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Co-creating formalized models: Participatory modelling as method and process in transdisciplinary research and its impact potentials

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ABSTRACT

The key challenge for transdisciplinary research aiming to integrate social and scientific knowledge is to produce societal and scientific impacts at the same time. Participatory modelling is a method that uses models in three ways: as a means to generate knowledge, to achieve knowledge integration and to enable societal impact. Agent-based modelling is a computer simulation technique that allows for simulating different actors as agents, the socioeconomic and natural environment they are embedded in, and the interactions among agents and between agents and their environment.

This paper presents projects developing agent-based models of Austrian regions with single farm households as agents. The models simulate how changes in socioeconomic and political conditions affect patterns of land use, agricultural production and the socioeconomic situation within this region. Farm households and their decision-making process with its ecological, economic and social implications represent the basis of the agent-based models. We discuss how and why participatory modelling can help foster the impact potentials of transdisciplinary research and what the limitations of the different types of models are.

We show that participatory modelling allows for the integration of the most relevant issues in the models and for the development of scenarios and strategies together with the stakeholders. Participatory modelling shows its strength in structuring communication on future scenarios and recommendations for action towards reaching the targets of the various groups involved in transdisciplinary research. Stakeholders can use the model for effective discussion and education processes to find sustainable pathways in agricultural development.

1. Introduction

Contemplating the complex global challenges of today motivates science and funding organisations to find new pathways for problem- or solution-oriented research. The UN Sustainable Development Goals are a first attempt to address social, economic and environmental challenges at the same time and for all nations (UN, 2015). Funding bodies like the EU Horizon program invite scientists to aim for social impact, awarding the Horizon Impact Award, which recognises and celebrates societal advancements through research and innovation (European Commission, 2019). The aim to investigate and understand the environmental, economic and social impacts - intended as well as unintended – of natural resource use needs interdisciplinary research cooperation. Sustainability research draws from many different bodies of knowledge and needs to bridge social and natural sciences in order to comprehend the whole picture of society–nature interactions (Fahy and Rau, 2013; Haberl et al., 2016). The quest to develop practices that conserve natural resources for future generations (Brundtland, 1987) must be pursued in cooperation with societal actors and politics in transdisciplinary cooperation to allow successful implementation and dissemination of results (Brandt et al., 2013; Dressel et al., 2014; Hirsch Hadorn et al., 2008; Thompson Klein et al., 2001). Sustainability research requires knowledge integration between various actors in order to enhance the probability of implementing innovative and sustainable solutions, and the integration of various types of knowledge to ensure that commonly created knowledge is effective is essential. This requires a joint effort by stakeholders, experts and scientists from various disciplines. Our approach is based on concepts of interdisciplinary and transdisciplinary knowledge integration developed by the Institute of Social Ecology in Frankfurt (ISOE) and the Faculty for Interdisciplinary Studies (IFF) (Dressel et al., 2014; Jahn, 2005; Winiwarter and Wilfing, 2002). Additionally, we use the concept of three types of knowledge - systems, target and transformation knowledge (Hirsch Hadorn et al., 2008; Pohl and Hirsch Hadorn, 2007) - to develop a process-oriented framework for transdisciplinary research. Providing data and previously gained results to address upcoming themes is a

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Table 1
Research projects.

Project	PartizipA[a]	GenderGAP[b]	LTSER Eisenwurzen[c]
Location	Two municipalities in Lower Austria, one grassland dominated, one cropland dominated	The same municipalities as in PartizipA	One municipality in Upper Austria (Reichraming)
Project Duration	2003–2007	2005–2008	2005–2009
Problem	Nitrogen load caused by regional agriculture, structural change in agriculture, small scale family farms	Structural change in agriculture and gender inequality, CAP reform	Rapid structural change, afforestation
Research question	How will nitrogen flows in the region change under rapid versus sustainable agricultural development?	How will the role of women in farming change under rapid versus sustainable future development?	How will new income sources in agriculture (regional label for products) foster sustainable regional development in the region?
Stakeholders involved in the participatory process	farmers, chamber of agriculture	women farmers, working group of women farmers, chamber of agriculture	Farmers, local stakeholders from local administration, business, education and health sector
Actors represented as agents in the ABM	Farmers only	Farmers only	Farmers, local administration, trade representatives, etc.
Scenarios	BAU (Business-as-usual), Sustainability, Globalization	BAU (Business-as-usual), Sustainability, Globalization	BAU (Business-as-usual), Sustainability, Globalization
Products	participatory developed model, CD Rom for educational purposes, publications	participatory developed model, CD Rom for working group and educational purposes, publications	participatory developed model, CD Rom for municipality and national park, publications
Means to try to achieve wider societal impact	Presentation and discussion with the federal administration	Public presentation at the Symposium for women farmers in Lower Austria, founding of a working group on women farmers in the chamber of agriculture	Public presentation of the project outcomes, where stakeholders presented the interactive model as our common product, follow up meetings of the women group after the projects´ end

