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Foresight Study: Research for a Sustainable Swiss Food System

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Zurich, June 2015

Preface

It is one of the most important tasks of research and policy to identify the challenges our society will be facing in the future early on, to address them, and to ensure that we develop smart solutions to meet these challenges successfully. One of the major challenges is food security. This is closely linked to the sustainable use of our planet which will also allow future generations to live a good life. These challenges can only be solved jointly: Research leads to knowledge that helps us find solutions, while policy provides the boundary conditions so that the needs of the population can be met in the future.

But what knowledge and which policies do we need to be well prepared for a rapidly changing world? Research takes time to produce reliable results. Political decisions often have a long-term impact that cannot be undone easily. Therefore, both researchers and policy-makers have to consider in advance which issues could become important in the future and where priorities should be set. By doing so, we can ensure to be well prepared and able to respond to both long-term trends but also sudden disturbances – despite limited resources.

For these reasons, this foresight study has been carried out. The report is based on national and international sources of literature and research agendas, and included the perspectives of almost 500 Swiss food system stakeholders. This report describes how the boundary conditions of the Swiss agri-food sector might change and what the challenges might be in the future. Furthermore, this report shows which research topics and research approaches were considered critical by almost 500 stakeholders to achieve a sustainable food system in our country and which of these topics are to be addressed already today.

This report cannot predict the future. However, the findings can give us important information about developments we should anticipate and prepare for already today. This report will form a basis to advance research toward a sustainable Swiss food system and to set the right priorities for the development of Swiss agricultural policy. This way we can jointly create the knowledge needed to best prepare the Swiss food system for a challenging future.

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Executive summary

Developing policies and identifying research needs toward a sustainable Swiss food system will be critical in order to react to the many challenges the Swiss society will be facing in the future. Here, we define the Swiss food system (SFS) as all food (and feed) products produced, but also consumed in Switzerland, while considering national actors and national economic, political, societal, and environmental boundary conditions. Although the SFS is clearly embedded internationally, in this foresight study, we mainly focus on Switzerland. In contrast to many earlier studies which focused on single sectors or actors, this study addresses all critical drivers, relationships and feedbacks as well as boundary conditions framing and affecting the food system.

In a first stage, we synthesized the global trends, their drivers and thus the big challenges the world food system will be confronted with in the next 20 to 30 years, based on a comprehensive literature review. We then identified five major research questions and corresponding sub-questions that need to be addressed to achieve food and nutrition security, environmental quality as well as social well-being.

In a second stage, we analyzed the key implications of these global macro-trends for Switzerland. Then, we carried out semi-structured interviews with eight leading representatives of Swiss federal offices to identify their views on the main challenges the SFS will be facing in the future, but also to detect gaps between the implications of global trends on the Swiss food system and current Swiss policies. Moreover, we used an online survey to ask decision-makers and stakeholders across the entire SFS to identify the most critical challenges, the most relevant research topics and research approaches to achieve a sustainable SFS within the next 20 years. Based on both the interviews and the online survey, the most critical challenges were identified across the entire SFS, ranging from scarce resources and climate change to demographic changes and food quality to the overall competitiveness of the SFS. However, according to the interviews, a coordinated, multi-stakeholder strategy to address these system challenges at the national level is lacking, partly due to sectorial policy priorities, partly due to the lack of political and societal pressure and urgency. Furthermore, a coordinated knowledge and communication platform was missed, and targeted research toward a sustainable SFS was asked for.

The online survey resulted in a very large, solid dataset, with respondents across the entire SFS and an average of 490 answers per question. The Top 10 research topics (out of 88) were (in decreasing order): soil health and fertility in agricultural production systems, resistance to antibiotics, energy-use efficiency along food value chains, reducing food waste, sustainable diets, nutrient-use efficiency along food value chains, impact assessment of local vs. global food production, reducing losses in food value chains, nutrient cycling in agricultural production systems, and policy development for sustainable food systems, clearly reflecting the importance for a systems approach in research. Also for the 10 lowest scored research topics covered all areas of the food system framework. Respondents did not favor their own sector or working area within the SFS. Even excluding researchers from the respondents and re-running the analysis resulted in the same top and lowest scored topics. Interestingly, research on topics highly relevant at the global scale, but currently underrepresented in Swiss research, such as on aquaculture or precision faming, were considered less critical than expected for the development of a sustainable Swiss food system. No research approach was favored over the others; education and outreach were considered as important as disciplinary or applied research. Thus, the diversity within and the complexity of the SFS were clearly recognized, supporting the results from the interviews with leading representatives of the federal offices.

Based on the interviews and this unique survey dataset, four main research areas were identified that are highly critical to build a sustainable SFS: (1) Research on efficient use of natural resources such as land, soil, water, nutrients and biodiversity at all levels (ecosystems, species, genetic resources) as well as their conservation, recycling and restoration. Here, efficient use of energy and materials, which are often produced from natural resources, as well as waste and losses of resources are included. (2) Research on a coherent policy framework that aims at national policies such as (but not exclusively) the agricultural policy, but also at international policies such as trade policies, which are strongly linked to the food system as well as to the food system boundary conditions. (3) Research on sustainable diets, not only considering environmental aspects, but also linking to nutrition, health and diseases as well as consumption patterns. (4) Research on cross-cutting issues within the entire Swiss food system, addressing their drivers, mechanisms and impacts along and across the food value chains.

Overall, we conclude that the Swiss food system can only become and remain competitive when a sustainable development of the Swiss food system can be achieved. This means, all three aspects of sustainability (i.e., economy, society, ecology) need to be balanced, which will also help to make it resilient against future challenges. Policies and research need to address the challenges the food systems will be facing in the future and to enable the development of the Swiss food system over time while keeping it “on track”. Thus, the system is enabled to provide the desirable food system outcomes (food and nutrition security, environmental quality, social well-being) and to stay competitive also in the future. We reckon that Switzerland can best respond to the future challenges at national and international levels when consciously developing a sustainable Swiss food system together with all actors and stakeholders.

Executive summary – *D*

Sowohl die Entwicklung von Politikmassnahmen als auch die Identifizierung von Forschungsbedarf für ein nachhaltiges Schweizer Ernährungssystem sind ausschlaggebend dafür, dass die Schweizer Gesellschaft auf die zahlreichen Herausforderungen der Zukunft reagieren kann. Im vorliegenden Bericht definieren wir das Schweizer Ernährungssystem (SES) als System, das alle im Land produzierten, aber auch konsumierten Lebensmittel (und Futtermittel)sowie alle nationalen Akteure berücksichtigt und das selbst in ökonomische, politische, gesellschaftliche und ökologische Rahmenbedingungen eingebunden ist. Obwohl das SES stark international vernetzt ist, wird in dieser Studie vor allem auf die Schweiz fokussiert. Im Gegensatz zu früheren Studien, die den Schwerpunkt auf einzelne Branchen oder Akteure legten, berücksichtigt die vorliegende Studie alle wichtigen Einflussfaktoren, Zusammenhänge, Rückkopplungen und Rahmenbedingungen, die das Ernährungssystem beeinflussen.

Im ersten Teil der Studie wurden – basierend auf einer umfassenden Literaturrecherche – die globalen Trends, ihre Gründe, aber auch die grössten Herausforderungen für das globale Ernährungssystem für die nächsten 20 bis 30 Jahre zusammengefasst. Darauf aufbauend wurden die fünf wichtigsten Forschungsfragen sowie weitere Unterfragen identifiziert, die beantwortet werden müssen, um global eine hohe Ernährungssicherheit, hohe Umweltqualität und hohes gesellschaftliches Wohl sicherzustellen.

Im zweiten Teil wurden die Auswirkungen dieser globalen Trends auf die Schweiz evaluiert. Mit führenden Mitarbeitenden verschiedener Bundesämter wurden semi-strukturierte Interviews geführt, um die zukünftigen Herausforderungen für das SES aus Sicht der Befragten, aber auch die Lücken zwischen den Auswirkungen globaler Trends auf das SES und der aktuellen Schweizer Politik zu identifizieren. Ausserdem wurde eine Internet-Umfrage mit Entscheidungsträgerinnen und Entscheidungsträgen, aber auch Interessengruppen des SES durchgeführt. Diese sollten Stellung nehmen zu den grössten Herausforderungen, aber auch 88 Forschungsthemen bewerten, um innerhalb der nächsten 20 Jahre ein nachhaltiges SES zu erreichen. Aufgrund dieser beiden Ansätze, der Interviews und der Umfrage, kristallisierten sich die folgenden Herausforderungen als die wichtigsten für das gesamte SES heraus: knappe Ressourcen, Klimawandel, demographische Entwicklungen, Qualität der Lebensmittel und Wettbewerbsfähigkeit. Zudem wurde in den Interviews beanstandet, dass es heute keine umfassende Strategie in der Schweiz gäbe, die diese Herausforderungen berücksichtige, wohl aufgrund unterschiedlicher Prioritäten in der Politik der einzelnen Sektoren, aber auch aus mangelndem gesellschaftlichen und politischen Druck. Ferner vermissten die Befragten eine gemeinsame Wissens- und Kommunikationsplattform und verlangten zielgerichtete Forschung, hin auf ein nachhaltiges SES.

Die Internet-Umfrage zu den Forschungsthemen, die von Personen aus dem gesamten SES ausgefüllt wurde, ergab einen grossen, soliden Datensatz, mit im Durchschnitt 490 Antworten pro Frage. Die „Top 10“-Forschungsthemen waren (in absteigender Rangfolge): Bodengesundheit und Bodenfruchtbarkeit in landwirtschaftlichen Produktionssystemen, Antibiotikaresistenz, Energienutzungseffizienz entlang der Lebensmittel-Wertschöpfungsketten, Reduktion von Lebensmittelabfällen, nachhaltige Ernährungsgewohnheiten, Nährstoffnutzungseffizienz entlang der Lebensmittel-Wertschöpfungsketten, Folgenabschätzung von lokaler vs. globaler Lebensmittelproduktion, Reduktion der Verluste in Lebensmittel-Wertschöpfungsketten, Nährstoffkreisläufe in landwirtschaftlichen Produktionssystemen, und Entwicklung politischer Strategien für nachhaltige Ernährungssysteme. Sie decken also das gesamte Spektrum des SES ab und zeigen so die Bedeutung eines systembasierten Forschungsansatzes auf. Auch die „10 Schlusslichter“, d.h., die am schlechtesten bewerteten Themen, fanden sich im gesamten SES. Die Teilnehmenden an der Umfrage zeigten keine Präferenz für Themen in dem Sektor/Bereich, in dem sie arbeiteten. Selbst wenn man die Rangfolge der Top 10 oder der 10 Schlusslichter ohne die Antworten der Forschenden betrachtet, die die grösste Gruppe der Teilnehmenden darstellten, ergab sich dasselbe Bild. Interessanterweise stuften die Umfrage-Teilnehmenden Forschungsthemen, die global überaus wichtig, aber in der Schweizer Forschung noch wenig vertreten sind, als weniger wichtig für die Zukunft des SES ein als erwartet. Zudem bevorzugten sie keinen Forschungsansatz; Bildung und Wissensvermittlung wurden als ebenso wichtig eingestuft wie disziplinäre oder angewandte Forschung. So bestätigte die Umfrage die Erkenntnisse aus den Interviews und beide zeigten deutlich, dass den Interessensvertreterinnen und –vertretern die hohe Diversität, aber auch die Komplexität des SES sehr wohl bewusst ist.

Mit Hilfe der Interviews und des einmaligen Datensatzes aus der Internet-Umfrage wurden vier Forschungsbereiche abgeleitet, die für die Gestaltung eines nachhaltigen SES als massgeblich eingestuft werden: 1) Forschung zur effizienten Nutzung natürlicher Ressourcen wie Land, Boden, Wasser, Nährstoffe und Biodiversität auf allen Ebenen (Ökosysteme, Arten, genetische Ressourcen), aber auch zu ihrem Schutz, ihrer Wiederverwertung und Wiederherstellung. Auch die effiziente Nutzung von Energie und Stoffen, die oft aus natürlichen Ressourcen produziert werden, sowie die Verschwendung oder der Verlust von Ressourcen sind hier berücksichtigt. 2) Forschung zur Entwicklung von kohärenten politischen Rahmenbedingungen im Bereich der nationalen Politik, wie z.B. (aber nicht ausschliesslich) der Agrarpolitik. Auch die internationalen Politikbereiche, wie z.B. die Handelspolitik, sind hier inbegriffen, da sie eine starke Verbindung zum Ernährungssystem oder zu seinen Rahmenbedingungen haben. 3) Forschung im Bereich nachhaltiger Ernährung, die nicht nur Umweltaspekte, sondern auch Ernährungs-, Gesundheitsaspekte und Konsummuster berücksichtigt. 4) Bereichs- und Sektoren-übergreifende Forschung im SES, die die Einflussfaktoren, Mechanismen und Auswirkungen entlang und zwischen den Lebensmittel-Wertschöpfungsketten bearbeitet.

