Using games to support multi-stakeholder decision-making for sustainable development of livestock production

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Abstract: Decision-making for sustainable development of agricultural regions is challenged by the complexity of the livestock system and the involvement of multiple actors. To support the decision-making process, model-based games could improve the understanding of possible consequences of decisions at hand. This study analyzed the opportunities to use model-based games in order to support the decision- making process in the Peelhorst region, an area with a high livestock density in the south of the Netherlands.

Stakeholders were interviewed to identify key issues in the decision-making process. This yielded two types of issues: 1) issues related to the sustainability of the livestock system; such as public health and odor and 2) process related issues, i.e. issues related to governance or stakeholder interaction, such as trust and awareness. For each issue a literature review was made and possible indicators and models were identified. For half of the issues clear indicators or models were found, whereas for the other half no clear indicator could be defined and additional research is needed. Tackling issues related to governance requires discussions or workshops with relevant stakeholders. Model-based games could feed into these discussions to encourage knowledge exchange and support decision-making.

Keywords: games, decision-making, livestock production, spatial planning, participation

Introduction

The sustainability of livestock production is a topic of fierce debate. On the one hand, the world's livestock sector significantly contributes to climate change, eutrophication, acidification, water pollution, and biodiversity loss. Current livestock production levels pose severe pressure on the environment via their emissions to air, water, and soil. The livestock sector, for example, is responsible for about 15% of the global anthropogenic emissions of greenhouse gases, whereas it uses about 70% of all agricultural land (Steinfeld et al., 2006; Gerber et al., 2013).

On the other hand, from a socio-economic perspective, livestock production contributes significantly to the agricultural gross domestic product and provides income and employment for many smallholders worldwide (Steinfeld et al., 2006; Van Calker et al., 2008). Nonetheless, the demand driven livestock chain has also caused a cost prize squeeze for farmers, resulting in measures to upscale production and minimize production costs (Wiskerke, 2009). As a result, the effect of livestock production on issues as the environment, public health, employment, food security and animal welfare are widely discussed in science and society (Boogaard et al., 2011; Alders, 2011). The need for a transition towards more sustainable livestock production is increasingly expressed (Bos et al., 2009; Le Gal et al., 2011).

A transition towards sustainable livestock production strongly depends upon the field of spatial planning as they constrain, enable and direct spatial developments. Spatial planning, however, is

making a shift towards more collaborative governance approaches (Termeer et al., 2013). Therefore, regional stakeholders play a key role in addressing current societal problems like sustainable development of livestock production. Nevertheless, the various dimensions of sustainability and possible conflicting consequences of decisions make decision-making for sustainable livestock production complex. In addition, uncertainty regarding the impact of decisions on complex issues, such as public health, hinders decision processes. Therefore, decision-making for sustainable livestock production requires insight in the trade-offs and synergies among economic, ecologic and social consequences (De Boer et al., 2011). Integrating different models can help in analyzing these trade-offs and synergies at a regional level (De Boer et al., 2011). Models are increasingly used to support policy makers by providing insight on possible consequences of policies and scenarios (Vayssieres et al., 2011; Klerkx et al., 2012). Modeling is considered to help to address holistic questions, provide a better understanding of how systems operate, and it can help to identify knowledge gaps, support decisions processes or calculate policy outcomes (Klerkx et al., 2012; Le Gal et al., 2011; Gouttenoire et al., 2011). Many models, however, focus on issues of importance for farmers and advisors and do not address a broader range of stakeholders, even though they are considered as crucial partners in redesigning the system (Le Gal et al., 2011; Klerkx et al., 2012).

Recently several papers have discussed the application of models in serious games to bridge the gap between science and society and to involve a broader range of stakeholders to decision-making processes (Martin et al., 2011; Vieira Pak & Castillo Brieva, 2010). Applying such games can help to understand complex systems, represent a problem, observe players behavior, obtain information on decisions, create space for sharing knowledge and creating consensus (Castella et al., 2005; Vieira Pak & Castillo Brieva, 2010).

This study, therefore, aimed to explore the opportunities of games to facilitate multi-stakeholder decision-making on sustainable livestock production at the regional level. To reach this objective three sub questions were distinguished:

- What are the issues at stake in decision-making on the future of livestock production?
- What indicators and models are available to quantify these issues?
- How can games support multi-stakeholder decision-making and integrate models?

Methodology

This research addresses economic, environmental and social issues of livestock production at a regional scale. The system boundary can be defined as the regional landscape in which livestock production is connected to other activities like manure processing and arable farming. Livestock production is dependent on other processes for its inputs (i.e. labor, feed, animals, fossil fuel, water, equipment, electricity, and construction material) and outputs (i.e. animal products, manure). In addition, the system influences the region through farm income, landscape quality, and the impact on public health, climate change, eutrophication and acidification. Therefore, changes in the livestock system have impact on multiple dimensions at the regional level.

