System Dynamics Model-Based Policy Evaluation Tool: the Case of Organic Farming Policy in the EU

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Paper prepared for presentation at the 148[th] seminar of the EAAE, ''Does Europe need a Food Policy?", Brussels, Belgium, date as in:

30 November – 1 December, 2015

Introduction

Organic farming is usually understood as a holistic approach to agriculture and food production with objectives built around four principles formulated by the International Federation of Organic Agriculture Movements (IFOAM): *health*, *ecology*, *fairness* and *care* (Darnhofer, 2014). *Health* means that organic farming is intended to provide high quality food without using mineral fertilizers, synthetic pesticides, animal drugs and food additives that may have adverse health effects. The *ecology* principle requires organic farming to fit into nature's cycles and balances without exploiting it, by using local resources, recycling, reuse and efficient management of minerals and energy. *Fairness* relates organic farming to a system that provides a good quality of life, contributes to food sovereignty, reduces poverty, enhances animal well-being and takes future generations into account. *Care* is a principle that argues for applying precaution and responsibility before adopting new technologies in organic farming practices (Tuomisto et al., 2012). In line with these principles organic agriculture is often reported to be able to produce wholesome food in an environmentally-friendly way (Giller et al., 2003; Lotter et al., 2003; Gracia and de Magistris, 2008; Aldanondo-Ochoa and Almansa-Sáez, 2009; Thierfelder and Wall, 2009) and with meeting high animal welfare standards (Wachter and Reganold, 2014). Organic farming is claimed to ensure viability of farm as a cornerstone of rural areas (Woodward et al., 1996; Names, 2009; Offerman et al., 2009; Ponti et al., 2012), create additional employment opportunities (Scialabba, 2013) and preserve rural communities (Mendoza, 2004; MacRae et al., 2007; Gruere et al., 2009; Prihtani et al., 2014). Therefore, organic farming is often positioned to be a prototype for sustainable agriculture and a promising alternative to conventional food production (Bellon & Penvern, 2014).

The concept of organic farming dates back to the publication of Steiner's (1924) *Spiritual Foundation for Renewal of Agriculture* and a small protest movement of farmers and consumers against the industrialization of agriculture in the 1920s. However, since 1980s in the EU and worldwide environmentalists, consumers, farmers and policymakers have recognized the aforesaid potentials of organic farming and started promoting its development in reaction to increasing concerns about negative environmental and other externalities caused by modern or 'conventional' agriculture (Tovey, 1997). Over the past decades the European Union (EU) has been an important pacesetter in the expansion of the organic farming sector (Darnhofer, 2014). At the end of 2013 in the EU a total area of 10.2 million ha (up from 5.7 million ha in 2002) was managed organically by more than 260,000 producers and retail sales totaled approximately 22.2 billion euros constituting 2% of the EU food and drink industry turn-over (a share that has doubled since 2004) (EC, 2014; Willer & Schaack, 2015).

The rapid growth of organic farming in the EU has been based on the special market arrangement accompanied by numerous legal, financial and communicative policy instruments to help farmers deliver the broader objectives and to compensate for the internalization of externalities (Stolze & Lampkin, 2009). According to policymakers and other key stakeholders, the unprecedented development of the organic food market is, however, far from ideal and smooth. One of the most important challenges currently facing this market is that the growth in supply lags behind and remains insufficient to meet the climbing consumer demand, despite the considerable political support (EC, 2014; David, 2012; Willer & Schaack, 2015). Looking at this challenge through the lenses of the commodity market (Sterman, 2000), model-based policy analysis (Walker et al., 2013) and food system (Ericksen, 2008, TRANSMANGO, 2015; Stave & Kopainsky, 2015) frameworks, the supply of organic food is influenced by numerous internal and external factors *inter alia* consumer behavior, availability of production inputs, installed human-made capital, condition of and access to natural capital, as well as institutional arrangements. The different factors are then linked through feedback mechanisms and interactively determine the investment decisions, profitability and the volume of organic food production. Due to the complexity arising from these interactions and associated uncertainties, the future development of the organic food market in the EU cannot be investigated easily. Consequently, it is not known whether and under what circumstances the overall objective of the EU political and legislative framework viz. the *sustainable development of organic production* (EC, 2014) can be achieved.

Striving for this overall objective, on the 24th of March 2014 the European Commission adopted a proposal for a new policy that aims at adjusting the political and legal framework to the current situation in the EU organic market, specifically by removing the obstacles to the development of organic food production in the EU; improving the legislation in order to guarantee fair competition for farmers and producers and to improve the functioning of the internal market; and maintaining or improving consumer confidence in organic products, so that the sector can further develop and respond to future challenges. The new EU political and legislative framework was developed based on insights gained from an extensive review process called Impact Assessment (IA), in which potential economic, social and environmental consequences of alternative scenarios for the evolution of the policy were evaluated. The IA relied solely on qualitative information provided by a wide range of stakeholders and literature because of data incompleteness on key variables relating to economics of organic farms, trade flows, prices, etc. (EC, 2014). Yet, the reliance on text, graphs and mental models as media for developing policies can be ineffective because of the limited human ability to reliably infer the behavior of higher-order dynamic systems such as organic farming (e.g. Sterman, 2000). Further, the review did not take a systems perspective to account for both dynamic effects and future uncertainties. Experience demonstrates, however, that policies crafted to operate within a certain range of conditions are often faced with unexpected challenges outside of that range. The result is that many policies have unintended consequences and do not achieve their objectives (Swanson et al., 2010).

In view of the whole narrative on the development of organic farming in the EU the following important research questions emerge:

- What are the main lines and future dynamics of the supply of and demand for organic food?
- Is the configuration of the organic food market sensitive to changes in factors inside and outside the market and policy range?
- What are the critical uncertainties in the organic food market?

- What are the potential leverage points for improving the performance of the organic food market?

- What future research priorities emerge from the analysis?

The central premise of this paper is that these research questions and shortcomings of the IA should be addressed by a research methodology that is able to capture the complex and dynamic nature of the organic food market in the EU along with uncertainties in modeling policy scenarios and evaluating their economic, social and environmental impacts (Bockermann et al., 2005; Elshorbagy et al., 2005). Acs et al. (2005) provide a comprehensive overview of modelling approaches used to study the development of organic farming and discuss their advantages and disadvantages. They classify research into two groups i.e., *empirical*, which searches for the factors influencing a certain dependent variable, and *normative*, which uses a given dataset to explore the effect of future changes. The applied methods range from econometric modeling (e.g., Piesse et al., 1996; Thirtle et al., 1996; Akinwumi et al., 2000) and mathematical programming (e.g., Acs et al., 2009) to other approaches such as scenario development (Zanoli et al.,2000; Zanoli et al., 2012), Bayesian network (Gambelli and Bruschi, 2010), decision trees (Darnhofer et al., 2005), or even agent-based models (Deffuant et al., 2002). From the abundance of existing studies, the majority approaches the growth of organic farming in terms of its effect rather than in terms of a dynamic process (Sylvander et al., 2006; Lamine & Ballon, 2009). Rozman et al. (2013) employ a highly aggregated system dynamics model based on the commonly known market absorption structure (Hines, 2005) for studying organic farming development to support government decision making in Slovenia. They conclude that this methodology has substantial advantages over other approaches while evaluating policy scenarios with limited access to data.

With the latter in mind, in this paper we investigate the long-term dynamics of the organic wheat market in Germany as a case study. Throughout the investigation we analyze the impacts of the divergent EU policy scenarios under parametrical and structural uncertainty on the dynamics and performance of the system. The study focuses on the case study of German organic wheat market, because:

- Wheat in the EU is one of the most important food commodities and organic cereals (with circa 432000 ha in production) used for both staple and higher value foods (David et al., 2014; Würriehausen et al., 2015).

- Germany possesses, after the Unites States, the largest and most mature organic food market worldwide in terms of total sales and the largest national market within the EU (Sahota, 2012).

The approach taken in this study is different from those present in the existing literature, as we do not report new data, demonstrate the existence of new variables, or test the strength of specific linkages between two variables. We contribute to the literature by deriving new insights from established variables and relationships in IA taking an explicit systems perspective. We base the analysis on an purpose-designed system dynamics model and consider sensitivity of the system's behavior to uncertainty in the parameters as well as in the alternative structural assumptions. Such analytical tools developed to assist IA are still rare (Podhora et al., 2013), *ipso facto* we provide useful understandings into an emerging field of research. More specifically, following Stave and Kopainsky (2015), we develop a systemic representation of the growth of the organic wheat market in Germany using causal loop diagramming and systems dynamics modelling that take into account the policy options put forward by the European Commission in its IA as well as other external factors. Second, we analyze simulations produced by the system dynamics model to characterize the impacts of policies and associated uncertainties to identify troublesome and advantageous system behavior.

In the reminder of this paper, first we present an integrative framework that captures insights form the IA and relevant theories. Second, we develop and analyze a causal loop diagram and a formal system dynamics simulation model of organic wheat market using Sterman's (2000) commodity market structure as a backbone. Third, the results of the base run and policy scenario analyses with associated uncertainties are presented and discussed. Finally, the paper ends with conclusions encompassing implications f or future research and practice.

Integrative framework

The development of EU organic farming: market and policy perspectives

From a market perspective, organic farming developed initially as a means to an end and consumers provided organic farmers with compensation to account for the positive externalities they generated (e.g. environment, animal welfare). Nowadays, the market is often seen as an end in itself with most consumers willing to pay price premiums for health, safety and quality attributes of organic food rather than for more altruistic concerns such as the environment, animal welfare and social justice (Stolze and Lampkin, 2009).

From a policy perspective, in the 1970s, when there was no label, organic farming was completely different from the current highly regulated at EU level organic farming in the 21st Century. Policymakers from Denmark, Austria and Switzerland were forerunners in recognizing the potentials of organic farming in the late 1980s and supporting it through national initiatives. In a few additional EU member states organic farming received support also from programs under the framework of the EU Extensification Program (Commission Regulation (EEC) No. 4115/88) (Lampkin et al., 1999; Lockeretz, 2007). Ever since, organic farming development has become more and more an instrument of state agricultural policy. In 1991, in the context of EU farm policy reform, the European Council of Agricultural Ministers adopted Regulation (EEC) No 2092/91 on organic farming and the labelling of organic farm produce and foods, thereby defining organic farming legally (Michelsen, 2009). This regulation created a basis for organic farming to be included as an element of the agri-environmental and other measures of the rural development programs and entitled organic farmers to receive additional financial incentives (Michelsen, 2009, Stolze and Lampkin, 2009). Currently, support for organic farming encompasses areas such as research, extension and marketing initiatives (Acs et al., 2005).

EU organic farming policy instruments

Over the years, many policy instruments have been used for supporting organic farming. Following Michelsen (2002), they can be classified into three types: *legal* (i.e., regulation), *financial* (i.e., economic incentives and disincentives) and *communicative* (i.e., promotion and information). Legal instruments are grounded in the authority and power of the state. Financial instruments utilize the price mechanism relating to the market and operate through economic incentives whether positive (i.e., subsidies) or negative (i.e., taxes and duties). Communicative instruments regard the mutuality and social norms of the civil society and implicate various direct and indirect interaction between the regulator and the regulated citizens (Stolze and Lampkin, 2009).

In the EU all three types of instruments are used, but to a different extent in the particular Member States. Table 1 summarizes instruments that have been used to support the development of organic farming by 2006. More detailed overviews of the EU policy instruments is provided in special issues of *Food Policy* 34 (2009) 237–244 in general, and by Stolze and Lampkin (2009) in particular.

Table 1 Organic food and farming policy instruments used in Europe by 2006 (Harablova et al., 2005, Nieberg and Kuhnerrt, 2006; Tuson and Lampkin, 2007)

POLICY INSTRUMENT	SUPPLY SIDE	DEMAND SIDE
Legal instruments	• EU-wide regulations cover the organic farming supply chain – from production, to control, and labelling. EU legislation ensures that 'organic' means the same for consumers and producers all over the EU.	
Financial instruments	• Producer support by area payments: conversion and/or maintenance • Inspection cost support • Investment grant • Animal welfare improvement programme	• Support for marketing initiatives • Public procurement projects • Investment grants for processing and distribution • Support for marketing of quality agricultural products • Support for new sales structure • Feasibility studies • Market analyses and inventories • Investment grants for consumer cooperatives
Communicative instruments	• Advice and technical assistance • Vocational training and education programmes • Research & innovation • Investment grants for demonstration projects • Support for capacity building and institutional structures • Financial reporting	• Information and promotion campaign • Public education • EU/state logo • Research • Support for fairs, exhibitions and organic events • Research • Production and market statistics

Current EU organic farming policy

At present, all Member States must comply with EU legislative instruments specific for organic farming, namely:

- Council Regulation (EC) No. 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No. 2092/91 (new proposal is under revision since 2014)

- Commission Regulation (EC) No. 889/2008 of 5 September 2008 with detailed rules on production, labelling and control (new proposal is under revision since 2014)

- Commission Regulation (EC) No. 1235/2008 of 8 December 2008 with detailed rules concerning import of organic products from third countries.

Besides, there are several support instruments of the financial and communicative type which target the supply and/or demand side(s) on the organic food market. In most cases of these instruments, the extent to which they are used depends on the particular Member State.

On the supply side, from 2015 under the new Common Agriculture Policy (CAP) rules, all EU Member States must use 30 % of direct payments to finance farmers for sustainable agricultural practices ('greening'). Organic farmers automatically qualify for these direct payments. Moreover, under the rural development programmes (2014-2020) new financial support is available for active farmers for conversion to, and maintenance of, organic farming practices. Member States can also provide additional support to organic farmers and producers through a variety of flexible funding opportunities to promote, for example: cooperation in the food chain to boost innovation; development of quality schemes for agricultural products; creation of producer groups or organisations etc. Under the new CAP also co-financing to organic farming associations, farmers' unions, environmental organisations and other stakeholders is available to support them in explaining organic farming under the new CAP to the public, and others active in rural areas. And last but not least, in the context of research and innovation the EU provides support for groups of farmers, researchers, advisors, businesses, NGOs, etc. from rural areas to work together on innovative projects through the EIP AGRI. Funding is available through the EAFRD and Horizon 2020, the biggest ever EU Research Innovation programme (EC, 2015).

On the demand side, there are two principal support initiatives. First, the EU funds voluntary schemes (i.e., is the School Fruit and Vegetables Scheme (SFVS) and School Milk Scheme (SMS)) enable schools to source organic products and integrate organic-related topics. This funding possibility strengthens links between school children and organic farming and helps ensure the demand for organic products in the long-term. Second, there is EU funding for trade/inter-trade organizations to support raising awareness of EU organic production, controls and logo among consumers. All kinds of promotion activities in the internal market and in countries outside the EU are considered. Usually the EU funds up to 50 %, the applicant at least 20 %, and Member States co-finance the remainder (EC, 2015).

Finally, to help organic farmers, producers and retailers adjust to the proposed policy changes and meet future challenges, in 2014 the European Commission has also approved an Action Plan on the Future of Organic Production in Europe. The Action Plan foresees to better inform farmers on rural development and EU farm policy initiatives encouraging organic farming, to strengthen links between EU research and innovation projects and organic production and to encourage the use of organic food, e.g. in schools (EC, 2015).

Impact Assessment (IA) of EU organic farming policy

The new Action Plan on the Future of Organic Production in Europe as well as the proposal for the legislative basis of organic farming in the EU i.e., Council Regulation (EC) No. 834/2007 on organic production and labelling of organic products and its implementing Regulations, are results of extensive consultations with the interested parties within the frame of a review process called IA.

The European Commission's instrument of ex-ante policy IA was first established in 2002 and is carried out for all legislative and non-legislative initiatives likely to have significant direct impacts. IA is a component of the EC’s overall strategy on smart regulation. The IA process operates at an early stage of the policy cycle when proposals are being developed, with the objective to ensure that policy initiatives are evidence-based and contribute to an effective and efficient regulatory environment. IA also contributes to informed and transparent policy making and helps ensure that EU action is justified and proportionate. Further, IAs aim to support sustainable development by assessing the likely intended and unintended economic, social and environmental impacts of a range of policy options including the no policy option.

The IA of the EU organic farming policy, informed by experts, academics, sector stakeholders and competent authorities from each Member State, compared three alternative options:

- Improved status quo, based on improvements and better enforcement of the current legislation.

- Market-driven option, which aims at providing the conditions needed to respond dynamically to further market developments with more flexible rules. Long-standing exceptional rules would be integrated in the production rules.

- Principle-driven option aiming at re-focusing organic production on its principles, which would be better reflected in the production rules. Exceptional rules would be ended.

The three policy options have been assessed against their potential to achieve the CAP 2020 objectives, specific policy objectives and operational objectives for the review, and in terms of effectiveness and efficiency.

The final conclusions of the process were that the principle-driven option performs better according to all criteria evaluated, followed by the market-driven option and lastly the improved status quo (EC, 2014). In accordance with the preferred principle-driven option, the legislative instruments were revised and Council Regulation (EC) No. 834/2007 with the implementing Regulations are currently under political negotiations.

IA potential improvements based on conceptual frameworks

In the context of the IA of the EU organic farming policy and organic farming being a food system itself, the literature provides a number of conceptual frameworks that are a starting point for a model-based analysis of policy (e.g., Walker et al., 2013) and food system performance (Ericksen, 2008; TRANSMANGO, 2015, Stave and Kopainsky, 2015). Figure 1 and Figure 2 present two such conceptual models.

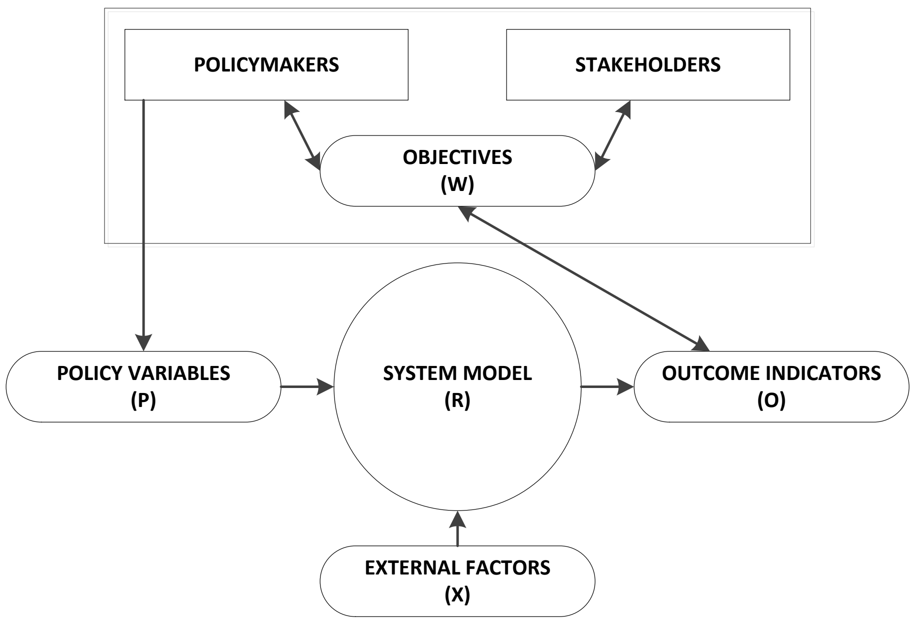

Figure 1 Model-based policy analysis framework (Walker et al., 2013)

Model-based policy analysis framework developed by Walker et al. (2013) describes five elements (Figure 1). There elements are: (1) value systems (W) of the stakeholders and policymakers which determine their objectives, (2) outcome indicators (O) that are determined based on the objectives of stakeholders and help assessing the impacts of policies, (3) policy variables (P) that are used to intervene the system and improve the outcomes, (4) external factors/uncertainties (X) that affect the system and (5) the system model (R) representing the real system within certain boundaries.