Wir ziehen daher den Schluss, dass das SES nur wettbewerbsfähig werden und bleiben kann, wenn dessen Nachhaltigkeit erreicht oder verbessert wird. Dies bedeutet, dass alle drei Aspekte der Nachhaltigkeit (d.h., Ökonomie, Ökologie und Gesellschaft) ähnlich gewichtet werden müssen, was auch die Resilienz (d.h., die Widerstandskraft) des Systems gegenüber zukünftigen Herausforderungen erhöht. Politik und Forschung müssen die Herausforderungen, die sich dem Ernährungssystem in Zukunft stellen werden, angehen und die Rahmenbedingungen und das Wissen schaffen, damit sich das SES erfolgreich entwickeln kann. So wird gewährleistet, dass das SES auch in der Zukunft die gewünschten Leistungen (Ernährungssicherheit, Umweltqualität, gesellschaftliches Wohl) bereitstellen und gleichzeitig wettbewerbsfähig bleiben kann. Wir betonen, dass die Schweiz am besten auf nationale und internationale Herausforderungen reagieren kann, wenn das Schweizer Ernährungssystem mit Umsicht und in Zusammenarbeit mit allen Akteuren und Interessensgruppen weiterentwickelt wird.

Executive summary – *F*

La mise au point de politiques et l'identification des besoins de la recherche en vue de l'instauration d'un système alimentaire durable seront décisives pour la capacité de la société suisse à relever les nombreux défis qui l'attendent. Dans le présent rapport, le système alimentaire suisse (SAS) recouvre toutes les denrées alimentaires et aliments pour animaux produits et consommés en Suisse ainsi que tous les acteurs nationaux. Il est par ailleurs tributaire de conditions-cadre économiques, politiques, sociétales et environnementales du pays. Cette étude se concentre sur la Suisse, bien que le système alimentaire soit solidement ancré dans un contexte international. A l'inverse des précédents travaux axés exclusivement sur des secteurs ou acteurs précis, cette analyse prospective aborde tous les facteurs, contextes, rétroactions et conditions-cadre importants qui influent sur le système alimentaire mondial.

Dans un premier temps, cette étude recense, sur la base d'une vaste compilation, les tendances mondiales, leurs origines, mais aussi les défis majeurs qui seront posés au système alimentaire dans les vingt à trente prochaines années. Il a ainsi été possible de dégager cinq principales questions et d'autres thèmes subsidiaires, dont le traitement aidera à assurer à un niveau élevé la sécurité alimentaire et nutritionnelle, la qualité environnementale et le bien-être social.

La deuxième partie de cette étude analyse les principales conséquences de ces tendances mondiales pour la Suisse. Nous avons réalisé des interviews semi-structurées auprès de huit cadres supérieurs issus de différents offices fédéraux pour connaître les principaux enjeux du système alimentaire suisse de demain, mais aussi les écarts entre la politique actuelle de la Suisse et les effets de ces tendances mondiales sur le système alimentaire. Une enquête en ligne a par ailleurs été menée auprès de décideurs et de groupes d'intérêt du système alimentaire suisse, qui ont ainsi pu donner leur avis sur les défis majeurs et évaluer 88 sujets de recherche dans la perspective d'un système alimentaire suisse durable au cours des vingt prochaines années. Ces interviews ont permis de mettre en évidence les plus grands défis auxquels seront confrontés tous les acteurs du système alimentaire suisse, à savoir la raréfaction des ressources, les changements climatiques, les évolutions démographiques, la qualité des denrées alimentaires et la compétitivité du système alimentaire suisse. Selon ces interviews, il n'existerait pas à l'échelle nationale de stratégie globale tenant compte de ces problèmes, à cause non seulement des priorités différentes des politiques sectorielles, mais aussi du manque de pression politique et sociétale. Les personnes interrogées ont en outre regretté l'absence d'une plateforme commune favorisant la communication et les échanges de connaissances et ont réclamé une recherche visant à créer un système alimentaire durable.

Le questionnaire en ligne sur les sujets de recherche, qui a été rempli par des personnes appartenant à l'ensemble du SAS, a fourni un jeu de données très important et solide, avec en moyenne 490 réponses par question. Le top ten des sujets de recherche était le suivant (par ordre décroissant): santé et fertilité des sols dans les systèmes de production agricoles, résistance aux antibiotiques, efficacité de l'utilisation de l'énergie dans les chaînes de valeur des produits alimentaires, réduction des déchets alimentaires, habitudes alimentaires durables, efficacité de l' utilisation de nutriments dans les chaînes de valeur produits alimentaires alimentaire, estimation des effets de la production alimentaire locale comparés à ceux de la production alimentaire globale, réduction des pertes dans les chaînes de valeur des produits alimentaire, cycles de nutriments dans les systèmes de production agricoles et développement de stratégies politiques pour des systèmes alimentaires durables. Ces sujets couvrent l'ensemble du spectre du SAS et montrent l'importance d'une approche systémique de la recherche. Les dix sujets les moins bien notés couvrent également l'ensemble du SAS. Les participants à l'enquête n'ont pas montré de préférence pour les thèmes appartenant au secteur/domaine dans lequel ils travaillent. Même en excluant les réponses des chercheurs, qui constituent le groupe le plus grand des participants, l'analyse donne les mêmes résultats. Il est intéressant de constater que les sujets de recherche qui sont très importants au niveau mondial, mais encore sous-représentés dans la recherche suisse, comme l'aquaculture ou l'agriculture de précision, ont été jugés moins importants que prévu pour l'avenir du SAS. En outre, aucune approche de recherche n'a été privilégiée; la formation et la transmission de connaissances ont été jugées aussi importantes que la recherche disciplinaire ou appliquée. L'enquête a ainsi confirmé les résultats des entretiens avec les principaux représentants des offices fédéraux et montre clairement que les représentants des groupes d'intérêt sont très conscients de la grande diversité, mais aussi de la complexité, du SAS.

Quatre sujets de recherche ont été identifiés comme étant essentiels pour la mise sur pied d'un SAS durable, sur la base des entretiens et du jeu de données unique provenant de l'enquête Internet: 1) recherche sur l'utilisation efficiente des ressources naturelles telles que les terres agricoles, le sol, l'eau, les nutriments et la biodiversité à tous les niveaux (écosystèmes, espèces ressources génétiques), mais aussi sur leur protection, leur valorisation et leur restauration. L'utilisation efficiente de l'énergie et des substances, qui sont souvent produites à base de ressources naturelles, ainsi que le gaspillage ou la perte de ressources, sont également pris en compte ici. 2) Recherche sur le développement de conditions-cadre politiques cohérentes dans le domaine de la politique nationale, telles que la politique agricole (mais pas exclusivement cette dernière). Les domaines politiques internationaux, comme p. ex. la politique commerciale, sont aussi compris, car ils ont un lien fort avec le système alimentaire ou avec ses conditions-cadre. 3) Recherche dans le domaine de l'alimentation durable, qui prend en compte non seulement les aspects environnementaux, mais aussi les aspects relatifs à l'alimentation, la santé et le comportement de consommation. 4) Recherche interdisciplinaire et intersectorielle dans le SAS, qui traite des facteurs d'influence, des mécanismes et des conséquences entre les chaînes de valeur des produits alimentaire et tout au long de ces chaînes.

Nous concluons donc que le SAS ne peut devenir et rester compétitif qu'à condition d'améliorer sa durabilité. Cela signifie que les trois aspects de la durabilité (à savoir l'économie, l'écologie et la société) doivent être pondérés de manière égale, ce qui améliore également la résilience (c'est-à-dire la capacité de résistance) du système vis-à-vis des défis du futur. La politique et la recherche doivent affronter les défis qui se poseront au système alimentaire et créer les conditions-cadre nécessaires à un développement réussi du SAS. Le SAS pourra ainsi fournir à l'avenir les prestations souhaitées (sécurité alimentaire, qualité environnementale, bien-être social), tout en restant compétitif. Nous estimons que la Suisse pourra mieux réagir aux défis nationaux et internationaux en développant volontairement un système alimentaire suisse en collaboration avec tous les acteurs et les groupes d'intérêt.

Executive summary – *I*

Sviluppare misure politiche e identificare necessità di ricerca in vista di un sistema alimentare svizzero sostenibile sarà fondamentale per reagire alle numerose sfide che la società svizzera dovrà affrontare in futuro. Nel presente rapporto, per sistema alimentare svizzero (SAS) intendiamo tutte le derrate alimentari (e alimenti per animali) fabbricati, ma anche consumati, in Svizzera, considerando tutti gli attori nazionali e le condizioni quadro economiche, politiche, sociali ed ecologiche. Malgrado il SAS sia chiaramente integrato a livello internazionale, in questo studio ci concentriamo soprattutto sulla Svizzera. Contrariamente a studi precedenti, incentrati su singoli settori o attori, il presente studio affronta tutti i principali fattori trainanti, interazioni, retroazioni e condizioni quadro che influenzano il sistema alimentare.

Nella prima fase dello studio, sulla base di una ricca rassegna bibliografica, abbiamo sintetizzato le tendenze globali, i fattori determinanti e quindi le maggiori sfide con cui il sistema alimentare mondiale sarà confrontato nei prossimi 20-30 anni. In seguito abbiamo identificato i cinque principali temi di ricerca e i relativi sotto-temi che occorre affrontare per conseguire sicurezza alimentare e nutrizionale, qualità ambientale e benessere sociale.

Nella seconda fase abbiamo analizzato le principali implicazioni per la Svizzera di queste tendenze globali. In seguito abbiamo effettuato interviste semi strutturate con esponenti di diversi uffici federali per identificare le loro visioni sulle principali sfide che il SAS dovrà affrontare in futuro, ma anche per rilevare lacune tra le implicazioni delle tendenze globali sul SAS e le attuali politiche nazionali. Inoltre abbiamo utilizzato un sondaggio online per chiedere a coloro che prendono decisioni, ma anche a operatori del SAS, di esprimersi sulle sfide principali, e di valutare gli 88 temi di ricerca per conseguire un SAS sostenibile nei prossimi 20 anni. Sulla base di tali approcci, delle interviste e del sondaggio online, le seguenti sfide sono state designate come principali all'interno di tutto il SAS: penuria delle risorse, cambiamenti climatici, sviluppi demografici, qualità delle derrate alimentari e competitività. Inoltre nelle interviste è stata riscontrata la mancanza di una strategia globale in Svizzera che consideri tali sfide, in parte a causa delle diverse priorità nei singoli settori politici, in parte a causa della mancanza di pressione politica e sociale. Si lamenta, inoltre, la mancanza di conoscenze coordinate e di una piattaforma di comunicazione, ed è richiesta una ricerca mirata nell'ottica di un SAS sostenibile.

Il sondaggio online sui temi di ricerca ha prodotto una gamma di dati molto ampia, solida, con risposte rappresentative di tutto il SAS, in media 490 risposte per domanda. I primi 10 temi di ricerca sono stati (in ordine decrescente): salute e fertilità del suolo nei sistemi di produzione agricola, resistenza agli antibiotici, efficienza dell'uso dell'energia lungo le catene del valore delle derrate alimentari, riduzione dello spreco alimentare, abitudini alimentari sostenibili, efficienza dell'uso di sostanze nutritive lungo le catene del valore delle derrate alimentari, valutazione dell'impatto della produzione locale rispetto alla produzione globale delle derrate alimentari, riduzione delle perdite nelle catene del valore delle derrate alimentari, cicli delle sostanze nutritive nei sistemi di produzione agricoli e sviluppo di strategie politiche per sistemi alimentari sostenibili. Questi temi ricoprono l'intera gamma del SAS e mostrano l'importanza di un approccio di ricerca globale al sistema alimentario. Anche gli ultimi 10 temi di ricerca della graduatoria, cioè quelli con le valutazioni peggiori, coprano l'intero sistema alimentare. I partecipanti al sondaggio non hanno mostrato preferenze per i temi del loro settore o area di lavoro. Perfino escludendo le risposte dei ricercatori dai primi o dagli ultimi 10 temi è risultata la stessa graduatoria. È interessante constatare che temi di ricerca molto rilevanti a livello globale, ma tuttora sottorappresentati nella ricerca svizzera, sono considerati meno importanti di quanto atteso per il futuro del SAS. Inoltre non è stato privilegiato alcun approccio di ricerca; l'istruzione e la trasmissione delle conoscenze sono state considerate altrettanto importanti quanto la ricerca disciplinare o applicata. Il sondaggio ha confermato i risultati dalle interviste, tutti e due mostrando la forte consapevolezza dei rappresentanti dei gruppi di interesse nei confronti dell'elevata diversità e della complessità del SAS.

