# Food Security as an Outcome of Food Systems

## A Feedback Perspective

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## Abstract

Hunger is an important topic still today: one out of eight people worldwide lives food insecure even after having received attention through the United Nation's Millennium Development Goals. This article looks at national food security as the outcome of food systems and tries to capture some of the system's complexity using a feedback perspective. Following a generic socio-ecological system approach a general food system framework on country level has been developed in form of a causal loop diagram. Based on the framework three examples of general food security oriented and sustainability enhancement strategies are discussed. These cases illustrate that there are trade-offs between different goals such as food security and sustainability or between different stakeholders. The cases illustrate further that the impact of policies depends on the country's specific context, the interlinkages within and related to the food system and the timing of implementation. This implies that there is no generally valid single solution and that a context specific understanding of the complexity of the system is needed for policy evaluation and formulation.


***Key Words**: Food Security, Food System, Socio-Ecological System, Framework, Agriculture, Feedback Loop, Causal Loop Diagram, Policy*

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## Introduction

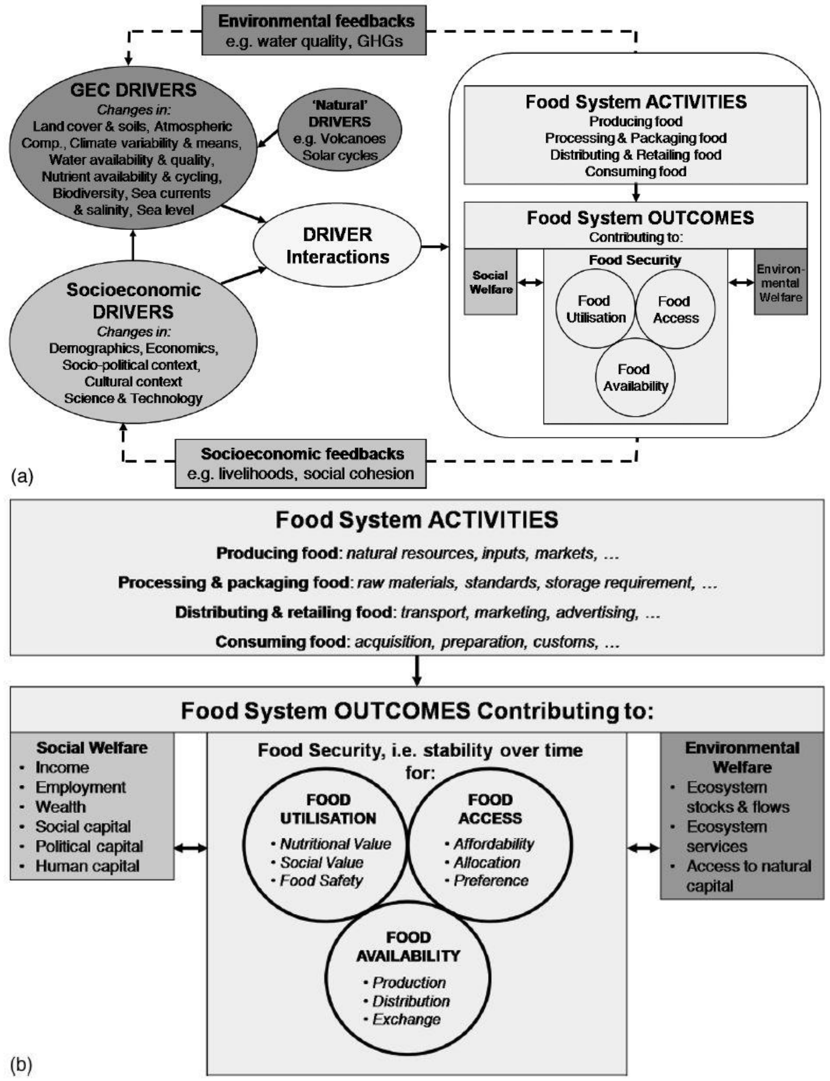
"To eradicate hunger" is part of the first United Nations' Millennium Development Goals (MDG; United Nations 2013). It implies that the share of undernourished people worldwide shall be divided in half from 23% in 1990 to 12% in 2015. Progress has indeed been reported, especially in increasing food production over the past decades (Charles et al. 2010). However, still about 870 million people or one out of eight of the world's population are at least seasonally undernourished today (United Nations 2013). Even though the MDG of reducing hunger is within reach, food security stays a major challenge also beyond 2015, particularly in the light of the rising world population, and especially in regions such as Sub-Saharan Africa where still 27% of the population are undernourished.

At the same time recent reports start to focus more and more on the interaction of food systems and environmental change which – at least partly – drive and affect each other (Liverman and Kapadia 2010). A feedback mechanism of global importance is climate change. It is seen as a major threat to food security (FAO 2008, Lobell et al. 2008, etc.), while agriculture and food systems themselves are major contributors to climate change with a share of 30-35% of the yearly global greenhouse gas emissions (Foley et al. 2011). However, also other environmental problems with a feedback nature such as loss of biodiversity, land use change or nutrient cycles attract attention (e.g. Rockström et al. 2009) and raise another challenge to food security: i.e. to increase food security without compromising natural resources (Ericksen et al. 2010a). Therefore new incentives and policies are needed to ensure the sustainability of ecosystem services and agriculture (Tilman et al. 2002).

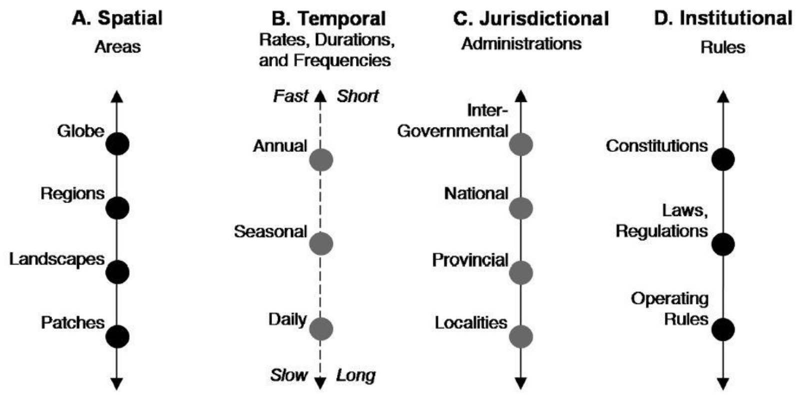
In addition to environmental change several socio-economic issues play important roles in food systems and determine outcomes such as food security (Ericksen 2007). Poverty is seen as an almost inevitably cause of food insecurity by Tanumihardio et al. (2007) and is also an outcome to those people involved in food systems with income generated activities (Ericksen 2007). However, various literatures points out other determinants and challenges such as gender (Quisumbing et al. 1995) and education (Rosegrant and Cline 2003), as well as other outcomes such as income, social and human capital.