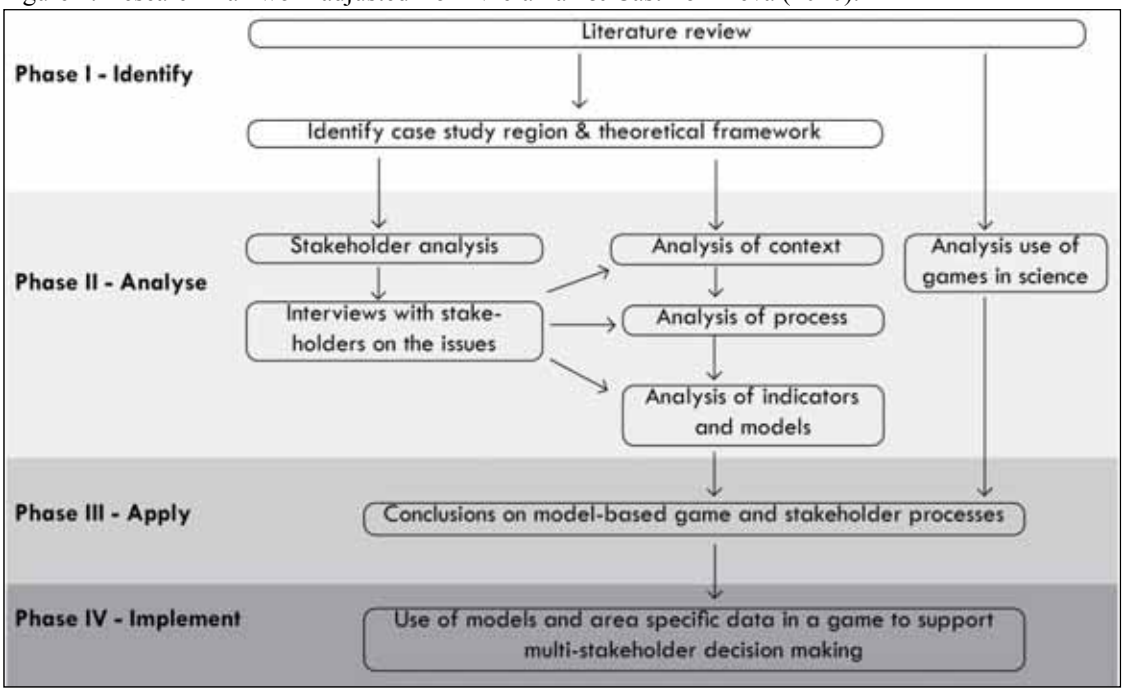
Research framework

Figure 1 shows four phases required to develop a game to facilitate multi-stakeholder decision-making. This research focused upon the first three phases. In phase I, a literature review was carried out to identify the case study region and to develop an analytical framework using the framework of Burgess & Chilvers (2006). The framework distinguishes five elements: the context, decision situation, engagement process, and the outputs and outcomes. The context includes

the institutional, political, cultural and environmental characteristics of the situation. The context influences the decision situation; the purpose, objectives and inputs of the process. The interaction between actors (who), the method (how) and the resources (time, money and expertise) define the engagement process. The results of the engagement process lead into outputs (plans, indicators, and instruments) and outcomes (material changes and learning outcomes) (Burgess & Chilvers, 2006). In this study, the framework of Burgess & Chilvers (2006) provided a structure for the analysis of the context, process, and issues involved in the decision-making on livestock production.

To gain insight in the issues involved in decision making on livestock production a case study, the Peelhorst region in the Netherlands, was selected. In the Peelhorst region, the municipality of Gemert-Bakel formed a focus area. The case study was selected on the basis of the high density of livestock in the region and the willingness of the local and regional government to cooperate. In addition, the literature review gave insight in the application of games in multi-stakeholder processes in agricultural, and land use sciences.

Figure 1: Research framwork adjusted from Viera Pak & Castillo Brieva (2010).



In phase II, a stakeholder analysis was carried out and interviews with stakeholders were organized. A stakeholder analysis matrix resulted in a list of relevant stakeholder organizations to interview in order to gain insight in the issues at stake (Grimble & Wellard, 1997). The stakeholder analysis included organizations currently involved in the Peelhorst Network (Appendix 1). The key stakeholders included two agricultural organizations of which one, the most actively engaged in the process (ZLTO), was selected for interviews. The municipality of Gemert-Bakel can be divided in an administrative part (policy makers) and a political part (political parties in the municipal council); interviews with both parts were carried out, and with two political parties. This resulted in a total of ten interviews. The interviews took on average one hour and were recorded and transcribed.

The interviews resulted in a list of issues that play an important role in the decision-making on livestock production in the Peelhorst area. Literature was studied to find (quantifiable) indicators to integrate the issues in a model. Information on available models was collected through literature study. The results of phase II were used to draw conclusions on the possibilities to integrate models into a game to support decision-making in a multi-stakeholder process (phase III). To

ensure the viability of the research, different sources of data (interviews, policy documents, publications and scientific literature) have been used in order to strengthen the evidence (Yin, 2003). The development and implementation of a game (phase IV) can be carried out in a follow-up project.

