (ii) sharpen visions and objectives of the energy region to strengthen joint efforts of all relevant actors of the transformation process; (iii) allow also private persons to become member of the energy region; (iv) make subsidies for photovoltaic homogenous within the region, that is equal for the different municipalities; (v) make the interface between the energy region and private people visible and the role of the mayors transparent; (vi) clearly differentiate between knowledge carriers and responsibilities.

References

Amtmann, M. (2010). Reference buildings -The Austrian building typology. A classification of the Austrian residential building stock. Vienna: Austrian Energy Agency.

Bedenik, K., Popp, M., Streit, A. v., Binder, C. R. (in preparation a). Energy efficiency standards of single-family houses in two Austrian regions: Factors of homeowners´ decision-making. *Energy and Environment Research.*

Bedenik, K., Popp, M., Streit, A. v., Watts, C., Binder, C. R. (in preparation b). Exploring homeowners´ decision-making process about energy efficiency standards in new building and renovation projects of single-family houses: Two Austrian case-studies. *Energy Policy*.

Bedenik, K., Chappin, E. J. L., Dijkema, G. P. J., Binder, C. R. (in preparation c). An Empirically based agent-based model of homeowners´ decision-making in building and renovation projects with focus on the selected energy-efficiency standards of dwellings. *Journal of Artifical Societies and Social Simulation (JASSS)*.

BEV, (2012). Bundesamt für Eich- und Vermessungswesen. Wien: *www.bev.gv.at.*

BMLFUW & BMWFJ, (2010). Energy Strategy Austria. Vienna: Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management & Austrian Federal Ministry of Economy, Family and Youth (Eds.).

BMVIT, (2007). Model region Güssing: Self-sufficient energy supply based on regionally available renewable resources and sustainable regional development. Nachhaltig Wirtschaften (1/2007). Vienna: Austrian Federal Ministry for Transport, Innovation and Technology (Eds.).

CIPRA, (2010). Energy self-sufficient regions. Schaan: Commission Internationale pour la Protection des Alpes (CIPRA International) (Eds.).

Chappin, E. J. L. & Dijkema, G. P. J. (2010), 'Agent-Based Modeling of Energy Infrastructure Transitions', *International Journal of Critical Infrastructures* **6**(2), 106--130.

Chappin, E. J. L. (2011), 'Simulating Energy Transitions', PhD thesis, Delft University of Technology.

EC, (2010). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy 2020. A strategy for competitive, sustainable and secure energy. Brussels: European Commission.

EEE, (2011). Regionales Energiekonzept *ökoEnergieland*. Güssing: European Center for Renewable Energy (EEE) (Eds.).

EEG. (2010). Heizen 2050. Systeme zur Wärmebereitstellung und Raumklimatisierung im österreichischen Gebäudebestand: Technologische Anforderungen bis zum Jahr 2050 (Endbericht zum Forschungsprojekt Nr. 814008, Programmlinie Energie der Zukunft). Wien: Energy Economics Group (EEG).

Energieregion Weiz-Gleisdorf, (2007). Energieregion Weiz-Gleisdorf: *www.energieregion.at.*

GRE. (2010). Energieeinsparung im Wohngebäudebestand. Kassel: Gemeinschaft für rationelle Energieverwendung (GRE).

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., et al. (2006). A standard protocol for describing individual-based and agent-based models. Ecological Modelling, 198(1-2), 115-126.

Grimm, V., Berger, U., Deangelis, D., Polhill, G. J., Giske, J., & Railsback, S. F. (2010). The ODD protocol: a review and first update. Ecological Modelling, 221(23), 2760-2768.

Hauber, J., Ruppert-Winkel, C., (2012). Moving towards energy self-sufficiency based on renewables: comparative case studies on the emergence of regional processes of socio-technical change in Germany. Sustainability, 4, 491-530.

Hecher, M., Vilsmaier, U., Akhavan, R., Binder R.C. (submitted): Combining energy flow analysis with agent and policy analysis to examine the transition of energy regions: the case study of the *ökoEnergieland* in Austria. Energy Policy.

IWU. (1997). Energiepaß Heizung/Warmwasser. Energetische Qualität von Baukörpern und Heizungssystemen. Darmstadt: Institut Wohnen und Umwelt GmbH (IWU).