In order to link these different challenges, food security can be understood as the outcome of different activities in the food system if the system is defined in a broad and general way (Ericksen 2007). Doing so Ericksen suggests a socio-ecological system (SES) approach including food system activities such as production, processing, distribution and consumption, food system outcomes (food security, social and environmental welfare) as well as environmental, social, political and economic determinants summarised in socioeconomic and global environmental change (GEC) drivers (Figure 1). The activities within and the factors around the food system interact on different scales and levels, where Cash et al. (2006) define different scales such as spatial, temporal, jurisdictional, institutional, management, etc. The term "level" refers to the units of analysis located at different positions within a scale (Figure 2).

The complexity of food systems arises from the interlinkage and interaction of these activities and drivers on various scales and levels. The complexity also might be one of the reasons why hunger is a problem still today and deciding which way to go in taking action not an easy task. An analysis which wants to capture this complexity therefore has to focus on the system's dynamics, interactions and feedbacks and has to be able to deal with non-linear relationships (Ramalingam et al. 2008, Thompson and Scoones 2009). Godfray et al. (2010) and Foley et al. (2011) point out some common policy options addressing sustainable food security enhancement, i.e. closing yield gaps, increasing resource efficiency, increasing production limits, shifting consumption patterns, stopping agricultural expansion and reducing waste. In order to evaluate such policies from different angels it is important to have meaningful tools being able to account for the complexity of the context.




Source: Ericksen et al. (2010a)
Figure 1: (a) Food systems and their drivers. (b) Components of food systems (detailed view of the food system in Figure 1 a).




Source: Cash et al. 2006
Figure 2: Different scales and levels critical in understanding and responding to food system interactions (exemplified selection).

Hammond and Dubé (2012) argue that system dynamics and agent based modelling are the two modelling approaches of particular interest for a systemic perspective on food security, namely because of their ability to deal with the elements of complexity stated above. And as a matter of fact different models in the field of food and nutrition have already been published within system dynamics – the more feedback oriented approach of the both. A common feature of these models is that they are designed to deal with a specific problem within the field of food systems and food security: a literature review can be found in Giraldo et al. (2008). However, there is not yet a framework on a conceptual, generic base to analyse food security from a feedback perspective.

The importance of a food system framework from a feedback perspective lies:

- In the conceptualisation of the system for studying and understanding its complexity and behaviour,
- In building a frame where different present and further questions and studies can be placed in a structured way,
- And especially in contextualising the policy environment to understand and evaluate possible policy implications in an interlinked and broad frame.

In this study a feedback based framework of a generic food system on a country level is developed in form of a causal loop diagram (CLD). The paper starts by presenting the framework's settings followed by a section elaborating on the conceptual framework. Then some examples of the most common, globally recommended food security and sustainability enhancement policies and their implications are discussed on country level based on the framework (i.e. "Closing Yield Gaps", "Increasing Production Limits" and "Stopping Agricultural Expansion" based on Godfray et al. 2010 and Foley et al. 2011). The paper closes with concluding remarks about these general policy options.

## Framework Setting

The framework was built on the food system approach of Ericksen (2007, Figure 1), where on the agricultural part the commodity cycle model of Sterman (2000) and for the socioeconomic environment the MacroLab Model of Wheat (2007) was used as an inspiration. Since especially GEC feedback mechanisms such as changing climate or land use changes paly out over long time periods the framework of this paper is designed to capture long time horizons and is designed to look at food security on a yearly basis. In order to capture a big part of the feedback mechanisms described by Ericksen (2007) endogenously and in order to capture the level where many decisions about food policies are taken (indicated by FAO 2014) this framework looks at an aggregated country level. This said it is clear that certain aspects of importance are left out such as food security on household level, seasonal variations, etc.

The framework was built as a CLD because this method offers the possibility to map causal links between different variables, feedback loops and define boundaries of any system (Sterman 2000). And in general, approaches built on causalities, for instance expressed as differential / difference equations such as system dynamics models, are strong in capturing feedback mechanisms and expressing the resulting behaviour (Rahmandad and Sterman 2008). However, due to their causal nature they have a limited capacity to capture the interaction of different actors and institutions. And referring to the nomenclature of Cash et al. (2006) feedback based approaches are strong in capturing cross-scale links, however have limitations in addressing cross-level trade-offs (Kopainsky et al. 2014).

These limitations of this feedback based framework therefore have implications on the expected applicability on food security outcomes (Table 1). On a national level it possible to include the activities of food production on an aggregated level. However, distribution is mainly the result of the interaction of different actors and therefore difficult to include in an aggregated framework (Gabbert and Weikhard (2001) for instance criticised the aggregated “prevalence of undernourishment” distribution concept of the food and agriculture organisation of the United Nations (FAO 1996)). Food exchange can be included to the extent of international trade, however, trade on lower levels such as intra-national trade and trade between households needs to be excluded. Affordability is reflected over the aggregated household income. Allocation depends on the functioning and interaction of individual distribution channels, which cannot be represented by an aggregated approach. Preferences, as well as social values are determined by various factors such as season, tastes, custom and tradition (Ericksen 2007) which are difficult to capture, among others due to their qualitative nature. Nutritional value can be determined on an average per capita base. And food safety is the result of regulations, and regulation enforcement on food related processes which is difficult to model with an endogenous character on a country level.

The strength of this approach lies in capturing the supply and demand oriented processes including elements of all three food security dimensions.

Table 1: Food security outcomes excluded and included in the food system framework in this paper.

| | **Included** | **Excluded** |
|---|---|---|
| **Food Availability** | Production<br>(Exchange) | Distribution |
| **Food Access** | Affordability | Allocation<br>Preference |
| **Food Utilisation** | Nutritional Value | Social Value<br>Food Safety |

## Conceptual Framework

Figure 3 displays the CLD of the generic food system framework on a country level. The CLD is able to give an idea of the complexity of food systems although it is methodological not possible to capture all elements of the food system and the GEC drivers suggested by Ericksen (2007). However, even this incomplete attempt of displaying the system is highly dens of information making it difficult to capture the details. The presentation of this section is therefore structured along the most important feedback loops within the diagram to provide some guidance. The colours of the variable names in the figures refer to the different categories of the original SES framework (the colour code is displayed in Figure 3). It is worth to mention that the categories interact in manifold ways. For instance the food security indicators in red colour derived from Table 1 are part of different feedback loops implying that they are not solely an outcome, however, also a cause at the same time.