Results

Analysis of the context

The Peelhorst area is a region located in the Dutch provinces of Noord-Brabant and Limburg. The high livestock density and its impact on the environment, public health and infrastructure results in pressure on the quality of life in the area (Provincie Noord-Brabant, 2011). The outbreak of diseases like Classical Swine Fever (1997), Foot and Mouth Disease (2001), Avian Influenza (2003) and Q fever (2007-2010) especially increased societal concerns about the impact of livestock production on public health (Smit et al., 2012). In 2009, a citizens' initiative 'Megastallen-Nee' was supported by 33.000 citizens of the province of Noord-Brabant, and expressed concerns regarding large-scale farms. A network (Peelhorst network) was set up by the province of Noord-Brabant to work on a more sustainable agriculture through facilitating dialogue and sharing expertise and ideas for the future of the Peelhorst (Netwerk de Peelhorst, 2013).

The municipality of Gemert-Bakel, located in the east of the province, is one of the municipalities where the impact of intensive livestock production is a topic of fierce debate. Although about 10%, of the employment in the municipality of Gemert-Bakel is connected to agricultural production; societal concerns regarding intensive livestock play an important role in the political debate in the municipality (Provincie Noord-Brabant, 2013; 2013*b*)

Analysis of the process

Interviews with stakeholders in the Peelhorst region resulted in insights in the engagement process: the interaction of stakeholders, methods and resources. A wide range of stakeholders is involved in the discussions on the future of livestock production in the Peelhorst region (Appendix 1). Key stakeholders in the discussion are governments, agriculture organizations, the environmental federation, tourism platform, and a local citizen group.

The interviewees indicated that to represent your stake and address the challenges in the area, joining networks and meetings is important. Stakeholders organize meetings to interact with their colleagues and provide information through newsletters and websites in order to develop their opinion and come up with suggestions. Also petitions, demonstrations and even excluding oneself from the dialogue are ways to raise awareness for local challenges and concerns.

Knowledge plays an important role in the discussion in the Peelhorst. Within the interviewed organizations and networks, experts are involved to gather up-to-date information on different issues connected to (the impact of) livestock production. In the area several networks are active to exchange knowledge and experiences, such as the Peelhorst Network but also more specifically the Brabants Zoonoses Network.

The stakeholders were asked to reflect on the role of the participatory process (dialogue) to find solutions for the livestock production related challenges in the region. Communication on the future of livestock production through organizing dialogue is considered as a good initiative. Stakeholders underline the need for a joint approach as the challenges in the area are part of a complex system and cannot be solved by one stakeholder alone. However, interviewees indicated that they haven't seen a lot of results yet, which results in skepticism about the outcomes of the dialogue. This skepticism results from a high level of distrust among citizens, farmers and gov-

ernments. Nonetheless, to make a change, trust between farmers, citizens and politicians is needed. However, in order to develop trust, statements or actions (i.e. first results) are needed; *'You end up in a chicken or the egg dilemma.'*

Analysis of the issues, indicators and models

Stakeholders were asked to mention the key issues related to the discussion on livestock production in the Peelhorst area. This resulted in a wide range of issues, on different levels of abstraction and related to different complex systems. To provide a structure in the issues, a division into three different parts was made: the livestock sector, governance, and stakeholder interaction (Figure 2). Issues connected to governance and stakeholder interaction can be defined as social processes, and cannot be quantified or modeled. Therefore, we make a distinction between issues and social processes.

Figure 2: Key Issues in the discussion on the future of livestock production.

Part	Theme	Issue
Livestock sector	**Sustainability**	Farm profitability External environmental impact Social acceptation
	Public health	Risk for mutation of viruses Particulates and endotoxines Noise Odor Use of antibiotics and antimicrobial resistance Communication on health risks
	Landscape quality	Landscape quality Visual impact of stables Spatial organization of the landscape Fitting-in of stables Scale of stables Distance to roads and houses Planting around stables
	Manure surplus	Manure processing Over fertilization
	Cycles	Regional production systems
Governance	**Decision making**	Willingness to make decisions Willingness to address challenges Limited proof for public health risks Conflicting stakes and policies Limited financial capacity
	Governance	From steering to facilitating and 'self steering' Involving the public
Stakeholders interaction	**Acknowledgement**	Know and acknowledge each other Talk with each other, not about each other Being taken seriously Recognition
	Trust	Trust
	Shared understanding	Different interpretations of terms
	Stakes	Pressure from members on spokesperson of organisations Difficulty to think beyond your own stake
	Awareness	Awareness of cultural, social and spatial characteristics Understanding of processes Caring for the area Image of the area Acknowledgement of producers

Livestock sector

Many of the issues mentioned by stakeholders refer to the livestock systems as the context of the challenges in the area. Appendix 2 provides an overview of issues connected to the livestock sector. Issues such as farm profitability, external environmental impact, particulates, endotoxines, and manure can be quantified and modeled. However, for issues such as public health and landscape quality defining a single indicator is troublesome as scientific research is ongoing and in some cases provides ambiguous results e.g. on the impact of odor pollution on neighboring residents. As a result, for half of the issues clear indicators and models were found, whereas for the other half no clear indicator could be defined and additional research is required.