Grazie alle interviste e alla gamma di dati del sondaggio online, sono state identificate quattro aree principali di ricerca ritenute determinanti per la creazione di un SAS sostenibile: 1) ricerca sull'uso efficiente delle risorse naturali quali terreno, suolo, acqua, sostanze nutritive e biodiversità a tutti i livelli (ecosistemi, specie, risorse genetiche) nonché su protezione, riutilizzo e ripristino di tali risorse. In questa categoria rientrano anche l'utilizzo efficiente di energia e materiali, spesso prodotti a partire da risorse naturali, nonché sprechi o perdite di risorse. 2) Ricerca per lo sviluppo di condizioni quadro politiche coerenti nel settore della politica nazionale, come ad esempio (ma non soltanto) la politica agricola; sono inclusi anche settori delle politiche internazionali, come la politica commerciale, in quanto strettamente connessi al sistema alimentare o alle sue condizioni quadro. 3) Ricerca sull'alimentazione sostenibile, considerando non solo aspetti ambientali, ma anche alimentazione, salute e modelli di consumo. 4) Ricerca su questione all'interno di tutto il SAS, che affrontano i rispettivi fattori trainanti, meccanismi e ripercussioni lungo e all'interno delle catene del valore delle derrate alimentari.

Concludiamo quindi dicendo che il SAS può diventare e rimanere competitivo solo se è possibile conseguire o migliorare la sua sostenibilità. Ciò vuol dire che tutti e tre gli aspetti della sostenibilità (cioè economia, società, ecologia) vanno bilanciati, incrementando anche la resilienza (ovvero la capacità di resistenza) del sistema nei confronti delle sfide future. Politiche e ricerca devono fronteggiare le sfide a cui il sistema alimentare andrà incontro in futuro e creare le condizioni quadro e le conoscenze per poter sviluppare il SAS in maniera efficace. In tal modo si garantisce che il sistema anche in futuro potrà fornire le prestazioni auspicate (sicurezza alimentare e nutrizionale, qualità ambientale, benessere sociale) e contemporaneamente restare competitivo. Ribadiamo che la Svizzera potrà rispondere al meglio alle sfide future a livello nazionale e internazionale sviluppando un sistema alimentare svizzero in maniera consapevole e in collaborazione con tutti gli attori e i gruppi di interesse.

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1. Introduction

1.1 Food systems

Food systems were first established when agriculture and domestication of animals allowed permanent settlements and enabled people to produce surpluses that could be shared. Ever since then, food systems have constantly become more complex, diverse and even global (Hueston and McLeod 2012). Systematic food production has provided economic opportunities and significantly improved livelihoods for vast numbers of people.

Today, the food systems concept integrates our understanding of activities such as agricultural production (including input production), processing, distribution and consumption, while at the same time considering food system outcomes such as food and nutrition security, environmental quality, and social well-being (Figure 1). Moreover, framing activities in relation to the production, the use, and waste and loss of any kind of resources and their interactions with system boundary conditions (i.e., environmental, social, political, and economic) are of major importance for understanding and shaping food systems and their outcomes (Ericksen 2008). Thus, taking a food systems approach requires dealing with complexity and working across disciplines, sectors and scales, but in turn provides a solid framework for development and implementation of policy, research, and planning.

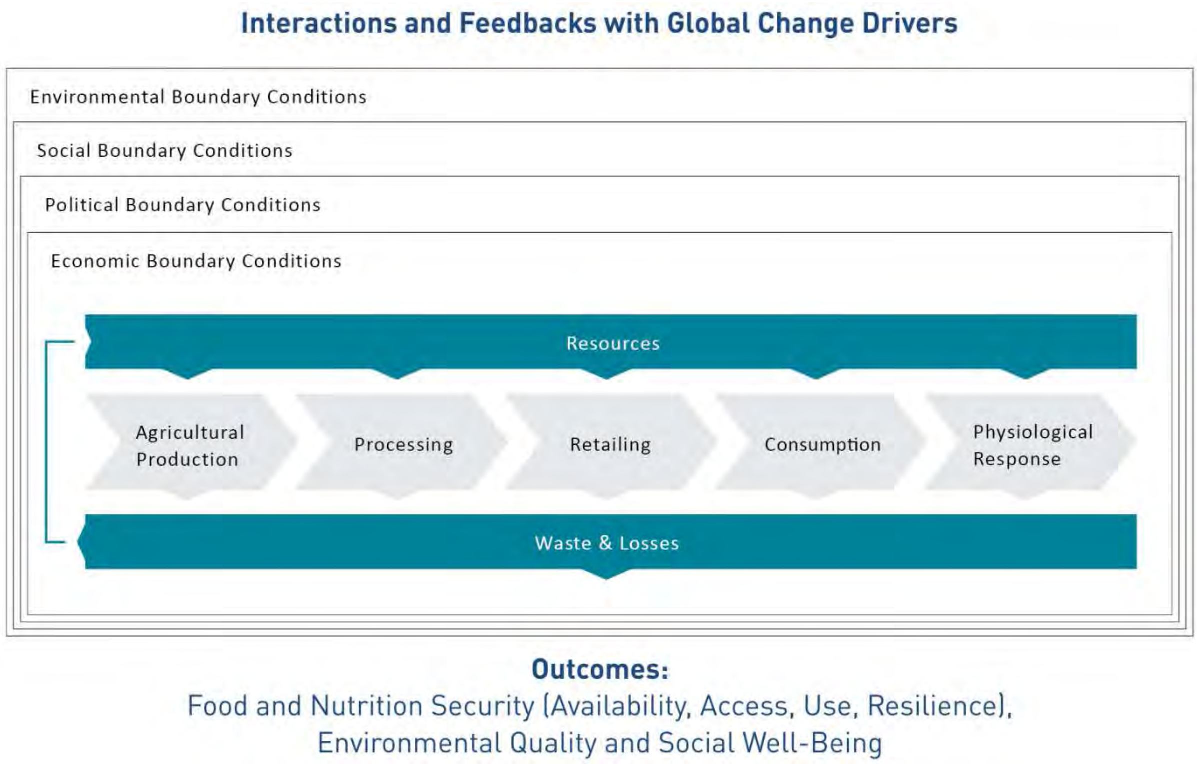

Figure 1: The simplified framework of food systems (courtesy of the World Food System Center).

In the coming decades, tremendous changes in the environment, the society, in global politics as well as in the global economy will challenge the world food system. An increasing world population will demand more food. This demand will cause an increasing pressure on natural resources such as water and (arable) land (Vermeulen et al. 2012). Achieving food and nutrition security within the context of sustainable development (Brundtland and WCED 1987) is thus a global issue (Baldwin 2009; Barilla Center for Food and Nutrition 2011; Smith 2013) and a so-called "wicked" problem, i.e., depending on complex interactions and involving many actors and stakeholders (Ingram et al. 2010). Defining successful strategies to address these challenges depends on our understanding of the system, including its multiple and related drivers, boundary conditions, feedback loops and connections. Nevertheless, constant improvement in food systems is required, not only for feeding the world, but also for providing environmental quality and social well-being (Zurek 2006). Three categories of drivers of the food system can be identified: 1) factors affecting demand, such as demographic changes (e.g., population growth), closely related economic changes (e.g., economic growth), and changes in dietary patterns and consumption (Chapter 3); 2) factors related to supply, such as the productivity of agricultural or fishery sectors (Chapter 3); and 3) factors defining environmental, social, political and economic boundary conditions for the food systems, such as climate change (IPCC 2013), ecosystem services and biodiversity (MEA 2005; Rockström et al. 2009), energy and resources as well as policies, politics, prices and market volatility (Chapter 4). Funding of or investments in scientific and technological developments as well as infrastructure and knowledge-based systems are further important indirect drivers. Whilst often not directly observable, they are crucial for development and improvement of food systems (Hubert et al. 2010; IAASTD 2009).

1.2 Foresight studies

Foresight studies are used to investigate past trends and develop future scenarios in order to predict likely futures, to recognize barriers and drivers in science, technology and innovation, and to inform decision-makers, i.e., policy-makers, federal offices, organizations, sponsors, researchers and development sections at local, regional, national and international scales. Foresight studies are usually based on a participatory process, including quantitative and qualitative methods, either evidence-based (e.g., scenarios, literature review, etc.), expertise-based (e.g., expert panels, interviews, etc.) or based on active interactions (e.g., future workshops, etc. (Popper et al. 2007). The outcomes have already informed many research and innovation policies addressing science, technology and society in the future (EC 2014b). To date, thousands of foresight studies have been completed and more than 1'000 global exercises covering diverse topics were examined by the European Foresight Monitoring Network (EFMN; EC 2009). Most of these studies were commissioned by governmental institutions, which were also the main audience for the outcomes. The time horizon predominantly covered by the analyzed foresight studies was 10-20 years into the future. Across all geopolitical regions, national levels were most commonly looked at. Most of the outcomes were policy recommendations. Within the next years, it is anticipated that the application of the foresight approach will increase and provide strategies for the future across a variety of sectors (EC 2009).

Within the past five years, multiple international foresight studies have addressed the issue of food and nutrition security as well as the sustainability of food systems. While only few of them addressed the world food system and its corresponding boundary conditions as a whole (Foresight 2011; Reilly and Willenbockel 2010), many of them focused on selected, important aspects of that framework such as agricultural production (Alexandratos and Bruinsma 2012; Bengtsson et al. 2010), the impact of climate change (Nelson et al. 2010) or resource use efficiency (Kopainsky et al. 2013). All these studies formulated multiple strategies and questions which will need to be answered in the future. In general, the studies – depending on their focus – agreed that the transition to sustainable food systems and to food and nutrition security needs to be consumer-, technology- and innovation-driven, but also consider governance and organizations (EC 2011). However, dealing with the global challenge of how to feed 9 billion people in 2050 while keeping within planetary boundaries requires a multi- and interdisciplinary approach to the world food system as a whole, with all its complexity, connectedness, and various boundary conditions across sectors and scales.

1.3 Aims of this study

In 2013, the ETH Zurich World Food System Center was commissioned by the Swiss Federal Office for Agriculture (FOAG) to conduct a foresight study that considers the implications of global trends and projections for the Swiss food system and informs the development of a research strategy to ensure a sustainable Swiss food system in the next twenty years. In this study, the definition of the „Swiss food system" includes food (and feed) produced and consumed in Switzerland as well as national stakeholders and national boundary conditions. Thus, although the Swiss food system is clearly embedded internationally, the main focus of this study is Switzerland.

The aims of this foresight study are to synthesize the current literature on global and national trends and drivers affecting the world as well as the Swiss food system now and in the future. Moreover, this study aims at identifying the major research questions which will need to be addressed considering these trends and drivers. In contrast to many earlier studies which focused on single sectors or actors, this study addresses all critical drivers, relationships and feedbacks as well as boundary conditions framing and affecting the world food system.

The two-stage study focuses around five main objectives: The first stage (1) synthesizes current literature on global trends and drivers affecting the world food system today and in the future, and (2) identifies major research questions that will need to be addressed to achieve food and nutrition security, environmental quality, and social well-being. These two objectives are addressed in Chapters 2 to 6.

Chapter 1 of this report provides an introduction to the food systems approach. Chapter 2 explains the methods, which were applied in this study. Chapter 3 presents key trends and projections which represent major challenges arising from and for the world food system. Chapter 4 presents and considers multiple boundary conditions of food systems, i.e., environmental, social, political as well as economic boundary conditions. Chapter 5 discusses the main outcomes of food systems, i.e., food and nutrition security, environmental quality, and social well-being, while Chapter 6 presents global research questions identified in this foresight study.

The second stage (3) analyzes key implications of the global macro-trends for Switzerland (as identified in the first stage); (4) identifies potential gaps between the implications of corresponding trends and current Swiss policies; and (5) identifies major research themes that are critical for building a sustainable Swiss food system within the next two decades and are important based on stakeholder perspectives. These three objectives are addressed in Chapters 7 to 10. The report concludes with recommendations for policy and research (Chapter 11), which are necessary to approach a sustainable Swiss food system within the next two decades.

2. Methodology

Research for Stage 1 of this foresight study was conducted between January and May 2014. It involved a comprehensive literature review and expert consultation in order to address the objectives of mentioned above.

Research for Stage 2 of this foresight study was conducted between August 2014 and March 2015 and involved a multi-methodological approach in order to address the objectives of the study. Three primary methods formed the basis for the analysis in Stage 2: (1) an extensive review of literature and current research strategies of Swiss research entities concerned with the Swiss food system (including federal offices, universities, and private institutions); (2) semi-structured interviews with leading representatives of federal offices; and (3) an online survey of Swiss food system stakeholders. In addition, the coverage of selected research topics in Swiss media was analyzed.