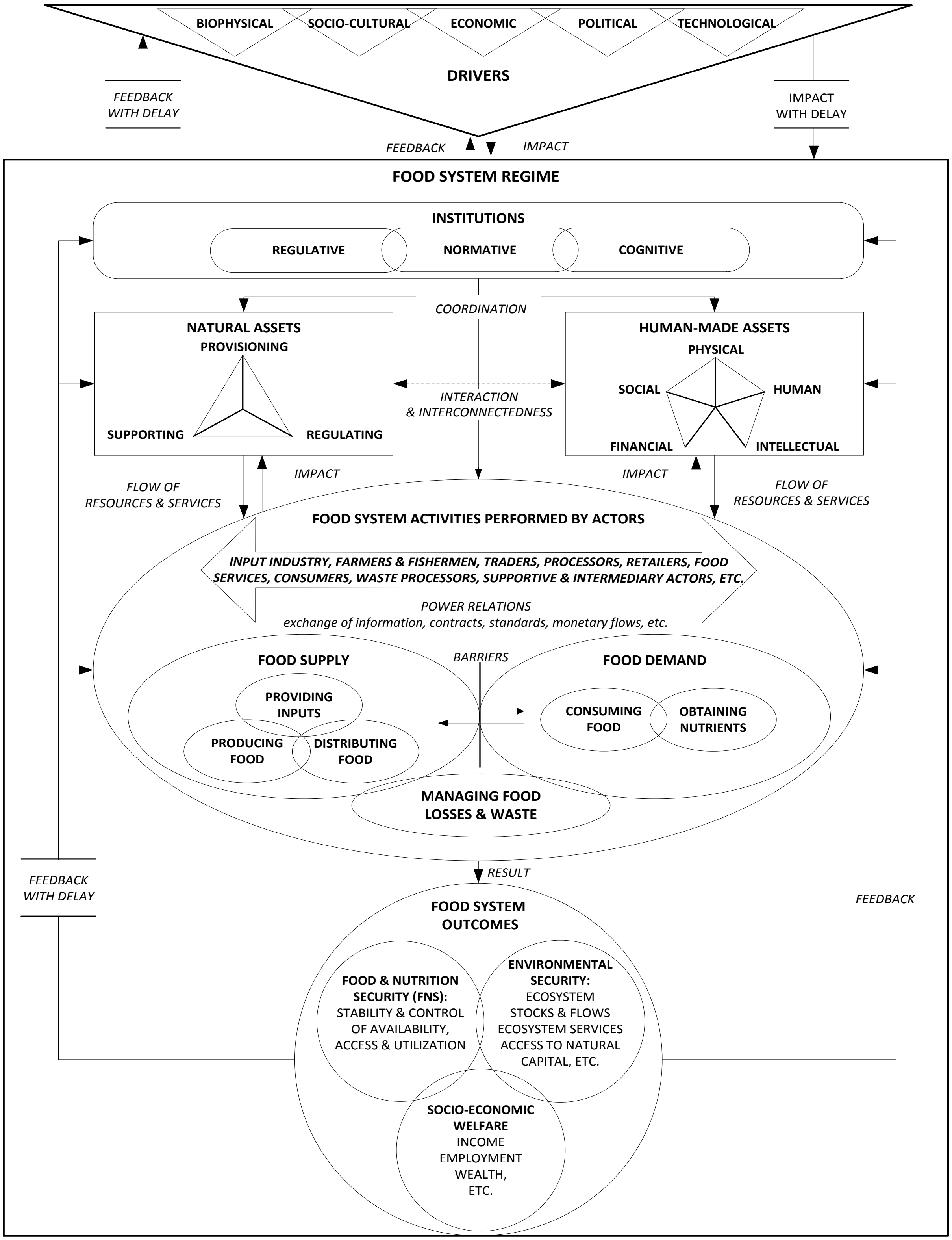

Figure 2 Food system analysis framework (TRANSMANGO, 2015)

Figure 2 presents a conceptualization of the food system that guides research conducted within the EU FP7 project TRANSMANGO. TRANSMANGO (2015) framework builds on Ericksen's (2008) influential approach to food system vulnerability assessment. Her broad definition of the food system includes complex interactions and feedbacks between socio-economic and bio-geophysical driving forces (factors), food system activities (e.g., agricultural production, food processing, distribution and consumption) and resulting from the activities' outcomes. In addition to this definition, the TRANSMANGO conceptual framework makes an analytical distinction of natural and human-made assets, on which the food system activities draw and opens up the black box of institutions by making the nature of institutional processes and their role in coordination of the dynamic interplay between food system activities, actors and assets an integral part of the food system analysis.

These high-level, aggregated conceptual models provide also useful insights into potential improvements of the European Commission's IA process in general, and IA on EU organic farming policy in particular. First, assessing impacts of divergent policy options on organic farming development requires a system's perspective and thus a more functional or operational representation of the mechanisms and feedbacks between variables of the organic food market. Second, the IA does not account for external factors that together with the system's parameters and structure create an environment of significant uncertainty under which decisions are made.

Stave and Kopainsky (2015) propose to use structural thinking tools of system dynamics to translate general influences, associations, and links in such kinds of conceptual models into causal relationships. Following them, in the next section we develop a systemic representation of the development of organic farming in the EU using a systems dynamics model based on variables and relationships established in the narrative of the European Commission's IA, considering explicitly the influence of uncertainties.

Methodology

To investigate the long-term future dynamics of the organic food market under uncertainty, the research methodology adopted in this study is system dynamics. The methodology originated in the 1960s with the work of Jay Forrester and his colleagues at the Massachusetts Institute of Technology. It is a computer-aided method used for studying and managing complex systems that change over time based on causal links and feedback loops (Forrester, 1961; Sterman, 2000; Ford, 2010). The central idea of this modelling is based upon the assumption the that structure of a system is based on differential equations, and solving these equations numerically generates the model's behavior. System dynamics modelling is an iterative process that consists of the following steps: (1) problem definition, (2) system conceptualization, (3) model calibration and validation, and (4) model analysis. The model is built up in steps of increasing complexity until the simulation show the dynamic pattern under study. It has to be noted that system dynamics models are not predictive; rather, they are designed for general understanding (Ford, 2010). In the following sections we present the structure of the organic food market model calibrated based on data from the organic wheat market in Germany.

Model specification

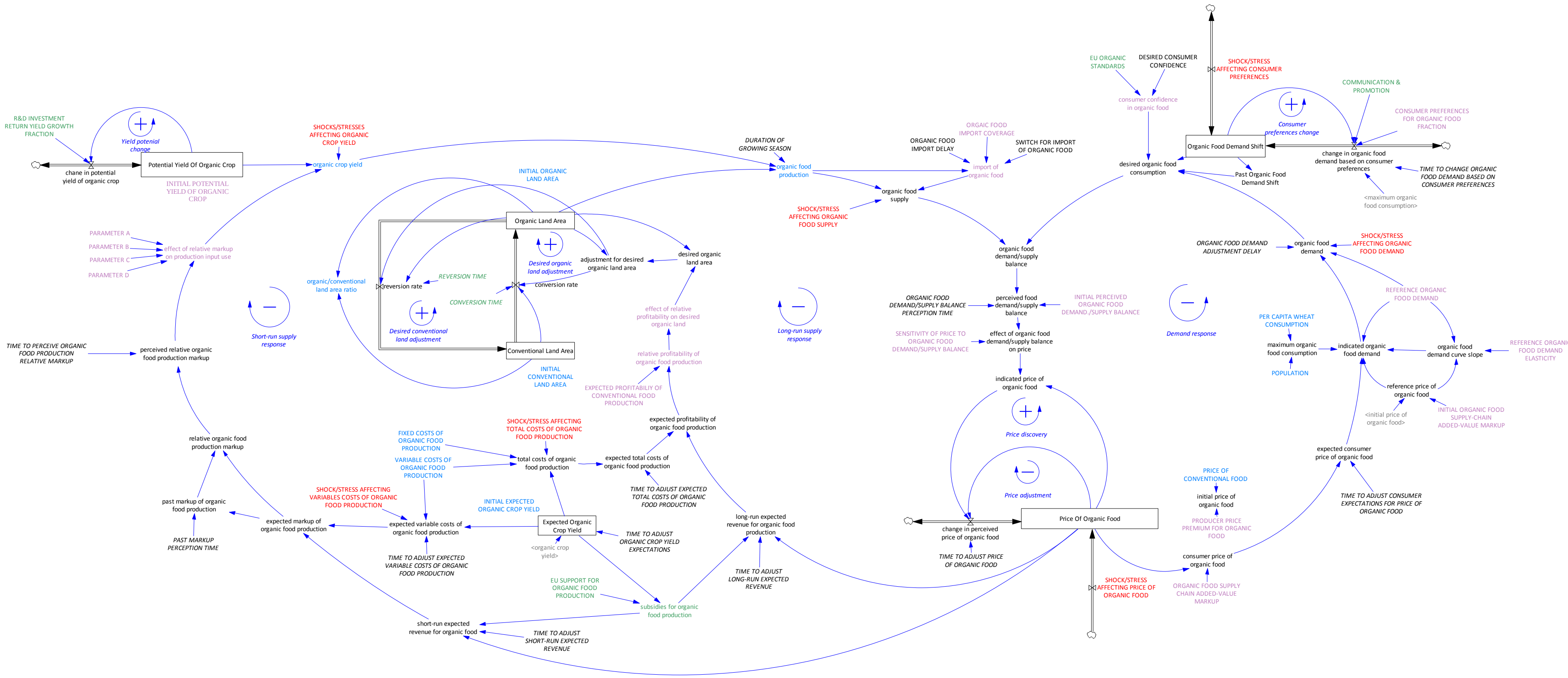

Figure 3 Stock-and-flow diagram of organic food market based on data for organic wheat market model in Germany; Note: food = wheat;
Legend: *italics* – major feedback loops with their polarities RED – exogenous factors uncertainties; GREEN – policy instruments uncertainties; PURPLE – parametrical / structural endogenous uncertainties; BLUE – variables determined by data; **for detailed model documentation contact the authors*

Problem formulation

Based on anecdotal insights from stakeholders the central problem-paradox on the organic food market is defined in the IA as follows (EC, 2014):

"*The overall objective of the current EU political and legislative framework, which is the sustainable development of organic production, is not met. Although the organic farming sector develops in the EU, the progression is not in line with market developments.*

[…] There is evidence of lost opportunities for EU producers, notably the fact that the organic production in the EU does not cover the demand: stakeholders have reported that the demand is far from being covered by the production in the EU, notably for fruit and vegetables and crop products, including protein-rich crops for feed."

Further, they conclude that: *"The EU political and legislative framework does not provide the appropriate basis for sustainable development of organic production.*"

System conceptualization and formulation

Considering the problem identified in the IA on the organic food market i.e., misbalanced supply and demand, along with insights from relevant literature on this challenge, we present in this section the concept of our system (Figure 3) in the form of a stock-and-flow diagram with identified major feedback loops and their polarities using Vensim DSS. Note that food = wheat, as the model is calibrated to the organic wheat market in Germany. Following the nomenclature used in Walker et al.'s (2013) framework, the system model (R) structure is based on the generic commodity market model of Sterman (2000, pp.798–824). This structure is built on the basic feedback structure of markets and consists of 4 sections – long-run organic wheat supply decision, short-run organic wheat supply decision, organic wheat demand and price of organic wheat – and several extensions as briefly described below. For detailed documentation of the model refer to the authors.

1. Long-run organic wheat supply decision (Figure 5)

Long-run organic wheat supply is determined by the amount of land allocated to organic wheat, while short-run supply is determined by the level of variable inputs applied. Organic land area is increased by conversion from conventional land area and decreases by reversion back to conventional land area:

$$\textit{Organic Land Area }(t+td)=$$
$$\textit{Organic Land Area }(t)+\textit{conversion rate }(t)\times dt-\textit{reversion rate }(t)\times dt$$

According to literature, the profitability of organic farming is the main determinant of the decision to convert (Läpple & Kelley, 2013) or revert (Sahm et al., 2013). Thus, we modeled it as a first-order process that adjusts organic land area to a desired organic land area, which is determined only by the long-run (= 5-year) expected relative profitability with regard to its conventional counterpart:

expected profitability of organic food production=
MAX(("long-run expected revenue for organic food production"-expected total costs of organic food production)/"long-run expected revenue for organic food production", 0)

desired organic land area=
Organic Land Area*effect of relative profitability on desired organic land

adjustment for desired organic land area= desired organic land area-Organic Land Area

conversion rate = IF THEN ELSE(adjustment for desired organic land area>=0,
MIN(adjustment for desired organic land area/CONVERSION TIME,
Conventional Land Area/CONVERSION TIME), 0)

reversion rate= (-1)*IF THEN ELSE(adjustment for desired organic land area<=0,
MIN(adjustment for desired organic land area/REVERSION TIME,
Organic Land Area/REVERSION TIME), 0)

For the long-run supply decision, we assume that in the long-run expected profitability of both organic and conventional wheat production systems must be positive. The relationship between long-run expected relative profitability of organic versus conventional organic wheat production:

relative profitability of organic food production= expected profitability of organic wheat production/(expected profitability of organic wheat production
+EXPECTED PROFITABILIY OF CONVENTIONAL FOOD PRODUCTION)

and its effect on desired organic land area is expressed in the form of a lookup function presented in Figure 4. The lookup function should be interpret as follows: if the long-run profitability of organic wheat production is equal the conventional counterpart then the relative profitability equals 0.5 and the effect on desired organic land is 1. The higher the long-run profitability of organic production with regard to the conventional counterpart (i.e., relative profitability >0.5), the more farmers desire cultivate land area organically and vice versa. The acquisition and abandonment of organic land area is delayed by respectively a conversion time of 2 years and a reversion time of 5 years, as required within the EU legislative framework.

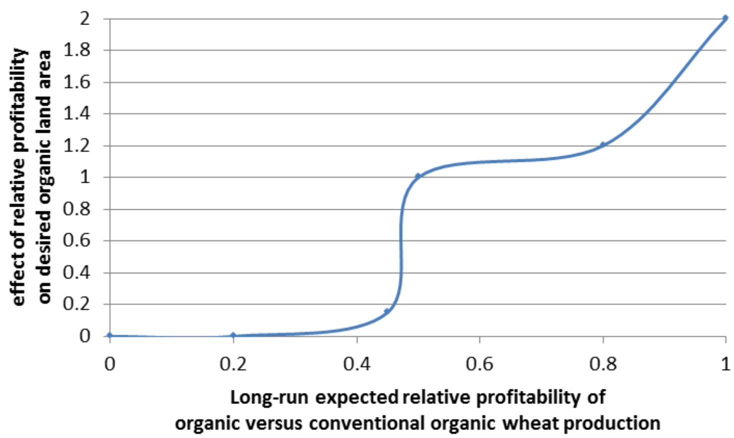

Figure 4 Effect of long-run expected relative profitability on desired organic land

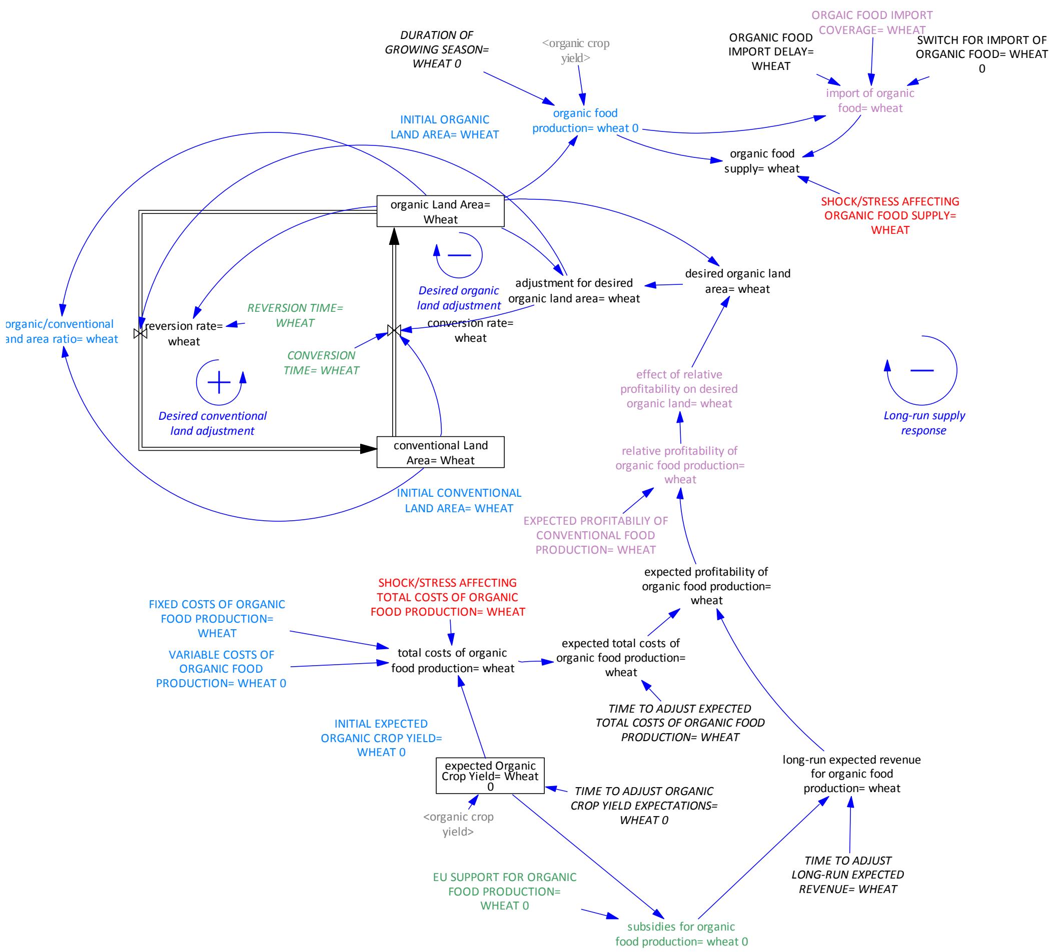

Figure 5 Formulation for long-run organic wheat supply decision

2. Short-run organic wheat supply decision (Figure 7)

Organic wheat yield is determined by simple multiplication of organic wheat yield potential (7.5 tonnes/ha) (Ponti et al., 2012) by effect of production inputs usage in organic wheat production on yield (i.e., aggregation of fertilizers, plant protection products, fuel, machinery, labor, etc.):

organic crop yield =
*Potential Yield Of Organic Crop*effect of production input usage on organic wheat yield*

The effect of production inputs usage on organic wheat yield (Y) depends on farmers' short-run relative perception of current to past markup of organic wheat production (X):

expected markup of organic wheat production=
short-run expected revenue for organic wheat/
expected variable costs of organic wheat production

relative organic wheat production markup=
expected markup of organic wheat production/past markup of organic wheat production

and is determined by the lookup function (Figure 6) translated to logistic equation of the from by using Excel's solver to find best fitting parameters by minimizing the sum of least squares:

$$Y = 0.995058 + \{(0-0.995058)/[1+(X/1.025921)^{5.951024309}]\}$$

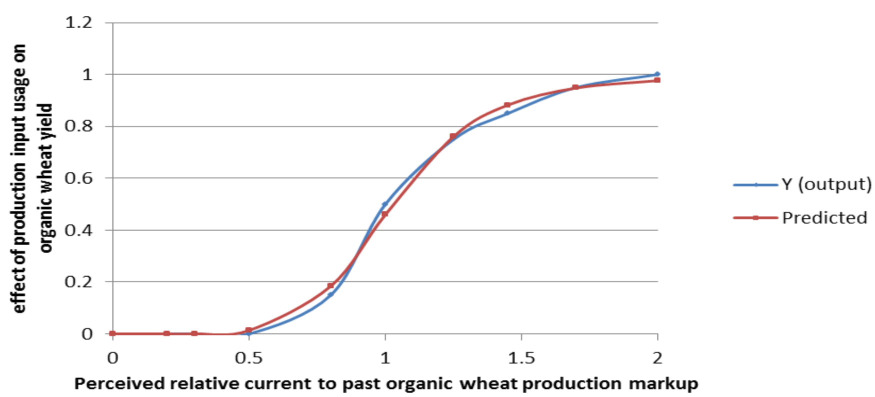

Figure 6 Dependence of effect of production inputs usage on organic wheat yield on the perceived relative organic wheat production markup

Following Sterman (2000) capacity utilization specification, we formulate the production inputs usage determined by relative markup and its effect on organic wheat yield at highly aggregated level, as the decision making related to this issue has still not been addressed in the literature and portrays one of the structural uncertainties remaining in the model. The relationship between relative markup and the effect of production input usage on organic wheat yield should be interpret as follows: how much additional organic wheat yield is generated by an increase in revenue of organic wheat in comparison with the revenue received last year, given the existing organic land area.

Organic wheat land area and organic wheat yield multiplied by each other determine the organic domestic wheat production that is delayed by the length of the growing season (1 year):

organic wheat production =
*(Organic Land Area*organic crop yield)/DURATION OF GROWING SEASON*

The organic wheat supply in this model adds up to the organic domestic wheat production with imports of organic wheat.