Jagnow, K., Horschler, S., & Wolff, D. (2002). Die neue Energiesparverordnung. Köln: Fachverlag Deutscher Wirtschaftsdienst

Jungbluth, N. (2007). Sonenkollektor-Anlagen. Duebendorf, Schweiz: Swiss Centre for Life Cycle Inventories.
Jungmeier, A. (1997). GEMIS Österreich Emissionsfaktoren und energietechnische Parameter im Prozesskettenbereich Endenergie-Nutzenergie. Graz: Joanneum Research Institute for Energy Research.
Keppler, D., (2013): Handlungsmöglichkeiten regionaler Akteure beim Ausbau erneuerbarer Energien. Dissertation. Berlin: Technical University Berlin.
Koblmüller, M., Schreuer, A., Späth, P., (2010). Entscheidungshilfen für Förderstellen und KoordinatorInnen von EnergieRegionen: Methodenhandbuch. Wien: IFZ und Österreichisches Ökologie Institut.
Koch, R., (2010). Aufbau eines lokalen Biogasnetzes in Güssing: Technisches und wirtschaftliches Konzept zur Realisierung. Nachhaltig Wirtschaften (9/2010). Vienna: Austrian Federal Ministry of Transport, Innovation and Technology (Eds.).
Koch, R., Brunner, C., Hacker, J., Urschik, A., Sabara, D., Hotwagner, M., Aichernig, C., Hofbauer, H., Rauscher, W., Fercher, E., (2006). Energieautarker Bezirk Güssing. Nachhaltig Wirtschaften (82/2006). Vienna: Austrian Federal Ministry of Transport, Innovation and Technology (Eds.).
Land Steiermark, 2013: Abteilung 15 – Energie und Wohnbau. Steiermark: *http://www.verwaltung.steiermark.at/cms/ziel/74836184/DE/*
LEV, (2013). LandesEnergieVerein Steiermark: *www.lev.at.*
Paasi, A., (2010). Commentary. Environment and Planning A. 42, 2296-2301.
Rogner, H.-H., Popescu, A., (2000). An Introduction to Energy, in: United Nations Development Programme (Eds.). World Energy Assessment: Energy and the challenge of sustainability. New York, pp. 29-38.
Rohracher, H., (2008). Energy systems in transition: contributions from social sciences. International Journal Environmental Technology and Management, 9(2/3), 144-161.
Späth, P., Rohracher, H. (2010). ‚Energy regions‘: the transformative power of regional discourses on socio-technical futures. Research Policy, 39, 449-458.
Späth, P., Schreuer, A., Koblmüller, M., Bärnthaler, J., Hannesschläger, M., Luttenberger, C., (2010). Entscheidungshilfen für Förderer und KoordinatorInnen von EnergieRegionen. Vienna: Austrian Federal Ministry of Transport, Innovation and Technology (Eds.).
Statistik Austria. (2001a). Gebäude: Gebäude-und Wohnungszählung 2001.
Statistik Austria. (2001b). Wohnungen: Gebäude-und Wohnungszählung 2001.
Statistic Austria. (2001c). Energieeinsatz der Haushalte ab 2003/2004.
Wilensky, U. (1999). NetLogo. Northwestern University, Evanston, IL: Center for Connected Learning and Computer-Based Modeling. http://ccl.northwestern.edu/netlogo.
Statistics Austria. STATcube Database: *https://portal.statistik.at/.*
Statistics Austria, (2012). Nutzenergieanalyse für das Burgenland 1993 – 2011, Stand Mai 2013, Wien.
Statistics Austria, (2011). Energiebilanzen Burgenland 1988 – 2011, Stand Oktober 2011, Wien.
Tischer, M., Stöhr, M., Lurz, M., Karg, L., (2006). „Auf dem Weg zur 100% Region" – Handbuch für eine nachhaltige Energieversorgung von Regionen. Munich: B.A.U.M.
UNFCC, (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations.

B) Projektdetails

6 Methodik

Conceptual framework and module description from proposal

The project was conceptualized as a transdisciplinary project. In each of the regions a co-leader of each of the energy regions was selected. The project was presented in the regional board meetings and a steering group supported the data gathering, reflected on intermediate results and provided a significant input into the modeling and policy development process.

The project itself was designed in three modules or work-packages: WP1: *System Characterization*; WP2: *Dynamic Modeling*; WP3: *Policy Development*. The work-packages built on each other and overlapped to some extent. That is, information in WP1 was collected in view of the model to be developed in WP2 and policies were designed and discussed already in the first and second year of the project.