[a] ‘PartizipA - Participative Modelling, Analysis of Actors and Ecosystems in Agro-Intensive Regions’ funded by the research program 'Kulturlandschaftsforschung' of the Austrian Federal Ministry of Science and Research.
[b] ‘GenderGAP - A gender perspective on the impacts of the reform of EU's Common Agricultural Policy’ funded by the research program 'Transdisziplinäres Forschen' of the Austrian Federal Ministry of Science and Research.
[c] ‘LTSER Eisenwurzen - Long-Term Socio-Ecological Research Eisenwurzen: An integrated actors/land use/material flow model of Reichraming, Austria’ funded by the Austrian Federal Ministry of Science and Research.

service to the community and helps to create systems knowledge and knowledge on systems dynamics. The systems dynamics perceived and articulated by experts and stakeholders show focus, importance and interrelations of key parameters within the framing concept of the sustainability triangle. Process-oriented participatory methods require a high level of engagement. Scientists can increase the interest in participating using modelling exercises with outcomes that are relevant to the stakeholders.

Analysing societal impact is a means to broaden the focus on scientific publications and citations in research evaluation. Different research communities and approaches, from Responsible Research and Innovation (RRI) to co-production of knowledge (Jasanoff, 2004) and policy counselling, have already started to discuss the societal impact of Social Sciences and Humanities (SSH) (Muhonen et al., 2019), of RRI (Hoven, 2013) and of environmental research (Felt et al., 2016). The Economic and Social Research Council of UK (ESRC) provides definitions and tools to measure societal impact assessment. This funding agency differentiates between academic and economic and societal impact of research. Both forms can then include instrumental, conceptual and capacity building impacts (ESRC, 2011). The means to analyse social impact include evaluation, measuring societal impact via assessments and data mining technologies (Krainer and Winiwarter, 2016). For research projects to achieve high scientific quality and societal impact, new and beneficial framework conditions within funding and research organisations are required (Irwin et al., 2018).

How to achieve a high quality of interaction in transdisciplinary cooperation and how to evaluate the societal impact of this research were the questions at the core of the TransImpact project. There, researchers evaluated transdisciplinary research projects from Germany, Switzerland and Austria and analysed possible interrelations of research methods and potential societal impacts (Bergmann et al., 2016). The analysis in TransImpact drew from the former approaches and the early concept of productive interactions (Spaapen and van Drooge, 2011). Comparing different approaches to analysing societal effects (Walter et al., 2007; Wiek et al., 2014) or outcome spaces (Mitchell et al., 2015) led to the joint development of a new framework to assess impact on three levels, as direct, indirect and diffused impact potentials (Bergmann et al., 2017). TransImpact findings are available and are the subject of ongoing discussion on the TD-Academy (https://td-academy.de/), which was created in this project.

This paper presents the method and process of participatory model building in three case studies on the rapid structural and ecological change of agriculture and land-use in Austria. We present a framework together with our experience of how it helps to address knowledge integration, to create societal impact potentials and to achieve high quality interactions.

We show examples of co-created and participatory development of computer simulation modelling as research method and process. Drawing from three case studies, we ask the following questions: (1) How does the development of computer models help to generate scientific knowledge and societal impact in transdisciplinary projects – in our cases on sustainable agricultural development in Austria? (2) How does quantitative modelling and scenario development foster an understanding of systems dynamics as well as robust knowledge and results for scientists and stakeholders? (3) What are the limitations and shortcomings of a research effort, which aims to translate system understanding developed in a transdisciplinary process into a formalized modelling exercise?

In this paper, we start with a description of the case studies in Section 2. We present the research process and the mix of methods in Section 3 and the results regarding societal and scientific impact potentials in Section 4. We proceed to discuss the learning from these projects in the light of the framework of potential impacts on three levels in Section 5 and summarize the findings and conclusions in the last section.

2. Sustainable development of Austrian land use: case studies

This paper presents a series of projects using agent-based models of Austrian regions with single farm households as agents. The models simulate how changes in socioeconomic and political conditions affect the decision making of land users (mainly farmers) and consequently land use patterns as well as agricultural production. Farm households and their decision-making process with its ecological, economic and social implications represent the basis of the agent-based model. The three case studies used here (see Table 1) represent municipalities in Austria, which show a clear structural change in the agricultural sector. For all of these regions we developed an agent-based computer model in order to understand how changes in the framework conditions, especially of the European Common Agricultural Program (CAP) effect ecological indicators such as nitrogen and carbon flows. Time-use data served as a means to formalize social processes as an indicator for quality of life and with the aim of integrating a gender perspective (Gaube et al., 2009b; Smetschka et al., 2016). We developed a new simulation model for each of the case studies. The overall structure was the same, but was adapted to the regional characteristics. The experiences from the previous projects were implemented as improvements to the model in the following projects.

The potential impacts of participatory modelling encompass both the societal impact in the field, the community and eventually on policies and the scientific impact on further research questions and methods (Bergmann et al., 2017; Wiek et al., 2014). We differentiate between two types of results/products: (1) the interactive model (see Fig. 1), and (2) the results related to the research questions, regarding how the regions will develop under different scenario assumptions. The interactive interface of the model includes the sliders and graphs most relevant to the stakeholders. Being able to change the parameters and start a new and model run is most relevant to stakeholders. The second type of result holds relevance both for the scientific community and for stakeholders.