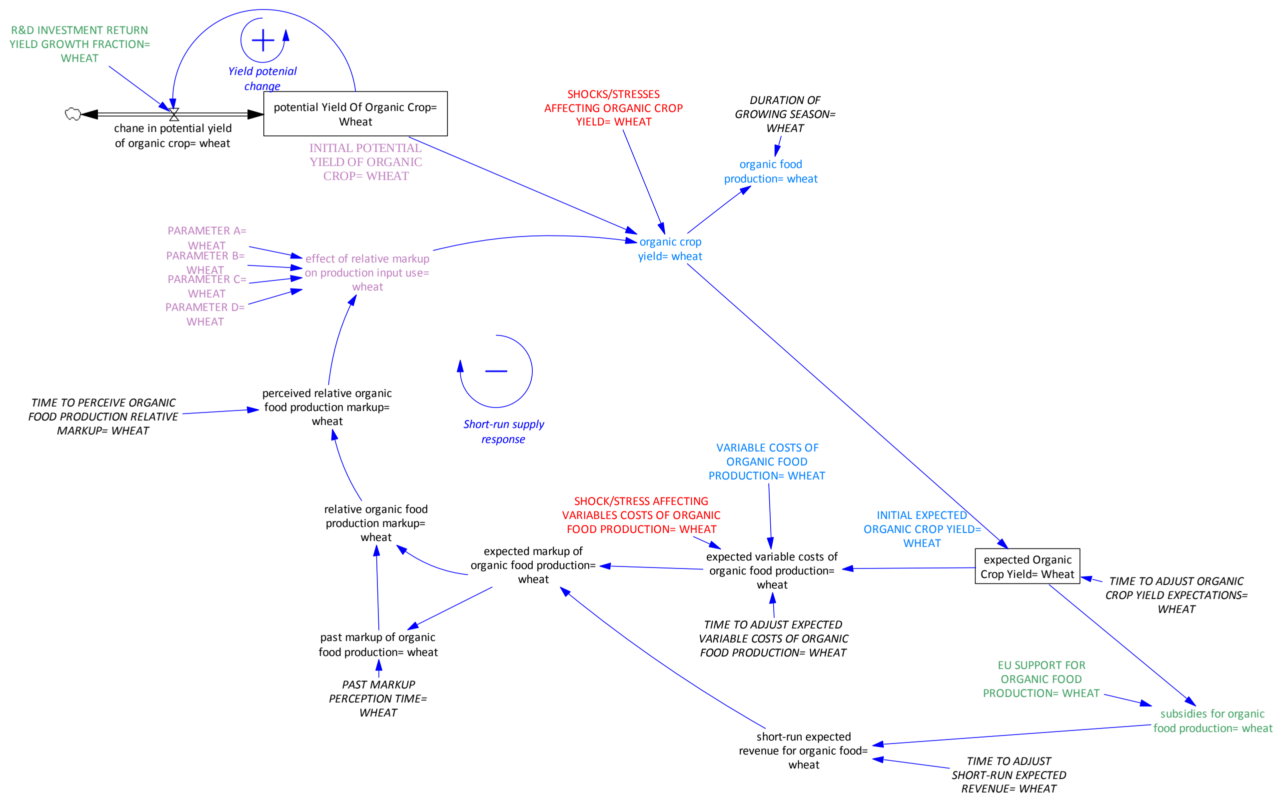

Figure 7 Formulation for short-run organic wheat supply decision

3. Organic wheat demand (Figure 8)

Demand for organic wheat is formulated based on Sterman (2000, pp. 811-813) by assuming a linear demand curve:

organic wheat demand curve slope=
*(-REFERENCE ORGANIC WHEAT DEMAND**
REFERENCE ORGANIC WHEAT DEMAND ELASTICITY)/reference price of organic wheat

We bound the linear demand curve with the MAX function to ensure that the demand does not fall below zero no matter how high the price and the MIN function to keep the demand within maximum amount (population in Germany multiplied by wheat consumption per capita in Germany) no matter how low the price:

*indicated organic wheat demand= MIN(maximum organic wheat consumption, REFERENCE ORGANIC WHEAT DEMAND*MAX(0,1 +organic wheat demand curve slope*(expected consumer price of organic wheat -reference price of organic wheat)/REFERENCE ORGANIC WHEAT DEMAND))*

*maximum organic wheat consumption= POPULATION*PER CAPITA WHEAT CONSUMPTION*

The demand is normalized to the reference consumer organic price (i.e., initial organic wheat price including initial supply-chain added-value markup) and to the reference organic wheat demand for 2004, the value of which is relatively higher than the respective supply based on anecdotal insights on demand exceeding the supply. Further, organic wheat demand is assumed to be elastic with the reference elasticity of own-price dependent demand equal to -1.19 (Bunte et al., 2007). With the formulation we capture the essential feature that demand falls when the price of organic wheat rise with a relatively short delay (2 months) as compared to the supply response (2 years or 5 years). The delay (2 months) aggregates the time for consumers to form price expectations and react to these expectations. Finally, we add organic food demand shift structure to be able to capture consumer that have strong preferences for organic and thus are not responding to the price changes. In effect, desired organic wheat consumption represents organic food demand with the demand shift based on preferences:

Organic Wheat Demand Shift (t+td)= Organic Wheat Demand Shift (t) +change in organic wheat demand based on consumer preferences (t)×dt

*desired organic wheat consumption= (organic wheat demand+Organic Wheat Demand Shift-Past Organic Wheat Demand Shift)*consumer confidence in organic food*

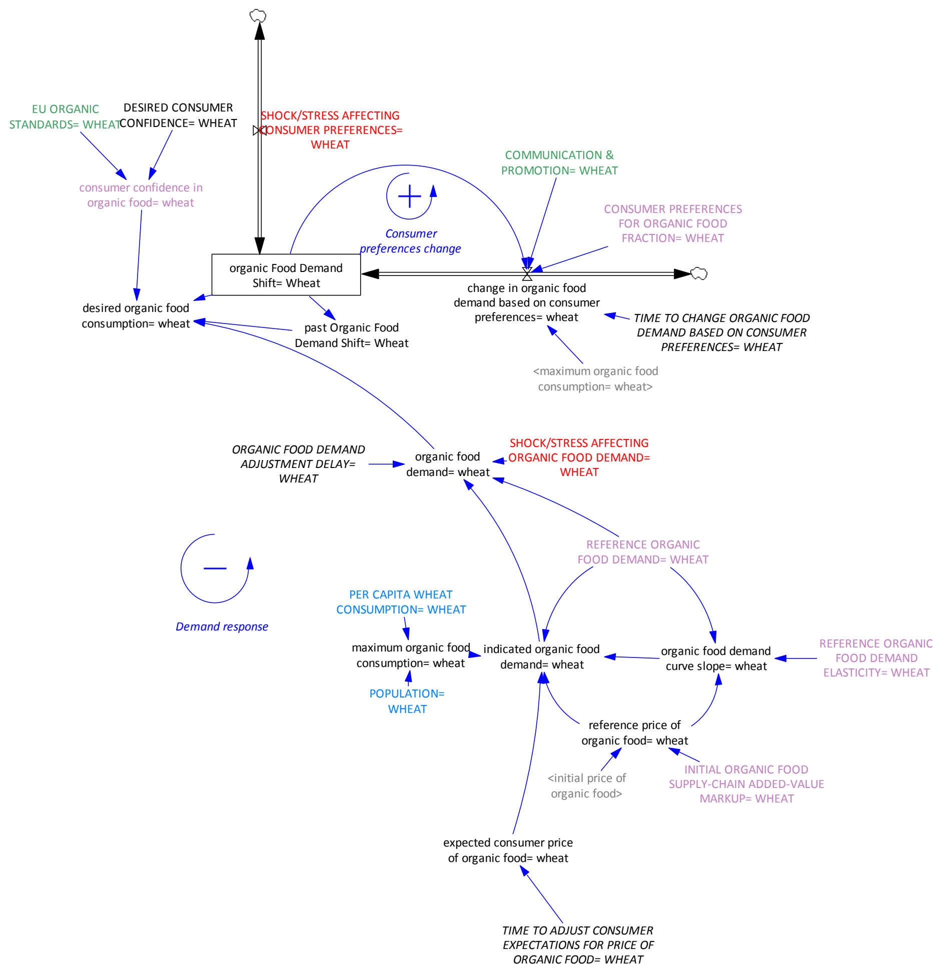

Figure 8 Formulation for organic wheat demand

4. Price of organic wheat (Figure 9)

The price of organic wheat is based on structure for hill-climbing search (Sterman, 2000, pp. 539). The information about true equilibrium price that will clear the organic wheat market is not known, thus market makers form price of organic wheat by anchoring on the current price and then adjusting it in response to the perceived balance between demand and supply. If the demand for organic wheat exceeds the supply, indicated price will rise. On contrary, the price will decrease, providing the supply of organic wheat exceeds the demand. Based on the simple economic theory we approximate the effect of organic demand/supply balance on price by the following formulation:

$$\textit{effect of organic wheat demand/supply balance on price} = (\textit{Organic wheat demand/supply balance})^{\textit{sensitivity}}$$

$$\textit{indicated price of organic wheat} = \textit{Price Of Organic Wheat} * \textit{effect of organic wheat demand/supply balance on price}$$

Price Of Organic Wheat (t+td)=
Price Of Organic Wheat (t)+change in perceived price of organic wheat (t)×dt

change in perceived price of organic wheat=
(indicated price of organic wheat-Price Of Organic Wheat)/
TIME TO ADJUST PRICE OF ORGANIC WHEAT

, where sensitivity >0 of the price to demand/supply balance. Because of data inconsistency on organic wheat price and demand, we could not estimate the value of sensitivity parameter, however in iterative model calibration process the value of 0.7 was most appropriate for replicating the historical behavior of organic domestic wheat production. The initial organic wheat price is assumed to be the conventional wheat price including price premium for organic wheat (ca. 150%):

initial price of organic wheat=
*(PRICE OF CONVENTIONAL WHEAT*PRODUCER PRICE PREMIUM FOR ORGANIC WHEAT)+PRICE OF CONVENTIONAL WHEAT*

The consumer organic wheat price is formulated as price of organic wheat with added supply-chain markup (ca. 60%) (EC, 2005; Crowder et al., 2014; David et al., 2015):

consumer price of organic food=
(Price Of Organic WHEAT"ORGANIC WHEAT SUPPLY CHAIN ADDED-VALUE MARKUP")*
+Price Of Organic Wheat

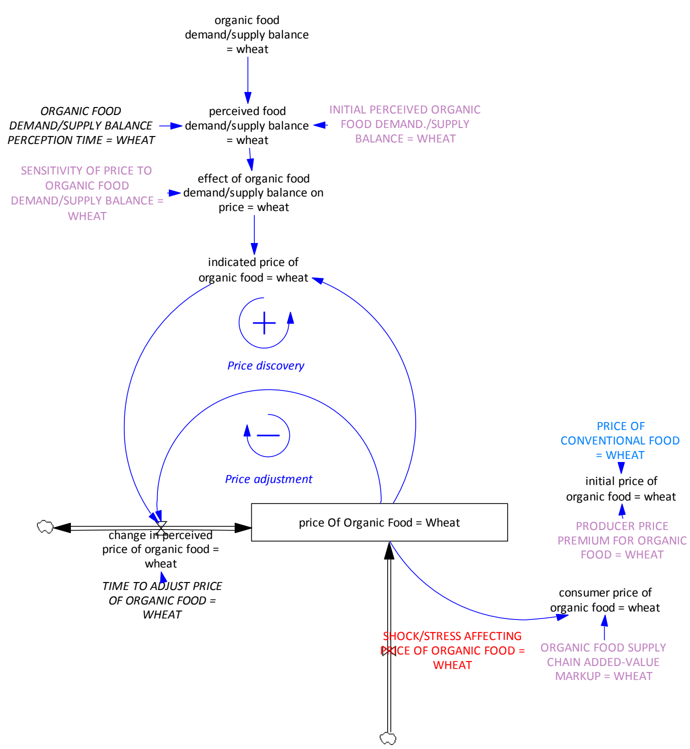

Figure 9 Formulation for price of organic wheat

5. Extensions

The main purpose of the system model developed in this paper is to propagate the effects of the uncertainties in market, policies and exogenous factors on the relevant outcome variables. Among the market structure we recognized the main outcome variables (O), namely the organic domestic wheat production (=organic domestic wheat supply), price of organic wheat and desired organic wheat consumption (=organic wheat demand). The policy variables (P) are highlighted in green and encompass selected EU organic farming policy instruments, i.e., subsidies received by organic farmers, lengths of conversion and reversion periods, investments in R&D to reduce gap yield between organic and conventional wheat crop as well as promotion and communication targeted at consumers. The external factors (X) are marked in red and indicate entry points for various exogenous shocks and stresses that can affect the system. Besides, there are areas signified in purple that signalize structural uncertainties in the model for which literature is scarce or even does not exist.

Model calibration and validation

The model was calibrated to the data on organic wheat market in Germany collected from various sources (Table 2 in Annex). The calibration was conducted for the period 2004-2012, because of data incompleteness and inconsistency for years before 2004.

With regards to model validation, following Barlas (1996), we performed two types of tests i.e., structural and behavioral. Structural validation of the model was conducted by iterative logic, extreme condition and boundary tests. We do not present the results of structural validation, as "*the qualitative and long nature of these tests makes it impossible to show the results in the context of such an article. We simply state that the model was found structurally reliable and show some results that demonstrate its behavior validity*" (Barlas, 1996). For the validation of behavior we conducted extreme condition, sensitivity and behavior reproduction tests. The baseline behavior pattern in the results section presents behavior validity by its comparison to historical data.

Model analysis

We investigate long-term dynamics of the system by setting the simulation period to 2004-2005. The system dynamics model contains many uncertain parameters. In order to examine the effect of their variation on simulation output, we performed sensitivity analysis by use of Vensim's Monte Carlo simulation, also known as multivariate sensitivity simulation (MVSS). For a selection of parameters that characterize uncertainty related to the market, policy and external factors in the model, we assigned the maximum and minimum values. Random Uniform Distribution was used so that any number between the assigned extreme values is equally likely to occur. Monte Carlo multivariate sensitivity worked by sampling 200 times values from within the bounded domains of the parameters and performing simulation with these values. The results are presented in the Annex in the form of time graphs with confidence bounds that display behavior of relevant variables, i.e., organic domestic wheat production, price of organic wheat and organic wheat demand, under the impact of differing parameters' values. For ease of understanding in the results section we translated the time graphs into tables with summarized results.

Results

Baseline 2004 – 2050

Assumptions for the baseline scenario on the constants and initial values in the model are summarized in Table 3 (Annex). In brief, with the baseline scenario we aimed the model to reflect the trend in the historical data based solely on the market-policy arrangement but excluding the influence of external factors. We calibrated the model with initial values set to reference values for the year 2004. The constants were chosen to reflect the reference year 2004 (e.g., reference organic wheat demand) or the average situation for the period 2004-2012 (e.g., subsidies, variable and fixed costs). It should be noted that the "baseline simulation" should not be interpreted as "most likely behavior". "*A single simulation seldom teaches us much about the system. Its purpose is usually to provide starting point for comparisons with additional simulations. Think of a simulation as a single simulation as one blade in a pair of scissors. Scissors are not designed to cut with one blade working alone. It's only when two blades work against each other the scissors serve their intended purpose. System dynamics simulations should work in pairs. By comparing one simulation against the other, the model will serve its intended purpose. If you find yourself uncomfortable working with pairs of simulations, you are probably looking for predictive model. In such case, you should turn to forecasting methods to serve you needs*" (Ford, 2010). Ford's (2010) statement fully reflects the purpose of the model and indicates the way for interpretation of the simulation results presented in this section.

Figure 11 present the behavior modes of the most important outcome (O) variables until 2050 accompanied by historical data for the period 2004-2012 (for which such data were available). We acknowledge that the simulation results do not replicate perfectly the historical data for several reasons. First, the boundaries of the model limit it to feedback loops strictly related to market dynamics involving supply and demand. In other words, we treat the additional factors affecting the system as exogenous constants. Second, in the baseline scenario exogenous factors have no influence on the supply-demand dynamics. However, based on comparison of the behavior of demand with regard to buyers/suppliers' market presented in the study of Wurriehausen et al. (2015; Figure 10), the important dynamic behavior of supply and demand responses to price changes on the organic wheat market are well captured in the system dynamics model. This gives credibility of the results and allows us to conduct further model analyses.

In this system four negative, i.e., *Short-run supply response*, *Long-run supply response*, *Demand response*, *Price expectation adjustment*, and three positive, i.e., *Desired organic land area adjustment*, *Desired conventional area adjustment*, *Price adjustment*, feedback loops play a significant role in equilibrating organic wheat supply and demand and generating behavior modes of the relevant outcome variables.

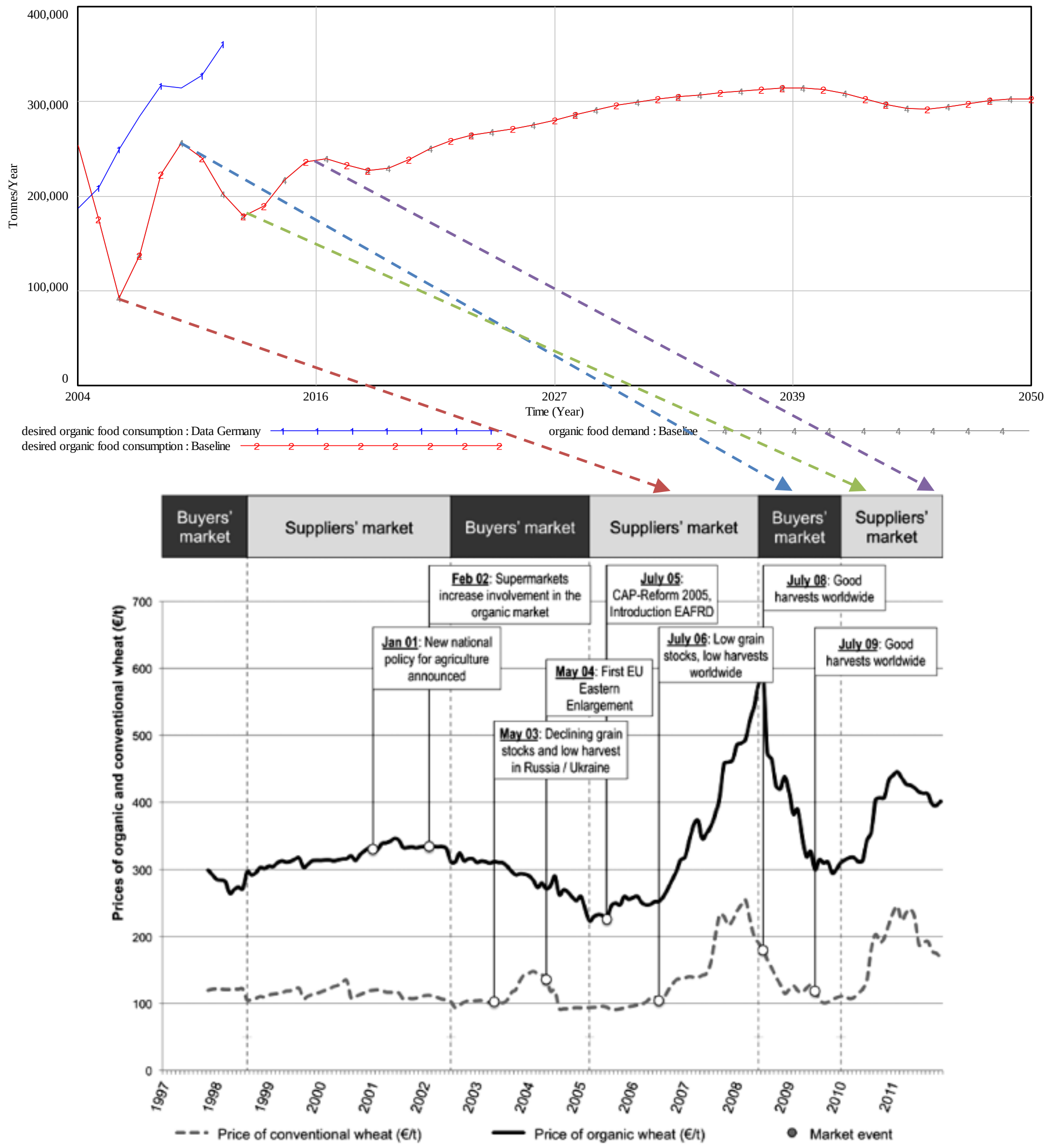

Figure 10 Baseline simulation results for and historical data (if available) for relevant outcome variables of the demand side in comparison with development of conventional and organic wheat prices in Germany in €/t at producer level and indication of match with "buyers'" and "suppliers" market situation (Wurriehausen et al., 2015 based on ZMP and AMI); Note: food = wheat

Feedback perspective in isolation

On the demand side, the organic wheat demand depends on its own price change. High organic wheat price reduces the relative value of organic wheat leading to organic wheat demand drop due to the balancing *Demand response loop*. This loop involves relatively short delays: consumers do not need much time to update their price expectations and change their buying habits.