<u>WP 1: System characterization</u>

For characterizing the energy transitions of the two study regions, we based ourselves on existing data sets from the study regions and applied methods from social as well as natural sciences. The characterization included: (i) development of the physical resource base of the region (e.g. agricultural area, forest area, areas covered with photovoltaic cells); (ii) development of energy demand; (iii) industrial development in the region (e.g. new energy-related firms, which located themselves in the region); (iv) socio-economic factors affecting households' investment and consumption decisions; (iv) policies and external boundary conditions; and (v) the development of the stakeholder map and network. The characterization was performed as follows:

Literature data and data from the study regions

For the overall characterization of both energy regions we used regional study reports (EEE, 2011; Energieregion Weiz-Gleisdorf, 2007) and gathered data from statistical institutes (Statistics Austria, 1990-2010, BEV, 2012). Since both energy regions include several member municipalities, respective data on the municipality level was necessary. For the ökoEnergieland (14 member municipalities) and the Energieregion Weiz-Gleisdorf (18 member municipalities) an analysis of the socio-economic development (i.e. population statistics, labor force statistics) and a comparison between 1990 and 2010 were conducted.

Energy flow analysis

For both energy regions an energy flow analysis was conducted for the reference years 2000 and 2010. Thereby, the regionally produced energy (i.e. renewable energy carriers) was compared with the energy consumed in the region resulting in the degree of energy self-sufficiency for each reference year. To calculate the amount of regionally produced energy by large-scale energy plants a more detailed analysis was made. Data was gathered for all regionally installed energy plants between 1990 and 2010. In the case of ökoEnergieland, regional study reports provided data for all installed energy plants including installed capacities, amount of biomass used, energy outputs, and the respective year of initial operation (EEE, 2011; Koch et al., 2006). In the case of the Energieregion Weiz-Gleisdorf, the same database was provided from the Styrian energy association in terms of biomass plants (LEV, 2013) and from the federal state of Styria in terms of hydropower plants (Land Steiermark, 2013). As the commissioning year of all energy plants was available, the development of the regional energy supply could be illustrated for both energy regions between 1990 and 2010. The regional energy demand for both energy regions was calculated based on the average energy needs per household and per employee using the energy consumption values on the federal state level (Burgenland and Steiermark). The total energy consumption of all sectors (i.e. private households, industries including transport, public and private services, and agriculture) is based on average energy needs per household, per employee in the industrial and service sector, and per employee in agricultural and forestry enterprises. The energy consumption data on the federal state level was obtained from Statistics Austria (2012) for all reference years. The number of households and employees in 2000 for both federal state level and regional level was obtained from national census data. For 2010 these numbers were estimated according to population and labor force developments. The energy consumption statistics on the federal state level also served as a basis to differentiate between the demand for fossil fuels (i.e. coal, oil, gas, petrol, and diesel fuel), electricity, and renewable energy carriers (i.e. district heat, firewood, solar heat, heating pumps, and photovoltaic panels) for each sector (Statistics Austria, 2012, Statistics Austria, 2011). Based on this data, the energy produced with individual heating systems and photovoltaic cells (small-scale renewable energy technologies) was calculated.

Regional energy potentials

For both study regions the regional energy potential for biomass (forestry and agriculture), solar power, and geothermal energy was calculated. For each of these, 3 scenarios were compiled: (i) the MAXI scenarios represent the respective maximum technical potential assuming that the total available area (e.g. area of land, roof area, façade area, etc.) is entirely used for energy generation not restricted through any other energy technology. The MIDI scenarios reflect the potentials assumed to be realizable within the observation period (2030). The MINI scenarios represent the minimum potential oriented towards the status quo.

Regional energy demand from buildings

For analyzing the regional energy demand a building stock model was developed, based on statistical data on different building types and their energy demand. Since this data is only partially available on the regional scale several buildings' and technologies' attributes have been calculated based on data sources on national and district levels. Four data sets were collected to initialize the model: (i) building stock data including number of buildings of a certain type, construction period, and energy carrier (study regions specific), (ii) average gross floor area per building type and construction period (district level), (iii) heating, hot water, and electricity demand data (national level), and (iv) heating technology specific data such as current efficiencies and expected efficiency increases (national level). In the following we briefly address the calculation and data sources for each of these in turn.

Regional energy demand (RED) is defined as the product of the total Energy Reference Area (ERA) and the End-use Energy Demand (EED) (Equation 1). The EED refers to the energy input at the building level.

$$\mathrm{RED}\ [\mathrm{kWh/a}] = \mathrm{ERA}\ [\mathrm{m^2}] * \ \mathrm{EED}\ [\mathrm{kWh/m^2a}] \qquad (1)$$

ERA data was derived for subsets of the building stock, as the EED is different for different building types, construction periods, heating systems, and energy carriers, by multiplying the number of building types in the region with their average energy reference area. However, data with such granularity was only available on the district level and not on the regional level (i.e. communities of the Energy Regions). Therefore, the number of buildings in the Energy Regions was multiplied by the percentage of buildings of a certain type and construction period on the district level, and their average floor area. Data about the Usable Floor Area (UFA) in these categories was available from Statistic Austria (2001a) which was divided by a reference factor f to account for the additional area heated.

