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Measuring regional resilience towards fossil fuel supply constraints. Adaptability and vulnerability in socio-ecological Transformations-the case of Austria

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Abstract

Resilience has become a prominent concept to understand system vulnerabilities and flexible ways of adapting to crises. Recently, it gained importance in discussions about the possible peak in oil production (peak oil) and its consequences, which might affect economic performance, social well-being and political stability, and thus also the energy transition to a low-carbon economy. The paper presents a new way of measuring resilience as absolute resilience related to a best practice-model of a resilient society. The resilience model is grounded in explicit theoretical assumptions. All indicators are justified by theoretical and empirical arguments. We present a case study of Austrian municipalities and broaderscale spatial types, which were defined according to their degree of urbanization. The mean resilience of Austrian municipalities is moderate, the difference between resilience values of municipalities is small. Significant differences between spatial types exist. Higher resilience is displayed by less urbanized types due to a higher share of agricultural activities and a more favorable level of GDP per capita. Austria has considerable latitude to improve resilience. Corresponding policies should target resilience components

Keywords: Resilience, Energy, Peak oil, Vulnerability, Innovation, Social capital

HIGHLIGHTS

• Mean resilience of Austrian municipalities towards peak oil is moderate.
• The difference between resilience values of municipalities is small.
• Significant differences in resilience between spatial types exist.
• Higher resilience is displayed by less urbanized types.
• Policies should target resilience components with the lowest values first.

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1. Introduction

Resilience has become a major concept in policy and scientific debates. In the context relevant to this paper, resilience, in general terms, denotes the ability of social systems to survive and cope with stress, disturbance or adversity by means of adaptation (e.g. Norris et al., 2008; Wilson, 2012). The increasing importance of the resilience concept is indicated by its growing use in the literature. From 1995 to 2011, the number of articles that mention resilience as a keyword had a tenfold increase, while within the same period scientific articles per year only doubled (Matzenberger, 2013). The resilience discourse seems to mark a significant shift in societal debates, as its upsweep coincides with a range of intertwined dynamics that are now often discussed as multiple economic, political, ecological, and social crises (Exner et al., 2013).

Indeed fears of further destabilization of climate, energy security, politics, economy or food supply are voiced regularly, as illustrated by the latest Global Risks Report (World Economic Forum/WEF, 2013). The report mentions "resilience" 28 times, references excluded, while sustainability appears only 10 times in the text. This is just anecdotal, though notable evidence of a shift in discourse from sustainability to resilience. While sustainability is a concept that focused on win-win-situations and a positive vision of increasing living standards, resilience is a paradigm that instead puts at the center the notion of survival and the threat of multiple catastrophes (Exner, 2013a). Thus, resilience as a discourse displays ambivalent characteristics. This explains that, beyond the usually unquestioned use in policy papers, the scientific assessment of the resilience discourse ranges between a very critical stance to appreciation. The critical position interprets resilience mainly as a tool for social control by way of leading certain agents to adapt to socially created crises, instead of pushing for remedies by reforming political and economic structures (Cooper and Walker, 2011, cf. special issue of Planning, Practice & Research, O'Hare and White, 2013). In a more positive view, resilience is seen as an interesting extension of social science approaches. It thus might improve the understanding of development challenges that communities have faced in the past and will do so in the future (Norris et al., 2008; Wilson, 2012). The most prominent strand of debate that has considerably shaped the notion of resilience is promoted by organizations such as the Resilience Alliance. Resilience here is seen as the core concept of a socio-ecological systems perspective. Accordingly, "resilience thinking" (Walker and Salt, 2006; see also Gunderson and Holling, 2001) is promoted, which is understood as a new scientific and political paradigm.

We will take up the issue of conceptualizing resilience in the next chapter, and will draw conclusions relating to our operationalization and measurement of resilience in the last chapter. First we want to focus our investigation on a particular type of challenge that is one of the most often cited in relation to resilience thinking, i.e., the impeding scarcity of fossil fuels, especially of oil. Though our study does not depend on the credibility of any specific view on the availability and price of oil, we take the peak oil theory as the starting point for a set of scenarios to investigate which factors might indicate resilience on a regional level, when such a challenge is assumed (see special issue of Philosophical Transactions of the Royal Society A, 2014, No. 372 for an update on this debate).

This approach, however, is not merely a thought experiment of theoretical value, but is linked to broadening policy debates on resilience in the face of threats to energy supply, which are often attributed to political constraints rather than only objective geopolitical facts. Yet, while the specific kind of shock or stressor is often not explicit in official political resilience papers such as in the UK (Cabinet Office, 2012), the peak oil theory informs a wide range of political and scientific resilience concepts. The peak oil theory, not least, frames the social movement of Transition Towns, that has spread particularly in the Anglo-Saxon world, and centers around the concept of resilience (Hopkins, 2011).