Different parts of the framework also (need to) have different levels of accuracy. While the focus was on the food system, other parts such as the GEC and socioeconomic drivers are less accurate and have an illustrative character. For instance population or other economic sectors as drivers are only displayed in relation to direct food system feedback mechanisms and rather important factors determining these variables such as health care system for population or labour markets for economy were left aside in order to hold the focus.

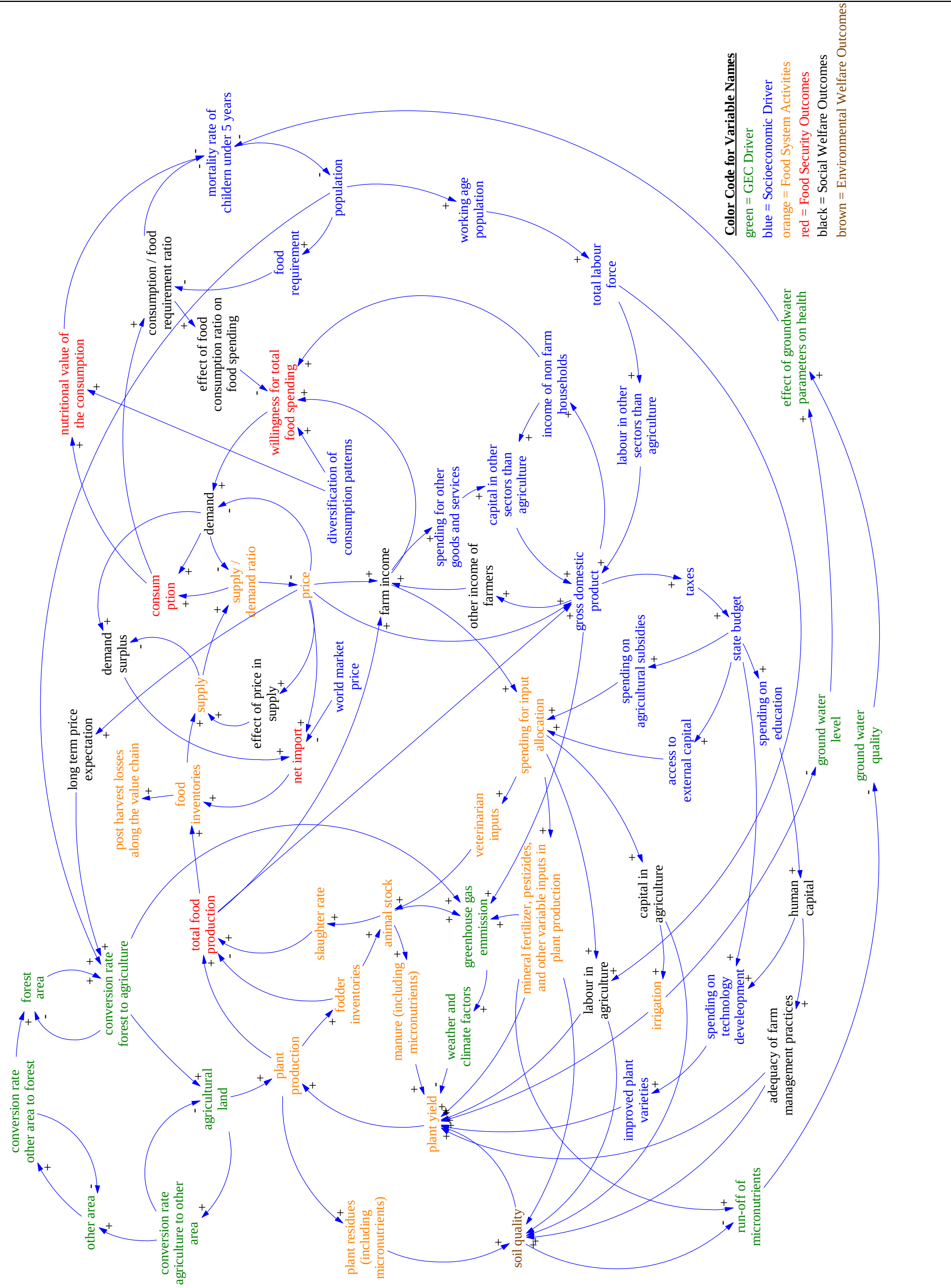



Figure 3: Generic framework of a food system with food security indicators on a country level in form of a causal loop diagram. An arrow between two variables indicates a causality directed by the arrow. A + or – sign at the head of the arrow indicates the polarity of the causal relation. A + means that an increase in the independent variable causes an increases of the dependent variable and a – indicates that an increase in the independent variable causes a decrease of the dependent variable. GEC: global environmental change.

***Production Related Loops***

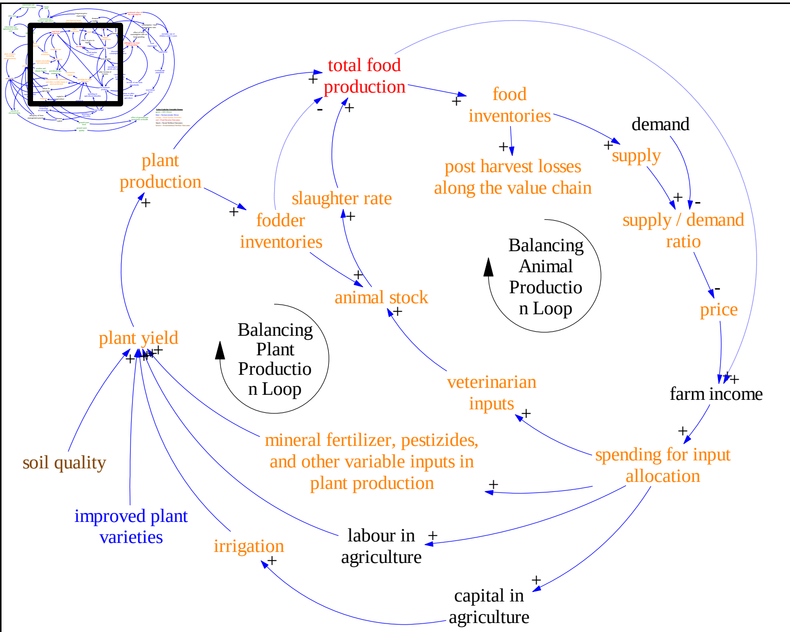



Figure 4: *balancing plant production loop* and *balancing animal production loop*

The main food production feedback loops are the *plant production loop* and the *animal production loop* (Figure 4). Both of them are balancing since more input allocation under normal conditions leads to more production (Schilling 2000), higher inventories and a higher supply (Sterman 2000). A higher supply itself has a decreasing effect on the food price causing a reduced farm income which allows for less input allocation (Varian 2007). The two loops include the whole food value chain with traders, processors, wholesalers and retailers which could be displayed in detail for example following the supply chain approaches of Sterman (2000). However, the focus of this framework is on an aggregated country level and therefore the value chain is summarised within the inventory and supply variable.