Governance

Interviewees mentioned several issues connected to decision-making and governance. Decision-making is a social process that is strongly dependent on the willingness to reach consensus. Decision-making is often supported by multi-criteria analysis, scenarios or models (Vayssieres et al., 2011; Klerkx et al., 2012). The issues governance and decision-making cannot be quantified or modeled. Nonetheless, surveys and interviews can help to gain insight in decision-making and governance approaches.

Stakeholder interaction

The third complexity in the discussion in the Peelhorst region has to do with stakeholder interaction and refers to acknowledgement, trust, a shared understanding, stakes and awareness. Insight in the level of acknowledgement, trust etc. can be obtained through in-depth interviews with stakeholders (Saarikoski, 2000; Blatner et al., 2001). The issues are of high importance in collaborative processes and can be addressed through workshops or games. Games are increasingly considered as a tool to raise awareness, understanding and trust amongst stakeholders (Vieira Pak & Castillo Brieva, 2010; Gourmelon et al., 2013).

The use of games

Game theory focuses upon interdependent decision-making among stakeholders with conflicting preferences regarding the outcome of decisions. Playing a game is an interactive way of learning in which players develop awareness, expertise, broaden their scope and can help to discuss complex systems (Klabbers, 2009). Several land use and agricultural studies have used games to gain a better understanding of decision-making in socio-ecologic systems (SES) (Washington-Ottombre et al., 2010; Martin et al., 2011; Gourmelon et al., 2013; Castella et al., 2005; Vieira Pak & Castillo Brieva, 2010). To show the diversity of applications of methods and games several studies are briefly described:

Board game

Martin et al. (2011) developed a board game *'forage rummy'* to engage farmers and extension services in livestock system design and evaluation. To support the process and define feeding requirements a computerized support systems was available for the players. The study stimulated discussions, reflective and interactive analysis, and learning about farming systems, management and the scope for their adaptation (Martin et al., 2011).

Role Playing Game (RPG)

Washington-Ottombre et al. (2010) uses multiple methods to qualify and quantify drivers of land-use decisions: RPG, GIS (Geographical Information System), LTM (land transformation model), and MCE (multi-criteria evaluation). The RPG was used to analyze land use drivers and decision-making processes. GIS was used to import maps developed by the participants. The LTM was used to measure the relative spatial importance of the land use drivers in each map produced by participants. Finally, the MCE was used to translate the discussion into quantitative variables. Integrating RPG with other methods in quantitative studies is considered useful to analyze complex land-use dynamics.

Participatory modeling

Vayssieres et al. (2011) developed a whole-farm model called GAMEDE, to evaluate the sustainability of dairy enterprises (Vayssieres et al., 2009). The model provided input for discussions with farmers about the different farm options. The integrated participatory modeling of actual

farms method supports interactive policy making. Qualitative data provided by the involvement of stakeholders was combined with quantitative data from farm surveys and simulations.

Discussion

Issues in decision-making on the future of livestock production

Interviews with stakeholders in the area resulted in a wide range of issues related to livestock production that are considered important in the decision process in the Peelhorst. Three groups of issues could be divided into issues connected to the livestock sector, governance, and stakeholder interaction. Studies on the sustainability of livestock production commonly focus on environmental, economic and social indicators. This study illustrates the importance of governance issues and stakeholder participation. These findings are in line with the recent published SAFA (Sustainability Assessment of Food and Agriculture Systems) guidelines of the FAO that included governance as a fourth domain of sustainability (FAO, 2013).

This study highlights the importance of public health in the discussion on the future of livestock production. The issue of public health is not regularly addressed in livestock studies or it is limited to issues like workers' health, food safety or antibiotic usage (Van Calker et al., 2008; Dolman et al., 2012). The ambiguousness of the impact of livestock production on public health and a lack of objectively quantifiable indicators could be a reason for the absence of public health in sustainability analysis studies.

Indicators and models to quantify the issues

To study the opportunities to develop a game to facilitate multi-stakeholder decision-making both livestock issues as well as social processes (i.e. governance and stakeholder interaction) need to be addressed. About half of the livestock issues can already be quantified and modeled, whereas for the other part multiple indicators, risk maps or expert opinions could be used to gain insight in the impact of these issues on the region. To address the social processes more qualitative approaches are needed using interviews, workshops and games.

The use of games to support decision-making

Games are commonly used to discuss complex issues in a participatory setting; it can encourage discussion, reflection and raise awareness and hereby support the decision-making process. Studies on the field of land use decision-making often integrate quantitative and qualitative approaches as a high level of uncertainty and lack of data is often involved (Washington-Ottombre et al., 2010). The use of games presents an interesting opportunity to combine the different issues of this research: (1) issues with a clear indicator and available models, (2) issues with uncertainty and multiple indicators or risk maps and (3) social processes.