The main results of the agent-based model show that increasing forest area caused by a decline of agriculture in Austria could be reduced in a sustainability scenario, which assumes that agricultural production becomes more attractive through fair prices and region-specific subsidy systems. Nevertheless, high or increasing workload on farmers and in particular on women farmers is perceived as a problem. Solutions to enhance the success of any effort towards sustainable development by integrating time use and gender aspects are needed.

3. Methods: participatory formalized modelling process

In the projects described in this paper, we have developed a transdisciplinary research framework for the process of participatory formalized modelling (Fig. 2). Here we present the key aspects of the project design generally and based on literature and include the experience we gained through our projects.

3.1. Problem framing

The initial phase of a research projects requires there to be a focus on defining research questions and goals. Joint problem framing is key to achieve cooperation and integration in transdisciplinary research projects (Bergmann et al., 2012; Jahn et al., 2012; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). Scientists shape project design and research process. The goals of co-creation and problem solving require plans for deliberation on the problem framing that allow enough time and utilize appropriate methods (Schäfer and Kröger, 2016). Within our participatory modelling process, we had a structure to elicit systems knowledge and offered space to create and exchange mental models.

Sustainable agriculture and regional development are the focus of a series of research projects at the Institute of Social Ecology Vienna. The research questions arise in the field of land use and land cover change studies pursued by the Social Ecology team. In the projects described in this paper, discussions among researchers, agricultural experts and local stakeholders led to the aim to find ways to cooperate in the endeavour to create new knowledge on land use change in Austria, to analyse environmental impacts of agricultural development and to find more sustainable pathways for land users, planners and politics. It is thus not an immediate local problem, which has to be solved. It is rather the shared perception of the need for greater understanding about how to pursue more sustainable development within Austrian agriculture, which drives interest in cooperation. This shared perception is based on national or regional policy strategies aiming at sustainable development or fostering bio economy as well as on the Paris agreement against climate change or the Sustainable Development Goals. Nonetheless, beyond or underneath this shared and abstract normative goal of sustainable development many different specific real world problems and research questions guide the cooperation. For farmers the imminent problem is structural change in agriculture leading to the abandonment of small-scale family farms. Regional planners, politicians and administrators are aware of the problem of unfavourable regional development, falling tax revenues or coping with national or EU regulations. Scientists have concerns regarding land use change, depletion of natural resources, options and challenges of agricultural development and food security, national and international inequalities, climate change, and many more. The

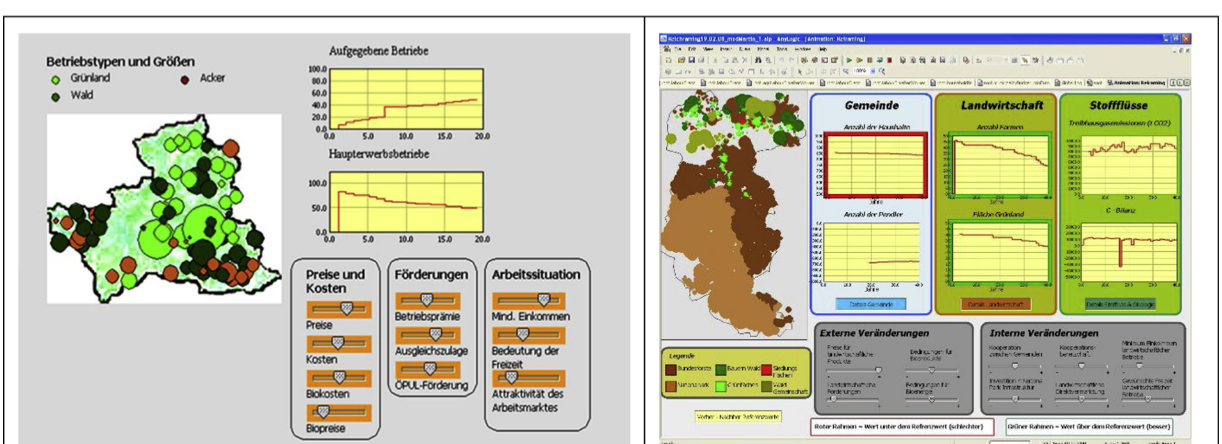

Fig. 1. Interface of agent-based models with interactive sliders and results in graphs.