On the supply side, high organic wheat price leads to high relative short-run expected markup to past markup earned on organic wheat production and accordingly higher production inputs usage resulting in higher yields of organic wheat. The reverse happens in case of lower price of organic wheat. This decision is governed by the *Short-supply response* loop.

If the high price for organic wheat persists, long-run expected profitability of organic wheat production is higher relative to conventional wheat production. As long as farmers believe organic wheat production is more profitable than conventional, each organic farmer would like to cultivate more land area with wheat than she or he does and conventional farmers will enter the organic wheat market converting their land to organic land area. When the organic wheat production is expected to be relatively unprofitable, the organic wheat land area is reduced. The decisions to convert or revert are guided by the major balancing *Long-run response* loop along with two reinforcing loops, i.e., *Organic desired land area adjustment* and *Desired conventional land area adjustment*, respectively.

Although both short-run and long-run supply respond to price changes, they differ in several relevant aspects. The expected markup of organic wheat production depends on the variable costs of the organic wheat production and the revenues determined by price and subsidies that farmers expect to realize when organic wheat production started in the short-run (i.e., 2 years to account for growing season and following sales year). In contrast, the expected profitability of investment in more organic land depends on total costs of organic wheat production, both fixed and variable, and on farmers' forecasts of what revenues based on price and subsidies will be over the long-run (i.e., 5 years to account for minimum time required by legislation to maintain in organic production system). The expectations with regard to costs, price and subsidies, may differ in the long-run and in the short-run.

The actual price of organic wheat depends on the balance between demand and supply of organic wheat. The formation process of the actual organic wheat price forms two feedback loops: reinforcing *Price discovery* loop, in which the indicated price is based on the actual price, and balancing *Price adjustment* loop, in which actual price adjusts to the indicated price. In effect, the price of organic wheat rises when the balance of organic wheat demand to supply increases.

Feedback perspective in the system

All the feedback loops interact together, influence each other and involve various types of delays. These interactions involving delays may hence cause instability and oscillations in the system.

In the baseline scenario, the demand for organic wheat in 2004 is 50% higher than the organic wheat supply (assumption based on anecdotal data; EC, 2014). In response to the high demand/supply balance (>1), the price of organic wheat is increasing through the *Price discovery* and *Price adjustment* loops causing the demand to drop through the *Demand response* loop.

On the supply side, with the increase in price, the short-run expected revenues go up influencing positively the production inputs usage that, in turn, boosts the organic wheat yield. At the same time, long-run expected revenue also is increasing, rising the relative profitability of organic wheat production and thus generating a desire to increase the organic land area. The desired organic land area is anchored to the actual level of organic land area and then adjusted up through the conversion rate, with a considerable 2-year long delay enforced by legislation, in line with the growing relative profitability. The latter formulation creates a positive feedback loop, the *Desired organic land area adjustment*. The increasing organic wheat yield and organic land area determine the increasing trend in the organic domestic wheat production characterized by a delay of the growing season period (i.e., equal in the baseline scenario to organic wheat supply, as imports are not taken into consideration).

As the demand for organic wheat decreases in response to the high price, the demand/supply balance decreases (*Demand response* loop). The decline in the demand/supply balance is reinforced by modestly (due to long delays) increasing supply of organic wheat (*Short-run* and *Long-run response* loops). As the demand/supply balance <1, the price of organic wheat reaches its maximum level (ca. 450 EURO/tonnes) with a relatively short delay, and soon afterwards starts decreasing. The demand side reacts quickly to the decline in price of organic wheat and starts increasing.

In the long-run the decrease in price and accordingly revenues is smooth due to long delays, slowing down the conversion rate, but not significantly enough to change the upward sloping trend in expansion of the organic land area. However, the falling price of organic wheat has significant negative effect on the short-run revenues affecting after short delay in dropping organic wheat yield. The latter causes a decrease in the organic domestic wheat production, while at the same time the demand is rising but the price of organic wheat is still decreasing. The price for organic wheat reaches its minimum while the demand is balanced by the supply (i.e., demand/supply balance = 1) and soon afterwards again starts rising again. The cycles repeat but the oscillations are being damped within each following cycle.

Since approximately 2020 until 2038 the organic wheat supply slightly exceeds the demand, but both variables are sloping upward. As long as the relative profitability of organic wheat production is higher than its conventional counterpart, the *Long-run supply* and the *Desired Organic area adjustment* loops dominate in the system, driving the growth in organic wheat land area and consequently the organic wheat production, even with decreasing yield. The increase in organic wheat supply pushes the price of organic wheat down, stimulating thereby growth in the demand for organic wheat through the *Demand response* loop, which in turn drives the price up. Therefore, as seen by the behavior of the decreasing conversion rate, the *Long-run supply* loop gradually loses its domination on account of the *Demand response* loop and the organic land area is increasing but decreasingly, reaching in around 2038 its maximum of about 90 000 ha. At this point, the demand for organic wheat equilibrates with supply (demand/supply balance =1) for a while, then overshoots the supply and the price of organic wheat starts increasing again. However, because of delay in the *Long-run supply* loop the organic land area decreases and only after a few years starts increasing again in response to the rising price, to which demand responds again by decrease. As above the cycles repeat but the oscillations are being damped to finally saturate at equilibrium of: organic wheat supply

= organic wheat demand = 310000 tonnes/year; price of organic wheat = 240 EURO/tonnes; organic land area = 85000 ha and organic wheat yield = 3.6 tonnes/ha.

It appears that the price of organic wheat is not simply a mirror image of demand/supply balance. Rather, the price is decreasing when the organic wheat demand/supply balance is at its minimum and continues to decrease for a little while even after the demand/supply balance begins to recover. The phase lag is partly a result of the time required for the market to perceive changes in demand/supply balance and largely is a consequence of the *Price discovery* loop, in which prices tend to rise as long as the demand/supply balance is inadequate.

Further, the price of organic wheat lies in the center of a network of negative feedbacks which act to eliminate imbalances between demand and supply. Yet, the supply side in general, and the long-run decision to convert to organic production system in particular, reacts to the changes in the price of organic wheat very slowly. Thus, the negative feedbacks with the time delays are making the organic wheat market prone to oscillations and instability.

In conclusion, the baseline scenario represents two distinct damped oscillatory modes. First, the organic wheat demand/supply balance, price, yield and production oscillate with a period of less than 5 years. Second, organic land area oscillates with a period of about 35 years. The short period is generated by the delays in the balancing *Short-run supply* loop and the long period is generated by the longer delays in the balancing *Long-run supply* loop. The cycles in the organic wheat market arise from the interactions of the physical delays in organic wheat production and investment decisions to convert to and/or expand the organic wheat land area with bounded rational decision making by individual organic wheat producers.

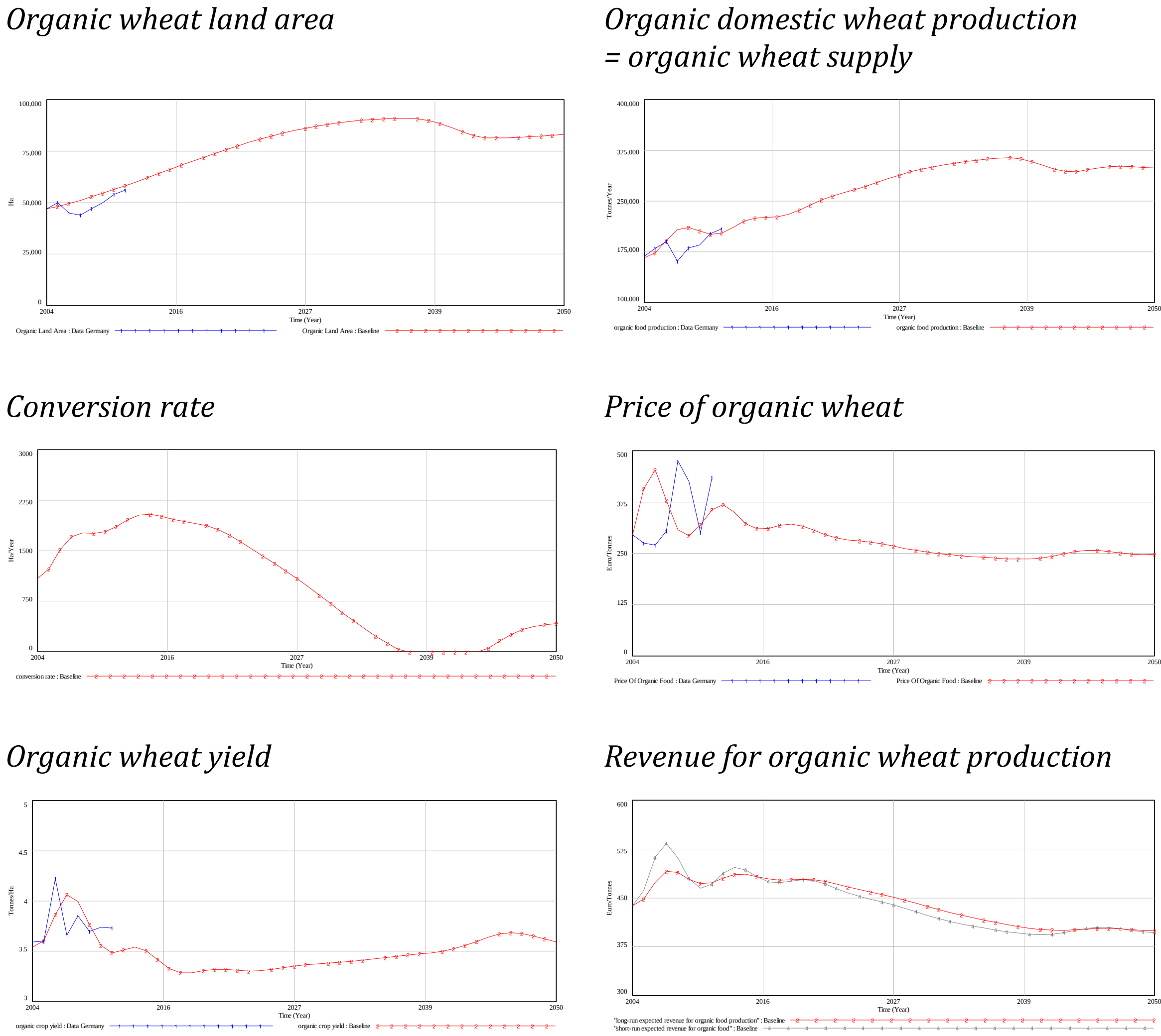

Figure 11 Baseline simulation results for and historical data (if available) for relevant outcome variables of the supply side; Note: food = wheat

Sensitivity analysis

The baseline scenario shows that the organic wheat market can exhibit oscillatory and instable behavior. In the model itself there are many areas with uncertain specification, both parametrical and structural (Figure 3 and paragraph on 1. Extensions in section on *Model specification*). In order to investigate the influence of the uncertainties on the underlying dynamics of the organic wheat market we conducted parametrical, univariate Monte Carlo sensitivity analyses, of which detailed results can be found in the Annex. For the majority of parameters, no matter if from outside or inside the model, the 50% confidence bounds (yellow fields) are wide and exhibit varying behavior modes within particular outcome variables. The simulation results thus suggest that the organic wheat market is highly sensitive to most of the parameters. In this section, we summarize the results of the sensitivity tests by presenting examples of the influence of selected uncertain parameters within the market, policy and external factors.

Market uncertainty

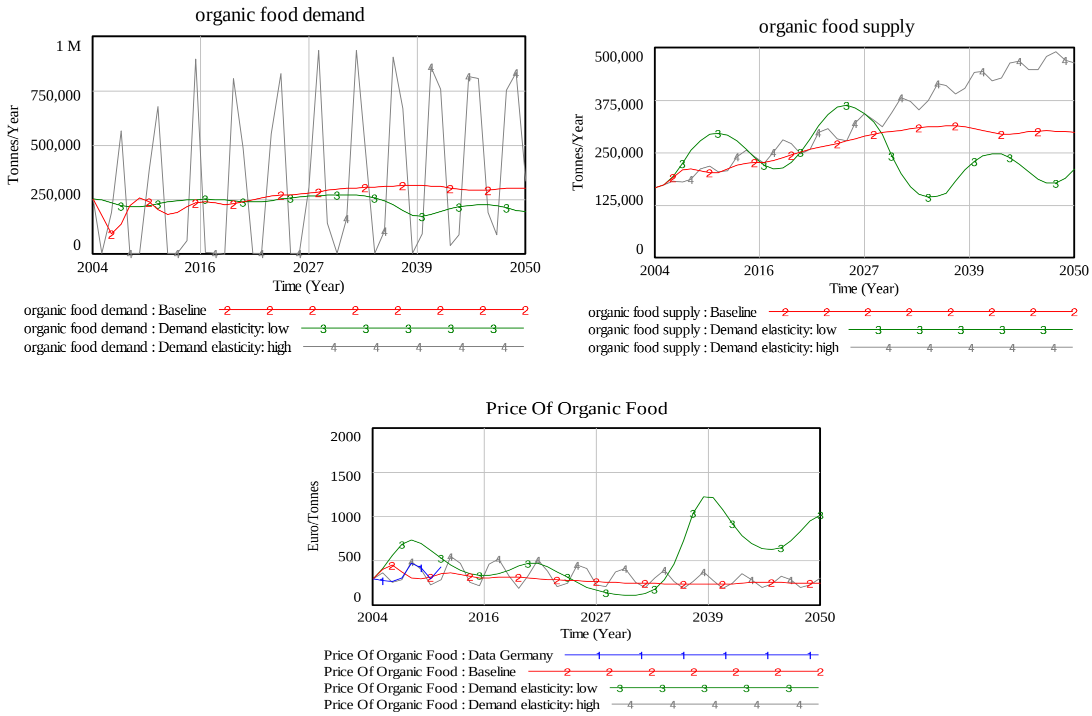

Figure 12 Sensitivity tests with different values of reference organic wheat demand elasticity Baseline: 1.19, Low: 0.1; High: 8; Note: food = wheat

Figure 12 shows the effect of varying the reference organic wheat demand elasticity (from 0.1 to 8; the baseline value is 1.19), which is uncertain, as its value is changing along with the organic farming development (Wurriehausen et al., 2015) and there are hardly any studies on this issue. Note that the reference elasticity is the elasticity at the initial operating point – because the assumed demand curve is linear, the actual elasticity is higher at higher prices and lower at lower prices.

Both higher and lower values of reference demand elasticities significantly destabilize the organic food market. Increasing/decreasing the reference organic wheat elasticity does not simply increase/decrease the movement of organic wheat demand relative to the reference organic wheat demand, but also changes the timing (phase) within the feedback loops. For example, by suppressing demand for organic wheat more when price is high, the higher elasticity shortens the delay of the *Short-run supply* loop.

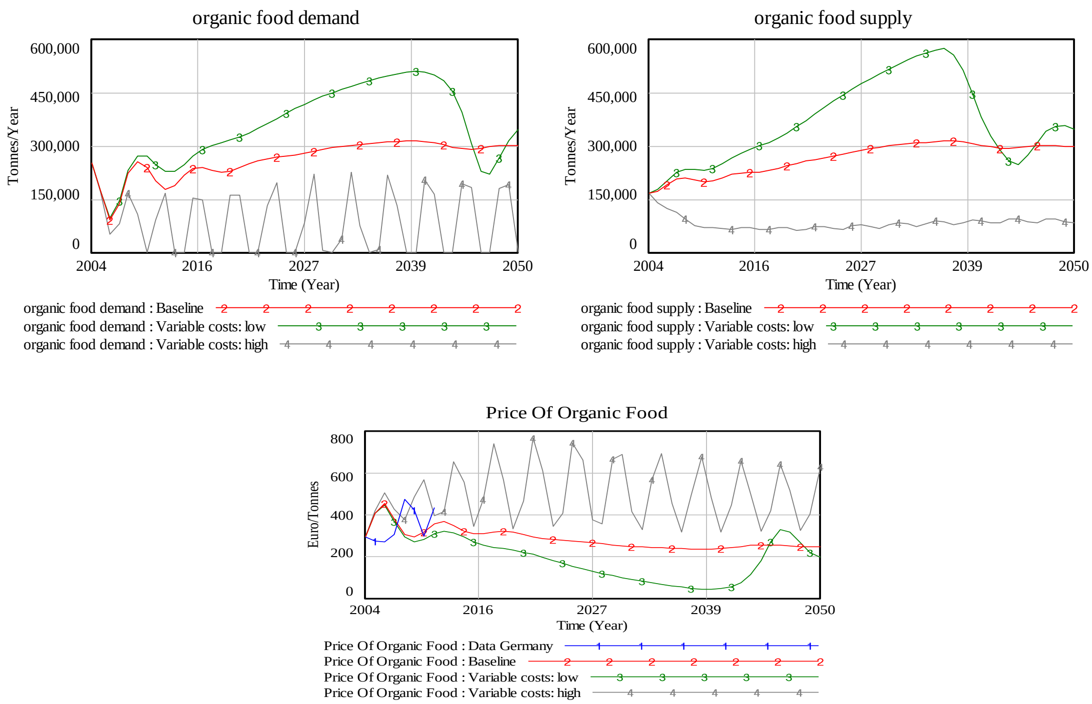

Figure 13 Sensitivity tests with different values of variable organic wheat production costs [EURO/ha] Baseline: 476.17, Low: 100; High: 1000; Note: food = wheat

Figure 13 represents sensitivity of the organic wheat market to various level of variable organic wheat production costs (from 100 to 1000; the baseline value is 476.17 EURO/ha), which are also highly uncertain, as the market of production inputs undergoes quick changes.

Changes in the variable costs again have significant effect on the stability of the system. They force the system to operate at different points on the linear demand curve, so the elasticity of organic wheat demand is higher than the reference value at higher prices and lower at lower prices.

Further, since changes in marginal costs drive variable costs, the scale of the organic wheat market has a strong impact on production inputs usage and accordingly organic wheat yield as well as on organic land area. For instance, due to rise in variable costs Organic wheat yield determined by the *Short-run supply* loop drops sharply compared to the baseline scenario. This decrease in organic wheat yield leads to a larger amplitude for the cycle because the resulting reduction in organic wheat supply forces prices higher in the next phase of the cycle. Different assumptions about the extent to which variable costs change compared to fixed costs will alter the character and stability of the dynamics.

Policy uncertainty

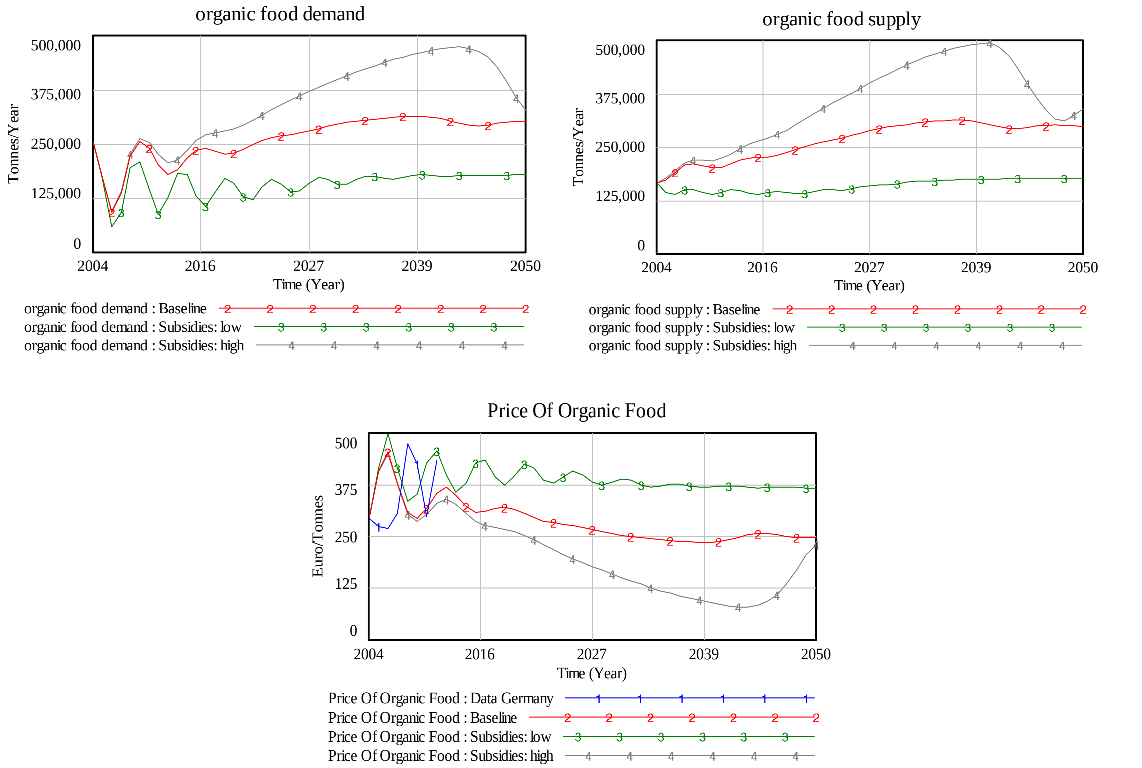

Figure 14 Sensitivity tests with different values of subsidies [EURO/ha]
Baseline: 538.286, Low: 100; High: 1000; Note: food = wheat

Figure 14 shows response of the organic wheat market to high (1000 EURO/ha), low (100 EURO/ha), and baseline (538.286 EURO/ha) level of subsidies that farmers receive in organic production system. We consider subsidies as one source of parametrical uncertainty, as in there is no long-term strategy until 2050 in this regard.