2.1 Review of literature – The world food system

Global trends and drivers affecting the world food system today and in the future were synthetized based on a comprehensive review of current literature. In a subsequent iterative process, questions arising from the key trends and developments identified in Chapters 3 to 5 were grouped around the previously defined structure of the food system. These included the above mentioned three food system outcomes as well as the political and economic boundary conditions (environmental and social boundary conditions were addressed in the food system outcomes, see Figure 1). For each of the five elements, one overarching question was formulated addressing the main challenge(s) for the respective food system outcome or boundary condition. The questions were deliberately formulated at a rather high level of abstraction to be as comprehensive as possible and to allow the formulation of more detailed sub-questions as the context required.

2.2 Review of literature and research strategies of Swiss institutions

For each of the trends and drivers of the global food system defined in Chapters 3 to 6, we screened academic publications, reports and data bases of Swiss research bodies, think tanks, research institutes, federal offices, governmental as well as non-governmental organizations which are concerned with the relevance of the trends for Switzerland. In addition, international literature was considered to identify the implications for Switzerland. This literature review provides the basis for the analysis in Chapters 2 to 9 of this report. We also performed a comprehensive analysis of recent research strategy papers, research agendas, and priority research areas of Swiss institutions working in one or more areas of the food system (Table 1), providing an understanding of the status quo regarding the focus areas for Swiss research institutions. This information was also used to develop the research topics that participants of the online survey were asked to evaluate.

Table 1: List of the origin of institutional research strategies, concepts, and papers analyzed.

Federal Offices and Institutions	Academic Institutions
Federal Office for Agriculture (FOAG)	Swiss Federal Institute of Technology (ETH)
Agroscope agenda for 2014-2017	University of Zurich (UZH)
Federal Food Safety and Veterinary Office (FSVO)	School of Agriculture, Forest and Food Sciences (HAFL)
National Research Programmes (NRPs)	Zürich University of Applied Sciences (ZHAW)
	University of Applied Sciences of Western Switzerland (HES-SO Valais)
	Vetsuisse Faculties Berne and Zurich
	School of Business and Engineering, Packaging Laboratory, Vaud (HEIG-VD)
Private Sector	**Others**
Research Institute of Organic Agriculture (FiBL)	Coop
Nestle Research Center	Migros
	European Technology Platforms (ETPs)

2.3 Semi-structured interviews

Eight semi-structured, face-to-face interviews with leading representatives from eight Swiss Federal Offices were conducted between October and December 2014 (Table 2). These interviews were conducted in order to understand the key stakeholders' perspectives about the development of the Swiss food system in light of the global challenges and corresponding implications for Switzerland. In addition, the interview data provided insights regarding gaps between the current Swiss policy regime and the policy framework needed to ensure a sustainable food system in the coming decades.

Federal offices and individuals to be interviewed were selected in consultation with the Federal Office for Agriculture. Each of the eight interviews lasted between one and two hours, was conducted in German, and was recorded and transcribed with the interviewees' consent. Data are kept confidential and responses are not connected with specific individuals.

Table 2: List of Federal Offices granting interviews.

Federal Offices	Official Abbreviation
Federal Food Safety and Veterinary Office	FSVO
Federal Office for Agriculture	FOAG
Federal Office for Spatial Development	ARE
Federal Office for the Environment	FOEN
Federal Office of Public Health	FOPH
State Secretariat for Economic Affairs/World Trade Organization	SECO/WTO
Swiss Agency for Development and Cooperation	SDC
Swiss Federal Office of Energy	SFOE

2.4 Online survey of Swiss food system stakeholders

An anonymous online questionnaire was selected to document and analyze the opinions of Swiss food system stakeholders about the country's most pressing challenges and critical research needs to establish a sustainable Swiss food system. Specifically, the research was designed to:

(1) determine what respondents perceived to be the most important challenges the Swiss food system would be confronted with in the next 20 years, and

(2) identify research topics considered by Swiss food system stakeholders to be most critical for building a sustainable Swiss food system in the next 20 years.

We set up this questionnaire using an online survey format (Survey Monkey, Gold Version) in order to reach a large number of stakeholders from a wide range of professional sectors and with experience across the entire food system. The online survey was pretested and offered in four languages (German, French, Italian, and English) and took approximately 20-25 minutes to complete. It was available for four weeks (between 8 December 2014 and 6 January 2015).

2.4.1 Sampling design and survey sample

The target population for this part of the study was defined as all Swiss food system stakeholders who hold professional positions within organizations, institutions, and companies involved in or concerned with the Swiss food system. This included, but was not limited to, members of governmental bodies; research, policy, and academic institutions; non-governmental and non-profit organizations; standard setting organizations; financial institutions; associations; and international organizations.

Given the wide scope of the population and large number of individuals in this group, the survey was set up using a non-probability sampling technique that combined a purposive sampling with a modified snowball sampling approach, i.e., rather than seeking a representative sample of the entire Swiss population, we identified the individuals included in the initial sample based on their fit with the target population and invited them to further distribute the survey to their colleagues as appropriate.

An initial sampling frame of 987 individuals was developed by the researcher team based on a variety of resources, including:

- a database maintained by the Swiss Federal Office for Agriculture,
- a database maintained by the ETH Zurich World Food System Center,
- the networks of the members of the ETH Zurich World Food System Center,
- directories and members lists of food system organizations and institutions.

Invitations to participate in the online survey were sent to this sample via email by ETH Professor Nina Buchmann, principal investigator for this study and Prof. Bernard Lehmann, Director of the FOAG. Each recipient was asked to respond to the survey individually, not as an representative voice of his/her institution and to forward the invitation to colleagues who fit the criteria for respondents, to help ensure the survey reached as much of the study population as possible. Large Swiss associations and institutions, such as Agroscope and SVIAL were personally asked (and subsequently agreed) to forward the invitation to all of their members and to inform them about the importance of their contribution.

The survey platform was set up to accept only one response per computer. All responses were kept anonymous and answers were not connected with individual respondents.

2.4.2 Survey design and questions

The survey focused on recording the opinions of respondents about food system challenges and research topics critical for building a sustainable Swiss food system in the next 20 years. Respondents were asked to provide up to three open-ended responses indicating what they believed were the most important challenges that the Swiss food system will be confronted with over the next 20 years.

To help identify research topics considered most critical for building a sustainable Swiss food system, respondents were asked to rate 88 research topics, using a scale of 1 to 6, with 1 = not critical and 6 = very critical. The topics were presented to each respondent in the same, random order in a series of five computer screens.

The 88 topics included in the survey were defined and selected using a multi-stage, iterative, and consultative process involving the interdisciplinary project team and an advisory group comprised of six professors and researchers associated with the World Food System Center. An initial list of more than 600 topics was developed based on a comprehensive review of the current research concepts and strategies of 16 bodies and institutions in Switzerland (Table 1). Several rounds of coding and categorizing these topics resulted in a short list of roughly 80 topics that were defined at a comparable level of analysis and incorporated all of the major themes and most of the sub-topics from the original list. After pre-testing the online survey with 20 persons who were not part of the target respondents group, this short list was revised and resulted in the 88 topics that were included in the survey. In order to account for any other topics that respondents felt were critical but missing from this list, there were free-text fields available for respondents to add up to five additional research topics. See Appendix 2 for a copy of the survey, including all 88 topics and topline results.

Another series of Likert items (i.e., questions) asked respondents to evaluate how critical they thought it was for food system researchers in Switzerland to have support for different approaches and activities, such as basic research, applied research, participatory research approaches, and education and outreach.

Respondents were also asked to identify both the area of the food system (e.g., agricultural production, processing, retailing, etc.) and the sector (e.g., industry, government, research, etc.) in which the majority of their professional activities was located. In addition, standard demographic information from each respondent was collected, including gender, age, education, and nationality.

2.4.3 Survey data analysis

Descriptive data analyses of research topics, the research approaches and the demographic data were carried out using the statistical analysis program SPSS (IBM SPSS Statistics 22). Significant differences between mean scores given to the research topics and research approaches by researchers and non-researchers were analyzed using the independent samples T test.

2.5 Content analysis of Swiss online media coverage

A media content analysis was performed to investigate the presence of selected topics with regard to a sustainable Swiss food system in the German language media in Switzerland. This analysis was conducted in order to identify news or topics in the media which could have influenced respondents' opinion of related research topics. The analysis was limited to online editions of Swiss media in German, which were screened for selected key words anywhere in the article by conducting an advanced search on google news. We selected key words that corresponded to the research topics falling in the top, middle, and lowest 10, according to ratings assigned by survey respondents. The search was limited to the timeframe of 1 December 2014 (one week before the survey was launched) to 6 January 2015 (the day the online survey was closed).

Assessment of the World Food System (Stage 1)

3. Global key trends and projections

3.1 Demographic changes

3.1.1 Population growth

Population growth is among the major drivers shaping the world's future with regard to food and nutrition security. Since 1950, the world population has increased by 4.5 billion people and reached 7.2 billion by mid-2013. This growth is projected to continue as indicated by the projections of three scenarios up to 2050 presented by the United Nations Population Division. The three scenarios include the "low-variant" (average of 1.53 children per woman), the "medium-variant" (average of 2.83 children per woman) and the "high-variant" (average of 3.33 children per woman). The assumptions underlying these scenarios will strongly affect the projected global population during the next decades (Figure 2; United Nations Population Division 2013b). The projections for 2050 range from 8.3 ("low-fertility") to 11.1 billion people ("high-fertility"; United Nations Population Division 2013b).

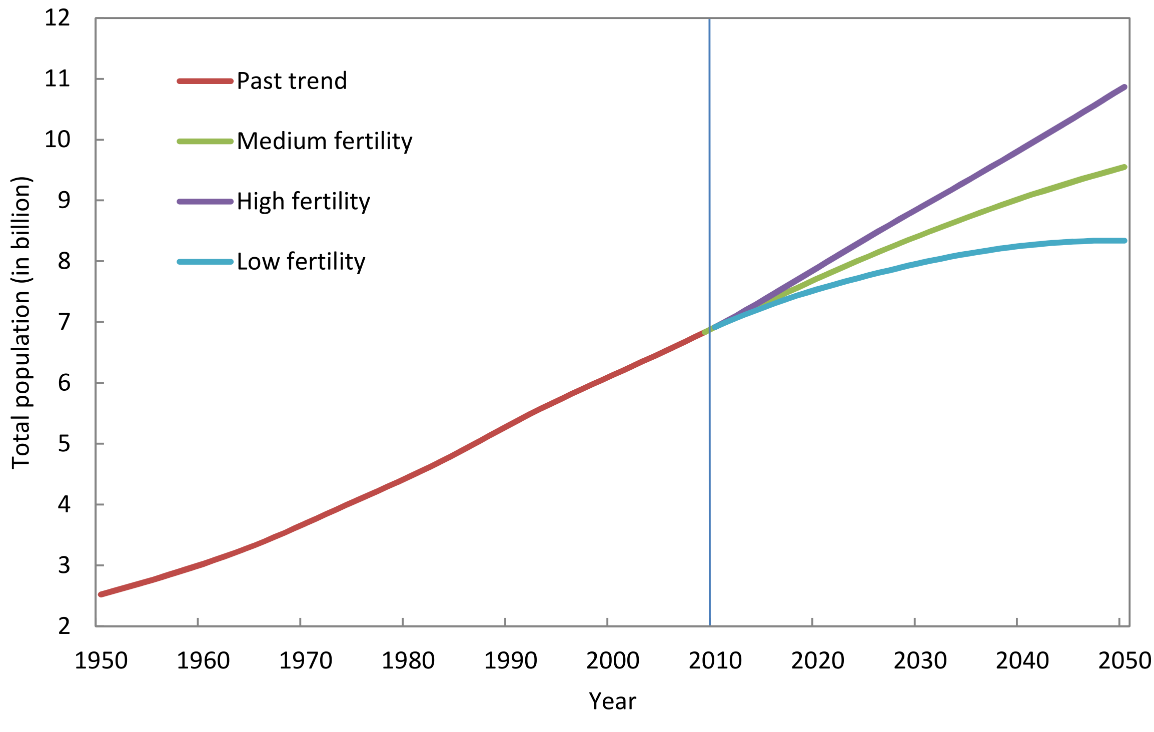

Figure 2: United Nations total population trends and scenarios reproduced using data from United Nations Population Division (2013b).