Within the *balancing plant production loop* and *balancing animal production loop* the farm income is a central variable which is determined by the price (through the described balancing loops) as well as the production quantity (through a reinforcing loop indicated by the arrow from total food production to farm income in Figure 4). Since they might seem to cancel each other out is important to understand which loop is stronger. The final answer can only be given by empirical analysis, however, in theory it is described that food commodity demand curves very oft are rather inelastic when treated aggregated (Gillespie 2007) and therefore the price effect through the balancing loop on the farm income is stronger than the quantity effect through the reinforcing loop.

It is further important to understand that the animal production loop is coupled with the plant production loop since domesticated animals such as cows, sheep and goats feed on plants. Out of this arises the trade-off between the production of resource and energy efficient plant products for human consumption and the production of protein rich, however, less resource and energy efficient animal products indicated by the arrow from fodder inventories to total food production in Figure 4 (the trade-off is there as long as the animal products are not produced on marginal land, where no plant production for human consumption is possible, Godfray et al. 2010). In order to keep track of this resource perspective a co-flow structure could be attached to the two production loops. And a similar trade-off could be displayed for any other agricultural production used for a non-food purpose such as biofuels or fibre crops. And of course to be more accurate plant production and animal production can be subdivided into more precise categories such as different crops, animal species etc.

Two important feedback loops for organic fertilization and soil quality are the *reinforcing plant residue loop* and the *reinforcing animal manure loop* (Figure 5). One of their major contributions is the addition of organic nutrients to the soil such as Nitrogen, Phosphorus and Potassium (Scheffer and Schachtschabel 2010, Schilling 2000). These loops include the nutrient cycles which could be displayed as a co-flow structure but were left away for simplicity reasons. However, even though they are reinforcing feedback loops when it is coming to fertilization in practice they need to follow the law of conservation of mass: More manure and plant residues lead to more yields (via more nutrients) and more yield leads to more fodder, more animals, more manure and more plant residues, respectively. Normally some parts of the yield are taken out of the farm cycles, e.g. for human consumption. This implies that only a share of the total nutrients taken up by the plants is fed back via the animals and plant residues to the soil. Without any external input it is therefore impossible to have an endogenous growth within this feedback loop. On the other hand plant residues and animal manure also add organic carbon to the soil which is important for the soil's quality such as soil structure, microbial activity, water and micronutrient storage, energy absorption, etc. (Scheffer and Schachtschabel 2010). The soil quality is also affected by other factors such as capital use, labour and other inputs. However, depending on the state of the soil quality and the application technique, such inputs might in- or decrease the quality and therefore it isn't possible to allocate a polarity to these arrows.

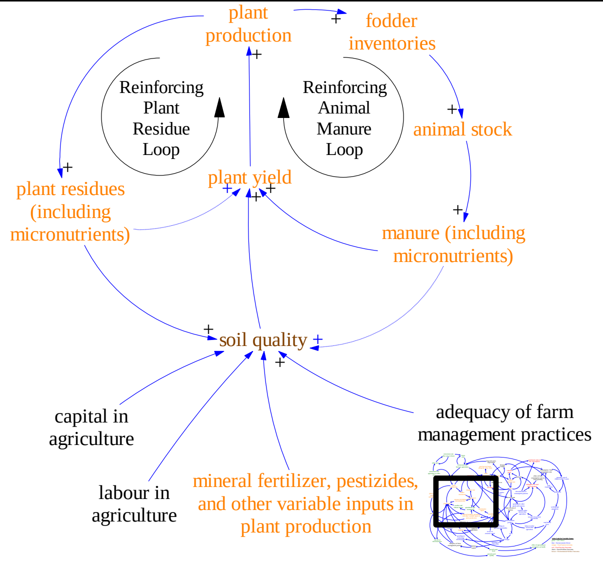



Figure 5: *reinforcing plant residue loop* and *reinforcing animal manure loop*

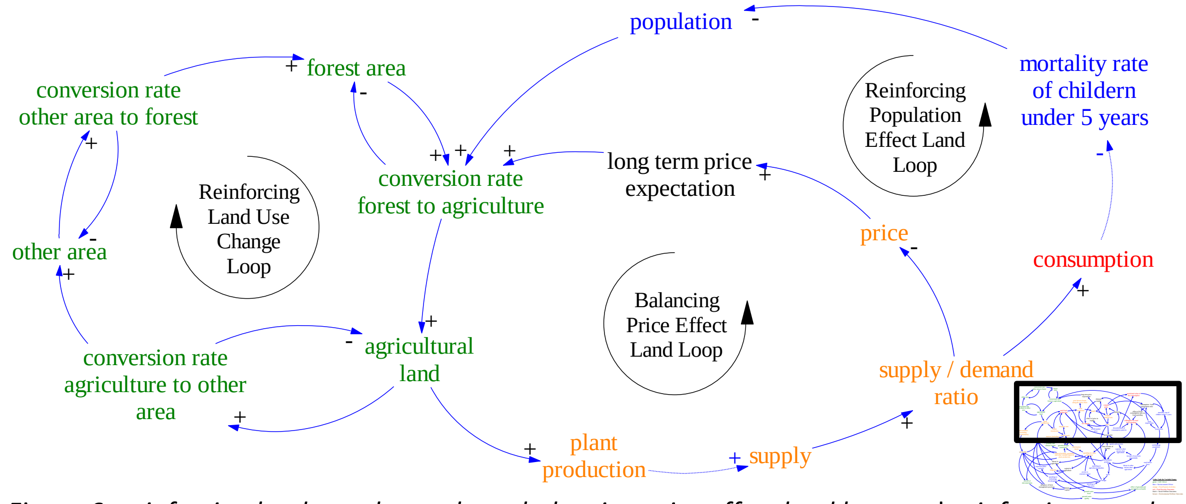



Figure 6: *reinforcing land use change loop, balancing price effect land loop* and *reinforcing population effect land loop*