Low subsidies significantly destabilize the system. In case of low subsidies, the growth of organic market is very limited. In addition, the system exhibits much stronger damped oscillatory behavior then in case of the baseline scenario. On contrary, high subsidies boost very strongly the growth of the organic wheat yield and organic land area, resulting in high organic wheat production. The latter pushes the price of organic wheat down which has twofold repercussions: increase in demand for organic wheat and reduction of the dependence on market mechanisms.

External factors uncertainty

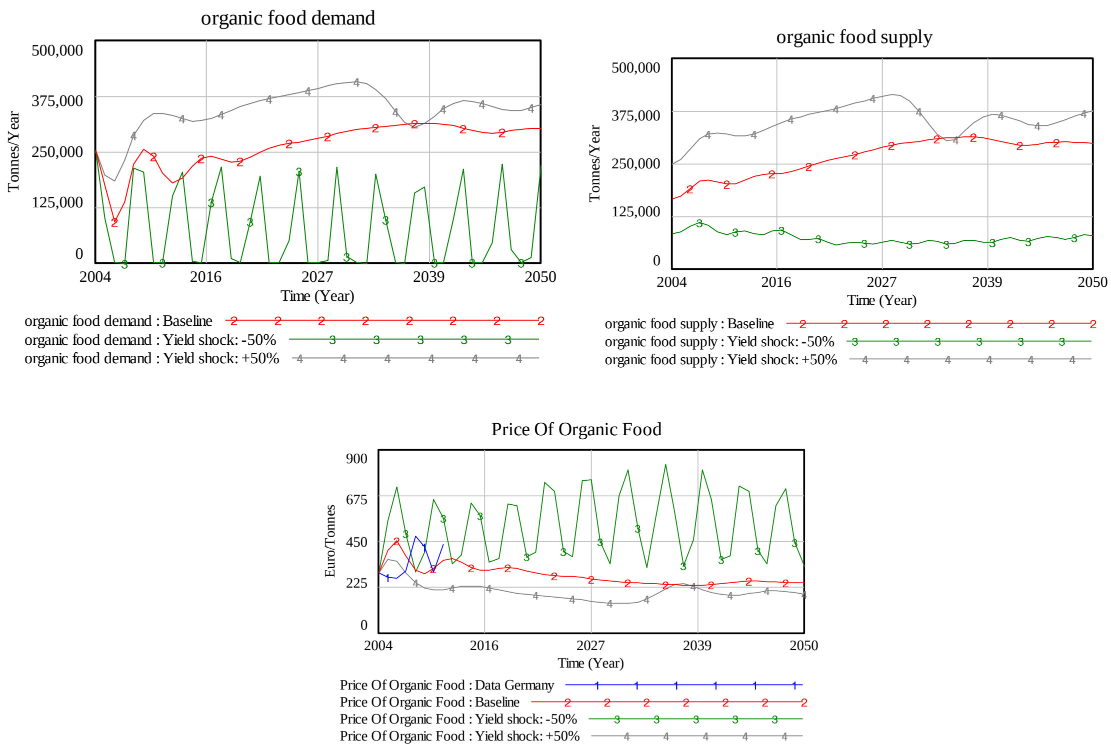

Figure 15 Sensitivity tests to yield shock +50% and -50% of normal yield; Note: food = wheat

Figure 15 represents sensitivity of the organic wheat market to positive and negative shocks (e.g., drought, flood, pests/diseases, innovative technology boosting yield, etc.), which respectively increase and reduces by 50% the organic crop yield.

The effect of reduced/increase yield of organic wheat is similar to respectively high/low variable costs. In particular, decrease in organic wheat yield causes oscillatory behavior and destabilizes the organic wheat market significantly.

Discussion and conclusions

Within European Commission's IA, based on anecdotal data provided by stakeholders, policymakers have identified that the central problem-paradox on the organic food market is that the growth in supply lags behind and remains insufficient to meet the climbing consumer demand, despite the considerable political support (EC, 2014; David, 2012; Willer & Schaack, 2015). In this study we contribute to the understanding of the identified problem of misbalanced supply and demand on the organic food market by deriving new insights from established variables and relationships in IA, while taking an explicit systems perspective. The IA on EU organic farming policy along with knowledge and theories from different disciplines were integrated to conceptualize, formalize and analyze a system dynamics model on the development of organic food market. The model was calibrated to the case of organic wheat market in Germany in order to examine its future long-term dynamics and sensitivity to uncertain parameters related to the market, policy and external factors.

The analysis of the baseline scenario along with sensitivity to selected uncertain parameters shows that the organic wheat market can oscillate and be unstable. The cycles originate from the interaction of the physical delays occurring in short-run organic wheat production and long-run investment in organic land area with boundedly rational decision making. Price of organic wheat in the system dynamics model functions to balance supply and demand. The price lies in the center of a complex of negative feedback which act to eradicate misbalance between demand and supply and to promote efficient allocation of resources on the organic wheat market. However, the reaction of partly demand but largely supply to price is on this market very slow. Therefore, the negative feedback loops with delays, foremost *Short-run supply response*, *Long-run supply response*, *Demand response*, *Price expectation adjustment*, are prone to cause oscillations and instability on the organic wheat market. These dynamics are reflected in Wurriehausen et al. (2015) study on historical development of organic wheat market in Germany (Figure 10).

The organic wheat market is accompanied by major uncertainties related to the market itself, political events, economic developments and many other external factors, which are important for the future dynamics of the supply and demand. The sensitivity analysis of the model to uncertain parameters shows that the organic wheat market is extremely sensitive to changes in factors inside and outside the market and policy range. The critical parameters' values, such as any value other than baseline of the organic wheat demand elasticity, high variable costs of organic wheat production, low subsidies, low organic wheat yields reduced by external shock significantly destabilize the organic wheat market, leading even to its decline. Therefore, policymaking in such uncertain environment is difficult.

The uncertainties around parameters as well as structure of the model, does not allow to identify the potential leverage points for improving the performance of the organic wheat market. Therefore, further research is needed to resolve the uncertainty existing around parametrical as well as structural model specification.

Acknowledgements

This paper originates from an EU FP7 funded project entitled TRANSMANGO *Assessment of the impact of global drivers of change on Europe's food security*; Grant agreement no: 613532; Theme KBBE.2013.2.5-01.

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Annex

Table 2 Sources of data used in the system dynamics model

VARIABLE ***Name of variable in the model*** ***= Name of variable in the dataset***	**DATA SOURCE**	**UNIT**
Organic land area ***= Organic wheat area***	AMI Informiert http://www.ami-informiert.de/	ha
Organic food production ***= Organic domestic wheat production***	AMI Informiert http://www.ami-informiert.de/	tonnes
Organic crop yield ***= Organic wheat yield***	FADN http://ec.europa.eu/agriculture/rica/index.cfm AMI Informiert http://www.ami-informiert.de/	tonnes/ha
Organic food supply chain added-value mark-up ***= Consumer price premium for organic wheat***	CALCULATION	dmnl
Producer price premium for organic food ***= Producer price premium for organic wheat***	CALCULATION	dmnl
Price of organic food ***= Price of organic wheat***	Wurriehausen et al. (2015) based on AMI Informiert http://www.ami-informiert.de/	EURO/tonnes
Price of conventional food ***= Price of conventional wheat***	EUROSTAT http://ec.europa.eu/eurostat/web/agriculture/data/database	EURO/tonnes
Conventional land area ***= Conventional wheat land area***	EUROSTAT http://ec.europa.eu/eurostat/web/agriculture/data/database	ha
Reference organic food demand elasticity ***= Organic bread demand elasticity***	Barkley (2002), Bunte et al., (2010)	dmnl
EU support for organic food production ***= Average subsidies for organic field crop farms***	FADN http://ec.europa.eu/agriculture/ric	EURO/ha

	a/index.cfm	
Total costs of organic food production ***= Total costs of organic wheat production***	KTBL http://ktbl.de/	EURO/ha
Variable costs of organic food production ***= Variable costs of organic wheat production***	KTBL http://ktbl.de/	EURO/ha
Fixed costs of organic food production ***= Fixed costs of organic wheat production***	KTBL http://ktbl.de/	EURO/ha
Desired organic food consumption ***= Desired organic wheat consumption***	ANECDOTAL based on IA and FiBL http://www.fibl.org/en/themes/organic-farming-statistics.html	tonnes
Organic food import ***= Organic wheat import***	ANECDOTAL based on IA and FiBL http://www.fibl.org/en/themes/organic-farming-statistics.html	tonnes
Population ***= Population in Germany***	EUROSTAT http://ec.europa.eu/eurostat/web/agriculture/data/database	citizens
Per capita food consumption ***= Per capita wheat consumption***	FAOSTAT http://faostat3.fao.org/	tonnes/capita

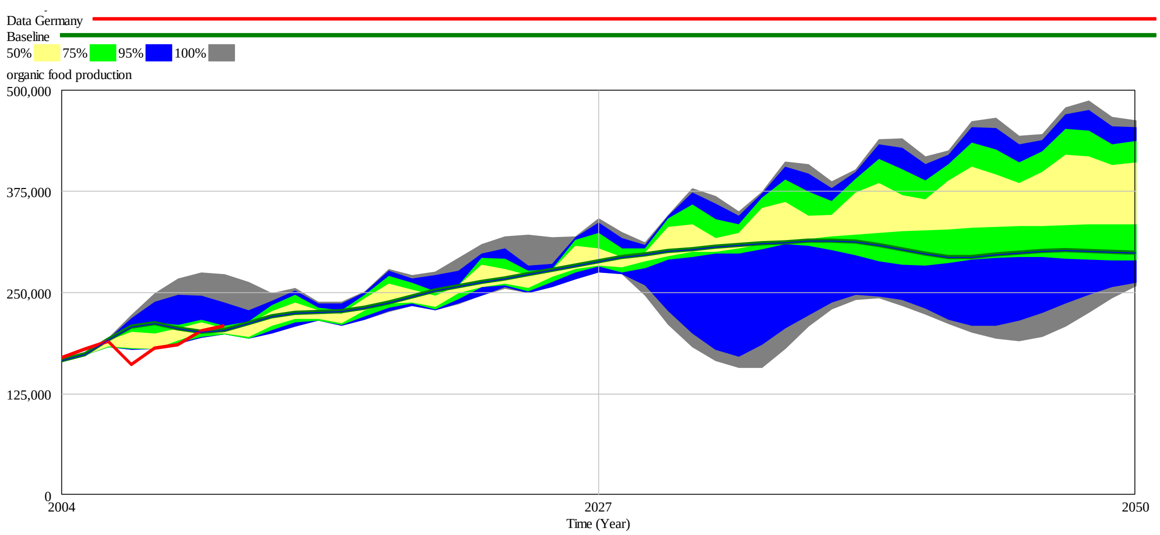
Table 3 Baseline model calibration of exogenous specification

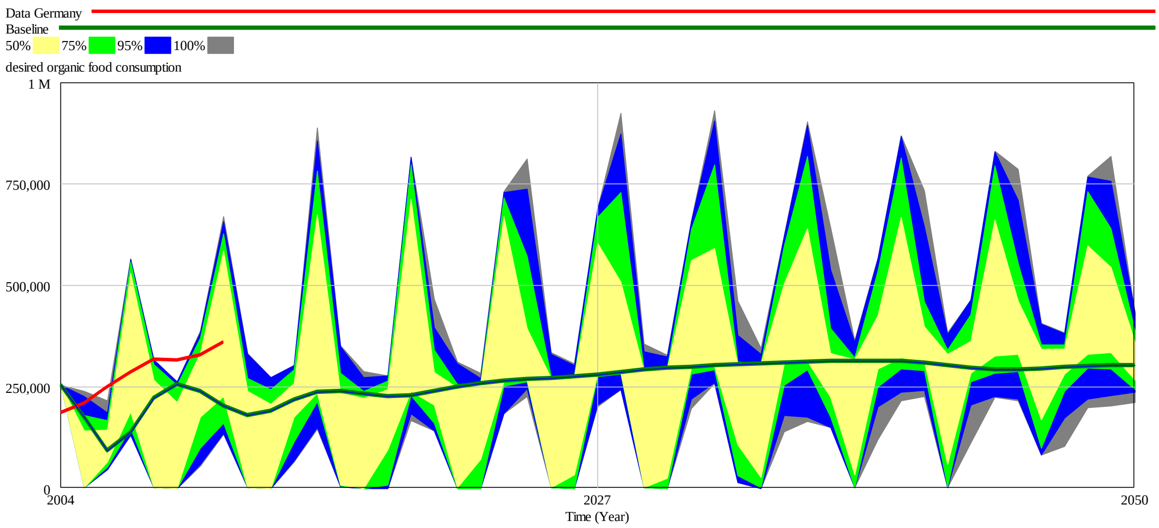
COMMUNICATION & PROMOTION=1 Units: Dimensionless
CONSUMER PREFERENCES FOR ORGANIC FOOD FRACTION= 0 Units: 1/Year
DESIRED CONSUMER CONFIDENCE=1 Units: Dimensionless
DURATION OF GROWING SEASON=1 Units: Year
EU ORGANIC STANDARDS=1 Units: Dimensionless
EU SUPPORT FOR ORGANIC FOOD PRODUCTION=538.286 Units: Euro/Ha
EXPECTED PROFITABILIY OF CONVENTIONAL FOOD PRODUCTION= 0.325 Units: Dimensionless
FIXED COSTS OF ORGANIC FOOD PRODUCTION= 463.12 Units: Euro/Ha
INITIAL CONVENTIONAL LAND AREA=3.1116e+006 Units: Ha
INITIAL EXPECTED ORGANIC CROP YIELD= 3.76288 Units: Tonnes/Ha
INITIAL ORGANIC FOOD SUPPLY-CHAIN ADDED-VALUE MARKUP=0.6 Units: Dimensionless
INITIAL ORGANIC LAND AREA= 47000 Units: Ha
INITIAL PERCEIVED ORGANIC FOOD DEMAND./SUPPLY BALANCE= 1.5 Units: Dimensionless
INITIAL POTENTIAL YIELD OF ORGANIC CROP= 7.5 Units: Tonnes/Ha
*initial price of organic food= (PRICE OF CONVENTIONAL FOOD*PRODUCER PRICE PREMIUM FOR ORGANIC FOOD)+PRICE OF CONVENTIONAL FOOD Units: Euro/Tonnes*
ORGANIC FOOD IMPORT COVERAGE= 1 Units: Dimensionless
ORGANIC FOOD DEMAND ADJUSTMENT DELAY= 0.16 Units: Year
ORGANIC FOOD DEMAND/SUPPLY BALANCE PERCEPTION TIME= 1 Units: Year
ORGANIC FOOD IMPORT DELAY= 2 Units: Year
ORGANIC FOOD SUPPLY CHAIN ADDED-VALUE MARKUP= 0.6 Units: Dmnl
PARAMETER A= 0 Units: Dimensionless
PARAMETER B= 5.95102 Units: Dimensionless
PARAMETER C= 1.02592 Units: Dimensionless
PARAMETER D= 0.995058 Units: Dimensionless
PAST MARKUP PERCEPTION TIME= 2 Units: Year
PER CAPITA WHEAT CONSUMPTION= 0.0790457 Units: Tonnes/People/Year
POPULATION= 8.25317e+007 Units: People
PRICE OF CONVENTIONAL FOOD= 118.1 Units: Euro/Tonnes
PRODUCER PRICE PREMIUM FOR ORGANIC FOOD= 1.49788 Units: Dmnl

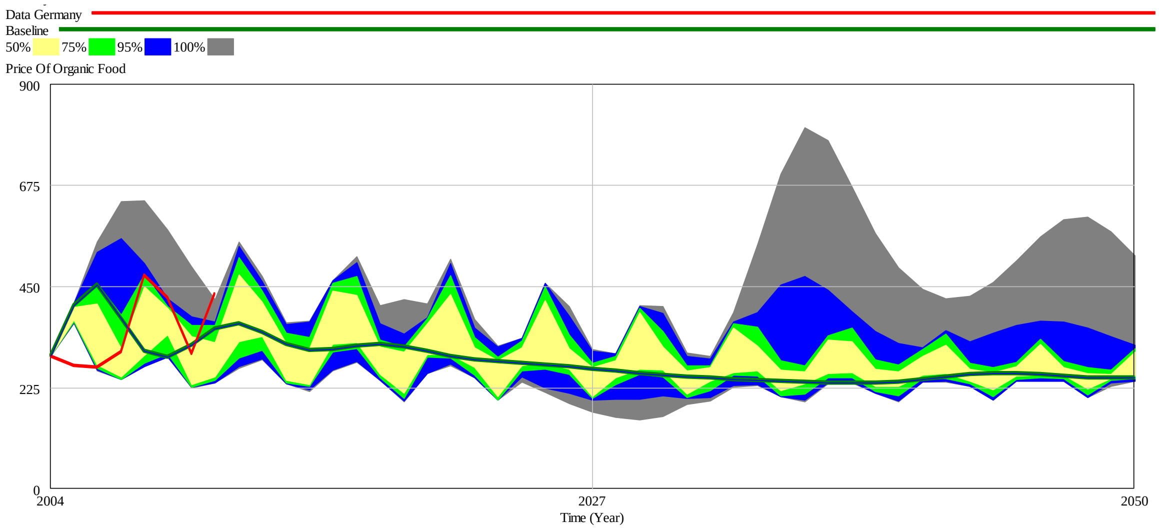
R&D INVESTMENT RETURN YIELD GROWTH FRACTION= 0 Units: 1/Year
REFERENCE ORGANIC FOOD DEMAND= 253500 Units: Tonnes/Year
REFERENCE ORGANIC FOOD DEMAND ELASTICITY= 1.19 Units: Dmnl
SENSITIVITY OF PRICE TO ORGANIC FOOD DEMAND/SUPPLY BALANCE"= 0.726954 Units: Dmnl
*SHOCK/STRESS AFFECTING CONSUMER PREFERENCES= 0 Units: Tonnes/(Year*Year)*
SHOCK/STRESS AFFECTING ORGANIC FOOD DEMAND= 1 Units: Dimensionless
SHOCK/STRESS AFFECTING ORGANIC FOOD SUPPLY= 1 Units: Dimensionless
SHOCK/STRESS AFFECTING PRICE OF ORGANIC FOOD= 0 Units: Dimensionless
SHOCK/STRESS AFFECTING TOTAL COSTS OF ORGANIC FOOD PRODUCTION= 1 Units: Dimensionless
SHOCK/STRESS AFFECTING VARIABLES COSTS OF ORGANIC FOOD PRODUCTION=1 Units: Dimensionless
SHOCKS/STRESSES AFFECTING ORGANIC CROP YIELD= 1 Units: Dimensionless
SWITCH FOR IMPORT OF ORGANIC FOOD= 0 Units: Dimensionless
TIME TO ADJUST CONSUMER EXPECTATIONS FOR PRICE OF ORGANIC FOOD= 0.16 Units: Year
TIME TO ADJUST EXPECTED TOTAL COSTS OF ORGANIC FOOD PRODUCTION= 5 Units: Year
TIME TO ADJUST EXPECTED VARIABLE COSTS OF ORGANIC FOOD PRODUCTION= 2 Units: Year
TIME TO ADJUST LONG-RUN EXPECTED REVENUE= 5 Units: Year
TIME TO ADJUST ORGANIC CROP YIELD EXPECTATIONS= 2 Units: Year
TIME TO ADJUST PRICE OF ORGANIC FOOD= 1 Units: Year
TIME TO ADJUST SHORT-RUN EXPECTED REVENUE= 2 Units: Year
TIME TO CHANGE ORGANIC FOOD DEMAND BASED ON CONSUMER PREFERENCES= 1 Units: Year
TIME TO PERCEIVE ORGANIC FOOD PRODUCTION RELATIVE MARKUP= 1.5 Units: Year
VARIABLE COSTS OF ORGANIC FOOD PRODUCTION= 476.17 Units: Euro/Ha