The particular view on the causes of supply shocks and energy stress has an impact on the indicators relevant for resilience, because the severity of such a shock for society depends on the concrete circumstances. Since fossil fuels, and oil in particular, are such important commodities for modern societies, a supply shock or restriction of any kind will have considerable repercussions. However, a limited shock in availability or a temporarily force reduction in oil use is different from a more far-reaching supply shock that is embedded in a general downturn of global oil production. First of all, the strategic perspectives of agents will differ according to whether the shock or stressor is temporary or not. This will lead to different forms of adaptation and, prospectively, of preparation in view of such risks. Secondly, and in relation with the first aspect, a temporary reduction of a vital resource, be it severe or not, does not put into question the basic viability of infrastructure, expectations and norms that are coupled to the qualities of the resource. To the contrary, a permanent and general downturn of the supply of a vital resource will forcibly change infrastructure, expectations and norms of all agents relevant in society. Thirdly, such a general downturn will affect more or less severely the abilities of a society to change its resource base and the infrastructure, expectations and norms that relate to it.

While a temporary shock or stress in the supply of a vital resource can be handled by conventional means of crisis and disaster management, a permanent reduction in supply, whether or not it takes on the form of a shock, cannot be handled by any conventional means, but points towards the necessity of a socio-ecological transformation, i.e., to transform the relations of society to nature, thus including the economy. Such a transformation will benefit from crisis and disaster management capacities since it will continue to rely on resources that might be affected by shocks and stressors, but cannot be reduced to it. Thus, a political constraint on oil supply, which will rather manifest itself as a sudden shock, will in general not have the same scope, temporality and modality as a long-term change in supply due to the geological peak oil – irrespective of possible short-term shocks, which can for instance be triggered by political supply constraints in addition to the long-term trend.

These general remarks can be put in relation with the specific issues the peak oil theory is likely to raise. Above all, a mere technical understanding of resilience as can be found in more conventional approaches to energy security, is not adequate if the whole web of social relations is put under stress by a permanent and increasingly narrow constraint on a resource supply, as the peak oil theory implies. The technological system of a society develops in relation to specific infrastructure, expectations and norms, and thus cannot be analyzed in separation from the socioeconomic system. Consequently, the notion of resilience takes on a holistic character, and one has to ask for the conditions of a
society’s resilience instead of the resilience of a specific technology or even of the energy system alone.

The state of resilience thinking concerning peak oil thus conceived, and further on in terms of a measuring approach built upon these premises, is still in the very beginnings. Currently, to the knowledge of the authors, the only peer reviewed approaches to measure resilience in a holistic sense are Cutler et al. (2010) and Sherrieb et al. (2010). On a conceptual level, there exist a greater number of approaches to holistic resilience, including rather general considerations such as those in Walker and Salt (2006) or Wilson (2012), or more detailed reflections as those published by Norris et al. (2008). However, until now, neither resilience conceptualization nor measuring has been applied to peak oil.

Our paper will improve on the important groundwork laid by the approaches cited above in so far as the assumptions of how the stressor or shock (peak oil) will affect the technological and the socio-economic system will be made explicit by theoretical models. Correspondingly, we will present a theoretically justified and empirically grounded model of resilience towards these effects. Finally, we will improve resilience measuring and take it to a finer grained scale than was attempted until now.

After this outline of the scope of the issues at hand, that will be operationalized in the following, we would like to summarize the issues that our research will treat. We firstly define how current approaches on resilience measuring can be improved. Our second task consists in building a firmer base for resilience debates within public fora, for policy makers and civic initiatives concerning energy issues by developing a new measurement approach. And finally, we will state hypotheses on what constitutes resilience towards peak oil, that can be tested for the sake of an evidence-based approach to resilience.

2. Models, methods and material

2.1. A theory-based model of resilience

Following Norris et al. (2008) and Wilson (2012), we conceive resilience as a process rather than a result, and thus lay the focus on the degree of adaptability that a society shows. Society always changes, and this happens in discontinuous ways due to crises of reproduction of social relations. It is thus not useful to define resilience as the ability to return to a specific state of social and ecological relations, but rather as the capacity to change those relations in a manner that upholds or increases well-being and reduces the susceptibility for harmful effects. We thus conceive social processes as being irreversible, as they are characterized by path-dependency. This brings resilience in close connection with innovation (Wilson, 2012).

Resilience literature often includes the notion of vulnerability, which can be seen as the opposite of resilience (e.g., Wilson, 2012). Yet we prefer looking at vulnerability and adaptability as two tendencies, whose relative strength defines resilience as a net quality. This has the advantage of allowing a clearer identification of the factors that constitute resilience under given circumstances. Thus, a society that has a high degree of vulnerability might not necessarily be of low resilience, if it is at the same time highly adaptable and vice versa (Matzenberger, 2013, 2014).

The notion of resilience always involves a normative approach (Wilson, 2012). Before any kind of measurement can take place, those features of society that shall remain functional or possibly improve have to be defined. We follow Norris et al. (2008) and Wilson (2012) in taking well-being as the measurement rod for the degree of resilience as related to the development path of a society under conditions of peak oil. In this sense, we conceive of resilience as community resilience (Norris et al., 2008). From this follows, that mere technical characteristics of, for instance, the system of energy production and distribution are not sufficient to characterize community resilience. While a certain degree of energy production is vital for well-being on a social level, energy is not an end in itself, but a means to satisfy concrete human needs such as food, housing, education, health services, work, mobility, and culture – i.e., the culturally adequate standard of living as related to such needs.