Another feedback loop having a major impact on food production is the *reinforcing land use change loop* (Figure 6), where the conversion to agricultural land is driven through the *balancing price effect land loop* and the *reinforcing population effect land loop.* An increase in agricultural land is assumed to be introduced by an increase in beneficial economic parameter, here represented by the long term price expectancy, as well as by an increasing population, where the later effect mostly might play out in developing countries (Lambin et al. 2001, Pinstrup-Andreas and Watson 2011). Increased agricultural land leads ceteris paribus to an increased production and through that to a reduced price. A reduced price itself leads again with delay to decreased long term price expectancy and decreased agricultural land. Mostly in developing countries, where many people live self-sustaining the primary driving force of land use change comes from an increasing population. For simplicity reasons it assumed that agricultural land is obtained from forests and will be converted into other area such as civilisation and unproductive area, however, this part could be enlarged and displayed on a more detailed level. Conversion from forests (or other land) often takes years since it includes physical change, legal questions, etc. And through increasing the agricultural area and at the same time decreasing the forest area ecosystem services and biodiversity are lost, especially in tropical regions (Foley et al. 2011). It is clear that this reinforcing loop is restricted by the total area of the country.

***Environment related Loops***

Schmidhuber and Tubiello (2007) find that climate change will affect all dimensions of food security. In this framework the focus lies in its effect on food availability and agriculture as a main emitter of greenhouse gases among others through deforestation, livestock methane emission and fertilizers (Foley et al. 2011, Figure 7). Since the effect of a changing climate on yield is expected to vary over time, crop and space it is not possible to allocate a polarity to the *animal greenhouse gas emission loop*, *plant greenhouse gas emission loop* and *deforestation greenhouse gas emission loop* (Loebell et al. 2008). It means that these climate change effects are very context specific and the loop polarity needs to be determined within this context. It is also important to mention that agriculture is not the only emitter of GHG which is indicated with the link from gross domestic product to greenhouse gas emissions.

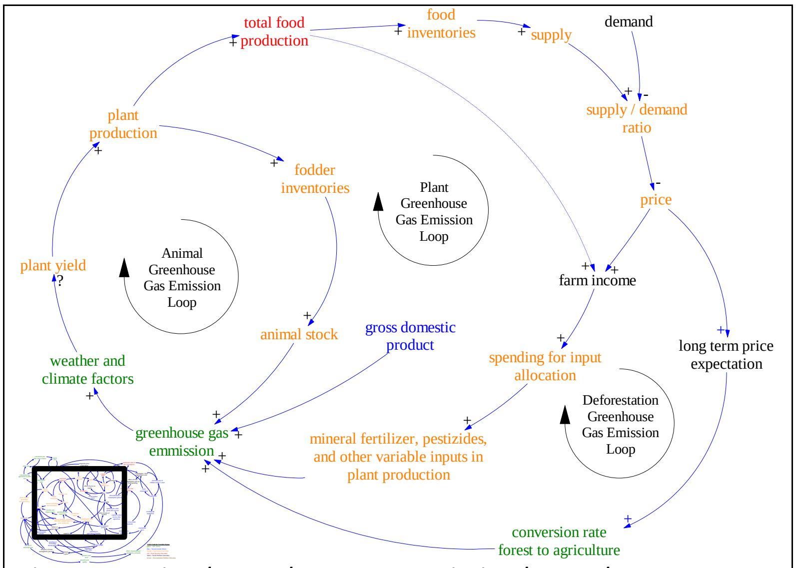



Figure 7: *animal greenhouse gas emission loop*, *plant greenhouse gas emission loop* and *deforestation greenhouse gas emission loop*

Even though the nature of the feedback loops depends on different, site specific parameters it is pointed out that in many food insecure regions yield of staple crops are likely to decrease due to climate change (Lobell et al. 2008).

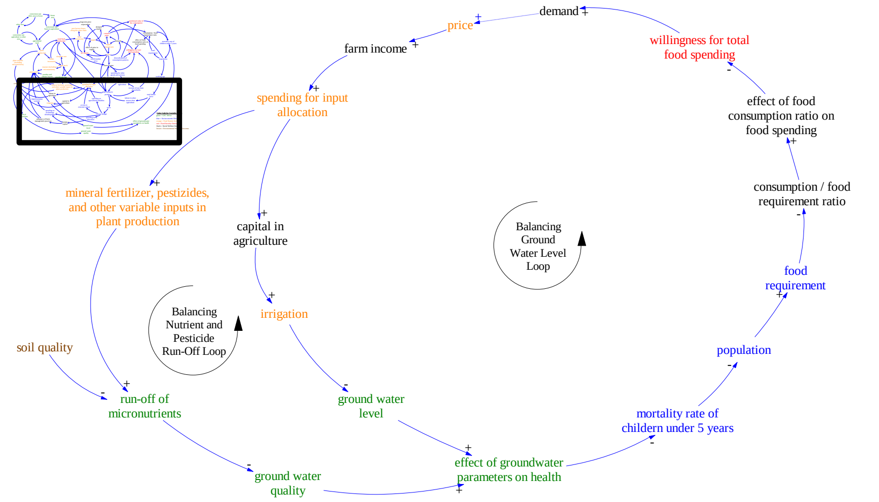



Figure 8: *balancing nutrient and pesticide run-off loop* and *balancing ground water level loop*

Tilman et al. (2002) point out that freshwater withdrawals for irrigation have reduced ground water levels. And agricultural inputs such as fertilizers and manure cause nutrient run-off into the ground water. The low level and bad quality of ground water cause health problems to people, if the loops as displayed in Figure 8 are not cut by introducing a water cleaning mechanism or alternative drinking water supplies.

***Demand related Loops***

The demand derivation is conceptionally based on the commodity cycle model of Sterman (2000), however, slightly adapted for this framework. For instance a reference demand is derived from the population size and the effects on price of substitutes (diversification of consumption patterns) are displayed exogenously among others because of its cultural nature. In order to focus on food systems many feedback mechanisms had to be neglected, e.g. as the effect of health services on population. Some of the loops therefore have an illustrative character to indicate the interlinkage of food systems with other areas going beyond this study.