Market uncertainty – results based on Monte Carlo sensitivity analysis

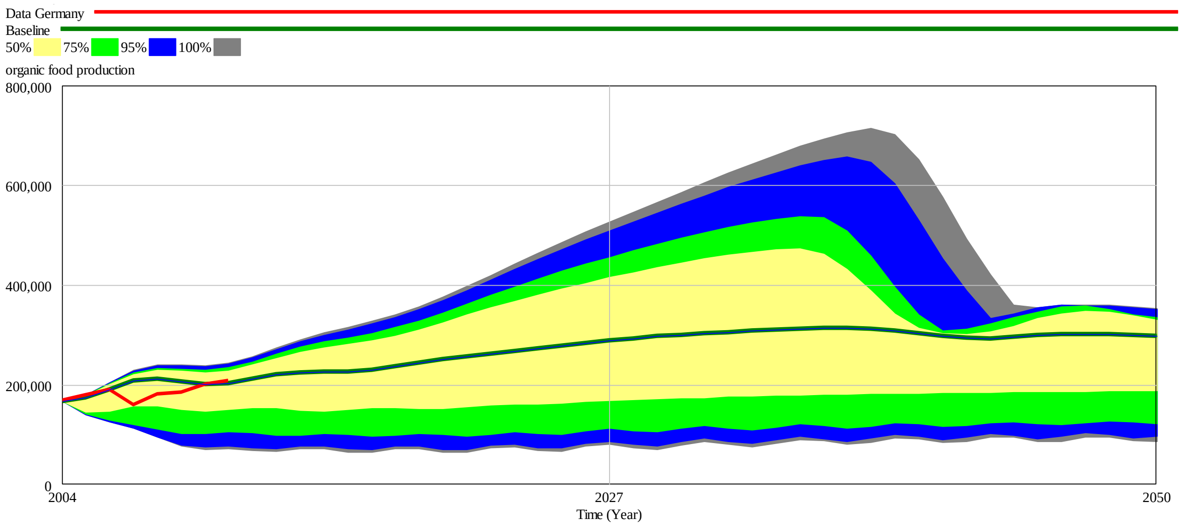
Organic wheat demand elasticity: 0.1 – 8

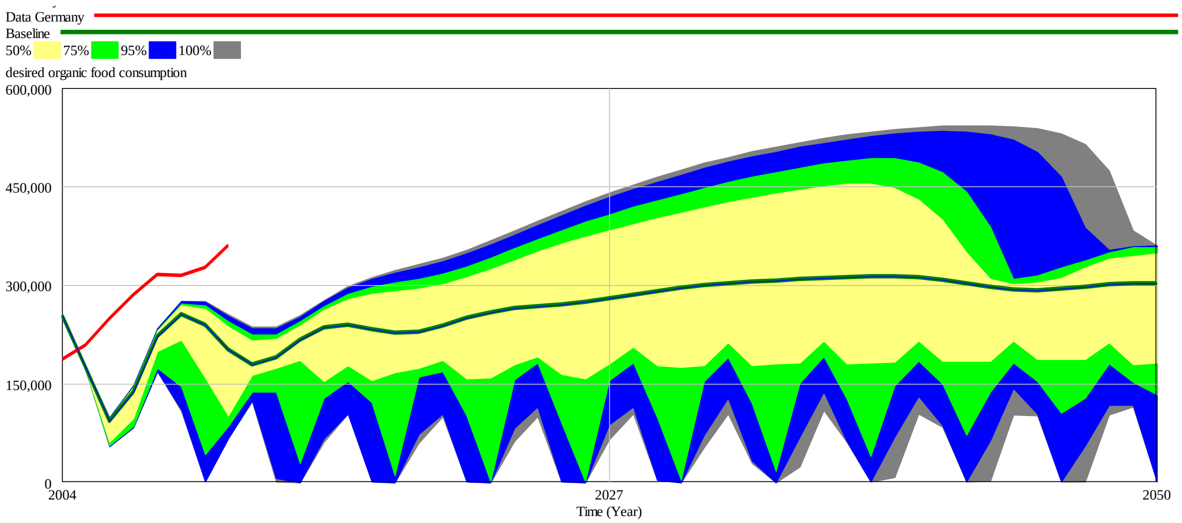


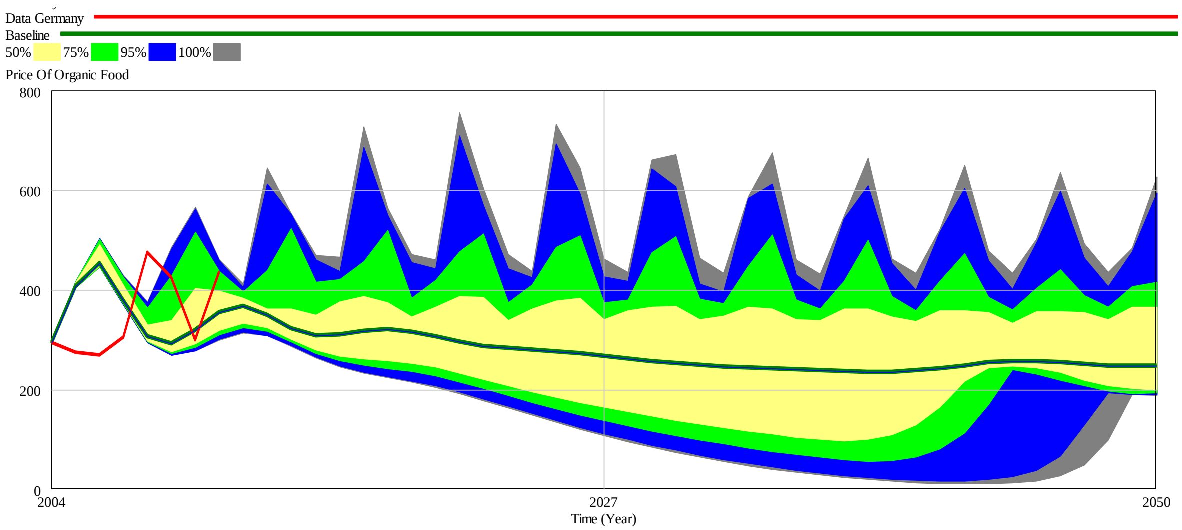




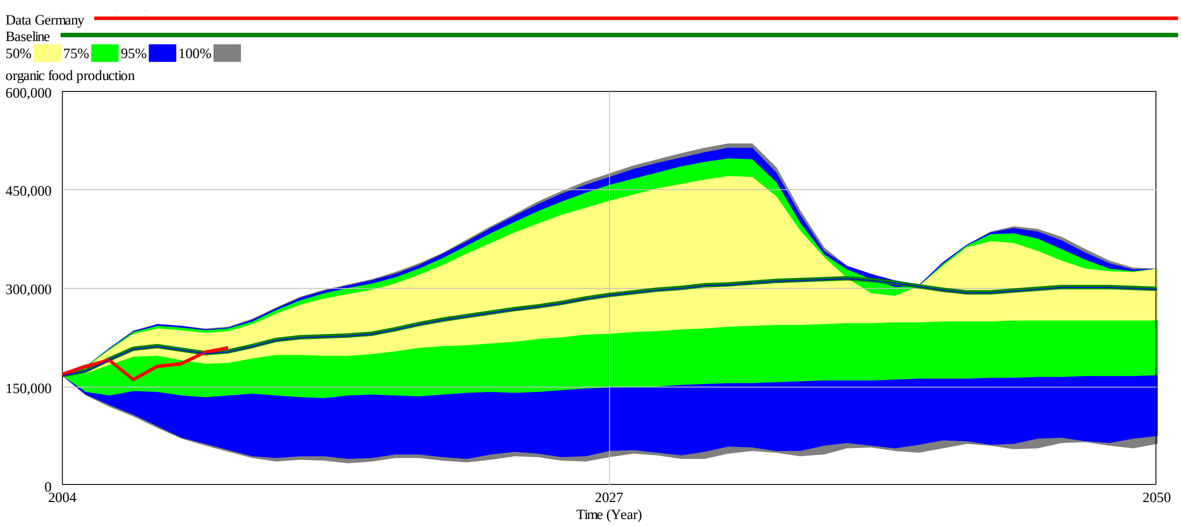
Costs of organic wheat production: 0 – 1000 EURO/ha

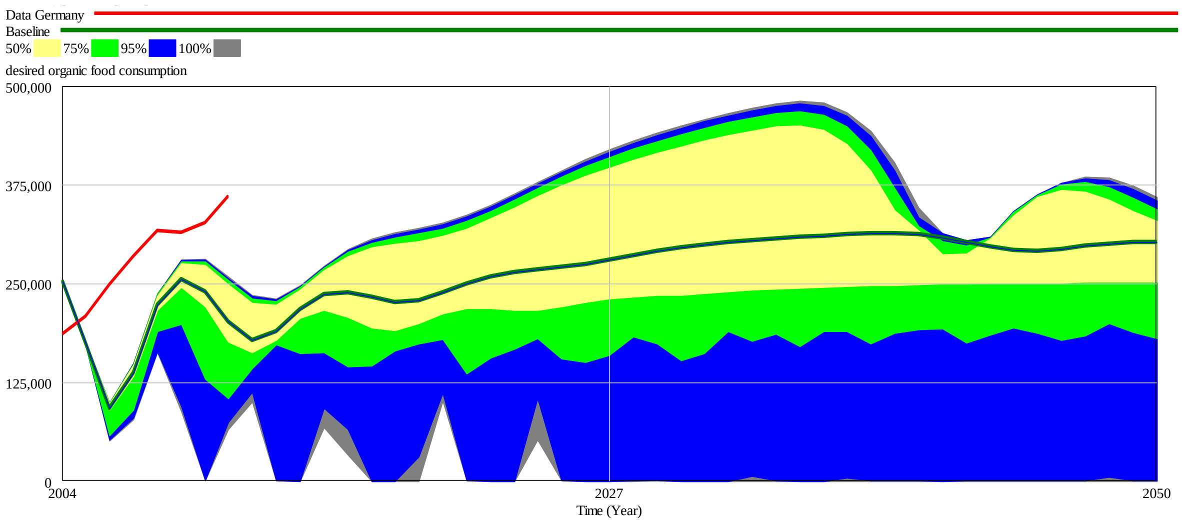


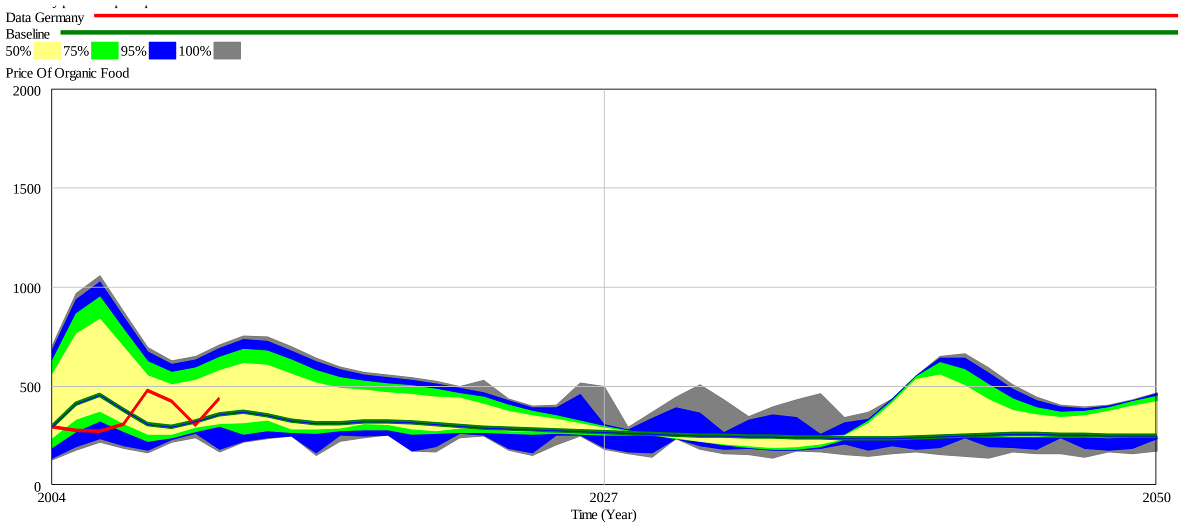




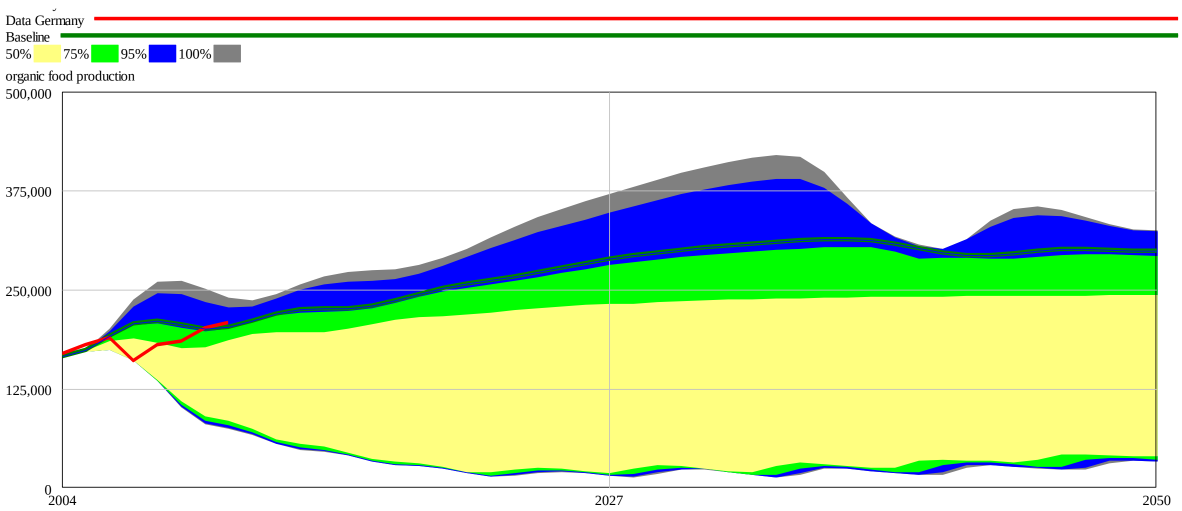
Producer price premiums for organic wheat production: 0 – 500%

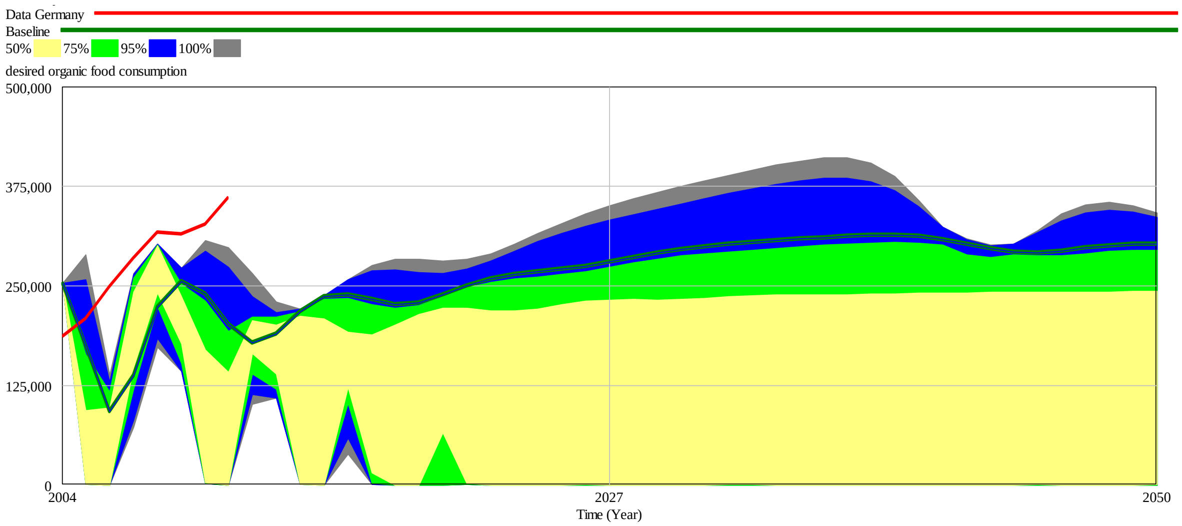


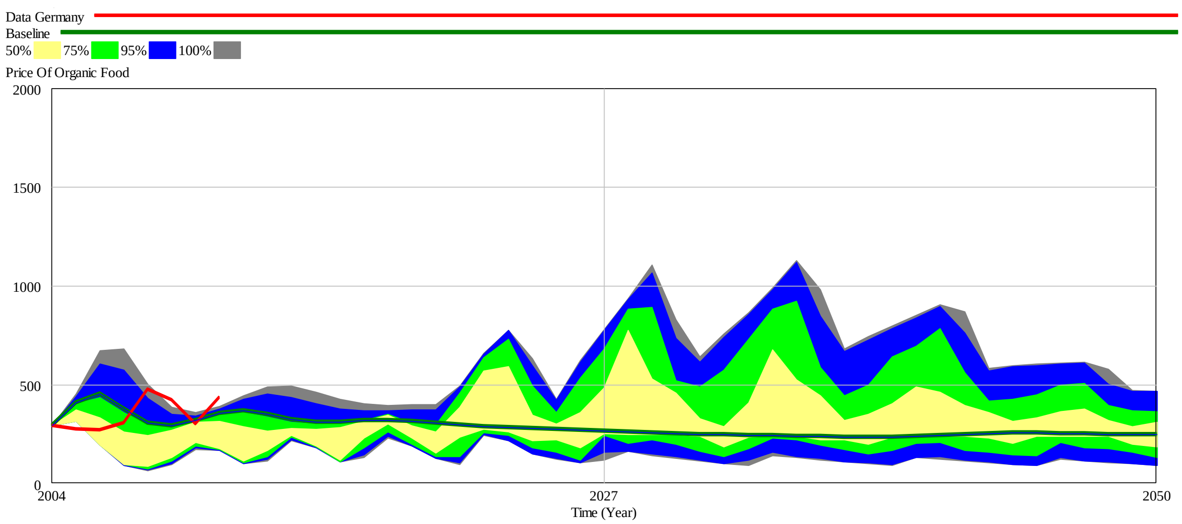




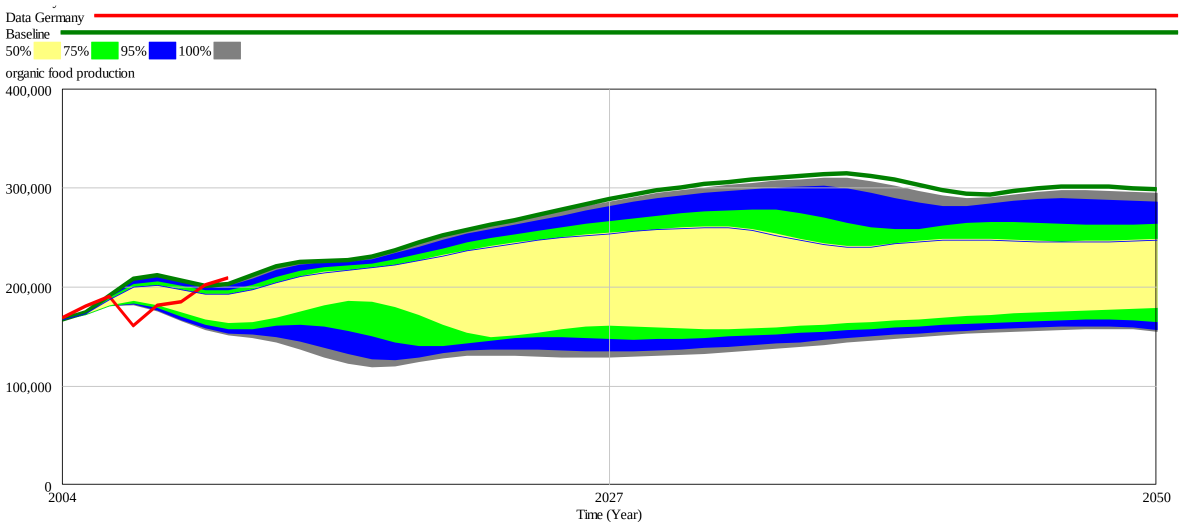
Producer price premiums for organic wheat production: 0 – 500%