The EED per building type and construction period is referred to as the sum of Heating Demand (HD), Hot Water Demand (HWD), and Power Demand (PD), and the Heating Technical Energy

Demand (HTED). HD is the energy necessary to heat the building, HWD the energy required to heat hot water, PD the electricity demand of the building, and HTED refers to the energy losses in the final conversion step (i.e. in the heating system and the in house distribution). The HD for the residential buildings were calculated based Jungmeier(1997), the EPC database ZEUS (Amtmann, 2010) and reference values for typical building indices in Germany provided from the Society of Efficient Energy Use (GRE, 2010). HD of non-residential buildings was derived from the ZEUS database (Amtmann, 2010), which provided energy audits (from 2008 until 2013) from the actual non-residential building stock, renovation plans and new construction measures. For HWD and PD reference values per square meter and year from literature were used. HWD is based on reference values from institute for housing & environment (IWU, 1997) and Energy Saving Regulation of Germany (EnEV) (Jagnov et al. 2002) for residential, and the ZEUS database (Amtmann, 2010) for non-residential buildings. PD for residential buildings were based on provincial data from the Statistic Austria (2001c) and again on the ZEUS database (Amtmann, (2010) for non-residential buildings. HTED is directly related to the efficiencies of the heating systems installed. Heating system efficiency indicates how efficient the respective energy carrier is converted into heat, for room heating and hot water. Therefore, literature values of efficiencies of different heating system technologies were collected, and the used to calculate the HTED in the building stock.

Stakeholder interviews – Agent and policy analysis

We performed and agent and policy analysis which consisted of three steps: In the first step, the key agents directly and indirectly influencing the transition of the energy region were identified in interviews (see Hecher et al., 2014). First, the steering board members were interviewed and relevant actors as well as their role in the different phases of the transition process of the energy region were identified. Results of these interviews have been jointly analysed in the steering boards of the study areas. Subsequently, further interview partners have been selected and the interviews extended. In a snowball system, further actors have been identified. In a second step the role of the agents and their resources were analyzed with respect to institution building in the region. We differentiated between (i) visionary leaders, who play a crucial role in the initiation of the transition process; and (ii) political representatives of municipalities who hold a substantial role as they are legitimized to realize agreements on the inter-municipality level (Hauber and Ruppert-Winkel, 2012; Rohracher, 2008; Späth and Rohracher, 2011). In the third step, milestones of the transition process were derived from both literature research and the interviews and were validated by the representatives of the energy regions' institutional body (Hecher et al., submitted). The milestones were categorized into visionary, institutional, physical (technological), and external institutional milestones. Visionary milestones were defined as densifications of guiding ideas, institutional milestones as permanent and binding agreements, physical milestones as infrastructural measures in the energy sector and external institutional milestones as events affecting the energy regions' development from outside (see Hecher et al., submitted)

Standardized survey

The goal of the in-depth household survey was to analyse the social, economic, and political factors affecting the investment and consumption decisions of households related to their energy consumption. Because 87% of total household energy demand accounts for heating and hot water supply (Bohunovsky, 2008), we decided to focus on decision-making related to the energy performance of dwellings, which is affected by policies, personal factors, as well as experts in the building sector. We limit the interviews to owners of single-family houses, which cover 80% and 88% of all buildings in the two study regions Energieregion Weiz-Gleisdorf (Styria) and ökoEnergieland (Burgenland), respectively. Therefore, the landlord-tenant problem is not included in this study.

Table 6: Overview of main behavioural drivers

Variable	Description	Survey question(s)
Preference in orientation phase	preferred energy efficiency standard in orientation phase	A4.1
Economic aspects	Household income, importance of investment and operational costs, project budget and importance of subsidies	B9.2, B9.3, C10.2, C10.3, E6, E7, G5, G6
Influence of experts	Discussion with experts about energy efficiency standards Expert´s recommendation	C2-C4 C7-C9
Technology acceptance	Acceptance of passive houses	B8
Knowledge	Knowledge about construction and renovation issues Knowledge about energy efficiency standards	B2.1-B2.4 B2.5-B2.7
Attitude	Importance of energy saving Importance of energy efficiency of building	A14 B9.1, C10.1
Energy efficiency in social network	Number of energy efficient renovations, number of very efficient new houses and number of passive houses within the household´s social network	D11.1-D11.3
Use of solar energy	Use of solar energy in house for heating, hot water or electricity production	A5, A6.1, A8, A11
Age	Age of head of household (interviewed person)	G2
Decision about energy standard	Selected energy efficiency standard	A15
Evaluation	Highest preferred energy efficiency standard today Highest recommended energy standard to a friend	D8 D9