However, it has to be taken into account that society is not a homogenous aggregate of individuals, but is highly differentiated (Wilson, 2012). Thus, perspectives of different social agents of what constitutes well-being – and resilience – might differ widely. Also in this regard, resilience measurement cannot escape a normative positioning. In the following, we will argue that social well-being as the target variable of resilience is constituted by both objective and subjective components. As objective components we would propose firstly the respect for human rights, i.e., the absence of discrimination along racial, sexual, age-defined etc. lines; secondly healthy life years. As a subjective component, the individual perception of life satisfaction would be a suitable measurement value (see e.g. OECD, s.d.).

From the target of resilience, one has to distinguish components of resilience (i.e., criteria and supercriteria, see below) and their indicators (see Fig. 1). However, this distinction cannot be made in a strict manner, above all because life satisfaction and the absence of discrimination also are important contributors to resilience since they affect the resilience component reciprocity (social capital). Thus, resilience creates its own conditions, and we have to deal with a feedback loop of resilience rather than with a one-way causal relation between resilience components and outcomes. The existence of feedback loops leads to the conception of resilience thresholds, below which a collapse of local or regional societies (as measured against the above mentioned factors) can happen (Wilson, 2012). On the other hand, positive ruptures can also occur, in the course of which, increasing resilience accelerates further adaptations of a society to certain stressors.

2.2. How does peak oil affect society?

In order to be able to define components of peak oil resilience, it is necessary to intersect the above mentioned model with a view of the probable effects of peak oil on society and the crucial pathways of its repercussions. This is a difficult task because a possible peak oil would present a historically unknown challenge. However, different ways of approaching the issue have been

![Figure 1: Relation between indicators, resilience components and target.](image-url)
proposed in recent years, and they can be grouped along the following lines: (1) econometric approach (Hirsch, 2008, Li, 2008), (2) profit rate analysis (Li, 2007, Exner et al., 2008a, b, Exner, 2013b), (3) economic modeling (Kerschner and Hubacek, 2009, Fleissner, 2010, D’Alessandro et al., 2010), (4) system dynamics (Korowicz, 2010), (5) geopolitical approach (Zettib, 2011), (6) historical approach (Friedrichs, 2010).

Although these approaches all have their specific assumptions and limitations, and of course do not necessarily converge in their conclusions, we can however draw some general lessons from them. The econometric approach demonstrates that, when making projections based on historical evidence, a reduction in GDP growth and, in the longer run, a decline in the output of the economy might be expected. An analysis of the dynamics of the profit rate, which acts as the steering variable in societies dominated by the capitalist mode of production, can show that increasing raw material prices including energy carriers will lead to a fall of profit rates, and thus probably will incite a decrease in investments and a general crisis of the capitalist economy. This conclusion can be confirmed to a certain extent by empirically based economic modeling, which points towards a certain probability of a decrease in economic growth and possibly also a fall in total economic output under conditions of peak oil. This can affect the conversion of the energy infrastructure to a renewable system due to the path dependency of this development. In principle, two scenarios may mark the borders of potential development paths: Firstly, renewables require investments that are most likely when economic incentives are strong and profit rates are increasing. Peak oil will foreseeably increase fuel prices, which makes investments in renewable energies economically more attractive. Secondly, peak oil might negatively influence the investment climate of economies. In addition, the extension of renewables requires physical infrastructures that will depend on oil and other non-renewables for the foreseeable future. When these decline or become more expensive, the extension of renewables might be further affected negatively. Therefore, it is not given that peak oil will automatically set (sufficient) incentives for investments in renewable energy supplies. This picture of causal links between peak oil and social changes can be further elaborated by including the political system. Economic crises by trend put governments under pressure and can undermine the state and its institutions. This might lead to social upheaval that can exert additional stress on a socio-ecological transformation towards renewables that is required in case of peak oil. The study of Friedrichs (2010) has investigated historical energy crises that might come close to the dimension of peak oil at least on a regional level. He concludes that a high level of social capital, and a supportive attitude of the state towards self-organization from the grassroots are important preconditions for resilience towards peak oil. Such factors help to adapt the political and social system to conditions of severe economic stress.

23. Components of a best-Practice model of resilience towards peak oil

From this model of peak oil effects, we can draw three general conclusions, that we used to structure the search for criteria of resilience and indicators that allow measurement: firstly, the capitalistic mode of production, which is geared towards economic growth instead of fulfilling concrete social needs, is less resilient than a type of economy that is primarily needs-based, such as solidarity economics or commons (including co-operatives); while capitalist enterprises are limited by profit expectations and forced to compete, non-capitalist economies are conducive to cooperation and more flexible concerning social needs (Lewis and Conaty, 2012). Secondly, social equality increases social capital (Wilkinson and Pickett, 2011), which in turn enhances the degree of inventiveness and social innovation necessary for the adaptability component of resilience (Wilson, 2012). Thirdly, social capital is higher where market relations are less important as compared to reciprocity (Wilkinson and Pickett, 2011).