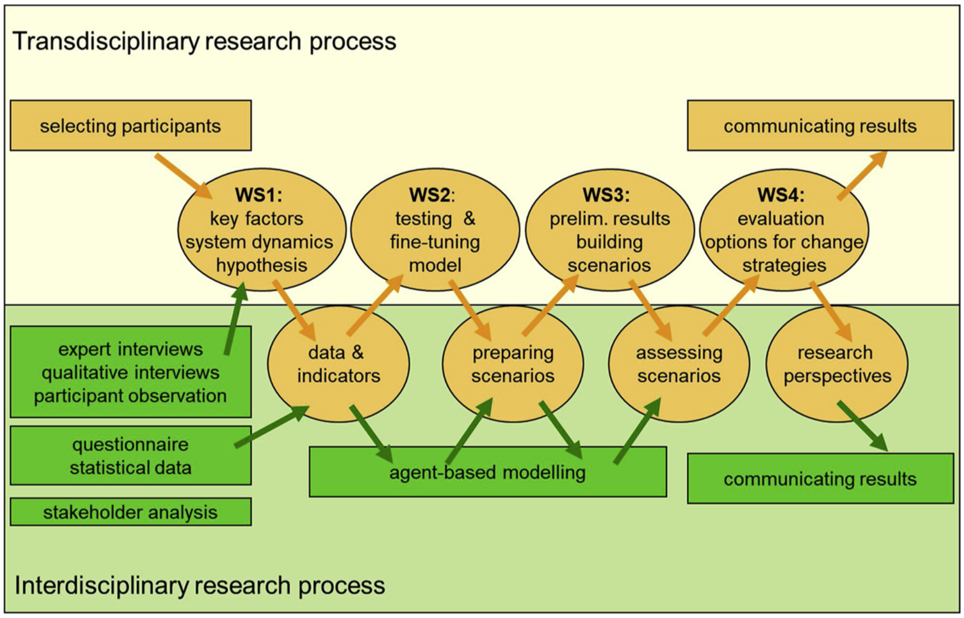

Fig. 2. Transdisciplinary framework and process.

challenges of meeting the Sustainable Development Goals or the normative goal of sustainable development only serve to bolster a shared and accepted framework basis for cooperation. The specific goals of each partner still need to be made explicit in order to guide the joint efforts and reduce both misunderstandings and conflicting expectations.

We show that problem oriented research does not necessarily focus on a concrete problem and does not need to find a directly linked solution as described in the case studies herein. The actors involved have different goals and expectations on various levels. Problem framing as a first step towards creating a sense of common interest and deciding on scale, system boundaries, possible and impossible outcomes is paramount when beginning with a transdisciplinary research process.

3.2. Participatory process: structuring communication

Steering a process and deciding on structure in a research process are key to securing high quality research outcomes (Donabedian, 1980; Haas, 2016). Decisions on participants (researchers, experts and stakeholders), theories and methods, scale and objectives form the structure of a research project. Planning and steering a research process is of particular importance, especially when involving diverse participants and pursuing an open, participative and evolving approach is the aim.

In our projects, we chose to structure communication along a transdisciplinary research framework including preliminary research conducted in the research team, a workshop series involving local experts and stakeholders iterating with the necessary interdisciplinary work packages between workshops (see Fig. 2). This communication structure was applied in all three case studies, with minor adjustments allowing for the specificities of stakeholders and regions.

The projects started by investigating qualitative and quantitative data on relevant actors and data availability. We began with a stakeholder analysis based on literature and discussion with experts and project partners. Expert interviews, qualitative interviews with farmers and participant observation on farms was complemented by research on data available on farms in the region. We selected and invited stakeholders as participants for the workshops in cooperation with the project partners from the Chamber of Agriculture, the Working Group of Women Farmers or the Mayor's office respectively (see Table 1). We wanted to establish working groups of people coming from different types of farms in one project or different sectors within the community in the others, who were willing to engage, invest time and professional expertise. The group was intended to represent different interests and organizational backgrounds and not to exceed 20 persons. The qualitative interviews conducted before establishing the working group provided enough contacts to ensure that all major stakeholder interest were represented. The farmers and other participating stakeholders were acting both as individuals and as representatives of a community role. They reflected these roles and took on responsibility to communicate and multiply the learning outcomes.

We invited participants to attend the entire series of four workshops, introducing the research project and the proposed aims and plans for each of the workshops. The workshops were held in places well known to the participants and within a short distance from their place of residence (e.g. chamber of agriculture). We had agreed upon timeslots, which could be integrated with their occupation and seasonal workloads. The intervals between workshops were different in each project, depending on when feasible dates could be found for all participants. Each of the workshop series of four workshops was held over two years. The project paid for participants' travel costs and meals.

The workshop series started with building an initial mental model to create a shared understanding of the system in question, in our case studies the rapid agricultural structural change in two municipalities or the regional development in a municipality at an LTSER site. We presented the idea of working with an agent-based model with farms as agents. We asked for factors of influence and the interrelations between these factors using the sustainability triangle as a base to structure the discussion in order to find factors representing the social, economic and ecological dimensions. In participatory modelling, it is very relevant to use concepts that act as bridge between qualitative descriptions of a problem and the quantitative modelling exercise. Relations between factors were defined as causal loops- that is positive / enhancing or negative / diminishing relations - according to system dynamic modelling. In one case this first step was designed using the method of Fuzzy Cognitive Maps (FCM) (Wildenberg et al., 2014). We asked participants to assign a degree of importance to the factors and to define key factors of influence that they felt should be represented in the model. Finally, we discussed options for and barriers to a more sustainable development, resulting in a summary of hypotheses to guide our research.

In the second workshop, we tested the initial model design with an interactive interface and asked for suggestions for fine-tuning the model according to the communicative and apprehensive needs and concerns of the group. In the third workshop, we were able to show some preliminary results and start to build scenarios. The participants were given the task of developing best- and worst-case scenarios using all the factors we had jointly decided on, but otherwise being free to choose a narrative or visual description in small working groups. All working groups decided to create best-case scenarios and presented them for discussion in the plenary group. The whole group then decided on three scenarios - business-as-usual, sustainable and globalized - to be assessed in model runs over a time-span of 25 years.