The questionnaire design is based on knowledge gained in 6 expert interviews (2 architects, a civil engineer, a researcher, a bank advisor, a construction company) and 10 explorative interviews with households (5 building and 5 renovation projects). Table 6 gives an overview on the main behavioural drivers.

Data for the survey sample was provided by the municipalities of the involved energy regions Energieregion Weiz-Gleisdorf and ökoEnergieland. In Weiz-Gleisdorf the municipalities supported the organisation of interviews by asking households per phone to participate in the survey (96 interviews). In ökoEnergieland the municipalities provided addresses (47 interviews). The household survey was performed by 15 trained students in face-to-face paper and pencil interviews from February till the middle of April 2013.

Different standard procedures of statistical analysis, such as contingency analysis, factor analysis, discriminant function analysis, and Structural Equation Modelling (SEM) were performed to evaluate the survey results.

Policies and external boundary conditions

Relevant policies and external boundary conditions related to the behavioural analysis were identified through a literature review and the evaluation of 6 expert interviews and 10 explorative interviews with households. The firstly identified relevant factors (policies, fuel prices and prices of different technologies) were, after a further evaluation of interviews, narrowed down to zoning law regulations and subsidies on state, department and municipality level.

To analyse the impact of identified factors on households´ decision-making, a semi-quantitative database of the impact of identified factors on households´ decisions was elaborated. For each factor, corresponding decision rules were elaborated, which determine households´ decision options and were an input for agent based (behavioural) modelling.

Module 2: Dynamic modeling

In Module 2 two simulation models were developed and integrated, a buildings' energy demand model and a behavioral model. The buildings' energy demand model aims to portray the building stock's energy demand dynamics and serves as a backbone for the behavioural model. The purpose of the behavioural model is to simulate and examine the decision-making of households related to the energy performance of dwellings.

Both components of the simulation model are agent-based models and are described applying the Overview, Design concepts, and Details (ODD) protocol (Table 2; Grimm et al. 2006, 2010). The model was implemented in NetLogo (Wilensky, 1999).

Table 2. The ODD protocol (Grimm et al. 2010).

Elements of the ODD protocol	
Overview	1. Purpose / 2. Entities, state variables, and scales / 3. Process overview and scheduling
Design concepts	4. Basic principles Emergence, Adaptation, Learning, Prediction, Sensing, Interaction, Stochasticity, Collectives, Observation
Details	5. Initialization / 6. Input data / 7. Submodels

Dynamic buildings' energy demand model

This model aims to portray the building stock's energy demand and heating systems transition in the energy regions. Furthermore, it is designed to test the effectiveness of different policy measures on overall energy demand, cumulative energy savings and energy source used. It is based on statistical data from regional energy demand as outlined above.

Buildings and a system level policy are the two (types of) entities modelled. Buildings are categorized by type of building (i.e. single family house (SFH), multifamily house (MFH), non-residential building (NRB)), construction period (i.e. building age), and type of heating system. Buildings' end-use energy demand is the sum of their heating, hot water and electricity energy demand [kWh/m^2] multiplied by the heated gross floor area (GFA) (i.e. useful dwelling floor area (UFA) times a reference factor). Heating demand is determined by the building's envelope standard, which itself depends on type and age and renovation of the building, for hot water and electricity fixed reference values from literature were used. End-use energy is provided through main heating systems and, in about 50% of the buildings, through additional secondary or supporting heating systems, primarily for hot water heating. Main heating systems are differentiated by type of centrality (i.e. district heating, central building heating, or room or flat heating systems) and energy source used (i.e. oil, wood, wood-chips, coal, power, gas, solar or heat pump, others, waste-heat), defining their conversion efficiency. The system level policy entity sets measures to influence the general building stock fluctuation (i.e. new construction and demolition rates), buildings' envelope renovation rates and standards, and renovation rates, standards and types of heating systems. The model has a one to one scale for the two energy regions meaning each building is represented. A distribution based artificial space representation is used for demonstrative purposes.