Conclusions

Stakeholders involved in the discussion on livestock production in the Peelhorst are concerned about the impact of livestock production on diverse sustainability issues (e.g. environmental impact, public health and landscape quality), and societal issues related to governance, and stakeholder interaction. For half of the issues clear indicators or models were found, for the other issues no clear indicator could be defined and additional research is needed. The social processes mentioned by stakeholders, like trust and awareness, could be studied by interviews or proactively addressed through games.

An integrative methodology is needed to cover both sustainability issues and social processes and discuss the complexity of livestock production in a participatory setting. Future studies should aim to integrate models and develop risk maps to support the integration of complex issues in

games. In addition, a prioritization of issues by giving weight could help to select a limited number of issues to start with, and to improve the overview and depth.

Past experiences highlight the useful application of games in stimulating discussions on complex processes like the one presented in this paper. A game could help to develop a shared understanding and raise awareness among stakeholders; it can provide input for policy development and design of livestock systems. Hereby, games can possibly help to address the divers challenges that the Peelhorst is currently facing, and facilitate the multi-stakeholder decision-making process.

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References

Abatih, E.N., Alban, L., Ersbøll, A.K., Wong, D.M.L.F. (2009). Impact of antimicrobial usage on the transmission dynamics of antimicrobial resistant bacteria among pigs. Journal of Theoretical Biology 256: 561–573.

Acosta-Alba, I., Lopez-Ridaura, S., Van der Werf, H.M.G., Leterme, P., Corson, M.S. (2012). Exploring sustainable farming scenarios at a regional scale: an application to dairy farms in Brittany. Journal of Cleaner Production 28: 160-167.

Alders, H. (2011). Van mega naar beter. Rapportage van de maatschappelijke dialoog over schaalgrootte en toekomst van de veehouderij, Ministerie van Economische Zaken, Landbouw en Innovatie, Den Haag.
Available online:

http://www.dialoogmegastallen.nl/art/uploads/files/110922%20Rapport%20Alders%20lowres%20def.pdf

Bairy, J., Parnell Jr., C.B., McGee, R.A., Wang-Li, L. (2012). Evaluation and modeling of PM10 emissions from laying hen operations (Conference Paper). American Society of Agricultural and Biological Engineers Annual International Meeting 2012., Dallas (TX).

Blanes-Vidal, V., Hansen, M.N., Adamsen, A.P.S., Feilberg, A., Petersen, S.O., Jensen, B.B. (2009). Characterization of odor released during handling of swine slurry: Part I. Relationship between odorants and perceived odor concentrations. Atmospheric Environment 43 (18): 2997-3005.

Blatner, K.A., Carroll, M.S., Daniels, S.E., Walker, G.B. (2001). Evaluating the application of collaborative learning to the Wenatchee fire recovery planning effort. EIA procedure. Environmental Impact Assessment Review 21: 241-270.

Boogaard, B.K., Boekhorst, L.J.S., Oosting, S.J., Sørensen, J.T.S. (2011). Socio-cultural sustainability of pig production: Citizen perceptions in the Netherlands and Denmark. Livestock Science 140: 189–200.

Bos, A.P., Groot Koerkamp, P.W.G., Gosselink, J.M.J., Bokma, S. (2009). Reflexive interactive design and its application in a project on sustainable dairy husbandry systems. Outlook on Agriculture 38 (2): 1-9.

Burgess, J., Chilvers, J. (2006). Upping the ante: a conceptual framework for designing and evaluating participatory technology assessments. Science and Public Policy 33 (10): 713-728

Castella, J.C., Tran Ngoc Trung, Boissau, S. (2005). Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system. Ecology and Society, 10 (1): 27

Castellini, C., Boggia, A., Cortina, C., Dal Bosco, A., Paolotti, L., Novelli, E., Mugnai, C. (2012). A multicriteria approach for measuring the sustainability of different poultry production systems. Journal of Cleaner Production 37: 192-201

De Boer, I.J.M., Cederberg, C., Eadyy, S., Gollnow, S., Kristensen, T., Macleod, M., Meul, M., Nemecek, T., Phong, L.T., Thoma, G., van der Werf, H.M.G., Williams, A.G., Zonderland-Thomassen, M.A. (2011). Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. Current Opinion in Environmental Sustainability 3: 423-431

De Vries, M., de Boer, I.J.M. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock Science 128: 1-11

De Vries, W., Kros, H., Velthof, G., Romkens, P., Gies, E., Voogd, J.C. (2004). A decision support system for the integrated evaluation of agricultural management on environmental quality. Proceedings of the 13th Clean Air and Environmental Protection, London, United Kingdom