In the final workshop, we were able to present results from modelling the scenarios, which showed that not only costs and prices but also a high workload, the desire for more leisure time and overall aspects of positive regional development are crucial factors for a desirable future. In a backcasting exercise participants defined possible next steps for action and persons or groups responsible for initial activities.

3.3. Participatory modelling

Building 'models' can mean many different things in inter- and transdisciplinary contexts, encompassing a wide range from mental models to calculations, algorithms and specialized modelling software and platforms. Nonetheless, defining models as abstract and simplified description of a system and its dynamics can achieve consensus.

The idea of participatory modelling is based on the concept of Group Model Building developed by Vennix (1996). Participatory modelling is a method, which uses models in three ways: (1) as a means to create knowledge, (2) to achieve knowledge integration and (3) to enable societal impact. Models can be used to obtain a better understanding of dynamics within a system, to reconstruct dynamics of past or poorly documented systems and to develop future scenarios on the one hand. On the other hand, they are useful to structure communication processes around recommended actions, allowing for the development of scenarios and plans for measures and activities. Many examples of modelling sustainable development without stakeholder involvement exist (e.g. IPCC, 2014). With participatory modelling, we propose to take a further step towards implementing knowledge regarding pathways for sustainable development in societal action.

In our case studies we used agent-based modelling, a computer simulation technique that allows for simulating decisions taken by different actors as agents. Agent-based models (ABMs) originated in the computer sciences in the 1970s through artificial intelligence research (Hare & Deadman, 2004), but have recently gained popularity in the social sciences. The strength of ABMs is their ability to simulate aggregate outcomes resulting from decisions made by many individual actors. General applications of ABMs have proven their utility in analysing the dynamics of socioecological systems in which decisions of actors influence biophysical dynamics (e.g. Janssen, 2004; Matthews, 2006; McConnell, 2001; Parker et al., 2002; Verburg et al., 2004). Generally, agent-based models consist of agents (which might represent stakeholders involved in the participatory modelling) with specific attributes, an agent behaviour, and an environment in which the agents live in and interact with each other as well as with the environment. Agents act goal-oriented (but not necessarily with an objective to optimize), autonomous and self-directed, with the ability to learn and adapt. The simulation of these agents and their interactions according to the needs of a transdisciplinary working group makes these kinds of models particularly attractive. The similarities with computer games add to this attraction. Additionally the equidistance of a computer game from the working practice of scientists and stakeholders involved helps to foster the transdisciplinary process, when bringing everybody involved to the same level of negotiating formalization and reduction.

3.4. Scenario building and backcasting

'Scenario' is another term, which lacks a coherent definition in interdisciplinary discussions. Again, we can see an array of meanings from a spatial scenario to future scenarios, from narratives to calculations or their integration. In environmental research, scenarios are used to envision and plan for the future. They are "defined as plausible, challenging and relevant stories about how the future might unfold that integrate quantitative models with qualitative assessments of social and political trends, scenarios are a central component in assessment processes for a range of global issues, including climate change, biodiversity, agriculture, and energy." (O'Neill et al., 2008). In this sense environmental scenarios are used in integrated assessment approaches (Alcamo, 2001; Mach and Field, 2017) and global environmental modelling (IPCC, 2014) and lately "by integrating social science and participatory approaches with climate and socio-economic scenario modelling outputs" (Pedde et al., 2019, p. 83)

Scenarios are differentiated either as open, explorative or normative scenarios. The former are built along opposing assumptions on future development. The latter are developed as business-as-usual, best- or worst-case scenarios encompassing specific sets of key factors. The desirable or undesirable futures defined in these scenarios can serve as a base for backcasting methods, in order to develop, discuss or analyse policies, actions plans or next steps to be taken (Kosow, 2015; Kosow and Gaßner, 2008; Vergragt and Quist, 2011). Using scenario techniques in transdisciplinary research requires decisions as to which parts of the scenario building need whose participation (see framework for this participatory process in Section 3.2).

Scenario methods and backcasting exercises have proven to be useful for stakeholder interactions in our case studies and can foster "higher-order learning from small-scale community initiatives" (Schröder et al., 2019). In our participatory modelling approach, the participants discussed and identified the most relevant factors for scenario building. The scientific team opted for developing three distinct scenarios using the concept of the scenario funnel: one business-as-usual (BAU) scenario, and two extreme scenarios. The participants developed stories and images based on different developing key factors in small working groups. After presenting the different scenarios these were synthesized into one BAU, one Globalization (GLOB) and one Sustainability (SUST) scenario. The participants debated which information should ideally be present on the model interface, which shows sliders and results in graphs. The scenario building techniques per se helps to structure discussion and enable the group to discuss conflicting issues and to clearly articulate diverging interests. Thus, they are useful for creating scenarios that are significant, feasible and adequately distinct.

However, it is only when calculating the scenarios in a formalized model that the quantitative results stimulate the analysis and debate of system dynamics towards deliberation and learning on next steps to be planned.