Behavioral Modeling (SEM and ABM)

We developed the behavioural model (Figure 3) based on data about external factors and empirical data collected in interviews and the household survey. The purpose of the model is to examine the decision-making of households, using the quantified factors, described in Table 1. The focus is the actual energy efficiency standard of dwellings, which is selected in a stepwise process influenced by different factors. The following methods were applied: Structural Equation Modelling (SEM), a statistical technique that allows for testing hypotheses regarding a set of causal relations between variables, and Agent-Based Modelling (ABM), which allows for simulating heterogeneous decisions of interacting agents, for instance applied to socio-technical systems, energy infrastructures, and sustainability transitions (e.g. Nikolic, 2009; Chappin and Dijkema, 2009, Chappin, 2011).

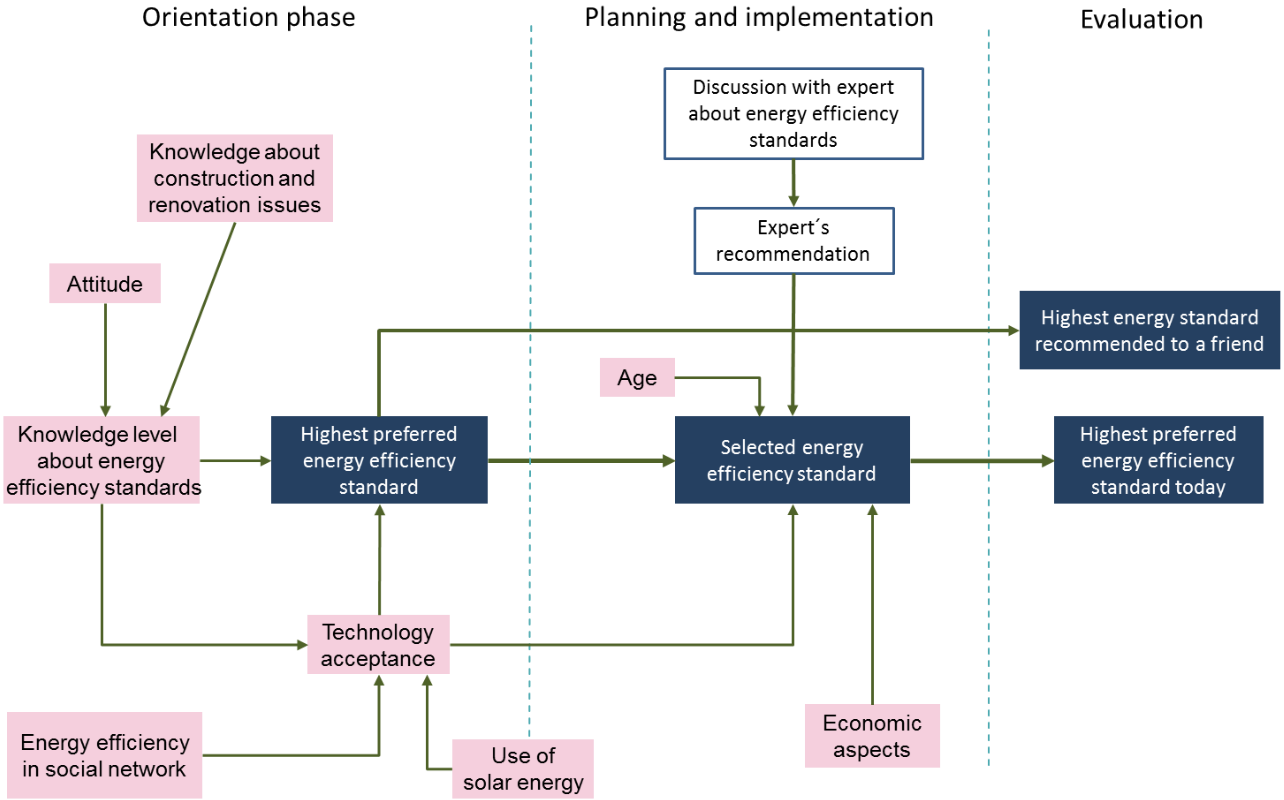


Figure 11: Behavioural model of households´ decision-making; adapted from Bedenik et al. (in preparation b).

<u>Module 3: Policy development</u>

The goal of Module 3 is to develop and assess a set of policies, which are expected to be able to support the development, the establishment, and the long-term maintenance of energy regions. We developed potential policies during the whole research process, in particular during the expert interviews. In a final workshop at Weiz-Gleisdorf (25.09.2013) specific policies were elicited regarding energy supply and energy demand.