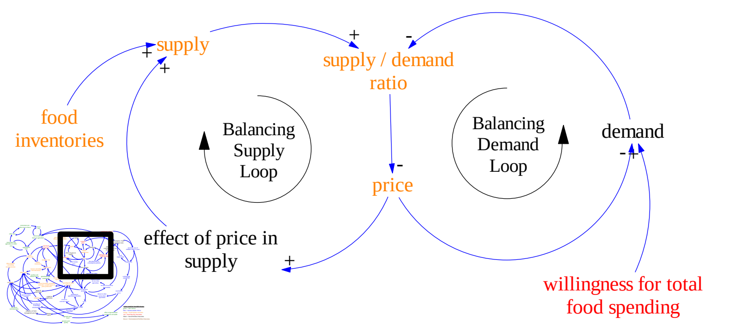



Figure 9: *balancing demand loop* and *balancing supply loop*

The most basic and only little delayed feedback loops on the demand and supply side are the *balancing demand loop* and on the supply side the *balancing supply loop* (Figure 9). An increase of the food demand causes a lower supply demand ratio which has an increasing effect on the food price and as a result food demand will decrease because people can afford less with their budget. On the other side the higher the food price, the more of the quantities in the inventory will be sold, causing the supply demand ratio to increase with a decreasing price as a result. Both, the supply and the demand are understood as food quantity per time determined by a monetary factor. On the supply side this monetary element is the price having an effect on the supply and how the quantitative aspect is derived can be seen in Figure 4. On the demand side the quantity results from the needs, the budget and preferences driving the willingness for total food spending, combined with the actual affordability represented by the price.

The willingness for total food spending is derived from the income standing for the aggregated household budget, as well as from diversification trends and the total food need from population. The income effect of farmers on food spending is somewhat special because it is based on the food price and affects it itself (*reinforcing farm income loop*, Figure 10). For non-farmers and farmers working outside agriculture the budget is – in the latter case at least partly – depended on the rest of the economy. The *reinforcing income of the rest economy loop* shows a feedback mechanism including quantitative (through consumption food requirement ratio) and qualitative (through nutritional value of the consumption) effects on population which feeds back through the workforce performance and the income. However, this second loop is very exemplary and different diet based health effects on economic performance could be displayed, especially in countries facing food insecurity situation.

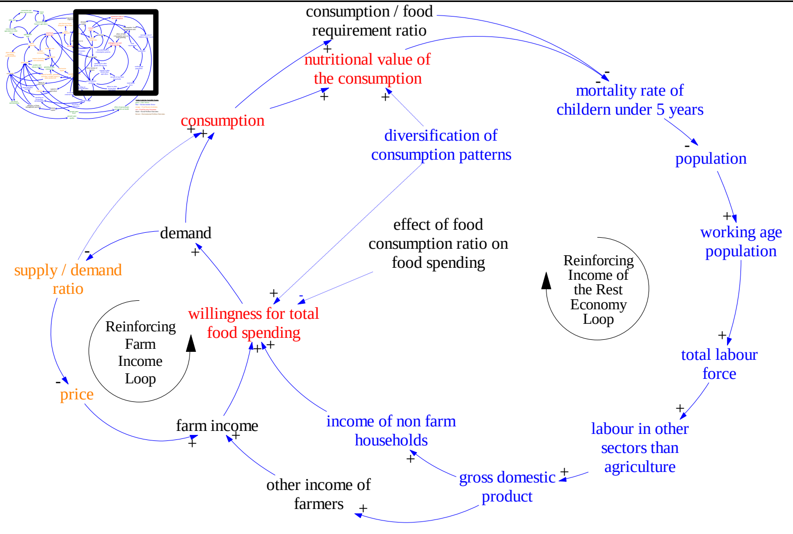


Figure 10: *reinforcing farm income loop* and *reinforcing income of the rest economy loop*

It is important to mention that there is a trade-off in spending the income between food and numerous other goods and services, such as savings or production inputs on farms. In the case of smallholder farmers where food insecurity coincides with poverty and being net- food -buyers this trade-off is of a sever nature.

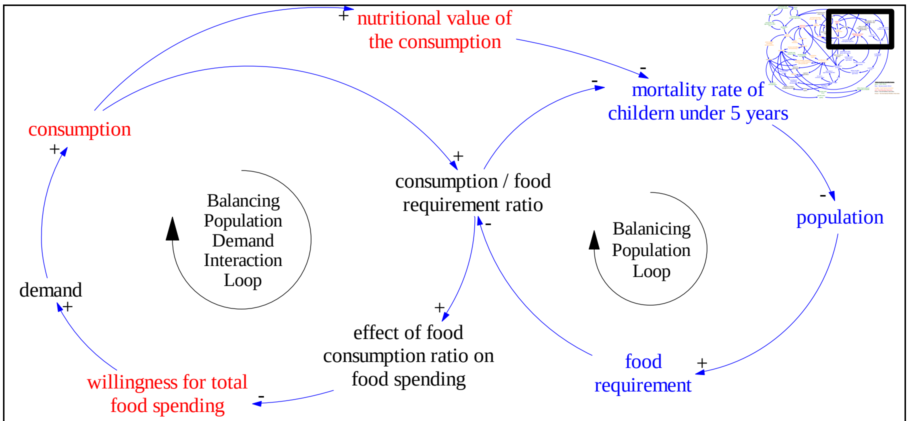


Figure 11: *balancing population loop* and *balancing population demand interaction loop*

Another important driving force for demand is the population which – besides the *reinforcing income of the rest economy loop* (Figure 10) - is part of a second important feedback loop: the *balancing population loop* (Figure 11). This loop compares the population and its food needs to the food consumption. A growing population has an increased requirement for food which itself decreases the consumption versus food requirement ratio. The decreased ratio through child mortality and – most probably – through less easy determinable influence (not displayed in the framework) has a decreasing effect on population. This balancing loop interplays with the *balancing population demand interaction loop* (Figure 11) which is also of a balancing nature. Its mechanism works that an increasing demand increases consumption, which increases the consumption versus food requirement ratio. The effect of this ratio then decreases the willingness to spend income for food resulting in a decreased demand. This loop illustrates parts of the trade-off between spending the income for food or alternative goods and services or savings, respectively.

***Socioeconomic Environment and Politics related Loops and Mechanisms***

As the demand related feedback loops so do the socioeconomic environment and politics related loops have an illustrative purpose to indicate the interlankages of food systems with other economic sectors. This implies that there is no intend to build a complete macroeconomic framework, however, only some special aspects instead.