4. Results: impact potentials

4.1. Societal impact – direct

Transdisciplinary transformative research has to address the three forms of knowledge: systems, transformative and target knowledge (Pohl and Hirsch Hadorn, 2007). The participatory research process described in this paper started with sharing perceptions and learning about the system dynamics. Developing a scenario representing a desirable future was key to reach a knowledge on the targets of the common effort. Transformative knowledge was then jointly created in the transdisciplinary research process and served as the base necessary to generate options for change and further action.

The participatory process had shaped the model according to the systems understanding of all stakeholders and scientist involved. Everybody had appropriated the model after a process of two years as their own and regarded it as a valid tool. The interactive interface shows the factors and results most relevant to the stakeholders. Analysing scenarios in order to get quantified results helped identify option spaces. Backcasting exercise guided the group to find and decide on entry points for changes. This led to defining first steps to be taken and strategies and action plans to be pursued. Pathways for a desirable and more sustainable development regarding social, economic and ecological dimensions were developed on individual, household and society levels. The participants agreed upon an action plan stating who would do what in the months to come.

In the project GenderGAP, for example, this included joint resolutions on how to change their own daily activities, decisions on farm production and activities linking with the regional administration and politics. "Good education and training opportunities for women farmers, effective public communication regarding the diverse roles taken by women farmers and support schemes for sustainable agriculture to the benefit of the wider society are further joint recommendations made by the transdisciplinary working group." (Smetschka et al., 2014) Due to the cooperative process lasting for two years the group of women farmers got to know each other well, shared experience learning and wanted to continue working together. They committed to carry on with the work started in the research project within the Working Group of Women Farmers.

4.2. Societal impact – indirect and diffused

Beyond the societal impact (the activities planned by participants and partners in the transdisciplinary research project) and the scientific impact (scientific publications) we describe here the further societal impact potentials we observed over the project duration. We are still in contact with some of the stakeholders and can build new cooperation on these project experiences, which have helped create a basis of mutual understanding and trust, necessary in all inter- and transdisciplinary research. However, we strongly recommend ex-post research on indirect societal impact potentials for each project.

Participating in transdisciplinary research represents a new experience for individuals from outside academia. They may not know what to expect and have reservations, believing that science is too abstract and detached from their own reality, and therefore not of practical relevance. These reservations hold especially for the prospect of working with computer modelling. Some may perceive science as being presumptuous and arrogant towards people lacking an academic education. Transdisciplinary research has to find ways to deal with these sometimes-contradictory expectations. The first societal impact consists of the way partners envisage science after having been involved in a research project. The participants in our case studies were critical of urban scientists who come to explain their problems. Yet they were interested and attracted by the possibility of contributing their perspectives from the very beginning. After two years of discussions in workshops they were planning to continue with these discussions for example in the Working Group of Women Farmers or by hosting classes on their farms.

Being aware of inequality in power and representation among stakeholders in the field, we choose to invite stakeholders of heterogeneous agricultural production, but of relatively equal social standing. We chose to undertake extra workshop series with women's groups to elicit the problems specific to women in farming and to enhance the possibility of their active participation. Research processes can foster empowerment of groups or persons by giving them a voice or the opportunity to gain new qualifications. Training in the communication of insights and presenting these to a wider audience was provided in the project, resulting in talks given by participants presenting the project at the Symposium of Women Farmers in Lower Austria in front of an audience of thousands.

The mix of participants in the workshops provided a new understanding of working conditions of other farmers and thereby of structural change in agriculture. A new understanding of overall dynamics and common interests leading to the creation of new networks across specific interest groups followed.

We assume that the broadened understanding of systems dynamics is owed to the intensive work in participatory modelling. New insights and training in thinking about causal loops, and interrelations of key factors led to robust knowledge, which was only possible by agreeing on quantifying these factors and discussing the results calculated for jointly developed scenarios.

4.3. Scientific results

The case studies all contributed to the methodological development of participatory modelling and of creating land-use models integrating natural and social science questions. Agent-based models are often used as optimization models in which the agents maximize profits. The use of the models in a transdisciplinary context, in which economic considerations are accompanied by many more social and cultural factors influencing decision-making, poses an exciting challenge to extend agent-based models to include non-rational optimization strategies. The results indicate leverage points and option spaces in agricultural and regional development.

The importance of infrastructure to support persons with caring responsibilities is an example of the insights gained. Capacity for the care of elderly people and small children in the immediate vicinity turned out to be particularly relevant for decisions regarding the type and amount of agricultural production on the farm. The same applies to the regional labour market: the more attractive the options for non-agricultural income are, the more flexibly farms can respond to changes in socio-economic conditions, making them more resilient. These methodological results and learnings and further results on option spaces for sustainable agricultural and regional development in Austria were published in scientific journals (Gaube et al., 2009a, 2009b; Smetschka et al., 2009) and in edited volumes (Smetschka et al., 2016, 2014).

5. Discussion

Participatory modelling allows for integrating the issues most relevant to stakeholders in the model and for developing scenarios (globalization, BAU and sustainability scenario) and strategies together with the stakeholders. The process of participatory modelling involves farmers and agricultural experts in designing the agent-based model and in creating scenarios. It shows its strength in structuring communication on future scenarios and on recommendations for action towards reaching the targets of the various groups involved in transdisciplinary research. Building a computer simulation model together requires discussing and deciding on very clear and explicit (quantitative) assumptions about how the system works and might work under different future pathways. That means the discussions leading to the jointly developed simulation models are structured in strict accordance with the modelling method. The stakeholders can use the model for discussion and education processes to find sustainable paths in agricultural development.