Taken together, we conclude that social factors of resilience are at least as important as technological ones. Both are to be seen in close relation with each other. We furthermore conclude that resilience is produced by four variables of social interaction that finally also shape the energy system of a society: social equality, reciprocity, trust and cooperation. These variables affect each other in a certain order that can be depicted as a virtuous circle of resilience. Thus, social equality — the opposite of capitalist class divides and income differentials — increases the extent of reciprocity (Exner, 2013b), which is the opposite of the anonymous, objectified relations of the market. Reciprocity in turn creates trust, which fosters cooperation. This factor by trend increases social equality, for instance by way of enabling groups threatened by marginalization to raise their voice and make their interests being heard and respected.

2.4. Temporal and spatial scales in a benchmarking approach

After the model of resilience and how it relates to peak oil have been clarified in general terms, the issue of the temporal and spatial scale of measuring resilience has to be discussed. Geoff Wilson (2012) argues to center resilience on the regional level, with community resilience being the issue of concern. This choice of scale involves the assumption that communities are the core unit of what constitutes resilience.

Wilson defines communities as “the totality of social system interactions (I.e., an affective unit of belonging and identity and a network of relations) usually within a defined geographical space” (Wilson, 2012, pos. 478). We interpret these as being identical to the notion of a sub-national region with shared facilities and a common political identity. Following Wilson, we do not conceive of communities as being homogenous, autonomous or characterized by equality, but rather see them as internally differentiated, dependent on lower and higher levels of social organization (from the household to the nation state and the global economy), and affected by power hierarchies and social domination. Choosing the community level for investigating resilience supports policies that could be enacted on this level to enhance resilience. This does not necessarily imply that the degree of collective choice is greatest on the community level, although in the past, e.g., many climate and renewable energy initiatives in Austria have targeted primarily this level. The preferred scale of political action is in itself a political question and subject to social struggles between different agents.

In light of these reasonings and caveats we operationalize our understanding of community resilience as the resilience of municipalities. This conceptualization grossly simplifies the features Wilson indicates in view of his notion of community resilience, but appears to be the best fit between this notion and the structure of statistical data that are accessible in the case of Austria. It shall be noted that municipalities (or communities in a more general sense) are not seen here as natural social units but rather as certain arenas of political action that integrate social forces, power relations and economic processes of other levels both with lesser (e.g., households) and higher complexity or scope (e.g., the country). In our view, community resilience should be seen as a condensation of resilience dynamics that act not only on a community level, but also on scale levels with higher and lower complexity or scope. Thus, we deliberately included both household resilience properties (such as household income or employment) as well as properties that directly determine resilience of...
higher scale levels (e.g., districts and the federal state-level) by way of resilience indicators.

Resilience dynamics actually run through different scale levels, with for instance the national scale affecting households both directly and indirectly as mediated through intermediate scale levels (such as federal states). Also, the household level (below the community scale, i.e., the municipality) influences the state level, again both directly (e.g., by paying taxes or voting) or indirectly (e.g., by exerting political influence on federal states). It should also be kept in mind that municipalities do not exist in isolation from each other. To treat them so by way of characterizing their resilience with a large share of data that describe municipality properties constrains the results that can be obtained. Seen in this perspective, higher scale level data that we included in a few instances (especially when these levels are the only meaningful level for certain resilience components) act as a counterweight to the doubtful assumption that resilience could be located solely on the municipality level.

Concerning the temporal scale of resilience measuring, our approach takes on an actualistic view. We apply the resilience concept as a way to assess current capabilities for innovation and socio-ecological transformation for the sake of reproducing or concept as a way to assess current capabilities for innovation and socio-ecological transformation for the sake of reproducing or increasing quality of life. We assume severe social and economic stress under present conditions, being caused by limits in oil supply, as the basic situation that this process of transformation has to face. The time frames of the data we used are different: to measure current resilience values, we always applied the most recent data available; to operationalize the best practice-model of a resilient society for the calculation of an absolute resilience value, we used best and worst data for resilience indicators since World War II for European countries (see further details and explanations below).

2.5. Indicators, statistics and regional types

Seen from the viewpoint of our resilience model, indicators of resilience are those that point towards a low degree of vulnerability of socio-economic, spatial and technological structures towards peak oil on the one hand, or that suggest a high degree of adaptability to the possible crises that peak oil may induce on the other hand. Appendix A gives an overview of all indicators we involved in our model. To construct indicators, we first defined relevant supercriteria as the general dimensions of resilience, which were then classified into criteria.

Supercriteria are (1) energy, (2) spatial structure and mobility, (3) reciprocity (social capital), (4) skills, (5) conventional economy, (6) organizational capacities and collective competencies. We defined these supercriteria according to our peak oil-resilience model outlined above, so that resilience components equally cover the energy system, technologies, spatial structures, social factors, economy related factors and organizational features. These abstract supercriteria contain resilience criteria, which are most immediately connected to resilience and thus the cornerstones of operationalization. Table 1 lists the criteria.