Dolman, M.A., Vrolijk, H.C.J., de Boer, I.J.M. (2012). Exploring variation in economic, environmental and societal performance among Dutch fattening pig farms. Livestock Science 149: 143-154

FAO (2013). SAFA Guidelines. Sustainability Assessment of Food and Agricultural Systems. Version 3.0. Food and Agricultural Organization of the United Nations, Rome. Available online: http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/SAFA_Guidelines_Final_122013.pdf

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G. (2013). Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome. Available online: http://www.fao.org/docrep/018/i3437e/i3437e.pdf

Gourmelon, F., Chlous-Ducharme, F., Kerbiriou, C., Rouan, M., Bioret, F. (2013). Role-playing game developed from a modelling process: A relevant participatory tool for sustainable development? A co-construction experiment in an insular biosphere reserve. Land Use Policy 32: 96-107

Gouttenoire, L., Cournut, S., Ingrand, S. (2011). Modelling as a tool to redesign livestock farming systems: a literature review. Animal 5: 1957-1971

Grimble, R., Wellard, K. (1997). Stakeholder methodologies in Natural Resource Management: A review of concepts, contexts, experiences and opportunities. Agricultural Systems 55: 173-193

Harvey, N., Reeves, A., Schoenbaum, M.A., Zagmutt-Vergara, F.J., Dubé, C., Hill, A.E., Corso, B.A., McNab, W.B., Cartwright, C.I., Salman, M.D. (2007). The North American Animal Disease Spread Model: A simulation model to assist decision making in evaluating animal disease incursions. Preventive Veterinary Medicine 82 (3-4): 176-197

Klabbers, J.H.G. (2009). The Magic Circle: Principles of Gaming & Simulation. Third and Revised Edition, Rotterdam, Sense Publishers

Klerkx, L., van Bommel, S., Bos, B., Holster, H., Zwartkruis, J.V., Aarts, N. (2012). Design process puts as boundary objects in agricultural innovation projects: Functions and limitations. Agricultural Systems 113: 39-49

Kuiper, J. (2000). A checklist approach to evaluate the contribution of organic farms to landscape quality. Agriculture, Ecosystems and Environment 77 (1-2): 143-156

Le Gal, P.Y., Dugue, P., Faure, G., Novak, S. (2011). How does research address the design of innovative agricultural production systems at farm level? A review. Agricultural Systems 104: 714-728

Louhichi, K., Kanellopoulos, A., Janssen, S., Flichman, G., Blanco, M., Hengsdijk, H., Heckelei, T., Berentsen, P., Oude Lansink, A., Van Ittersum, M. (2010). FSSIM, a bio-economic farm model for simulating the response of EU farming systems to agricultural and environmental policies. Agricultural Systems 103: 585-597

Martin, G., Felten, B., Duru, M. (2011). Forage rummy: A game to support the participatory design of adapted livestock systems. Environmental Modelling & Software 26: 1442-1453

May, S., Romberger, D.J., Poole, J.A. (2012). Respiratory Health Effects of Large Animal Farming Environments. Journal of Toxicology and Environmental Health, Part B: Critical Reviews 15 (8): 524-541

Modin-Edman, A.K., Öborn, I., Sverdrup, H. (2007). FARMFLOW – A dynamic model for phosphorus mass flow, simulating conventional and organic management of a Swedish dairy farm. Agricultural Systems 94: 431-444

Mollenhorst, H., De Boer, I.J.M. (2004). Identifying sustainability issues using participatory SWOT analysis: a case study of egg production in the Netherlands. Outlook Agriculture 33: 267–276

Netwerk de Peelhorst (2013). Netwerk de Peelhorst. [online] Available at: www.netwerkdepeelhorst.nl – De Peelhorst – Netwerk de Peelhorst. Accessed on: 18-04-2013

O'Shaughnessy, P.T., Altmaier, R. (2011). Use of AERMOD to determine a hydrogen sulfide emission factor for swine operations by inverse modeling. Atmospheric Environment 45: 4617-4625

Provincie Noord-Brabant (2011). Structuurvisie Ruimtelijke Ordening Provincie Noord-Brabant, Den Bosch. Available online: https://www.brabant.nl/dossiers/dossiers-op-thema/ruimtelijke-ordening/-/media/83CCCCCE87C74CC9B882B36188158E5F.pdf

Provincie Noord-Brabant (2013). De Peelhorst. [online] Available online: www.brabant.nl – Beleidsdossiers – Ruimtelijke Ordening – Gebiedsontwikkelingen – De Peelhorst. Accessed on: 12-04-2013

Provincie Noord Brabant (2013b). Provincie Noord-Brabant, feiten en cijfers, vestiging en banen 2010. [Online] Available online: http://www.brabant.databank.nl/quickstep/QsBasic.aspx?cat_open_code=c59&# Accessed on: 23-03-2013

Reed, S.E., Boggs, J.L., Mann, J.P. (2012). A GIS tool for modeling anthropogenic noise propagation in natural ecosystems. Environmental Modelling & Software 37: 1-5