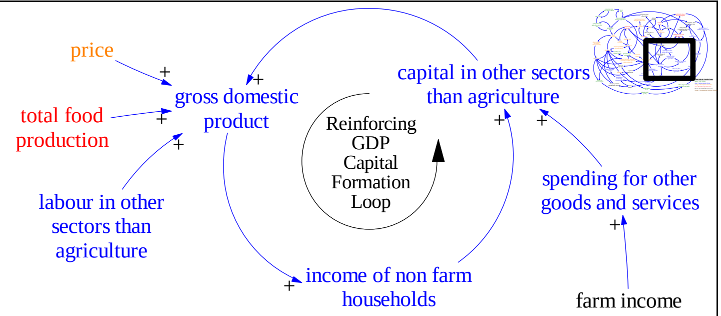



Figure 12: *reinforcing GDP capital formation loop* and other GDP formation

The gross domestic product formation (GDP) is conceptionally based on Wheat (2007), however, simplified for this purpose. The value added from the agricultural sector is directly introduced to the GDP indicated by the production quantity and its price (Figure 12). The effect of the rest of the economy is indicated by the influence of labour and capital. Besides the *income demand loop rest of the economy* (Figure 10) there are other loops feeding back from GDP to total labour force. However, in order to focus on the food system framework these links are skipped for simplification. And in a simplified way also the *reinforcing GDP capital formation loop* is shown (Figure 12, the more GDP the more income, the more income the more savings and investment in capital, and the more capital the higher GDP).

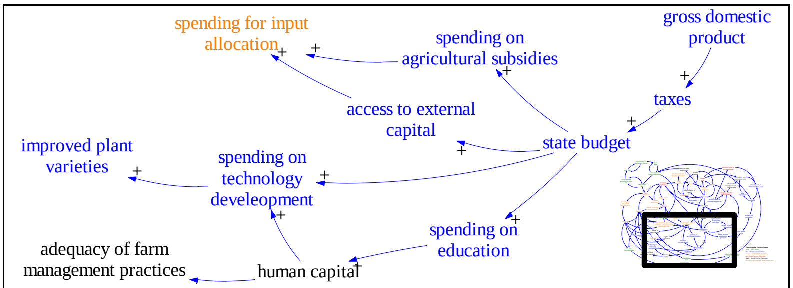



Figure 13: *State Budget Allocation Mechanism*

An important function of economic performance in regard to policy formation is the ability to generate state income through taxation (Figure 13). The expenditure of state income on different budget position is determined during a political process. For simplicity there are only state budget positions in the framework influencing the food sector directly and other government expenses influencing the food system in a more indirect way were left aside, e.g. retirement provision scheme through the *balancing population loop* (Figure 11). Through education and extension services human capital on farms can be enlarged leading to more adequate farm management practices. An increasing human capital in research stations combined with spending on technologies can lead to improved plant varieties, a climate change adaptation and food security strategy. Or by providing access to finance or subsidies an increasing number and amount of input factors can be allocated to agricultural production.

Instead of producing food within the own country it can be imported or in case of a production surplus exported if the trade regimes allows for it. The *balancing quantity trade loop* and the *balancing price trade loop* bring the food supply in balance with the demand (Figure 14). If the supply versus demand ratio decreases the food price will increase. This raises the potential for more net imports (imports minus exports). As a consequence the food inventories and supply increase, causing the supply versus demand ratio to decrease.

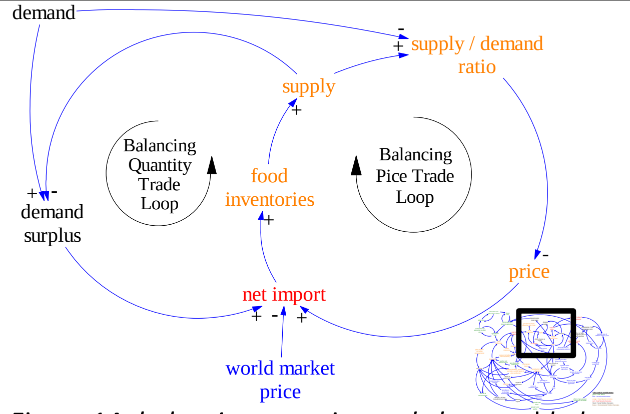


Figure 14: *balancing quantity trade loop* and *balancing price trade loop*

An important precondition to purchase food in the international market is to have enough foreign exchange, most probably coming from the rest of the economy.

## Policy Discussion

On a global scale it is predicted that food demand will increase drastically over the next decades driven by an increasing population and consumption patterns shifting towards a more resource intensive diet. The challenge is to meet this demand with enough supply in a sustainable manner (e.g. Tilman et al. 2002). Among others Godfray et al. (2010) and Foley et al. (2011) discuss common, global strategies to tackle the challenge, i.e. by closing yield gaps, increasing production limits, stopping agricultural expansion, increasing resource efficiency, shifting consumption patterns and reducing waste. In the following sections the first three of these common strategies are presented and discussed from a feedback perspective based on the framework presented in Figure 3. Since the strategies are recommended globally, however, FAO (2014) indicates that decision and implementation power often remains nationally the analysis focus on a country level.

*Closing Yield Gaps:* One major strategy to enhance food security is to close the existing yield gaps (Godfray et al. 2010, Foley et al. 2011), where yield gap can be defined as the difference between a yield under optimal conditions and the actual yield, both at a given place. Closing the yield gap results in a higher food supply often received through a higher input use or an increasing resource efficiency, such as nutrient or water efficiency through better farm management practices. The size of the gap varies among regions and Foley et al. (2011) find that the biggest potential for yield gap reductions lies in parts of Africa, Latin America and Eastern Europe. However, despite the increasing production, also environmental risks often are linked with the strategy such as increasing greenhouse gas emissions, nutrient run-off, water shortages, soil degradation and a loss of biodiversity. Godfray et al. (2010) state about the strategy that "*substantially more food, as well as the income to purchase food, could be produced with current crops and livestock if methods were found to close the yield gaps.*"

In order to discuss this common strategy with the framework in Figure 3 it is needed to contextualise a case on a country level: Therefore the illustrative (but common) case is used that a state puts a policy instrument in place to provide fertilizer inputs in order to increase production by closing the yield gap.