Then we defined indicators using variables that literature showed to be relevant, and collected data for measurement, either through Statistics Austria or by way of additional research. Indicators are mere devices to measure criteria, and thus do not necessarily constitute a meaningful policy target. However, in some instances, due to lack of data, only one indicator was available per criterion (see Appendix A; also for literature references concerning the choice of indicators). As suggested in Cutter et al. (2010), the consistency of this list of proposed indicators was then tested by measuring the correlation among the different indicators by means of 2-tailed Spearman rank-order correlation coefficients (hereinafter simply rho or Spearman rho). The consistency of the supercriteria was evaluated by the same test. In both cases, the objective of the analysis was to assess whether the chosen indicators and supercriteria exhibited undesired redundancy.

Cutter et al. (2010) and Sherrieb et al. (2010) both have followed a route of measuring regional resilience in a relative way, by constructing a regional ranking. In contrast, we attempted to assess resilience in relation to an absolute standard of resilience. This is a benchmarking approach, which assumes an ideal type of a highly resilient integrated social, spatial and technological system, that can be described by way of indicators. This seems to be more relevant to policy makers and other social agents than a mere comparison of resilience in the frame of a nation, since a high relative resilience can easily correspond to a dangerously low level of resilience in a more global perspective if the overall resilience of the regions that enter the comparison is low.

Benchmarking again involves normative decisions, which are also documented in the Appendix (A). For it appears to be questionable to simply assume the worst or best international figures of a certain indicator as a benchmark for Austria, we rather took either European countries after World War II as our basis to find historical examples for a realistic benchmarking of resilience indicators, or we theoretically argued benchmarks in rare cases. When European comparisons were not possible due to a lack of easily accessible data, we opted for a national comparison either with a historical perspective or by looking at the contemporary situation. In general, we marked up worst and best cases to capture a certain room for improving or deteriorating situations in comparison with empirical examples.

Resilience was measured by creating an index for each municipality by first calculating the average of all resilience indicator values per criterion, and then of all criteria per supercriterion, and finally, of all supercriteria. For reciprocity, minimum values of criteria were taken into account in the average value.

Table 1

<table>
<thead>
<tr>
<th>Supercriteria</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Share of bad quality houses</td>
</tr>
<tr>
<td></td>
<td>Electricity consumption</td>
</tr>
<tr>
<td>Spatial structure and mobility</td>
<td>Dependence on fossil fuels</td>
</tr>
<tr>
<td>Reciprocity (social capital)</td>
<td>Bonding</td>
</tr>
<tr>
<td>Skills</td>
<td>Manufacturing and agricultural skills</td>
</tr>
<tr>
<td>Conventional economy</td>
<td>Regional economic performance</td>
</tr>
<tr>
<td></td>
<td>Elementary regional economic functionality</td>
</tr>
<tr>
<td></td>
<td>Income equality</td>
</tr>
<tr>
<td></td>
<td>Labor market</td>
</tr>
<tr>
<td>Organizational capacities and collective competencies</td>
<td>Social security</td>
</tr>
<tr>
<td></td>
<td>Resilience of tax income</td>
</tr>
</tbody>
</table>
Normalization to a common scale required to set minimum and maximum values for each indicator. Five classes were set for each indicator scale. This allowed for constructing non-linear relationships between certain indicators and resilience. Classes were either defined by equal or unequal steps (see Appendix A).

Data availability constrained our analysis. It not only led us to select the scale of the administratively defined municipality as our spatial unit of community resilience, as was already discussed. It also means that some indicators, which would differentiate municipalities meaningfully, were not available at this scale level, but only with higher spatial aggregations. Table 2 shows the distribution of indicator data along scale levels. It shall be noted, however, that not every indicator makes sense on every scale level. The share of indicator values that were only available or made only sense on the state scale is small (5 out of 41), while all other values refer to either the federal state level (17) or levels below (19), with 10 values available at the municipality scale level.

To allow for the interpretation of the patterns of community resilience values, we formulated the hypothesis, that resilience depends upon the spatial type of the region. Thus, five regional municipality types (“Cities”, “Suburban Towns”, “Suburban Areas”, “Rural Small Towns” and “Rural Areas”) were identified and a regional aggregation of the indicators and resilience criteria (which are based upon the indicators) was performed in the same way as for municipalities. In a first step of distinguishing spatial types, municipalities (in total app. 2,400) were clustered into three groups according to number of inhabitants 420,000; 20,000 to 5,000; 5,000 to 20,000; 20,000 to 50,000; 50,000 to 5,000,000. Secondly, this population-based classification was linked with the list of municipalities which are members of the Austrian Association of Cities and Towns (Städtebund, 2013). We assumed that the membership reflects the self-understanding of municipalities as towns and cities and therefore represents corresponding characteristics of urbanity. In a third step, the functional relations between core zones (e.g., cities) and suburban zones (e.g., surroundings of cities) were considered based on the distinction between urban and suburban regions (Statistik Austria, 2001). Finally, based on this three-step process, Austrian municipalities were categorized according to the five different spatial types “Cities”, “Suburban Towns”, “Suburban Areas”, “Rural Small Towns” and “Rural Areas” (see Fig. 2).

The importance of indicators for the resilience values of municipalities was determined in a two step approach. At first the most important indicators were selected by a machine learning algorithm called cforest. Secondly, Principal Component Analysis (PCA) was applied to select the indicators with the highest explanatory power and to explore the relationships among them.