Saarikoski, H. (2000). Environmental impact assessment (EIA) as collaborative learning process. Environmental Impact Assessment Review 20: 681–700

Sarr, J.H., Goïta, K., Desmarais, C. (2010). Analysis of air pollution from swine production by using air dispersion model and gis in quebec. Journal of Environmental Quality 39 (6): 1975-1983

Schinasi, L., Horton, R.A., Guidry, V.T., Wing, S., Marshall, S.W., Morland, K.B. (2011). Air pollution, lung function and physical symptoms in communities near concentrated swine feeding operations. Epidemiology 22 (2): 208-215

Sharp, J.S., Tucker, M. (2005). Awareness and Concern about Large-Scale Livestock and Poultry: Results from a Statewide Survey of Ohioans. Rural Sociology 70 (2): 208-228

Smit, L.A.M., van der Sman-de Beer, F., Opstal-van Winden, A.W.J., Hooiveld, M., Beekhuizen, J., Wouters, I.M., Yzermans, J., Heederik, D. (2012). Q Fever and Pneumonia in an Area with a High Livestock Density: A Large Population-Based Study. PLoS ONE 7 (6): e38843

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C. (2006). Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf

Termeer, C.J.A.M., Stuiver, M., Gerritsen, A., Huntjens, P. (2013). Integrating Self-Governance in Heavily Regulated Policy Fields: Insights from a Dutch Farmers' Cooperative. Journal of Environmental Policy and Planning 15 (2): 285-302

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J., Huirne, R.B.M. (2008). Maximising sustainability of Dutch dairy farming systems for different stakeholders: A modelling approach. Ecological Economics 65: 407-419

Van Calker, K.J., Berentsen, P.B.M., de Boer, I.J.M., Giesen, G.W.J., Huirne, R.B.M. (2007). Modelling worker physical health and societal sustainability at farm level: An application to conventional and organic dairy farming. Agricultural Systems 94 (2): 205-219

Vayssières, J., Vigne, M., Alary, V., Lecomte, P. (2011). Integrated participatory modelling of actual farms to support policy making on sustainable intensification. Agricultural Systems 104 (2): 146-161

Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z., Oenema, O. (2009). Integrated assessment of nitrogen losses from agriculture in EU-27 using MITERRA-EUROPE. Journal of Environmental Quality 38 (2): 402-417

Vieira Pak, M., Castillo Brieva, D. (2010). Designing and implementing a Role-Playing Game: A tool to explain factors, decision-making and landscape transformation. Environmental Modelling & Software 25 (11): 1322-1333

Wallensten, A., Moore, P., Webster, H., Johnson, C., van der Burgt, G., Pritchard, G., Ellis-Iversen, J., Oliver, I. (2010). Q fever outbreak in Cheltenham, United Kingdom, in 2007 and the use of dispersion modelling to investigate the possibility of airborne spread . Euro Surveillance 15 (12):19521. Available online: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=19521

Washington-Ottombre, C., Pijanowski, B., Campbell, D., Olson, J., Maitima, J., Musili, A., Kibaki, T., Kaburu, H., Hayombe, P., Owango, E., Irigia, B., Gichere, S., Mwangi, A. (2010). Using a role-playing game to inform the development of land-use models for the study of a complex socio-ecological system. Agricultural Systems 103 (3): 117-126

Wiskerke, J.S.C. (2009). On Places Lost and Places Regained: Reflections on the Alternative Food Geography and Sustainable Regional Development, International Planning Studies 14 (4): 369-387

Yin, R.K. (2003). Case Study Research: Design and Methods. Third Edition. Thousand Oaks (CA), SAGE Publications

Appendix

Appendix 1. Stakeholder analysis

Organizations	Stake	Affected by situation?	Influence on situation?	Key stakeholder?	Interview
Mental healthcare East Brabant	Public health	Yes	No	No	0
Provincial Council for Public Health	Public health	Yes	No	No	0
Veterinary service Peelhorst	Animal health	Yes	No	No	0
Foundation Men, Animal and Peel	Livability	Yes	Yes	Yes	1
Village consultation Elsendorp	Livability	Yes	No	No	0
Livable Elsendorp	Livability	Yes	No	No	0
Dutch Union for pig farmers (NVV)	Farming	Yes	Yes	Yes	0
Dutch Federation for Agriculture and Horticulture – South (ZLTO)	Farming	Yes	Yes	Yes	1
Environmental Service Region Eindhoven (SRE Milieudienst)	Environment	No	No	No	0
Regional Environmental Service (RMB)	Supporting governments	No	No	No	0
Province of Noord-Brabant	Divers	Yes	Yes	Yes	1
Peelhorst Network	Facilitate dialogue	Yes	Yes	Yes	1
Municipality of Gemert-Bakel - Policy makers - Political parties	Divers	Yes	Yes	Yes	3
Ministry of Economic Affairs	Divers	Yes	Yes	Yes	1
University of Applied Sciences (HAS Den Bosch)	Education	No	No	No	0
Environmental Federation Brabant (BMF)	Environment	Yes	Yes	Yes	1
Tourism Platform Brabant (TOP)	Tourism	Yes	Yes	Yes	1