Moreover, there is a significant difference in population growth across regions, countries and continents (OECD 2012b). Developing countries are expected to experience the largest increase in population size (from 5.9 billion in 2013 to 8.2 billion in 2050; +2.3 billion), while comparable minimal changes (+200 million) are projected for more developed regions based on the medium-variant. In the 49 least developed countries (as defined by the United Nations General Assembly), population is projected to double from 898 million inhabitants in 2013 to 1.8 billion in 2050. Much of the overall increase between 2013 and 2050 is projected to take place in high-fertility countries, mainly in Africa, as well as in countries with large populations, such as India, Indonesia, Pakistan, the Philippines and the United States of America. Population growth rates are assumed to be low in the OECD countries (on average 0.2% p.a. between 2010 and 2050), while some countries might even experience a decreasing population (e.g., Japan, Korea and some European countries). In the "BRIICS" countries (Brazil, Russia, India, Indonesia, China and South Africa), the population growth is projected at 0.4% p.a. on average, with higher rates in India and most likely negative rates in Russia (OECD 2012b). Beyond 2050, the population growth rates are projected to decrease (United Nations Population Division 2013b). By the end of 2080, the only region with continued population growth is expected to be Sub-Saharan Africa (SSA; Alexandratos and Bruinsma 2012).

Population growth not only increases the number of people to feed, but also affects economic transitions through an increase of the working-age population. This provides a labor force which can contribute to economic growth, especially in emerging countries (Chapter 3.2).

3.1.2 Migration

Food and nutrition security is not only related to population growth and changing demographic patterns, but also to migration. On the one hand, migration plays an important role within national boundaries, for example by increasing urbanization. Ensuring food and nutrition security for an urban majority compared to a rural majority requires a different approach to food production and distribution. On the other hand, migration occurs across international boundaries as a result of civil unrest, war, drought or other catastrophes (Crush 2013; Lacroix 2011). But migration also occurs due to family, professional and economic reasons (OECD 2012b). Globally, the countries with the largest net immigration of international migrants between 2010 and 2050 are expected to be the USA (+1 million), Canada (+2.05 million) and the United Kingdom (+0.8 million). Countries such as Bangladesh (-331'000), China (-300'000) or India (-284'000) are expected to experience largest net emigration within the same time period (United Nations Population Division 2013b). Thus, migration will affect (local) food demand, both in quantity and products demanded, but also food supply, e.g., in terms of production areas and distribution.

3.1.3 Aging

Globally, the population group aged older than 60 years (60+) is projected to grow the fastest and the population group aged younger than 5 years (<5) is expected to decline the fastest. Today, 12% and 9% of the current world population are in the age groups 60+ and <5, respectively. By 2050, the share of the two groups is projected to be 27% and 6%, respectively (assuming the medium-variant population; United Nations Population Division 2013a). Nonetheless, there is a significant difference in age development across regions, countries and continents (OECD 2012b; United Nations Population Division 2013a). In developed countries, the population aging is expected to progress at 1.0% p.a. up to 2050 and will then slow down (0.11% p.a., 2050 to 2100). The proportion of older people in developed countries is projected to increase, while younger population groups such as <5 or 5-15 aged will rather stay constant. The largest share of young people can be observed in least developed countries, where almost 60% of today's population is younger than 25. By 2050, this number is projected to increase by 2.9% p.a., with a slow down toward the end of this century (0.9% p.a., 2050 to 2100). An increased life expectance is one of the major reasons for the projected patterns of aging in these countries.

In Europe, the projected population increase (from 501 million in 2010 to 525 million in 2040) results from slightly rising fertility rates combined with further life expectancy gains. Demographic changes in Europe are congruent with those of other developed countries – a significant reduction in the population aged 15-64 and an increase in persons aged 65 or more. However, countries within the European Union are projected to follow different population change trajectories (Eurostat 2013). Overall, aging populations will not only cause changes in lifestyle and consumption; this development will also diminish the workforce (as predicted for China) and, moreover, affect the demand for health care and other services (EC 2011; OECD 2012b).

3.1.4 Urbanization

The global population has been and is becoming increasingly urbanized. While in 1900, approximately 15% of the population was urban, in 1970, 36% of the world's population lived in urban areas (Satterthwaite et al. 2010). This number further increased drastically and reached 50% of the world's population in 2009. By 2050, almost 70% of the world's population are projected to live in cities (6.25 billion, Figure 3; OECD 2012b; United Nations Population Division 2012). During the same time, the rural population will decrease by 0.6 billion globally (United Nations Population Division 2012). Least urbanized areas, such as SSA (37% in 2010), are projected to reach urban populations of 60% in 2050.

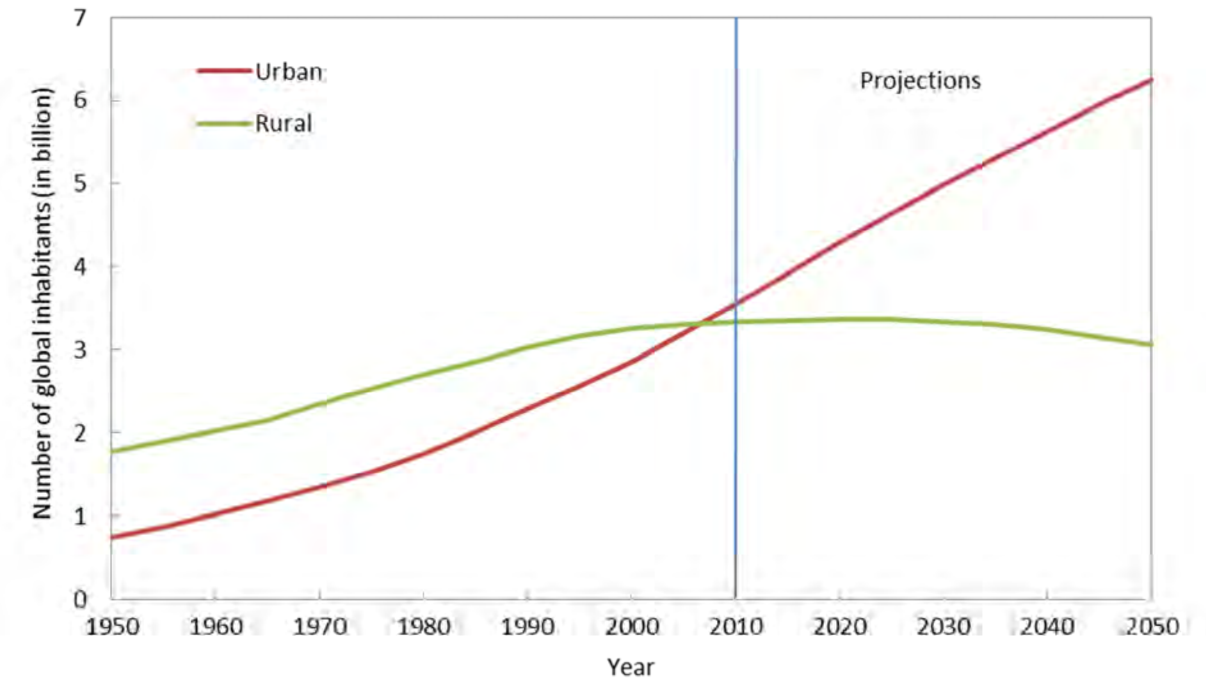

Figure 3: United Nations total urbanization trends and scenarios based on data provided by the United Nations Population Division (2013b).

Rapid population growth in urban areas and a continuously growing proportion of the economically active population working in industry and services (which are predominantly located or established in urban areas) are causes for urbanization (Satterthwaite et al. 2010). In general, urban areas are expected to increase economic growth. Overall, an urban population consisting of net food-buyers is highly dependent on a functioning food value chain to meet the demand for "imported" food. This implies national (e.g., from rural areas) as well as international imports (Kennedy et al. 2002). Nonetheless, there will be numerous urban areas with less prosperous economies, where basic nutritional needs cannot be met due to lacking accessibility or affordability of food. However, very often there is a combination of both trends – prospering megacities with growing slums in the periphery. One out of three city dwellers worldwide lives in a slum, where environmental and health conditions are increasingly severe (OECD 2012b).

Furthermore, urbanization will increase air pollution, transport congestion, competition for fertile land, and the management of waste and water resources. By 2050, air pollution, such as the distribution of particulate matter, is projected to become one of the major causes of environmentally related deaths worldwide (OECD 2012b). However, urbanization will also concentrate many activities. Food, energy, infrastructure and services will reach the population much easier and might improve economic growth. Thus, the effects of urbanization on the world food system are numerous, spatially highly varying, and affecting all aspects of food systems (see Figure 1).

3.2 Global trends in food demand

3.2.5 Demand through economic growth

Food systems are strongly connected to economic processes at local to global scales (van der Mensbrugghe et al. 2011). The global demand for agricultural products is expected to grow at a lower rate (1.1% p.a., 2005/2007-2050) compared to 2.2% p.a. in the past four decades (Alexandratos and Bruinsma 2012). This increasing demand for food by an increasing world population is strongly related to changing incomes (often measured as gross domestic product (GDP) as per capita) and to changes in diets (Alexandratos and Bruinsma 2012; Kearney 2010; Tilman et al. 2011; van der Mensbrugghe et al. 2011). On the other hand, economic growth will not only affect the food demand (Godfray et al. 2010b), but also the supply side (Chapter 3.3).

Gross Domestic Product

The global economy, measured by the real gross domestic product (GDP), has increased fourfold during the past four decades, a positive trend that is projected to continue (OECD 2012b). Assuming a constant USD (2010 level), the global real GDP is projected to grow on average by about 3.5% p.a. from 2010 to 2050 (Table 3). As a result, GDP will quadruple in the coming four decades (Fouré et al. 2010; Hawksworth and Chan 2013; OECD 2012b; van der Mensbrugghe et al. 2011). Tilman et al. (2011) projected a two-fold increase in food demand by 2050 solely due to changes in per capita GDP.

Economic growth patterns are highly variable across regions and countries (Fouré et al. 2010; OECD 2012b). High growth rates are projected for China, India or Africa (>4% p.a. in 2010 USD), with the highest growth rates projected for Africa. However, SSA (+6% p.a.) will most likely remain the poorest region at the end of the projection period (OECD 2012b). In developing countries, the growth rate of GDP will be much higher than in developed countries.

Table 3: Annual average real GDP growth rates according to OECD baseline scenario (2010-2050) modified from OECD (2012b).

Country or geopolitical region	Annual average real GDP growth rates (in %)			
	2010-2020	2020-2030	2030-2050	2010-2050
Canada	2.5	2.3	2.1	2.2
Japan & Korea	2.1	1.6	1.0	1.4
Oceania	2.8	2.4	2.2	2.4
Russia	3.0	2.80	2.2	2.6
United States	2.2	2.3	2.1	2.2
EU-27 & EFTA	2.1	2.0	1.7	1.9
Rest of Europe	4.7	5.0	3.6	4.2
Brazil	3.7	4.0	3.2	3.5
China	7.2	4.2	3.0	4.3
Indonesia	5.0	4.5	4.2	4.5
India	7.3	6.2	4.8	5.7
Middle East & North Africa	4.1	4.6	4.1	4.2
Mexico	4.5	3.6	2.9	3.5
South Africa	4.2	3.8	3.3	3.6
Rest of the world	4.4	4.5	4.5	4.5
OECD	**2.3**	**2.2**	**1.9**	**2.0**
BRIICS	**6.4**	**4.5**	**3.5**	**4.5**
World	**4.1**	**3.6**	**3.1**	**3.5**

Furthermore, global GDP growth will be driven by emerging markets. By 2050, China (expected GDP of 25 trillion USD, at constant 2000 USD level) will have overtaken the United States (expected GDP of 22 trillion USD) as the world's largest economy. Considering a ranking of the 100 largest economies in 2011, multiple countries are projected to gain (+) or lose (-) 20 or more ranks on that list. Countries such as Tanzania (+34), the Philippines (+27), Bolivia (+25), Ethiopia (+23), Ghana (+22), Uzbekistan (+22) and Peru (+20) are projected to improve the size of their economy, whereas the economies of countries such as Denmark (-29), Luxembourg (-24), Qatar (-23), Slovenia (-23), Norway (-22) and Sweden (-20) are projected to grow less (Ward 2012). In general, the development of economic growth will be highly dependent on the development in education, technological progress and the increase of labor force (Johansson et al. 2012; Ward 2012).

Share of economic growth among nations

Within the next decades, the economic balance among nations is predicted to change rapidly (Dadush and Stancil 2010). In 2010, OECD countries held a major share of global economic activities (54%) and a much higher per capita income level compared to BRIICS countries and the rest of the world. In 2050, it is anticipated that BRIICS countries will contribute more than 40% to global economic activities, while the OECD's share will have declined to 32% (OECD 2012b). Accounting for relative price variations, China is projected to strengthen its position as a world economy in 2050. Its share of global economic activities (33%) will be larger than those of the United States (9%), India (8%), the European Union (12%), and Japan (5%). In general, the difference in wealth between countries will narrow substantially over the coming decades.