Cforest is an implementation of the random forest (RF) algorithm (Breiman, 2001). It differs from the original implementation in so far as it produces more robust models in presence of variables with many categories and continuous variables that influence the variable selection in the trees (Strobl et al., 2007). Furthermore, it reduces the bias that could possibly arise from highly correlated variables (Strobl et al., 2008). One of the advantages of

Table 2

<table>
<thead>
<tr>
<th>No. of indicators per scale level and resilience dimension.</th>
<th>State</th>
<th>Federal states</th>
<th>Judicial parishes</th>
<th>NUTS3</th>
<th>Districts</th>
<th>Municipalities</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SM</td>
<td>1</td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>2</td>
<td>6</td>
<td></td>
<td>1</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CE</td>
<td>1</td>
<td>2</td>
<td></td>
<td>2</td>
<td>1</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>OC</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>5</td>
<td>17</td>
<td></td>
<td>2</td>
<td>6</td>
<td>10</td>
<td>41</td>
</tr>
</tbody>
</table>

E% Energy, SM% Spatial structure and mobility, R% Reciprocity (Social capital), S% Skills, CE% Conventional economy, OC% Organizational capacities and collective competencies.
Moreover, random forest calculates a measure of the models accuracy called "Out Of Bag" (OOB). OOB accuracy is a built-in feature of RF. During the computation, each tree of the forest is trained using two thirds of the data. The remainder is used to cross-validate the resulting tree.

The forest algorithm is implemented in the R-package "party". This algorithm has two parameters, namely the number of trees (ntree) to be grown in the forest and the number of variables (mtry) used to split each tree node. OOB accuracy was extracted from the model using the R-package "caret". This has the advantage of returning both the accuracy and a K statistic, defined after Cohen (1960), as a measure of goodness of model fit. The model was at first fitted by iterative adjustment of the ntree and mtry parameters. As a result, the ntree and mtry yield of the model with the highest OOB accuracy were selected. In a second step, in order to test the stability of the fitted forest model, 30 iterations were performed. OOB, K statistic and the variable “importance” were recorded for each iteration, thus providing an estimate of the robustness of the fitted model. Indicators with constant values across the whole country were excluded from this analysis since the algorithm would not have accounted for their effect.

A drawback of using importance is that there is no an out of the box criterion to leave out “less important” variables. To this end, PCA was also used to re-rate the indicators with the highest explanatory power (explained variance). Elimination proceeded by feeding to the PCA function all the indicators that, according to the RF importance ranking, were evidently higher than the others. At each PCA run, the indicator with the lowest importance was removed and another PCA was run performed until the maximum of explained variance was reached.

The PCA was as well computed in R, using the `prcomp` function of the “stats” package. The analysis was performed on the correlation matrix of the scaled indicators to reduce the bias possible due to large differences in the variance of the indicators.

3. Results and discussion

The degree of correlation and associated significance level (see Appendix C) among indicators is in most cases very close or weak. However, the test revealed a few indicators with a moderate degree of association. Nevertheless, all indicators were retained for the following analysis because the rho coefficient was less than 1.7, which in similar studies has been adopted as a rejection threshold for correlated indicators (Cutter et al., 2010). Table 3 displays the results of the correlation analysis among the super-criteria. Also in this case, some weak and moderate correlations appear, but since they are below the 0.7 threshold, the super-criteria can be deemed to be consistent.

The correlation analysis shows how the selected indicators and aggregated supercriteria represent a set of measures (indicators) and composite indices (supercriteria), that do not carry redundant and returned a mean accuracy of 0.79 and a mean K of 0.7, thus confirming the goodness of fit of the RF model. The average indicators’ importance for the determination of resilience of municipalities are displayed in Fig. 4. The small dimensions of the standard error (SE) bars confirm the stability of the fitted RF model. "Share of persons with manufacturing or agricultural

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Energy</th>
<th>Spatial structure and mobility</th>
<th>Conventional economy</th>
<th>Organizational capacities and collective competencies</th>
<th>Social Capital</th>
<th>Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spearman’s rho</td>
<td>1.000</td>
<td>– .427*</td>
<td>– .488**</td>
<td>– .214**</td>
<td>– .203**</td>
<td>– .215*</td>
</tr>
<tr>
<td>Spatial structure and mobility</td>
<td>– .427*</td>
<td>1.000</td>
<td>.438*</td>
<td>– .076</td>
<td>– .042</td>
<td>.305**</td>
</tr>
<tr>
<td>Conventional economy</td>
<td>– .488*</td>
<td>.438*</td>
<td>1.000</td>
<td>– .023</td>
<td>– .004</td>
<td>.410*</td>
</tr>
<tr>
<td>Organizational capacities and collective competencies</td>
<td>– .214*</td>
<td>– .076</td>
<td>– .023</td>
<td>1.000</td>
<td>– .176</td>
<td>.021</td>
</tr>
<tr>
<td>Social Capital</td>
<td>.203*</td>
<td>– .042*</td>
<td>– .004</td>
<td>– .176*</td>
<td>1.000</td>
<td>.098</td>
</tr>
<tr>
<td>Skills</td>
<td>– .215*</td>
<td>.305*</td>
<td>.410*</td>
<td>.021</td>
<td>.098*</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (2-tailed).
**Correlation is significant at the 0.05 level (2-tailed).
professions” (Sk_agrimanu) is the indicator with the highest
importance followed by “share of agricultural produce in total value
product” (Ec_agrishare). Other important indicators are “activity in
climate policy” (O_clim), “regional GPD per capita” (Ec_gdp), “Share of households with agricultural activities” (Sp_agrihouse)
and “Turnout of voters in national parliamentary elections” (R_elections)
and, to a lesser extent, “index of authoritarianism” (R_auth), and “Share of members of religious associations” (R_rel).