Issue	Indicator / description	Approach / model
Sustainability		
Farm profitability	Net Farm Income (NFI) (Dolman et al., 2012)	FSSIM: bio-economic farm model to assess policy impact on regional level (Louhichi et al., 2010)
External environmental impact	External environmental impact:	IMITATOR: assessment of environmental impact on regional scale. Life Cycle Assessment (LCA) to assess environmental impact along the chain (Acosta-Alba et al., 2012; De Vries & De Boer, 2010).
• Climate change	• Greenhouse gas emissions in CO_2 equivalents (Dolman et al., 2012)	
• Eutrophication	• Eutrophication in NO^-_3 equivalents (Dolman et al., 2012)	
• Acidification	• Acidification in SO_2 equivalents (Dolman et al., 2012)	
• Land use	• On-farm and off-farm land use in hectares (Dolman et al., 2012)	
• Water quantity	• Water usage in m^3 (Van Calker et al., 2008)	
• Water quality	• Water quality expressed in nitrate concentration NO^-_3 mg/l (Van Calker et al., 2008)	
• Energy use	• Non-renewable energy use in GJ (Acosta-Alba et al., 2012)	
• Phosphorus	• Phosphorus application in P equivalents (Modin-Edman et al., 2012)	
• Land degradation	• No reliable indicator (Dolman et al., 2012)	
• Biodiversity	• No reliable indicator (Dolman et al., 2012)	
Social acceptation	Acceptation of livestock production based on social issues like animal welfare, food safety, landscape quality, employment and labor safety (Mollenhorst & De Boer, 2004; Castellini et al., 2012).	Questionnaires to analyze people's awareness, concerns and social demographical characteristics (Boogaard et al., 2011; Sharp & Tucker, 2005).
Public health	Results on the impact of livestock production on public health are ambiguous. As public health covers a wide range issues no single indicator can be defined.	
Risk for mutation of viruses		
• Avian influenza	• Infection with influenza A-virus originating from birds.	NAADSM: simulates spread of contagious diseases in animals (Harvey et al., 2007)
• Q fever	• Q fever infection in goats, density of goats and proximity of populated areas (Smit et al., 2012).	NAME: atmospheric dispersion model to study spread of Q fever (Wallensten et al., 2010).
Particulates and endotoxines	Particulate Matter (PM10 and PM2.5) and the concentration of endotoxines are often related to inflammatory and respiratory health problems (May et al., 2012).	AERMOD: air dispersion model to predict dispersion of PM10 in poultry (Bairy et al., 2012)
Noise	Noise emission in Lden (day-evening-night equivalent) expressed in decibels (dB)	No studies were found that address the noise of livestock production. SPreAD-GIS could be used as it studies noise propagation in natural ecosystems (Reed et al., 2012).
Odor	Odor pollution results from a mixture of gases, their concentration and interactions, which makes it difficult to measure. In addition, perception of odor varies among persons (Blanes-Vidal et al., 2009). NH_3 and H_2S are used as indicators for odor annoyance (Blanes-Vidal et al., 2009; Schinasi et al., 2011).	AERMOD: to predict H_2S and NH_3 emissions (O'Shaughnessy & Altmeier, 2011; Sarr et al., 2010).
Use of antibiotics and antimicrobial resistance	Quantity of antimicrobial usage (daily doses per animal per year) (Abatih et al., 2009).	
• MRSA	• Livestock Associated MRSA can be transmitted to humans through contact with livestock and farm workers.	No models concerning the spread of LA-MRSA were found.
• ESBL	• A wide variety of risk factors for the introduction and spread of Extended Spectrum Beta Lactamase (ESBL) can be identified.	No models concerning the spread of ESBL were found.
Communication on health risks	Several studies reported concerns of local residents living near livestock farms. Risk communication provides transparency on potential risks and can reduce concerns.	The issue can be studied through questionnaires on occurence of risk communication, preventive measures and research.
Landscape quality	Landscapes are social-ecological systems that result from the interaction of biophysical and social processes. These complex interactions are often studied through extensive lists of indicators (Kuiper, 2000; Van Calker et al., 2007).	No models to assess the landscape quality were found.
Manure surplus	Manure balance can be made using regional animal numbers, excretion/emission factor and manure/fertilizer distribution (De Vries et al., 2004).	IMITATOR: calculates excretion, deposition and leaching of N and P (De Vries et al., 2004). MITERRA-Europe assesses N and P levels on a regional scale (Velthof et al., 2009).
Cycles	To assess the opportunities for more regional livestock systems, an overview of social, economic and environmental impact is needed. No single indicator can be identified.	QRS: started to analyse different scenarios for livestock production in the Netherlands using a Quick Response Spreadsheet (Van Grinsven et al., 2011).