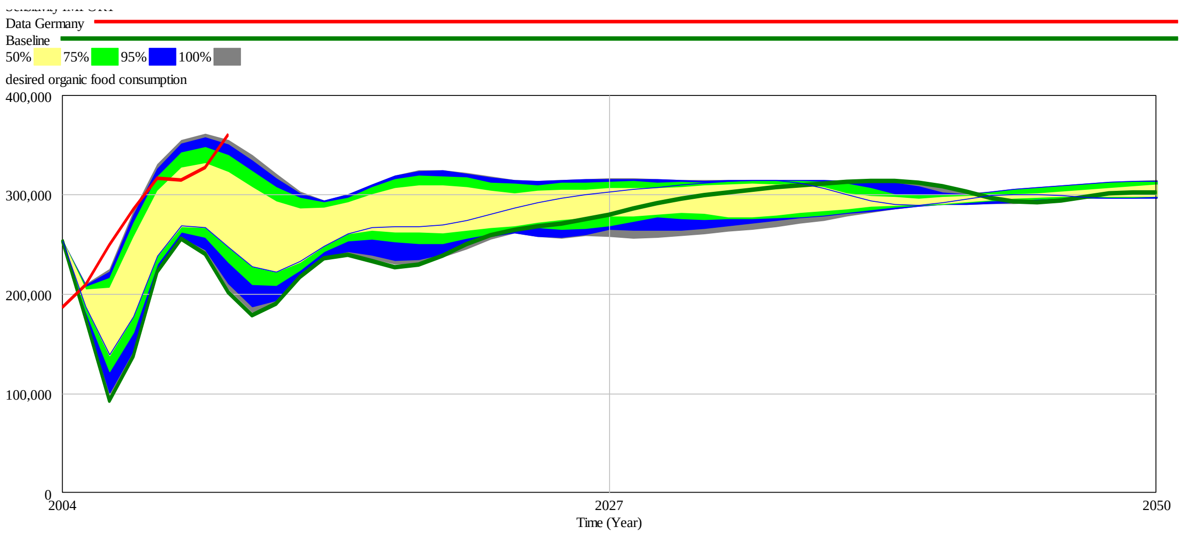


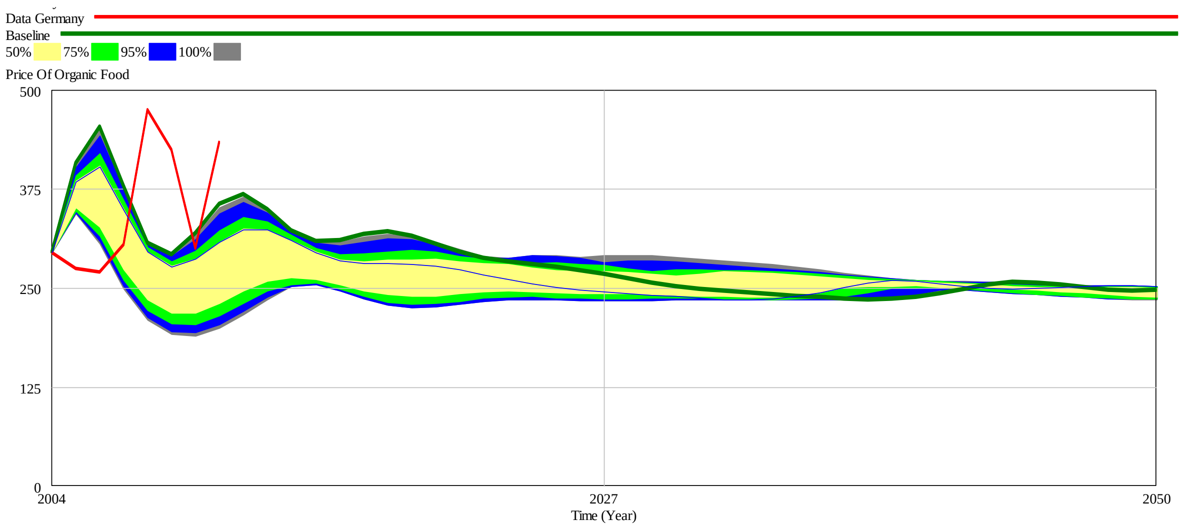




Import of organic wheat: 0 – 100% of organic domestic wheat production

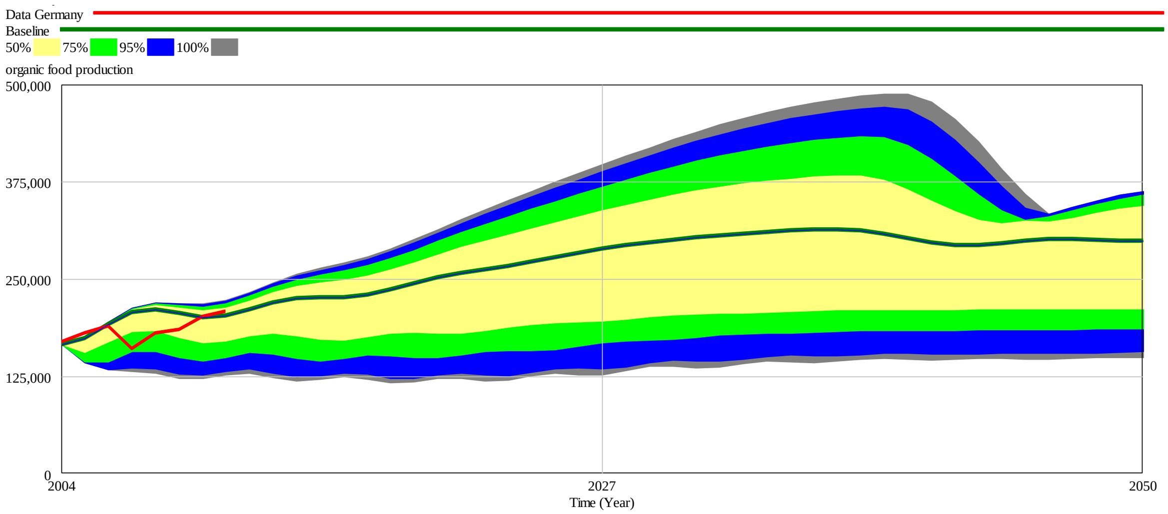


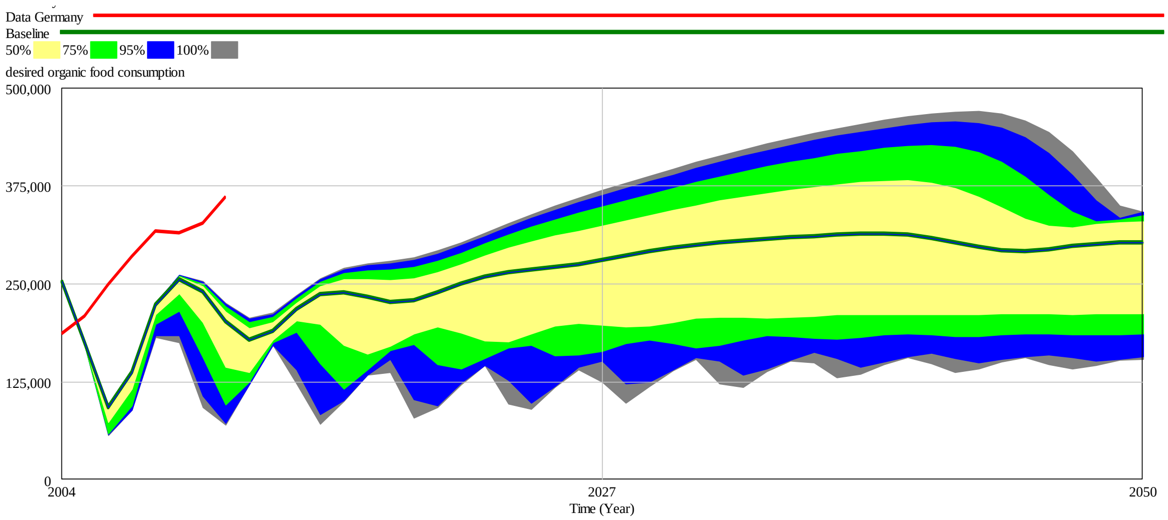

Data Germany
Baseline
50%
75%
95%
100%
desired organic food consumption
400,000
300,000
200,000
100,000
0
2004
2027
2050
Time (Year)

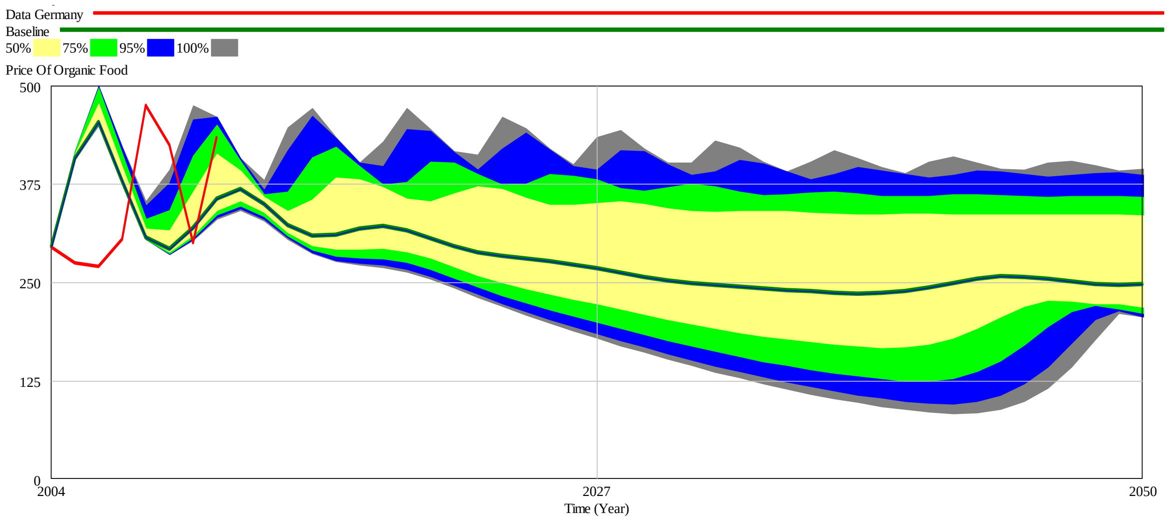

Data Germany
Baseline
50%
75%
95%
100%
Price Of Organic Food
500
375
250
125
0
2004
2027
2050
Time (Year)

Policy uncertainty – results based on Monte Carlo sensitivity analysis

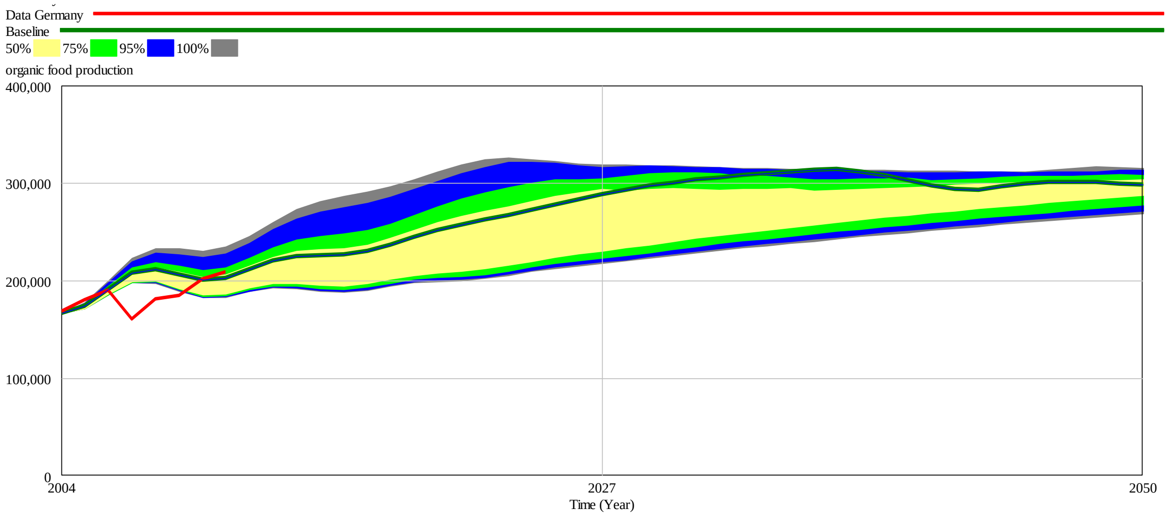
Subsidies for organic wheat-based farming system: 0 – 1000 EURO/ha