Simulation and assessment of policies

The dynamic building model allows for simulating different scenarios and their impact on the regional energy demand, and energy carrier distribution. Renovation rates and building standard regulations were the key parameters varied in the scenarios.

The prototype integrated model implemented in NetLogo allows simulation experiments for both energy regions with switches and sliders (on the left in Figure 2), which allow varying the different parameters, described in Table 1. The output of the model is presented as plots and monitors (on the right in Figure 2) for demographics, social parameters, energy efficiency standards portfolio and heating systems. For data generation an experiment was executed with 250 runs per region.

7 Arbeits- und Zeitplan

The project consisted of a kick-of workshop and three work packages (or modules). The Table 8 also contains an overview of all stakeholder and partner meetings, meetings with the steering group and the time of delivery of publications.

The originally planned schedule was revised in the interim reports. The processing time of each work package has been delayed because of changes in staff and delays concerning the stakeholder process in the two study regions (also see Section 3.3). Dates of the held meetings and workshops are also contained in Table 8.

Table 8. Time schedule and overview of project meetings and delivery of publications

Year	**2011**				**2012**				**2013**				**2014**	
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2
WP 1: System characterization														
WP 2: Dynamic modelling														
WP 3: Policy development														
Stakeholder involvement														
Workshops		**Kick-off 4.5.**									**Final 25.9.**			
Meeting partners (energy regions)		2.5. WG, 12.5 Ö	19.9. Ö			12.4. WG				2.5 . WG				
Meetings steering group		05.5	07.7			31.5	30.6				25.9			
Publications (see annex)			P1				P2, P3							P4-P7

originally deviation from plan (additional time

8 Publikationen und Disseminierungsaktivitäten

Publication: In the following the publication and dissemination activities carried out during the project period are listed (project workshops, publications, and presentations at external events):

General dissemination activities

- The project homepage is available at http://www.geographie.uni-muenchen.de/department/fiona/department/sozialgeographie/forschung/terim/index.html.
- The project brochure in German and English language was distributed to interested stakeholders and experts in Austria and especially in the study regions, as well as to interested students at University of Graz and Ludwig-Maximilians Universität Munich.

- The project was presented on 23.11.2012 at a meeting with Thomas Kohl and Ludwig Hartmann, representatives of the green party of Bavaria, who were interested in learning from successful cases from Austrian energy regions.

Project workshops in study regions

- Project presentation at the board meeting of the Energieregion Weiz-Gleisdorf on 5.10.2010.
- Start-up Workshop in the Energieregion Weiz-Gleisdorf on 4.5.2011.
- Steering committee meetings in Energieregion Weiz-Gleisdorf were held on 5.5.2011 and 7.7.2011.
- Project presentation at the board meeting of the ökoEnergieland on 19.9.2011.
- The first results of the orientation interviews were discussed with the project partners (TERIM steering board, board of the Energieregion Weiz-Gleisdorf).
- Project results presentation and project workshop at the board meeting of the Energieregion Weiz-Gleisdorf on 25.9.2013.

Published conference abstract and publications

Bedenik, K., Binder C.R. 2011, The role of actors in the transition towards energy self-sufficient regions: the case of Güssing, Austria. RESS Conference: Changing the Energy System to Renewable Energy Self-Sufficiency. C. Ruppert-Winkel, J. Hauber. Freiburg: Zentrum für erneuerbare Energien, Albert-Ludwigs-Universität Freiburg (peer-reviewed)

Bedenik, K., Binder C. R. (2012). Operationalization of an agent-based model of householders´ decisions concerning energy efficiency and the use of renewable energy sources. 8th Conference of the European Social Simulation Association. Salzburg, Austria. (peer-reviewed).

Binder, C. R., Hecher, M., Vilsmaier, U. (2014). Visionen, Institutionen und Infrastrukturen als Elemente der Energietransformation. In: Böschen, S., Gill, B., Kropp, C., Vogel, K. (Eds.), Klima von unten - Regionale Governance und gesellschaftlicher Wandel.

Knoeri, C., Goetz, A. Binder, C. R. (2014). Generic bottom-up building-energy models for developing regional energy transition scenarios. 9th Conference of the European Social Simulation Association. Barcelona, Spain (peer-reviewed).