Per capita income

An accurate prediction of a nation's food demand requires the consideration of the distribution of the per capita incomes and how this distribution is reflected in food purchases (Godfray et al. 2010). Overall, relative expenditures for food decrease as incomes increase (Engel's law; Cirera and Masset 2010). In the past decades, average per capita income levels increased globally. However, this trend was not spread evenly across and within geopolitical regions and per capita GDP levels increased twice as fast in the BRIICS countries (3.4% p.a., 1970-2009) compared to other regions (1.9% in OECD countries and 1.6% in the rest of the world excluding developed countries; OECD 2012b). By 2050, per capita incomes are projected to have increased significantly (Ward 2012). From currently 45 developing countries with per capita incomes <1'000 USD (low-income group according to the World Bank), 15 are projected to remain in this group by 2050. Consequently, poverty may prevail in many countries (Alexandratos and Bruinsma 2012; Ward 2012), and large income gaps within and among geopolitical regions will persist (Table 4). Furthermore, highest incomes will remain in advanced economies and incomes will just very slightly catch up in emerging countries (Hawksworth and Chan 2013). Thus, while the world is expected to become richer and characterized by less pronounced average income gaps between developed and developing countries by 2050, large inequalities might still exist within populations.

Table 4: Average income and income growth rate projections (2010-2050) for major geopolitical regions considering the current 100 largest economies (Ward 2012).

Geopolitical region	Per capita income (in 2000 USD)		Income growth rate per decade (in %)			
	Group average	Range	2010-2020	2020-2030	2030-2040	2040-2050
Developed world	27'200	14'939-52'388	1.7	2.0	2.1	2.2
Asia	4'220	16'463-34'110	4.8	4.6	4.5	4.4
Central & South America	4'228	1'192-10'517	3.3	3.6	3.6	3.7
Central & Eastern Europe	7'000	987-15'510	5.2	4.8	4.4	4.1
Middle East & North Africa	11'158	565-38'466	2.0	2.4	2.7	3.0
Sub-Saharan Africa	1'543	1'310-33'710	2.1	2.8	3.5	4.2

3.2.6 Demand through changing per capita food consumption

Over the last decades, there was a continuous increase of per capita food consumption (expressed in kilocalories (kcal) per capita and day), due to economic growth and increasing per capita income worldwide. Average global calorie consumption increased from 2'373 kcal per capita and day to 2'772 kcal per capita and day (1969-2007; Figure 4). Although this change in per capita food consumption is highly variable across countries and regions, the Near East and North Africa as well as the developed countries reached a daily per capita consumption of 3'000 kcal by 2005/2007. But one has to note that these numbers do only reflect energy availability and do not provide any information on nutritional quality or micronutrient deficiency.

In the future, the global average per capita food consumption per day is projected to increase by 24% and reach 3'070 kcal capita per day by 2050 (Figure 4). More than half of the world's population (52% or 4.7 billion) will, on average, consume >3'000 kcal per capita and day by 2050. Only SSA and South Asia will then still have per capita consumptions <3'000 kcal per capita and day. The share of people living in countries with an average food consumption <2'500 kcal per capita and day might decrease from 35% (2.3 billion) to 2.6% (240 million; Alexandratos and Bruinsma 2012). This could result in decreasing total numbers of undernourished people in the future (currently 842 million; FAO 2013f), although this trend might be counteracted by increasing populations.

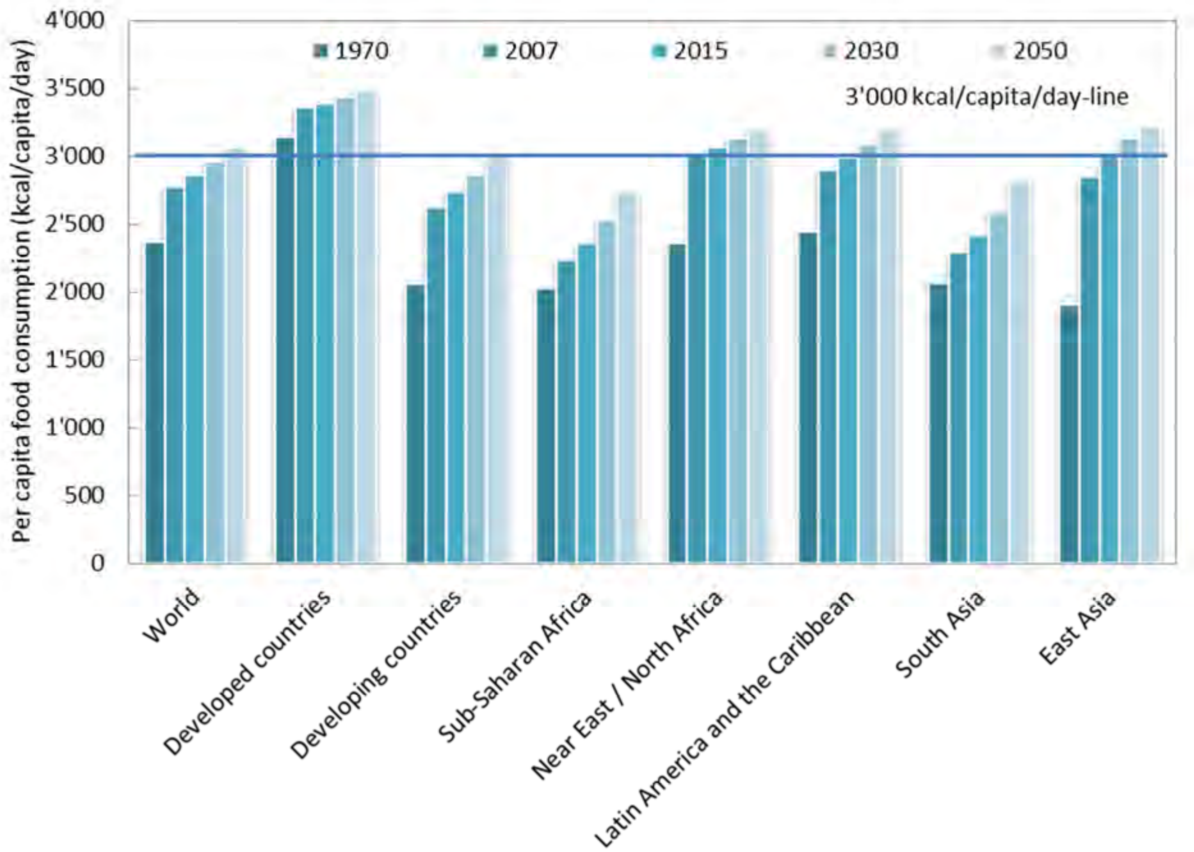

Figure 4: Average per capita food consumption according to stages of development and in major geopolitical regions based on data presented by Alexandratos and Bruinsma (2012).

3.2.7 Demand through dietary changes

Cereals

Cereals are the most important source of calories in total food consumption. Currently, cereal staples such as maize, rice, and wheat contribute around 50-60% to the human caloric energy intake, globally (IAASTD 2009). On average, the consumption of cereals will stay relatively constant, with 158 kg per capita p.a. in 2005/2007 to 160 kg per capita p.a. in 2050. However, the importance of cereals is highly variable among countries and regions. For example, in Uganda, cereals are of minor importance and only contribute 20-30% to the caloric energy intake per capita, while they account for 70-80% of the per capita calories in North Africa (Alexandratos and Bruinsma 2012). The growth of global cereal demand is projected to slow down from currently 1.4 to 0.4% p.a. until 2050. These changes in per capita cereal demand will also be highly variable. While decreasing demands are projected for East Asia and the Pacific region (-27 kg) as well as in Latin America and the Caribbean (-11 kg), per capita cereal demand in SSA is projected to increase (+21 kg; Hubert et al. 2010).

On the other hand, more than one third (36%) of cereals produced globally are used for animal feed, in particular coarse grains such as maize (Alexandratos and Bruinsma 2012). In developing countries, the demand for feed is projected to increase continuously, mainly due to increasing meat production. In contrast, cereals are projected to lose importance for feed in developed countries, but gain importance for biofuel production (Alexandratos and Bruinsma 2012; Kearney 2010). The global maize demand is projected to originate from animal feed (60%), food (24%) and biofuels (16%, Hubert et al. 2010).

Animal proteins

Economic growth drives the increasing demand for animal proteins. The annual consumption of meat is projected to increase from 38.7 kg per capita p.a. in 2005/2007 to 49.4 kg per capita p.a. in 2050, at the global scale. However, global growth rates for the consumption of meat and dairy products are projected to decline from 2.9% p.a. during the past four decades to 1.3% p.a. within the next four decades. Developing countries will still consume less animal proteins compared to developed countries until 2050, and major countries such as China and Brazil will continue rapidly adopting western consumption patterns (Alexandratos and Bruinsma 2012), leading to an increase in the per capita demand for animal proteins in South Asia, SSA, East Asia and the Pacific region (+100%) as well as in the Middle East and North Africa (+50%). In contrast, a small average increase is projected for developed countries (+4%) until 2050.

The contribution of fish as animal protein to human nutrition is highly dependent on the region's stage of development, trade, and the availability of aquacultures and fishery (inland and marine). Today, approximately 3 billion people cover at least 15% of their average protein consumption by seafood (WWF 2010). While developed countries are consuming a high quantity of fish per capita (22-24 kg per capita p.a.), the contribution of fish to animal protein intake with 9-18 kg per capita p.a. is much higher in developing countries (19%). Since 1960, world fish consumption has grown dramatically (3.2% p.a.), from per capita seafood consumption of 9.9 kg per capita p.a. (live weight equivalent) to >18.4 kg per capita p.a. (FAO 2012b; FAO 2013b). However, due to slower population growth and increasing fish prices (OECD 2013c), the growth in fish consumption will decelerate from currently 1.8% p.a. to 0.6% p.a., reaching 20.6 kg per capita p.a. by 2022.

Consumptions trends in developed countries

Currently, three major trends in food consumption can be observed in developed countries or geopolitical regions such as the European territory. First, the variety of food and drink consumption has increased due to the expansion of agri-food trade and markets as well as due to social and technological developments within the corresponding sectors. Moreover, the regional differences in food purchase and preparation have been declining within Europe. However, there are and will still be substantial differences in food consumption and food preparation across Europe in 2050. Second, habits of food consumption are changing. Diets include an increasing share of convenience foods, prepared with an increasing range of appliances for storage and cooking. These changes result from changes in lifestyle in general, including the changing role of women in society, changing household structures and incomes, and the availability of enriched food (e.g., functional food). Third, there is a trend toward divergent diets of the rich and the poor. Due to higher income, rich consumers tend to adapt their diets in a manner characterized by an increase in novel and specialist foods, for example vegetarian, organic, or foods for special health requirements such as allergies. However, the diets of the poor tend to not adapt, for example to more fruits and vegetables, due to the higher costs of non-staple foods (EC 2007; EC 2011). Since nourishing food is available and consumed all over Europe, diet-related diseases such as obesity, type 2 diabetes, hypertension, osteoarthritis, and cancer are on the increase.

3.3 Global trends in food supply

Food supply from food systems depends on value chain activities such as production, processing, distribution, retail, consumption and physiological responses. Throughout these food value chains, inputs and outputs such as resources are required. At the same time, waste and losses are produced (see Figure 1). The increasing food demand outlined in Chapter 3.2 needs to be balanced by an increasing food supply in order to achieve well-functioning food systems, particularly under changing environmental conditions. Agricultural products can either be products directly provided to the consumer or being processed to various degrees before being sold to the consumer locally to globally. Overall, global agricultural production and food processing has changed considerably over the last decades. Two centuries ago, 90% of the US inhabitants were farmers, able to feed themselves and the rest of the population. Today, only 2% of the US population produces the food eaten by the total US population and agricultural products and food that are exported to many other countries. This trend continues (Prax 2011).

3.3.1 Agricultural production

This increase in production efficiency was possible, particularly during the second half of the last century, because productivity in agriculture increased dramatically due to the “Green Revolution” (FAO 2014e). This has also led to more land being cultivated more intensively. Nevertheless, nowadays, 500 million farms are still family owned and are responsible for 56% of the global agricultural production (FAO 2014h; FAO 2014i). Whereas absolute yields are projected to increase also in the future (Alexandratos and Bruinsma 2012; OECD 2013c), the production growth of the agricultural sector will strongly depend on population growth and on the share of the world’s population reaching saturation of consumption (Bruinsma 2009). At the minimum level, agricultural production growth until 2050 has to be 0.8% p.a. in order to keep pace with global population growth. In the least developed countries, this average growth rate has to be 1.8% p.a. (van der Mensbrugghe et al. 2011). Based on the assumption that current levels of wastage and losses remain constant, global food production in 2050 needs to be approximately 50-60% higher than currently (Alexandratos and Bruinsma 2012). While in developed countries, a 24% increase will be sufficient, food production needs to be about 80% higher than today in developing countries. Economic growth, demographic changes, changing climatic conditions, technology and innovation, energy prices and demand as well as resource scarcity and policies are major drivers for change in agricultural production (ESF and COST 2009). Multiple disciplines such as plant and animal breeding, agronomy, soil science, water management, phytopathology are involved in the agricultural production (Hubert et al. 2010).