The first step of the PCA analysis was to define a subset of indi-
cators with the highest explanatory power. The initial indicators
set encompassed Sk_agrimanu, Ec_agrishare, O_clim, Ec_gdp,
Sp_agrihouse, R_elections, R_auth and R_rel. After the elimination
procedure, the indicator list contained: Sk_agrimanu, Ec_agrishare,
O_clim, Ec_gdp, Sp_agrihouse and R_elections. Table 4 summarizes
the components’ statistics and cumulative explained variance, while Fig. 5 depicts the correlation among variables and components.

According to the PCA results, Sp_agrihouse, Sk_agrimanu and
Ec_agrishare are positively and strongly correlated among each
other and have the largest dimension on Principal Component 1
(PC1). Fig. 5 displays the orientation of the eigenvectors of the
indicators plotted on Principal Component 1 (PC1) and Principal

<table>
<thead>
<tr>
<th>Importance of components according to PCA axes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
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<tr>
<td>Standard deviation</td>
</tr>
<tr>
<td>Proportion of variance</td>
</tr>
<tr>
<td>Cumulative proportion</td>
</tr>
</tbody>
</table>

Component 2 (PC2): The variable Ec_gdp is negatively correlated to
Sp_agrihouse, Sk_agrimanu and Ec_agrishare and has the largest
dimension on the PC1. The variable O_clim shows a weak corre-
lation to the other variables (its vector is almost orthogonal to the
others), and has a PC2 dimension that is by far larger than the
other indicators. Spatial types appear to be partitioned into three
groups: Rural areas and suburban areas are located along PC1; cities and suburban small towns are instead more aligned to PC2; finally, rural small towns are found in an intermediate (diagonal)
position between the two PCs.

The results of RF and PCA suggest that, on the Austrian level,
resilience is influenced by factors related to the degree of urbanization of the communities. This pattern emerges at first from the RF analysis: Most of the variables are in fact related to social and economical aspects that describe the degree of the dependency on agriculture of a local community. A second relevant aspect highlighted by the PCA is the regional gross domestic product and its negative relationship to the agriculture related aspects. Communities with the highest degree of urbanization are more related to Ec_gdp and, not surprisingly, less to agricultural factors. Climate policy aspects are instead quite unrelated to dominant economic or urbanization aspects. This implies that investments or actions that impact climate policies will have consequences on the resilience of all spatial types, regardless of economic structure.

A certain caveat has to be made regarding the role of the transport sector in our analysis, since one might assume that public transport, which is largely independent of fossil fuels in Austria, is less developed in terms of transport capacity per inhabitant the more rural a region is. Data on fossil fuel use of the transport sector would not have directly reflected this, since data are available at federal state level only. In so far as the more rural regions are more dependent on fossil fuel use in transport, we may have assessed them too optimistically in our approach. However, even if vulnerability may be higher in more rural regions, this has to be put into relation to adaptability, since we regard resilience as the balance between vulnerability and adaptability. Thus, the capacities for self-organization and self-provision in a region are equally important. Furthermore, the fossil fuel dependency of transport was included in two ways, though it was not measured separately: firstly directly by the overall dependence on fossil fuels for the supercriterion energy, which includes the share of fossil fuel excluding electricity in total gross domestic consumption (see also Appendix A), secondly indirectly by the fossil fuel dependency of several components of the resilience supercriterion spatial structure and mobility, with most of the variables being available at district level (which thus allows to distinguish rural from urban regions). This supercriterion measures factors of the capacity to adapt to peak oil that affect transport in terms of options to uphold social services, civil life, the production of food in particular and the provision of goods and services in general. The indicator accommodation quality as being operationalized by the share of multi-unit housing is also relevant indirectly for transport, since the higher the share of multi-unit housing, the higher the degree of population density.

4. Conclusions and policy implications

This paper demonstrates a feasible and transparent, theory-informed approach for measuring community resilience in a peak oil scenario. Its result in the case of Austria shows that regional variation in community resilience might not be very important in a European high-income country. At the same time, ample space to increase resilience towards a hypothetical, normative best practice model exists. Such a strategy of resilience enhancement has to first acknowledge regional strengths and weaknesses, while shifting federal state and state level policies that affect all municipalities towards this best practice model at the same time.