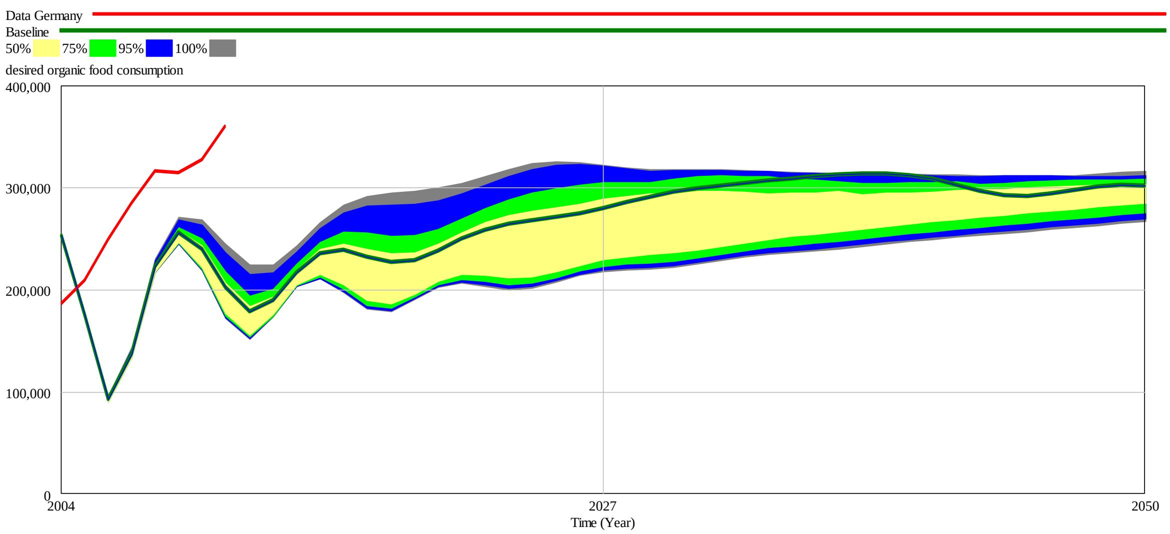


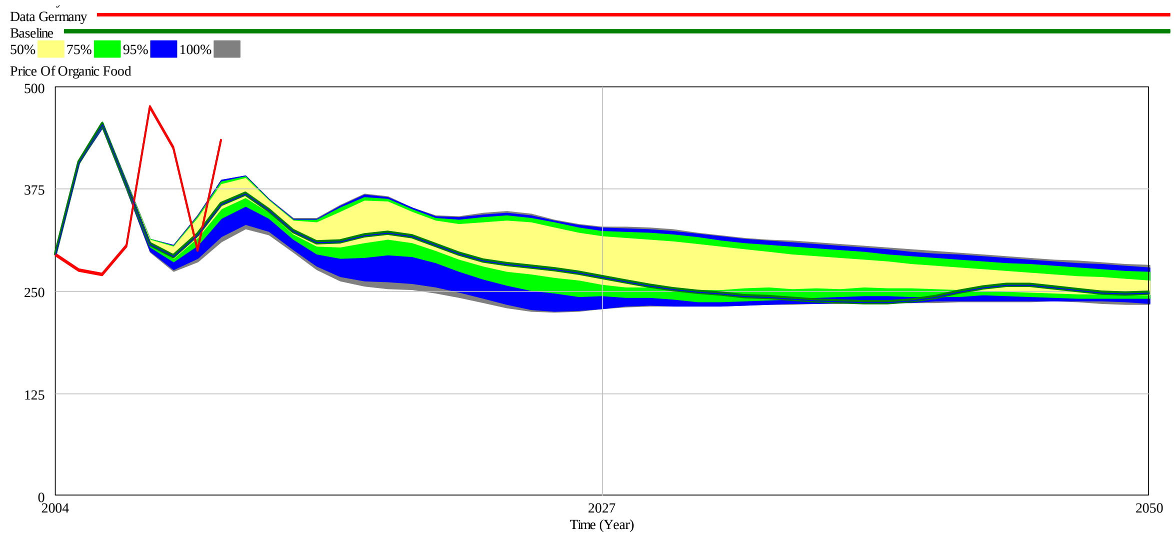




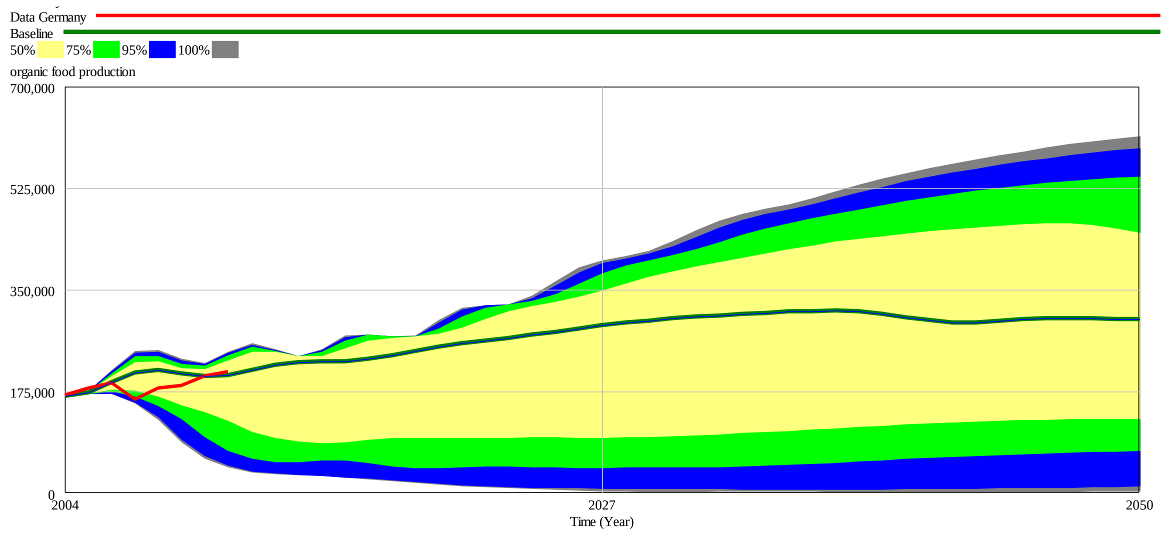
Conversion period: 1 – 3 years

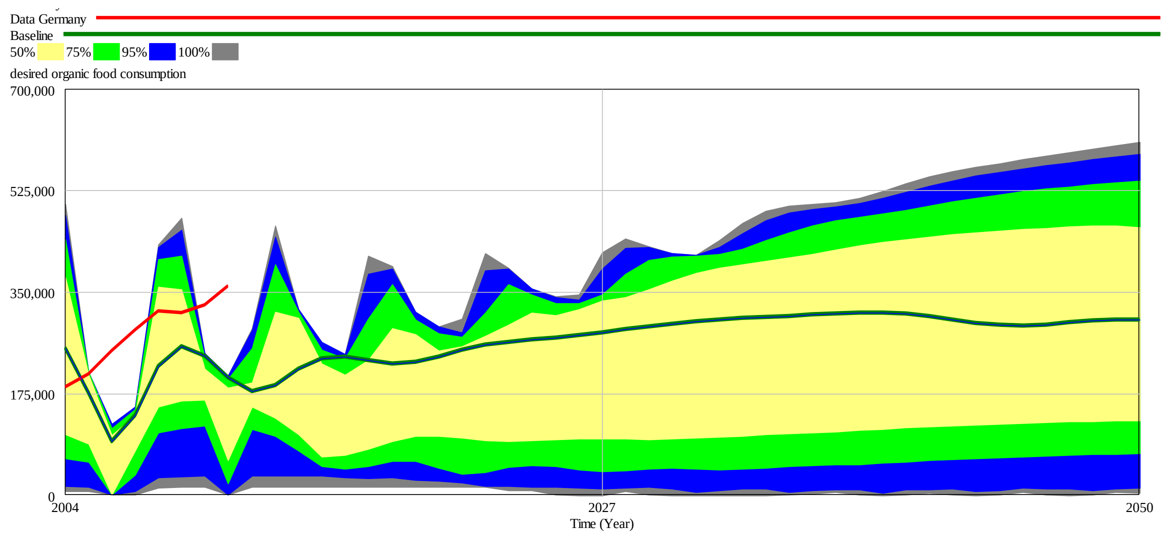


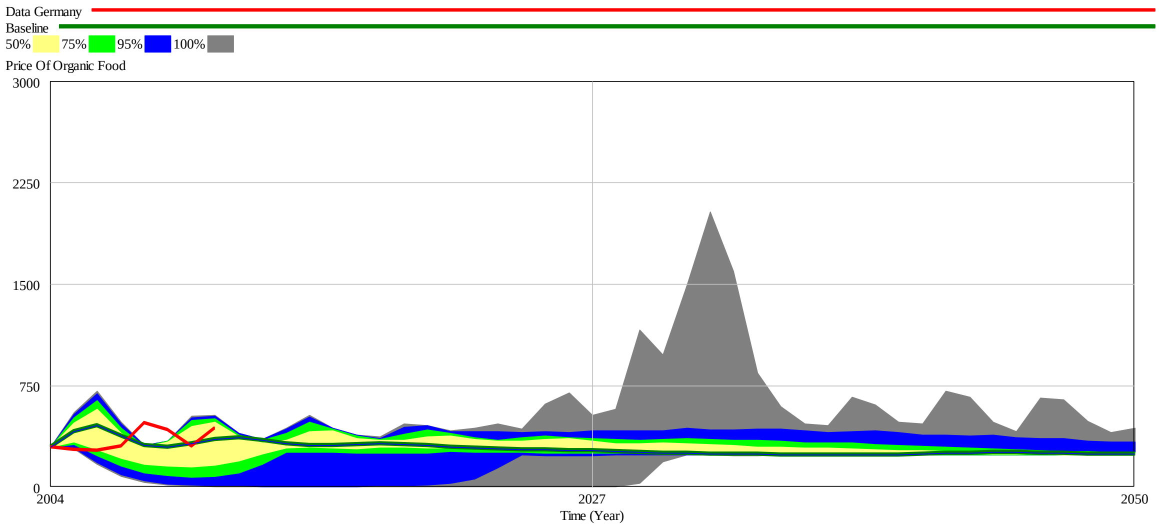




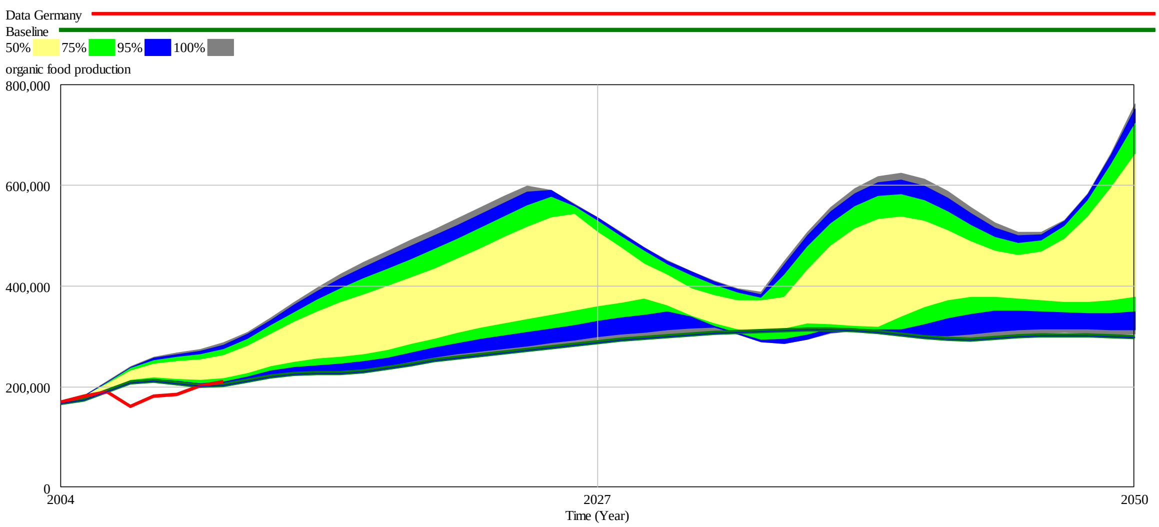
EU standards: 0 (not strict) – 2 (extremely strict)

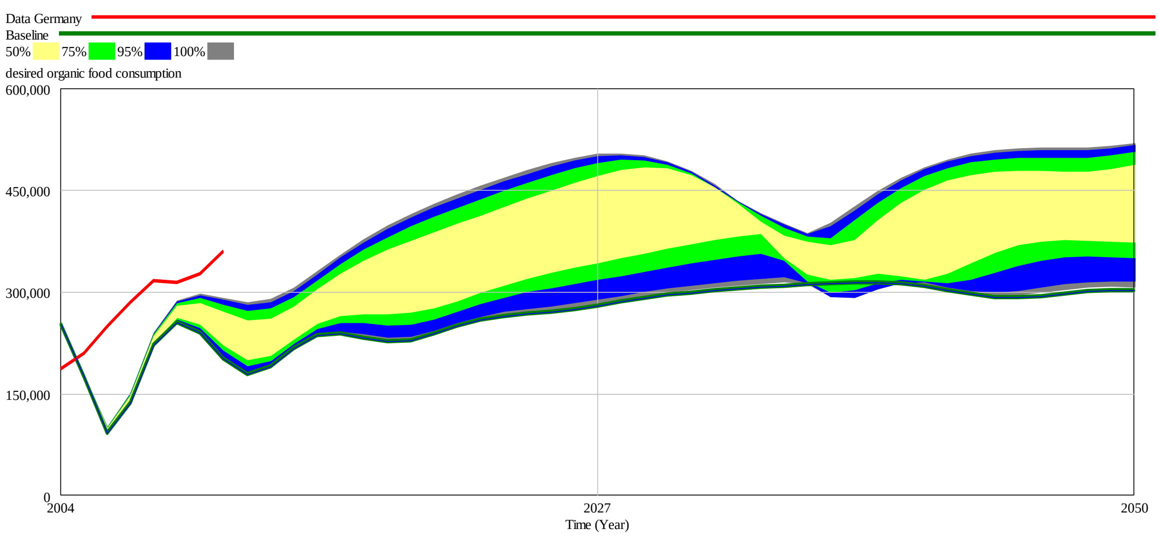


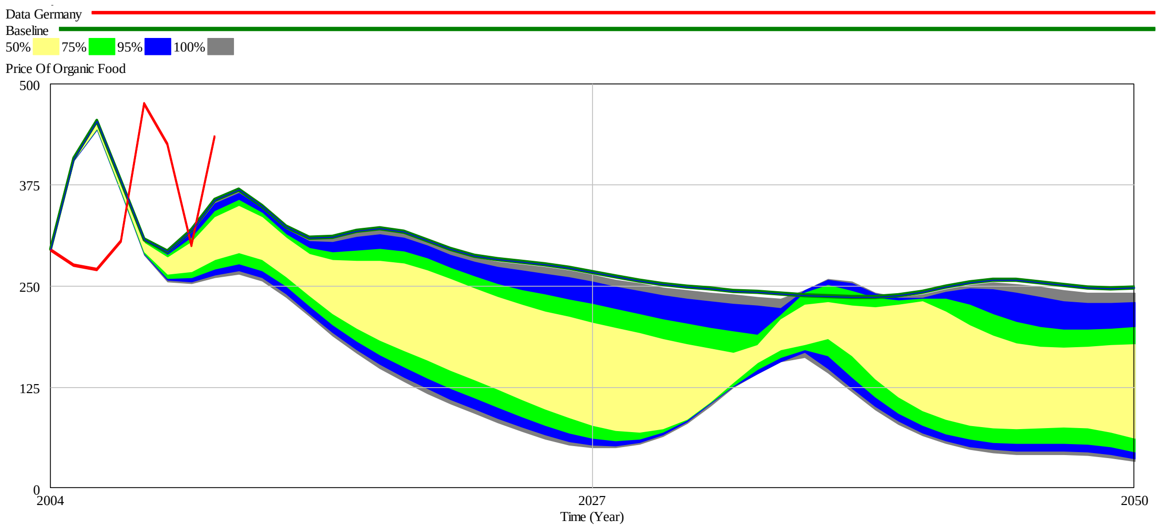




Investments in R&D to increase yield: 0 – 5% return on investment

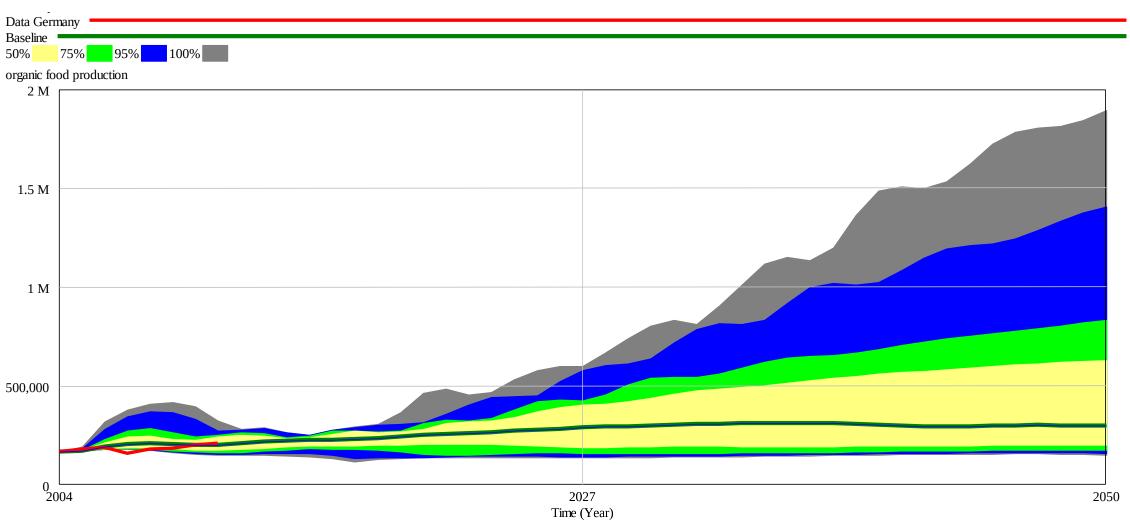


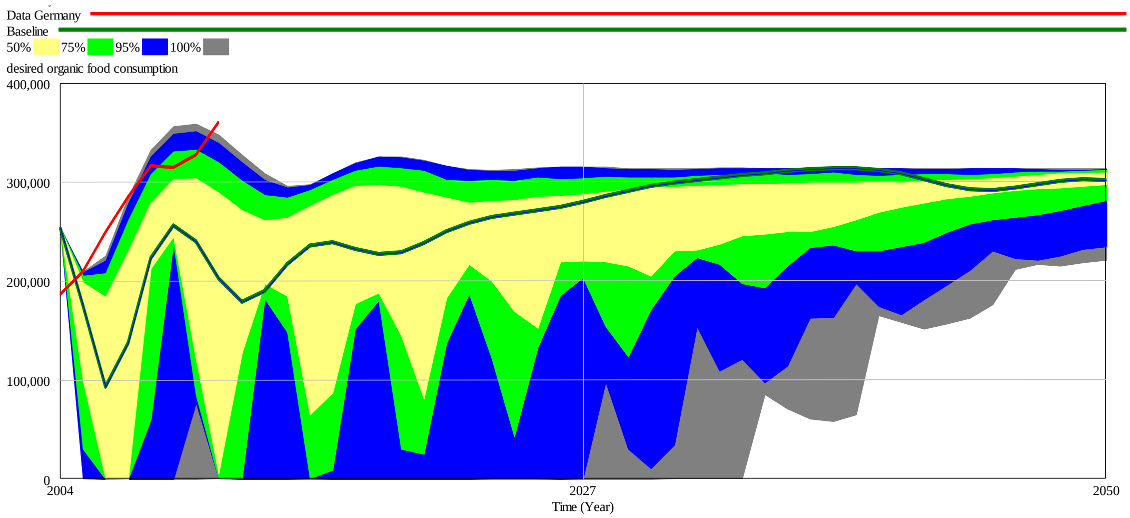


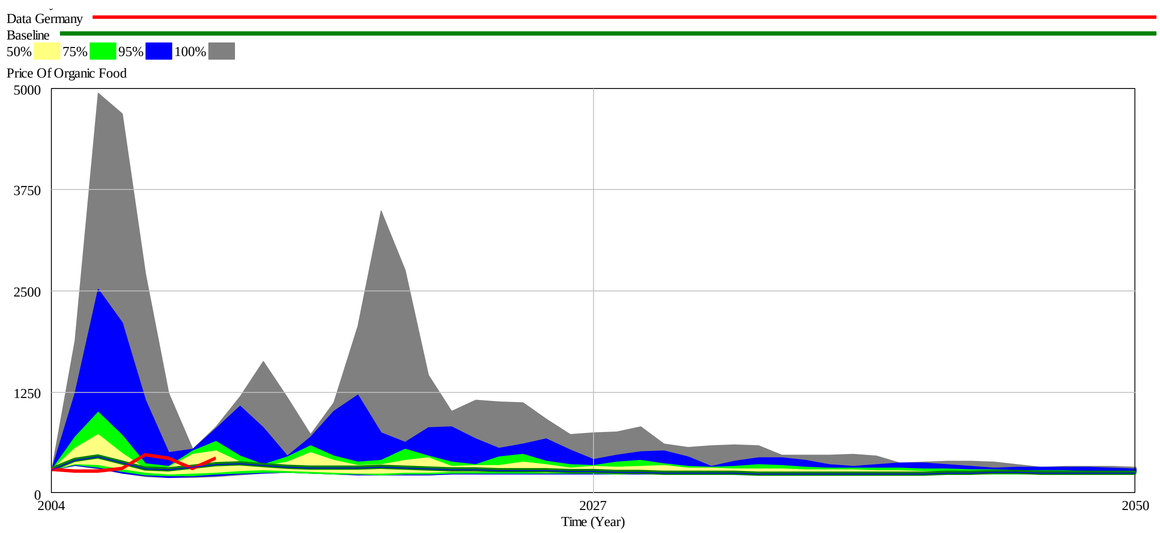


External factors uncertainty – results based on Monte Carlo sensitivity analysis

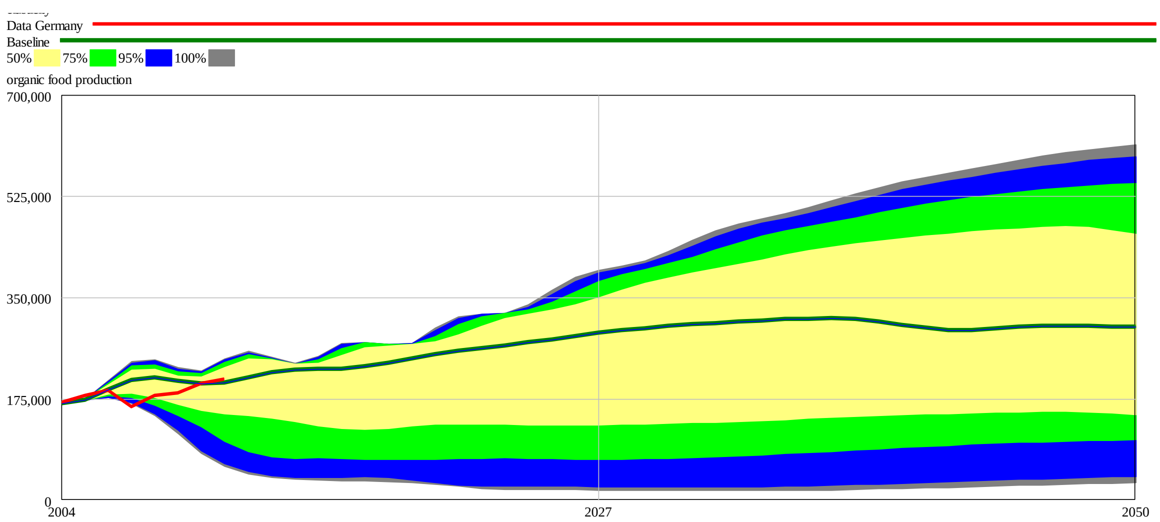
Organic wheat supply shock: 0.1 (significantly reduced) – 2 (doubled)

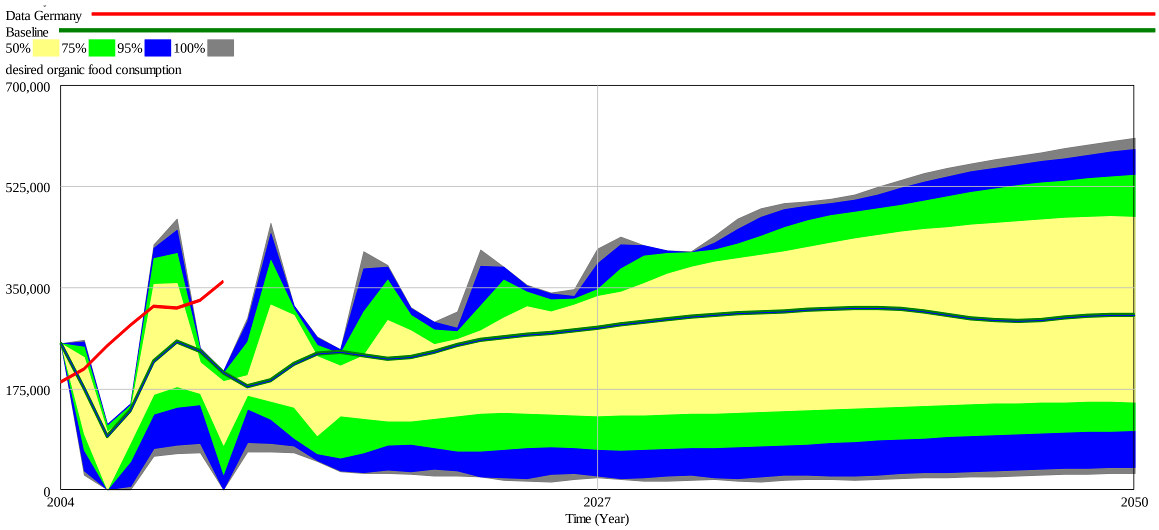


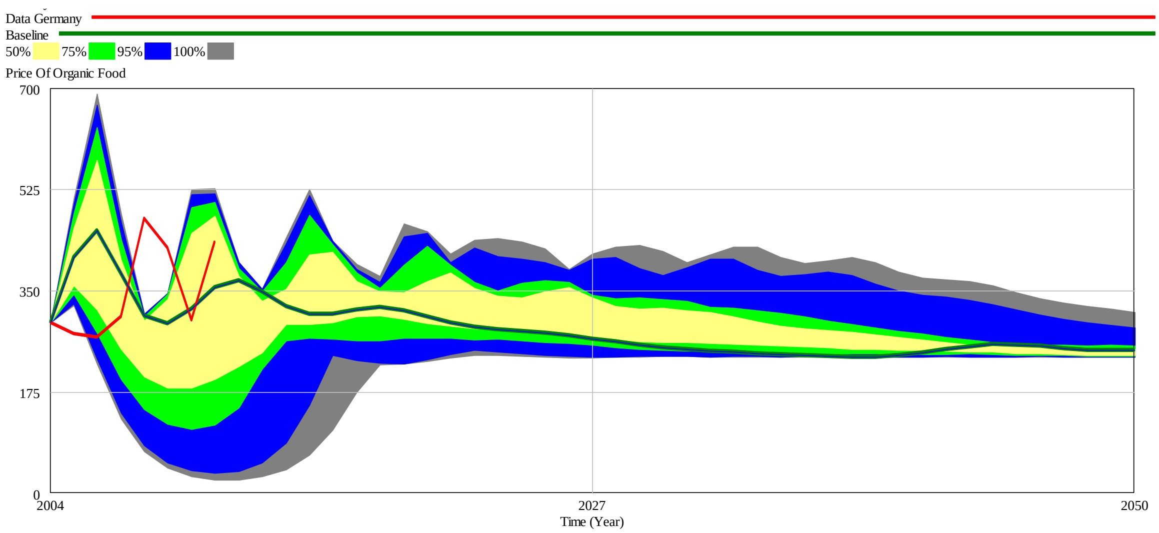




Organic wheat demand shock: 0.1 (significantly reduced) – 2 (doubled)




Data Germany
Baseline
50% 75% 95% 100%
desired organic food consumption
700,000
525,000
350,000
175,000
0
2004
2027
2050
Time (Year)


Data Germany
Baseline
50% 75% 95% 100%
Price Of Organic Food
700
525
350
175
0
2004
2027
2050
Time (Year)