Crop yields

In the past decades, crop yields have increased tremendously due to intensification of agricultural production, plant protection and improved crop cultivars. For example, global wheat yield tripled between 1960 and 2012 (to 3’113 kg per hectare), whereas the harvested area increased by only 10 million ha within the same time (215’489’485 ha in 2012). This trend can be observed for the yield and harvested area for aggregated cereals, too (FAO 2014e). In the future, crops such as cereals, root and tuber crops, and grain legumes will probably remain major sources of caloric energy intake for humans on the global scale. Recent scenarios based on models balancing crop demand from rising population, diet shifts, and increasing biofuel consumption, estimated specific growth rates of maize, rice, wheat, and soybean production of 1.6%, 1.0%, 0.9%, and 1.3% p.a., respectively (Neumann et al. 2010; Ray et al. 2013). This translates into an additional production growth of 0.9% p.a. or an additional 1 billion tons of cereals p.a. are required to meet the projected food and feed demands by 2050 (Alexandratos and Bruinsma 2012; Bruinsma 2009), with ca. 460 million tons of the projected production used for human food, and ca. 430 and 160 million tons used for feed and biofuel, respectively (IAASTD 2009). However, the average projected growth of cereal production in the next 40 years will be much lower (0.9% p.a.) compared to that during the second half of the last century (1.9% p.a.; Alexandratos and Bruinsma 2012).

Furthermore, major gains in production are projected to arise from yield improvement and intensification in developing countries, while the annual crop production growth will be lower in developed countries (Hubert et al. 2010). Plant breeding will remain a major contributor to crop productivity improvement. Although there are already discussions about breeding approaches being close to reaching the top of yield increase in certain regions there are multiple breeding strategies which will allow further yield growth. Conventional as well as modern breeding techniques (e.g., molecular breeding) are continuously providing new approaches (McClung 2014). The improvement of light, nutrient and water use efficiency as well as the improvement of biotic and abiotic stress tolerance still has potential to be exploited. Moreover, currently minor or under-used crop species such as cassava, quinoa or amaranth might be able to add to the local food and nutrition security (Jaggard et al. 2010).

Livestock production

Currently, livestock production is the largest land-use sector globally and one of the fastest growing agricultural sectors, with an asset value of 1.4 trillion USD (Herrero and Thornton 2013; Thornton 2010). At least 1.3 billion people are employed in the livestock sector globally and the livelihood of approximately 600 million poor smallholder farmers is directly supported by livestock farming (Thornton 2010). In general, livestock systems provide positive effects on economic growth and public health, but their effects on natural resources, climate change, social equity and animal welfare are of critical concern (The World Bank 2008). Assuming current consumption patterns and population growth at medium level, an additional meat production of approximately 200 million tons p.a. will be required in 2050 (Bruinsma 2009). Historically, growth rates have been achieved by domestication, improvement of feeding, and conventional livestock breeding techniques, while future yields are projected to result also from new breeding techniques (IAASTD 2009; Thornton 2010). Still, growth rates for the production of meat and dairy products are projected to decline at the global level, with developed countries having relatively low growth rates in meat production (0.4% p.a.) in 2050. Here, production systems are probably going to be improved with regard to efficiency and environmental sustainability. In contrast, growth rates in developing regions such as SSA and South Asia are projected to be high (3.0% p.a. and 4.2% p.a., respectively), due to constantly increasing demand (Alexandratos and Bruinsma 2012). Absolute quantities produced yearly are projected to double from ca. 250 million tons (2005/2007) to ca. 500 million tons (2050; Alexandratos and Bruinsma 2012). While animal numbers will increase in general, the numbers of monogastric animals (pigs and poultry) are projected to grow faster than the number of ruminants (Herrero and Thornton 2013).

Fisheries

Fish and fishery products are major and valuable sources of protein and essential micronutrients and thus represent an important source of high-quality food (Godfray et al. 2010). In 2012, capture fisheries and aquacultures provided 156.2 million tons of fish (93 million from capture, 63 million from aquaculture) with a total value of 258 billion USD. The greatest share (132 million tons) was used for human consumption (18.6 kg per capita p.a. in 2011). In the past, major growth resulted from harvesting to capacity or overexploitation which had significant impacts on health and resilience of fish stocks and marine ecosystems. Consequently, there will be almost no scope for increasing productivity in marine fisheries. On the other hand, since 1980, fish production from aquaculture grew at an average rate of 8.8% p.a. globally. But in order to keep pace with the increasing demand for fishery products until 2020, production has to increase by a total of 23 million tons (FAO 2012b). Any of this additional demand for fish needs thus to be supplied by aquaculture which has to be carried out environmentally- and animal-friendly in the future (Bostock et al. 2010; EC 2011; FAO 2012b; FAO 2013b; Garcia and Rosenberg 2010; Godfray et al. 2010).

3.3.2 Processing, distribution and retailing

In the future, also processing, distribution and retailing will change, partly due to changes in consumer behavior (Chapter 3.2), but also due to economic reasons (Chapter 4.4). First, the demand for processed food is projected to increase within the next years (Chapter 3.2.7; Hauser 2012). Second, there is a continuously growing role of large food and beverage processors, distributors as well as retailers in food sales due to concentration of markets (Satterthwaite et al. 2010). Third, the presence of large agricultural producers, processors and retailers within the food sector will increase due to economic and logistic reasons (EC 2011; Kennedy et al. 2002). Fourth, a growing proportion of employment within the food systems will be related to transport, food processing, retailing and vending rather than agricultural production (Cohen and Garrett 2009).

Processing

During the past century, traditional food processing, i.e., post-harvest processing of raw materials, changed tremendously, mainly driven by the demand for convenient as well as healthy and safe food and facilitated by science and technology (ESF and COST 2009). Today, processing of food includes 1) stabilization (e.g., prevention of microbial growth), 2) transformation (e.g., from milk to cheese), 3) production of ingredients (e.g., sugar from sugar beet), and 4) the production of fabricated food (e.g., desserts, sauces, etc.; Hubert et al. 2010). Key issues for economically viable processing are the efficient use of resources (e.g., raw material, water), the consideration of customers' perception as well as social and cultural demands (e.g., kosher food). The focus within the processing sector will be progress in the provision of fresh food (e.g., increasing shelf life) as well as functional and convenient foods, the valorization or minimization of waste, and improved product screening and monitoring. Moreover, intelligent packaging is of increasing concern in food processing in order to add additional value to a healthy and safe product (Dainelli et al. 2008; ESF and COST 2009; Mahalik and Nambiar 2010). Overall, the processing sector experiences increasing consolidation on the global market. In 2009, the top ten food and beverage processing companies (incl. Nestlé, PepsiCo, Kraft, etc.) accounted for 37% of the revenues earned by the top 100 global companies (food and beverage processing). On the other hand, important companies from emerging countries such as the Mexican baker *Grupo Bimbo* are heading toward other emerging as well as developed markets (ETC Group 2011).

Distribution

The distribution of food and food products comprises various steps along the food value chain such as packaging, storage and transport. Within the past decades, globalization and geographical shifts of the production have changed raw material and food product distributions. The transport of food among producers, processors or retailers is highly diverse and dependent on the supply chain of each product. For example, food products can go from the producer directly to the consumer at local markets, whereas at global markets, food products may have passed multiple processors or retailers traveling thousands of kilometers (ESF and COST 2009). These changing distribution patterns are predominantly promoted by the emergence of major retailers and their supply chains, changes in retailer sales/consumer demand (e.g., all-year supply), but also by socio-economic changes such as the changing demand of consumers toward more diverse and convenient food (ESF and COST 2009). Globally, this resulted in increased distances travelled and more steps within distribution paths, in addition affected by production and trade policies at national and international levels as well as by agreements at commodity markets (ESF and COST 2009).

In 2009, the global packaging industry generated a turnover of more than 500 billion euros. The food sector held a share of 60% in the global packaging industry (Duriez 2009). The increasing demand for convenience food and for information about food products (e.g., nutritive value, presence of allergens) also changed the food packaging industry. Moreover, increasing requirements with regard to food preservation and safety, such as the protection from microorganisms, insects, water, oxygen, and physical damage, also show their impacts on packaging trends (ESF and COST 2009; Hubert et al. 2010). Today, packaging is of major importance for both the distribution and the storage of food on an increasingly globalized market, using innovative technologies and integrating concepts from chemistry, microbiology, and engineering (Robertson 2012). Nevertheless, while packaging has improved supply chain functionality and reduced losses caused by wastage and damage, it also became a problem of non-organic waste (e.g., plastic, card board, etc.; Marsh and Bugusu 2007). In addition, technological innovations include the use of clean materials (e.g., less additives, vegetable solvent-free inks) or smart packaging (e.g. traceability, avoidance of damage) with radio-frequency identification chips (Duriez 2009). Overall, major trends of packaging in food supply chains will need to address the quality of materials and their substitutes, food safety and convenience issues as well as the attractiveness of the final product in the future.

Retailing

One of the major trends in retailing is the growth of supermarkets within the past century (Ellickson 2011; Fernie 1997). The success of supermarkets has several reasons, including their efficient supply chain integration, management of logistics as well as their marketing, while increasing product values, setting standards, and shaping the consumer’s demand (ESF and COST 2009). Within the past three decades, the impact of retailers in food systems increased, while shifting away from the producer and the processor or manufacturer. Today, big food and grocery retailers are highly complex organizational structures, present all over the world. The retailing companies Walmart, Carrefour and the Schwarz group accounted for 43.5% of the revenues earned by the top 100 grocery retailers in 2009. Moreover, an increasing number of retailing companies seek their economic growth in emerging markets as in China or Brazil (A.T. Kearney 2010; ETC Group 2011; Sharad et al. 2011). In the future, retailing of food as well as non-food products will be increasingly formed by online shopping as well as by the influence of social media and mobile device which are continuously delivering information are going to allow a multi-channel and personalized consumption based on large data set of consumer information (Mansour and Zocchi 2012).

3.3.3 Waste and losses

Today, resource efficiency not only comprises the efficient extraction and use of resources along the food value chain, mainly based on technological improvements and innovation, but it also considers the sustainable use of resources and the avoidance of waste and losses along the whole supply chain within any given food system. Discussions about food waste and losses only gained increasing attention within the last few years. However, the waste of food is one of the major losses within the food system and consequently a loss/waste of resources. Approximately one third (1.3 billion tons) of the food produced for human consumption is lost every year (Gustavsson et al. 2011). Food waste is a global problem with regionally very different patterns, depending on the product and the level of economic development (FAO 2013c; Lipinsky et al. 2013; Parfitt et al. 2010). In developing countries, major losses of food result from inefficient food value chains (e.g., post-harvest, processing and transport losses), while in developed countries, food loss mainly results from food spoiled after purchase by consumers, and food waste produced during processing (e.g., due to food safety regulations) and within the distribution systems (e.g., in restaurants, retailers or at home). In total, food wastage in developed countries is as high as the total net food production in SSA. In general, food waste is not only the loss of food, but also causes the wastage of blue water (250 km^3 p.a.), the "unnecessary" management of land for production purposes (1.4 billion ha), wasting a value of 750 billion USD each year (FAO 2013c). Moreover, wasted food causes 6 to 10% of the human-generated greenhouse gas emissions within the food sector (Vermeulen et al. 2012).

Until 2050, waste reduction offers an efficient strategy to promote sustainable food systems and food and nutrition security (Lipinsky et al. 2013). Important reasons for present and future food wastage include the relatively low share of food expenditures in developed and emerging countries, increasing product and safety standards, and an increasing disconnection of the consumers from the products. On the other hand, increasing prices and resource-efficiency, policy incentives, and behavioral change might reduce wastage. Nevertheless, the total quantity of food waste produced is expected to increase with an increasing population reaching higher consumption levels (FAO et al. 2011; Parfitt et al. 2010). Assuming "business-as-usual" scenarios, the reduction of food waste and losses by 50% until 2050 would close approximately 25% of the gap between the calories available today and the calories needed in 2050 (Lipinsky et al. 2013).

4. World food system boundary conditions

Processes such as agricultural production, processing, distribution, retailing and consumption of food are highly complex and interconnected in multiple ways at local, regional, national and international levels (Figure 1). In addition, these processes along the food value chain and within the food systems are framed and affected by various boundary conditions, in which the food systems are embedded/nested within and with which they have multiple interactions. These boundary conditions are relevant for the existence, performance and resilience of food systems, namely the environmental boundary conditions such as the availability of resources, social boundary conditions such as demographic changes or consumption patterns (Chapter 3), the political boundary conditions such as policies and governance as well as the economic boundary conditions such as markets, trade and prices.