By subsidising fertilizer initially the total fertilizer input increases. Following the balancing plant production loop of the framework (Figure 4) this leads to a higher yield and production, however also to

a decrease in price and to a lower farm income. And with a lower income, farmers spend less on inputs such as fertilizer. In order to hold the production level, the government is forced now to maintain its subsidy level (for example by generating taxes through the reinforcing GDP capital formation loop, Figure 12), because farmers may substitute privately allocate fertilizer with subsidised fertilizer (Mason and Ricker-Gilbert 2013). From the lower food price the consumers will benefit through the balancing demand price loop (Figure 9) and consume more – which is a wishful impact in food insecure regions. On the other hand more micronutrients are likely to run-off into the ground water due to higher fertilizer use if human capital is not formed adequately. This either imposes water cleaning costs or does harm to people drinking it, which in the sum might feedback to a reduced food demand (balancing nutrient and pesticide run-off loop, Figure 8). Another effect of decreased food prices is that agricultural land decreases in the long run through the balancing price effect land loop (Figure 6), most likely with a positive effect on biodiversity if the abandoned area becomes fallow land and then forest through the land use change loop (Foley et al. 2011).
This case illustrates that even if a policy measure is taken for a specific goal, such as increasing the use of inputs (e.g. through subsidies) or more efficient resource use (e.g. through better farm management) for closing the yield gap, it very likely affects different parts of the food system which are not necessary closely linked with the policy or its intended outcome. Unintended outcomes such as increasing nutrient runoffs might appear and bring up trade-offs. The case further illustrates that different stakeholders are affected in different, but interlinked ways. For instance the farmers who are expected to gain a higher income (Godfray et al. 2010, statement above) might in fact even gain less income depending on the country's specific demand situation (demand elasticity). Or the government can become bound to a certain policy by shifting the burden to itself and is forced to find resources to support its policy (e.g. through taxation in the rest of the economy).

*Increasing Production Limits*: Both studies, Godfray et al. (2010) and Foley et al. (2011), mention plant genetics as a possible strategy in order to increase yields among others through breeding resource efficient plant varieties.
A higher yield through plant breeding technology can have various impacts depending on the strength of different loops. Entry point of the strategy into the food system is the balancing plant production loop through improving plant varieties (Figure 4): An increasing production causes prices, farm income and input allocation to decrease. Interference into this mechanism can –among others - come from the balancing demand loop (Figure 9) driven by an increasing population and demand. If the production in the balancing plant production loop grows faster than the demand in the balancing demand loop then the system comes into the situation of the agricultural treadmill (e.g. Von Witzke et al. 2008) which is characteristic for bio-technical progress (Rieder and Anwander 1994). Real food prices sink, which is beneficial to consumers, however, not to farmers. In the long run structural change in the farming sector might occur. Von Witzke et al. (2008) argue that this treadmill effect characterised world agriculture from 1870 until 2000 and that during the last decade the population and wealth driven balancing demand loop became stronger than the balancing plant production loop leading to rising real food prices. This observation might be true on a global level, however there might be still countries "running" in the treadmill.
In addition to the detection that there are trade-offs between different stakeholder there arises another observation: By managing the time of introduction of new technologies and varieties (and therefore controlling the strength of different loops) some management of the treadmill effect can be achieved. E.g. if in a country with a growing demand and restricted trade the new variety is introduced early it might cause a supply surplus in favour of consumers. On the hand if the new variety is

introduced later it might be in favour for farmers due to a demand surplus and rising prices. Managing the timing of technology implementation and especially accounting for its delays therefore can be crucial in order to meet the objectives of the policy.

*Stopping Agricultural Expansion*: Foley et al. (2011) argue that expanding agriculture into sensitive ecosystems has negative impacts on the environment. These negative consequences are especially large in the case of deforestation of tropical forests. Since the yields in these regions are rather small compared to temperate regions the contribution to world food production is limited and could be compensated elsewhere.
The policy of stopping agricultural expansion in the tropics might be meaningful from a global, environmental perspective. However, what are its implications on food security in an affected country in the tropics, especially with an increasing population? In the tropic regions food insecurity is a challenge (United Nations 2013) and therefore increasing food availability is an important goal. By stopping agricultural expansion one option to increase food production is omitted and alternatives to increase food supply need to be found such as increasing yields or increasing imports. Yield increasing strategies through the balancing plant production loop (Figure 4) are often based on knowledge and input availability which both are costly and constrained in many tropical countries. A higher demand coming from an increasing population as seen in many tropical countries could induce higher food prices and higher farm income allowing for more input use through the balancing demand loop (Figure 9). However, in order to do so the consumers need enough income provided by other sources through the reinforcing income of the rest economy loop (Figure 10), pointing at the relation of agriculture and the rest of the economy. And the other option to increase food supplies would be to import food through the balancing quantity trade loop (Figure 14). However, also this option is in many countries restricted either through economical, physical or legal trade barriers.
This feedback based reasoning does not limit the importance of preserving sensitive ecosystems. However, it illustrates some of the systemic interlinkages and problems, as well as the trade-offs linked with a decision, not to expand agriculture.

## Conclusions

Fallowing the general food system approach of Ericksen (2007) a feedback based framework for food systems on country level was developed in form of a causal loop diagram. The contextualisation of the system allowed discussing the illustrative food security and sustainability enhancement strategies “Closing Yield Gaps”, “Increasing Production Limits” and “Stopping Agricultural Expansion” from a systemic feedback perspective. Even though the suggested strategies might serve important targets on a global level such as enhancing food security even under increasing demand or strengthen ecosystems and their services, the feedback based policy discussions demonstrate that:

- These strategies imply trade-offs between different goals such as food security and (environmental) sustainability or between the wealth of different actors such as farmers, state and consumers.
- In order to manage the trade-offs it is needed to understand the system and take a multidisciplinary perspective.
- From one country to another the same strategies might be evaluated differently depending on a country’s specific context.

- A decision in one domain of the food system affects other domains through the system's interlinkages; and its impact is affected by other domains. Unintended consequences are likely to occur.
- By managing change and deciding the implementation timing of measures some feedback loops can be strengthened compared to others depending on the targeted beneficiaries of the policy.

This implies that there is no obvious, generally valid, single solution to enhance food security in a sustainable manner; however, most likely a context specific mix of interventions needs to be designed and implemented. This finding is in line with Ericksen et al. (2010b) who find that there are no more (technical) silver-bullet solutions as there were in the past and that instead there are several options which need to be applied side specific. And it also implies that a fundamental understanding of the food system and its environment is needed in order to evaluate and prioritise different policy options and policy mixes.

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