5.1. Societal impact

TransImpact developed a framework to assess societal impact potentials on three levels: direct, indirect and diffused (Bergmann et al., 2017). In Table 2 we indicate the outcomes of the case studies as direct and indirect research products achieved by our method. We differentiate between the actual product of research projects as direct and indirect products of interest to the life world (Pohl and Hirsch Hadorn, 2007) and the scientific realm.

It is not possible to evaluate the direct impact of research or specific methods, as causality cannot be traced and the temporal gap between

Table 2
The direct and indirect research product achieved by our method as perceived in life world / science.

		Method	Life world	Science
Product	direct	A model developed jointly and agreed upon by all persons involved	CD Rom with interactive model, public presentation, publications	scientific publications
	indirect		capacity building	qualification of researchers

Table 3
Three levels of potential impacts achieved by project activities and perceived in life world / science.

Impact potential	Achieved by activity	Life world	Science
direct	participatory modelling	changed activities of farmers	new design of model
indirect	participatory process, systems thinking	learning, capacity building, network effects; changed perception of science; new understanding of interest of other participants;	teaching
diffused	public relations, stakeholders as multipliers	in expert discourse and administrative / policy sector	in scientific discourse

research and impact cannot be accounted for. However, analysing the impact potential of the projects presented and the methods used we can discern relations between methods and impact potentials. In Table 3 we describe the potential societal impact on three levels and how this is achieved by specific activities within our methodological framework.

In our experience the key elements fostering or hindering the impact potentials of transdisciplinary research with the method of participatory modelling were these:

- Schaepke sees "… social learning, empowerment and social capital as important and hitherto under-conceptualised aspects of the sustainability transition literature" (Schaepke et al., 2017; abstract). In participatory modelling, we aim to achieve these aspects by fostering learning and networking in the participatory process.
- Systems knowledge is of high interest to experts and stakeholders. For a productive cooperation researchers have to provide relevant data and facts and at the same time have to be able to elicit further knowledge from stakeholder discussions and translate them into scientific knowledge and back to expert knowledge. With participatory modelling the need for adequate data gives structure to a process, where conflicting interests, relevance of factors and reduction are discussed.
- Models can be attractive intermediary objects for knowledge integration and co-production. Interactive tools and attractive interfaces enhance the potential of co-creation and thereby the societal impact through the interest of a wider audience.
- Problem-oriented or curiosity driven research makes a difference in terms of the type and amount of stakeholder engagement and activities and thereby in the form of products to be designed and impact potentials expected.
- Long-term partnerships with stakeholders and interest groups enhances mutual trust and furthers understanding and levels of cooperation.

5.2. Scientific impact

Engaging with experts and stakeholders in research processes is demanding and implies a lot of uncertainty, fuzziness and subsequently doubts in the course of the research process. We show some strengths and weaknesses of different approaches experienced by the authors and discussed in the project teams in Table 4.

The effort of participatory research is primarily inspired by the hope of achieving more robust knowledge and the potential impacts due to improved communication among scientists and other stakeholders. However, it is also motivated by the search for a better understanding and learnings about the system analysed, methods employed and communication. Participatory development of simulation models can provide a shift of perspective on a problem. Additionally, it fosters dialogue around stakeholders' preferences and the importance of key factors to be analysed can shed new light on research questions. Transdisciplinary cooperation therefore will always 'irritate' any research process. This irritant function can be useful for developing methods adequately, shaping innovative research questions and focussing on neglected aspects of analysis. The agent-based model has evolved during our research projects and is now a genuine product of a co-creation process, eliciting better scientific results along with new forms of communicating them.

5.3. Combined impact potentials

Transdisciplinary research aims at both addressing the complexity of life-world phenomena and focussing on problems relevant to stakeholders. Scientists can support this process by providing 1) data on different scales and issues, 2) knowledge about ecological, economic and social contexts and 3) skills in transdisciplinary process-oriented methods. Methods of participatory modelling can address all three challenges and serve the purpose of knowledge integration as well as creating societal impact.

We analyse the advantages and disadvantages of the components of the participatory modelling approach we employed in our case studies in Table 4. It is possible to design a participatory research process using mental models only. This is an approach, which can guide an open participatory process, where the focus lies on improving communication and problem understanding between stakeholders. Fostering dialogue is the most prominent feature of such an approach. The weaknesses lie in the

Table 4
Advantages and disadvantages of components of participatory modelling methods.

	→	combined to	←
	Participatory research using mental models	**Participatory development of formalized simulation models**	**Formalized / agent-based modelling**
Strengths	Robust knowledge; Open process improved communication	Results for scenarios; Integration across social and natural sciences; Enables deliberation	Abstract, complex; Logical rigor, accuracy; Need for reduction
Weaknesses	Doubts on accuracy and effectiveness	Time consuming; Demanding	Abstract, complex; Alienating to some disciplines
Expected achievement	Dialogue	Creative irritation; Interactive interface; Options for change	Systems thinking

doubt, which can arise on both sides, about the effectiveness of the process.