Submitted publications and publication under revision

Bedenik, K., Popp, M., Streit, A. v., Binder, C. R. (submitted). Energy efficiency standards of single-family houses in two Austrian regions: Factors of households´ decision-making. *Energy and Environment Research.*

Hecher, M., Vilsmaier U., Akhavan, R., Binder C.R. (under revision). Combining material flow and actor analysis to characterize the development of energy regions in Austria. *Energy Policy.*

Publications in preparation

Bedenik, K., Popp, M., Streit, A. v., Watts, C., Binder, C. R. (in preparation). Exploring households´ decision-making process about energy efficiency standards in new building and renovation projects of single-family houses: Two Austrian case-studies. *Energy Policy*

Bedenik, K., Chappin, E. J. L., Dijkema, G. P. J., Binder, C. R. (in preparation). An Empirically based agent-based model of households´ decision-making in building and renovation projects with focus on the selected energy-efficiency standards of dwellings. *Journal of Artifical Societies and Social Simulation (JASSS)*.

Binder, C.R., Knoeri, C., Bedenik, K., Hecher, M., Kislinger, M., Kreuzeder, A., Vilsmaier, U., (submitted) Analyzing the sequence of transition pathways in energy transitions: conceptual framework and empirical evidence. *Research Policy*

Chappin, E. J. L., Bedenik, K., Dijkema, G. P. J., Binder, C. R. Exploring policy options for a transition towards more energy efficient single-family houses using an agent-based simulation. Environmental Innovation and Societal Transitions. *Energy Policy*.

Knoeri, C., Goetz, A., Binder C. R. (in preparation). Renovation rates and energy standards: Buildings' efficiency dynamics in energy regions. *Energy and Buildings.*

Binder, C. R., Dijekma, G., Chappin, E., Knoeri, C., Bedenik, K. (in preparation). Co-evolution of socio-technological systems; The case of energy regions. *Applied Energy*.

Presentations

Knoeri, C., Goetz, A., Binder C. R., (2014). Generic bottom-up building-energy models for developing regional energy transition scenarios. 9th Conference of the European Social Simulation Association. Barcelona, Spain.

Knoeri, C., Goetz, A., Binder C. R., (2014). Sequence of transition pathways in energy transitions; The need for understanding technology acceptance, and developing common visions, 2nd Energy & Society Conference, Krakow, Poland, June 4-6 2014 (in collaboration with Bedenik, Kisslinger, Vilsmaier, Kreuzeder).

Binder, C. R., Knoeri, C., Hecher, M., Schilling, T., von Streit, A., (2014). The role of resilience for sustainable transformations: Insights from energy regions, 2014, Mobilizing for transformation, Montpellier, 5-8 May, 2014.

Binder, C. R., Absenger-Helmli, I., Bedenik, K., Chappin, E., Dijkema, G., Goetz, A., Hacker, J., Hecher, M., Knoeri, C., Vilsmaier, U., (2014). Transition Dynamics in Energy Regions, 15. ÖSTERREICHISCHER KLIMATAG, 2.-4. April 2014, Innsbruck.

Binder C. R., (2014). Keynote lecture including project results 2014.Transition of the energy system: an integrative analysis. Joint JST-NSF-DFG Workshop Distributed Energy Management Systems, Hilton Waikiki Beach Hotel, Honolulu, Hawai'i USA, January 11-13, 2014 (in collaboration with Bedenik, Goetz, Knoeri, Hecher and von Streit).

Binder, C. R., Akhavan, R., Bedenik, K., Hecher, M., Vilsmaier, U., (2013). Visionen, Institutionen und Infrastruktur als Elemente der Energietransformation, Klima von Unten: Die regionale Ebene als Ort des Wissens und Handelns, Munich, Germany on 31.1.2013.

Bedenik, K., Watts, C., Binder, C. R., (2012). Conceptualization of an agent based model of householders' decisions concerning energy efficiency of dwellings and their use of renewable energy sources. 8th European Social Simulation Conference, Salzburg, Austria on 14.-18.9.2012.

Hecher, M., Vilsmaier, U., Binder, C. R., (2012). Combining material flow analysis and actor analysis to characterize the development of energy regions in Austria MFA-ConAccount Section Conference 2012: Socio-economic metabolism, Darmstadt, Germany, 16.9.2012.

Bedenik., K., Binder C. R., Absenger-Helmli, I., Chappin, E., Dijkema, G., Goetz, A., Hacker, J., Hecher, M., Knoeri, C., Vilsmaier, U., (2012). Transition Dynamics in Energy Regions, Project poster presentation at the Österreichischer Klimatag 2012, BOKU, Vienna, 14.-15.6.2012.

Bedenik, K., Binder, C. R., (2011). The role of actors in the transition towards energy self-sufficient regions: the case of Güssing, Austria, RESS Conference: Changing the Energy System to Renewable Energy Self-Sufficiency, 15.9.2011 Freiburg, Germany.