Resilience policies should decouple quality of life in the sense of social equality and the absence of discrimination and exclusion from economic growth. Rural features of spatial types should be strengthened, especially when it comes to spatial structures supporting short distance supply and non-motorized transportation like biking and walking. This means to integrate food production in the local mix of functions to the extent appropriate for the spatial type (Stoeglehner et al., 2011): In urban areas (including small towns), this will concern a certain, but maybe minimal coverage primarily of the fresh food demand, in suburban areas fresh food demand should be provided for the urban centers and the suburban areas themselves, and rural areas have to provide the main resource base and agricultural production for society. Instead of either urbanization or peripheralization of rural areas, their specific resilience strengths should be developed. At the same time, a re-introduction of rurality into urban space should be considered, with urban community gardening or food coops, together with more “frugal lifestyles” being prominent examples for such a transformation of urban space which might enhance resilience.

Energy efficiency measures, the increase in decentralized renewable energy production and innovative e-mobility concepts certainly play a role as well, but certain caveats apply. First of all, our approach measures resilience in terms of the relation between vulnerability and adaptability. Secondly, our model assumes that the technological system and the social system are equally important for resilience— not least because the transformation of a technological system inter alia relies on the qualities of the social system. Certainly, increasing decentralized renewable energy production decreases vulnerability towards peak oil and thus, the importance of adaptive capacities. Increasing energy efficiency, on the other hand, has a paradoxical effect: as long as the efficiency of fossil energy use is low, it decreases vulnerability, whereas high efficiency in this regard has a negative effect on resilience, since an energy user is not able to adapt to supply limitations by further efficiency increases. In general, the relation between efficiency and resilience as such is seen as problematic in the literature, and therefore should be assessed together with robustness (which makes adaptation less important), redundancy (which enhances resilience by lowering vulnerability, but decreases efficiency), resourcefulness and rapidity (that constitute adaptability) (Tierney and Bruneau, 2007, see also Norris et al., 2009). E-mobility already has a large share in Austria regarding railway infrastructure, while the potential for innovative e-mobility solutions appears to be limited for several reasons: first by the source of electricity, which is not necessarily renewable, second by the comparatively high costs of batteries (which may or may not become significantly cheaper in the future), third by geological restrictions (although availabilities are not exactly known), since scarce metal resources would be demanded in high quantities if innovative e-mobility shall acquire a large share in worldwide transport systems, fourth by the change of electricity demand patterns that would require a specific and costly infrastructure to safeguard a continuous energy supply (see e.g. Exner et al., 2015).

It is important to note, that our approach does not take into account linear causalities. Thus, it is neither possible to interpret the measurement approach nor the analysis of its results in such a way that each supercriterion or criterion has equal importance to increase or safeguard resilience. When calculating total resilience values, however, we did not weigh supercriteria or criteria for the lack of sufficient knowledge on the relative importance of resilience components in this respect. Due to the integrated, holistic conception of community resilience in this paper, it rather seems likely, that those resilience criteria that have the lowest values will limit the overall resilience of a community. Thus, it might not be the average values as used for the measurement approach in this paper that count in a dynamic perspective, contrary to a static measurement, but rather the negative extremes. This hypothesis could be named the "law of minimum resilience" and was only applied for the calculation of reciprocity values (see above).

In the final instance, the question which criteria are most likely to cause an increase in resilience, and whether average or extreme values are more important, can only be answered by qualitative research. To this aim, qualitative considerations, i.e., theoretical approaches and causal models are necessary. Since to date, geological constraints on oil production have not led to a development...
in Austria or worldwide that corresponds to the scenario assumed as stressor in this paper, this research has to take on a historical perspective. As our approach has exemplified, the normative and theoretical assumptions of a resilience measurement determine the result to a very large degree. Normative assumptions are inevitable as benchmark, and a theoretical model (see chapter 2.2.) able to represent the possible effects of a clearly defined stressor is necessary to justify and define resilience indicators that are relevant and allow an interpretation of results in view of policy recommendations.

As a general policy-related conclusion, our results cast doubt on the approach to focus resilience policies primarily on the regional scale. Obviously, in the case of Austria, and referring to an overall community resilience value, resilience strengths and weaknesses are distributed so evenly that we can assume an overall similarity of processes and structures in the country, that vary little from municipality to municipality when compared to a resilience best practice model. This at the same time implies that regions (as municipalities) are highly integrated – otherwise such similarities could not be explained. Of course, municipalities are interlinked via state and federal state policies, regulations and financial flows, they cooperate on higher level scales, exchange goods and services, and overall are all highly dependent on external sources of (non-renewable) raw materials and energy, which is not entirely reflected in the relatively low import dependence of the Austrian economy. Furthermore, municipalities are in similar ways an integrated part of an unstable and vulnerable world economy. In order to safeguard a relatively high level of well-being and quality of life, regions thus will have to cooperate on higher levels in order to perform successfully in the course of a transformation from a non-renewable to a renewable energy (and material) system. Furthermore, a regionalization strategy, when pushed to its extreme, might hamper resilience due to increasing inter-regional inequalities, decreasing economies of scale and lower capacities to buffer regional weaknesses by cooperation and exchange.

Acknowledgments

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Appendix A Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2015.12.031.

References