Modelling approaches tend not to consider the use of participatory processes, as they represent highly abstract methods with the aim to find ways to calculate data across complex and interdependent facts and conditions. The strength of logical rigour and the need for reduction is both a strength and a weakness, as it fosters systems thinking and accuracy, but alienates people and disciplines, who are not used to it and fear that in particular data that are not easily quantifiable could be neglected. Qualitative assessment giving different degrees of values and relevance to these data is a solution that requires creativity, experience and co-creation. Thus, formalized modelling is not the first choice for many inter- and transdisciplinary research projects.

Combining participatory approaches with formalized computer models is a method that can achieve a great deal of the integration needed for a better knowledge on options for sustainable development. It is very demanding and time consuming to develop a formalized simulation model in a participatory mode. This inter- and transdisciplinary effort has to acknowledge the trade-off in that the advantages of both parts are weakened when combining them. Yet, as we have demonstrated in our case studies, it has a high potential for impact on society and science by producing creative 'irritation', providing interactive interfaces and thus the basis for strategies on options for change.

6. Conclusions for transdisciplinary research

Impact potentials cannot be directly linked but are related to methods and process, to stakeholder selection and to the type of problem and level of engagement. Designing a research process must take into account the necessities stemming from problem characteristics, stakeholder selection and scientific and societal goals of the research project. From our case studies we find that systems thinking and participatory modelling including scenario development and backcasting exercises are methods which ensure continuing interest and learning for stakeholders in order to achieve the goal of generating new scientific and socially robust knowledge (Nowotny et al., 2001).

Transdisciplinary, transformative research combines analytic, strategic and normative perspectives. Strategies and action plans for fostering more sustainable development must be based on scientific analysis while also being developed through participatory processes including women and men, older and younger persons as stakeholders in their everyday life. Shaping transformations requires an open and creative process, including and engaging multiple groups, fostering participation and discussion, taking into account power relations, social inequalities and political processes. In interdisciplinary and transdisciplinary teams, the combination, critical assessment and integration of scientific knowledge, experts' knowledge and new ideas on dynamics and constraints via a process of participatory modelling can lead to pathways for change toward more sustainable everyday living. In this paper we have demonstrated how models integrating the social, economic and ecological dimension of sustainability and participatory developed scenarios lead to clear simulation results. This can help to create options for change, that are viable for the people involved and possibly leading to a broader impact in society.

We have continued to develop the method of participatory modelling in further projects. In LUBIO[1] and Alisen[2] we focus on using agent-based land-use models in order to link them with ecological models such as species distribution and denitrification models. In terms of participatory modelling, the way in which the results of the ecological models affect stakeholders is of particular interest. In INSOURCE[3] we are using the process of participatory modelling described in this paper and combining it with spatially explicit models of urban infrastructure (virtual 3D city models, City GML). Thus, we hope to learn how to address the weaknesses described and to improve the process of combining participatory modelling with simulation tools. If funding could be provided, a follow-up to our case studies would be extremely helpful to learn more about adequate methods and impact potentials.

The debate in TransImpact on societal impact included the role and agency of science policy and funding bodies. The overall quest for research to be innovative, socially responsible, relevant for societal advancement and scientific excellence is at the least very demanding, if not impossible. Science policy and academic administration can ease the task with adequate systems of promoting and evaluating transdisciplinary research within academia (Irwin et al., 2018; Krainer and Winiwarter, 2016). Funding bodies aiming to foster the societal impact of research projects may draw upon the principles summarized from TransImpact discussions (Smetschka et al., 2018). We fully agree with the findings from a recent survey, where 62% of respondents "consider longer projects as an essential improvement, adding the importance to follow up on project work by 'monitoring societal and sustainable effects after project ended' and getting feedback from stakeholders on research results" (Mielke et al., 2017).

In the case studies described in this paper, we have learned that trust, reflexivity and process orientation are essential for high quality, transdisciplinary, transformative research. Long-term relations, building trust and mutual understanding are as important within the interdisciplinary team as they are in relation to stakeholders and funders. Allowing for open, iterative research processes and providing accompanying evaluative research supports effective societal impact potentials on the direct, indirect and diffusive levels. We have experienced that computer models are an appropriate means to maintain the interest of experts from the field and from administration. Scenarios, simulations and results calculated from these models can generate new insights and robust knowledge.

UNESCO provides evidence that by engaging people in carefully co-created learning-by-doing processes, people become more 'futures literate', ask new questions and open up new horizons for innovative actions (Miller, 2018). Activating future literacy and anticipatory system knowledge through participatory modeling can have an important societal impact in this era of climate crisis and complex global challenges, when we urgently need to achieve the Sustainable Development Goals.

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[1] 'LUBIO - Land Use, climate change and BIOdiversity in cultural landscapes' funded by the Austrian Academy of Sciences

[2] 'ALISEN - Analyzing LInkages of SocioEcological Nitrogen flows' funded by the Austrian Science Funds

[3] 'INSOURCE - INtegrated analysis and modeling for the management of sustainable urban FWE ReSOURCEs' funded by Belmont Forum

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