4.1 Environmental boundary conditions

4.1.1 Climate change

Observations and measurements unequivocally document a warming trend due to anthropogenic greenhouse gas emissions, with average global surface temperatures having increased by around 0.85°C from 1880 to 2012. This warming is further observed in increased ocean temperatures, decreases in snow and ice masses, rising sea levels, and more extreme events, such as heat waves and droughts (IPCC 2013). Changes in precipitation over the past century are less clear and were probably small on the global level. Regional trends in rainfall are also not clear, only the precipitation increase in the Northern Hemisphere is reliable (IPCC 2013). However, the occurrence of extreme weather events has changed in the 20th century. While cold extremes were less frequent, regional increases in the frequency of for example heat waves, heavy precipitation events, and droughts were observed (IPCC 2012, 2013). The atmospheric concentration of the three main greenhouse gases CO_2, CH_4 and N_2O has increased by 40%, 150% and 20%, respectively since 1750 (IPCC 2013). The increasing CO_2 concentrations contribute most to the increasing radiative forcing and in addition also cause progressive acidification of the oceans (IPCC 2013). These observed climate change trends are projected to continue in the future. The magnitude of change depends on the emission scenario, especially for projections beyond 2050 (IPCC 2012, 2013). For the period 2016-2035, a further increase of the global mean surface temperature between 0.3°C and 0.7°C (compared to 1986-2005) is projected by all of the scenarios. Projections for future precipitation differ both regionally and seasonally. Projections show decreasing precipitation in many dry regions and increasing precipitation in many wet regions, associated with an increase of extreme precipitation events in many regions (IPCC 2013). The temporal distribution of precipitation is expected to change toward more heavy precipitation events (less snow), which – in combination with increased temperatures – might cause higher flooding risks (IPCC 2012). Due to higher temperatures globally, also during the main cropping time, droughts might intensify in some regions, but here projections are less certain, mainly due to the ambiguity of future precipitation patterns (IPCC 2012).

The impacts of climate change and weather extremes on the world food system are manifold and affect all aspects of food and nutrition security (IPCC 2013; Vermeulen et al. 2012). Agricultural production might be most directly affected by climate change, with effects on crop health and yields as well as on soil degradation, but also on food processing (e.g., availability of water, energy, quality of ingredients), distribution (e.g., flooding risks, markets) and retailing (e.g., prices). People from marginalized groups are particularly vulnerable to climate change and to adaptation/mitigation measures (IPCC 2014). In addition, climate change affects the distribution of species, be it crop, aquatic or livestock species, weeds or pests (IPCC 2014). Other negative climate change effects are the decrease in nutritional quality under elevated CO_2 (Myers et al. 2014; Taub et al. 2008) or decreased food safety due to food-borne pathogens (Vermeulen et al. 2012). Overall, the effects are predominantly, but not exclusively, negative (IPCC 2014). Without adaptations within the world food system, the impact of future climate change are expected to be negative (IPCC 2012).

On the other hand, the world food system is not only affected by climate change, but it is also an important contributor to climate change. Food systems are reported to have caused at least 30% of the anthropogenic greenhouse gas emissions in 2005 (WRI 2005). About half of these emissions (ca. 14%, Figure 5) originated from agricultural production (FAO 2013a; Vermeulen et al. 2012; WRI 2005), the other half from further up the value chain (Vermeulen et al. 2012). In addition, ca. 18% of the total greenhouse gas emissions are related to land-use change, much of which is tied to conversion of land for agriculture (Baumert et al. 2005).

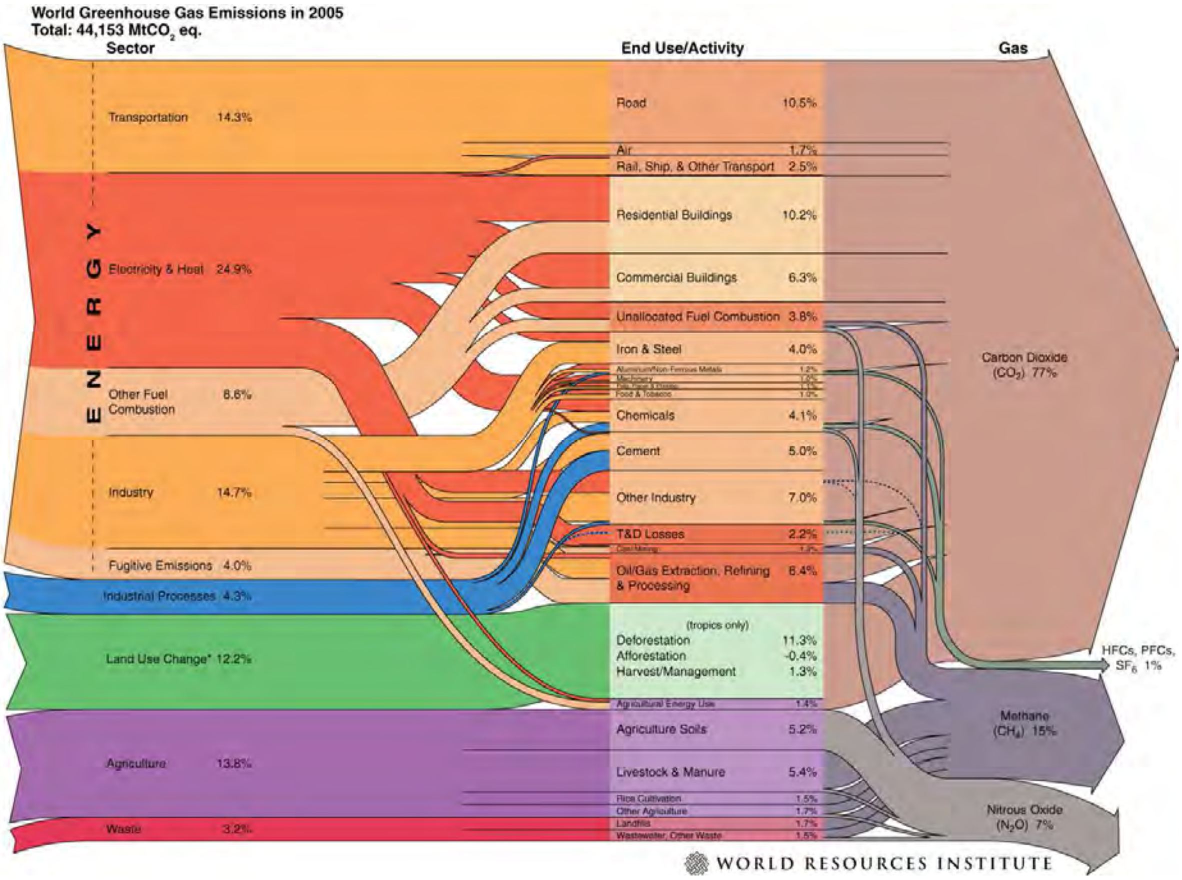

Figure 5: G**lobal anthropogenic greenhouse gas emissions (Baumert et al. 2005), updated version from (WRI 2005).**

Since the concept of food systems is much wider than the general understanding of "agriculture", the options but also the challenges to mitigate climate along the agricultural value chains and within food systems are numerous, both in terms of increasing sinks but also decreasing sources. They also go further than the proposals aimed at involving mainly agriculture in mitigation policies, with activities ranging from improved soil and manure management to a reduction in ruminant numbers. Thus, any such mitigation activity in agriculture and beyond is likely to have strong implications on the global food supply and the demand for resources in the future (Hertel 2011).

4.1.2 Natural resources (nutrients, water, land)

Increasing scarcity of natural resources such as nutrients/fertilizers, water as well as land (both in terms of area and quality) is widely considered a major threat to future food production (but also processing), and thereby also to global political stability and economic prosperity (Odegard and Van der Voet 2014; Rockström et al. 2009). Increasing resource scarcity, mainly due to depletion of reserves, over-exploitation and degradation, will lead to increasing costs for these resources, which in turn can aggravate poverty, disturb international trade, finance and investment, and destabilize governments. Increasing competition for resources may promote mistrust between nations and in response enhance protectionism (van Schaik et al. 2010). All these scarcity-related factors might constrain the sustainability of food systems and thus also food and nutrition security, not only within the environmental realm but also affecting the political and socio-economic boundary conditions. Consequently, ensuring a sustainable use of natural resources has been identified as one of the major challenges for the 21st century (EC 2011; OECD 2012b).

4.1.3 Nutrients

Nutrients are essential for human nutrition as well as for plant and animal growth. Macro-nutrients such as nitrogen, phosphorus and potassium are needed in large quantities for agricultural production and, consequently, food supply. During the past century, humanity has had a substantial effect on nutrient flows at local to global scales, mainly due to the intensification of land-use. Although fertilizer use has increased tremendously over the last decades in many parts of the world, leading to increased agricultural production, lack of nutrients is still limiting agricultural productivity in many regions of the world, with strong impacts on food and nutrition security in these regions (Dawson and Hilton 2011). On the other hand, high loads of nutrients have also threatened ecosystem health and stability in the past, not only of single ecosystems but also of adjacent/down-stream ecosystems, due to lateral flow or atmospheric deposition (Mountford 2011; Sutton et al. 2013), a prime example for the connectedness within food systems.

Nitrogen

Nitrogen (N) is an essential nutrient for plants. The gaseous di-nitrogen (N_2) is most abundant in the Earth's atmosphere (78%) and theoretically constitutes an infinite reserve of the element. However, this unreactive chemical is unavailable for most biological processes. Other forms of N such as nitrate (NO_3^-), ammonium (NH_4^+) and ammonia (NH_3), gaseous nitrogen oxides (NO_x), nitrous oxide (N_2O) and many other inorganic and organic nitrogen (e.g., amino acids and proteins) forms are less abundant than N_2, however, also less available for biological processes and thus often limiting productivity (except: highly polluted areas). In contrast, biotic N_2 fixation by root-associated bacteria of legumes (herbs and trees) constitutes a major N input in legume-based plant and animal systems (Galloway et al. 1995, 2004). The dependence of agricultural production on N, already present in the late 19th century, had also large economic effects due to the import of mined salpeter and guano. This dependence increased in the 20th century, when the Haber-Bosch process revolutionized the availability of cheap synthetic N fertilizers (Sutton et al. 2011). However, although atmospheric N_2 reserves seem infinite, the strong dependence of modern agriculture on synthetic fertilizers has been criticized due to its energy demand, the low nitrogen use efficiency of plants (globally <50%) and the negative impacts of high fertilizer loads on the environment (McAllister et al. 2012). Thus, despite increasing trends of fertilizer use, food systems will need to rely on more sustainable production in the future.

Phosphorus

Phosphorus (P) is an essential element for all organisms (e.g., in DNA, RNA, ATP, phospholipids, bones) and thus for food production. It ensures soil fertility, maximizes productivity through yield improvements and thus supports farmer's livelihood and nutritional security (Cordell et al. 2009; Cordell and Neset 2013). However, compared to nitrogen, phosphorus is a finite resource, predominantly mined from phosphate (PO_4^{3--}) rock. This mineral provides the main P form available to plants. Although resources of rock phosphate are available on all continents (total $67*10^3$ Mt P in 2014), three quarters of the global reserves are located in Morocco and the Western Sahara ($50*10^3$ Mt P; USGS 2014). Major concerns are the depletion of P resources (discussion on "peak phosphorus") as well as the unequal access to P fertilizers. On the other hand, similar to N, also high P loads contribute to negative impacts on the environment, e.g., by increasing eutrophication of water bodies (Rockström et al. 2009; Ulrich 2013) or by high energy and water demands during P-mining and processing. Consequently, the efficient use of nutrients and the implementation of options to reduce losses (e.g., by increasing fertilizer use efficiency or recycling of P-containing waste) are essential to reduce the increasing dependency on scarce resources in future food systems (Ulrich 2013).

4.1.4 Water

Water is one of the major resources on Earth (Ringler et al. 2013) as it is critical for human livelihoods as well as for environmental processes and ecosystem health. Within the framework of food systems, water issues are not only related to the availability of water. Moreover, the access to water of good quality, efficient use of irrigation water, water supply and sanitation, water-related hazards as well as equitable share and use of transboundary waters are major aspects that need to be considered in global food systems.

Water availability and access to water

Today, food systems are major users of water resources and the production of food (agriculture only, without processing) accounts for 70% of the world's annual freshwater use (2'703 km^3 in 2012), compared to 20% by industries and 10% by cities (de Fraiture and Wichelns 2010; FAO 2014a). While the majority of global cropland is rainfed (>80%), the global irrigated area has almost doubled to 300 million ha within 50 years (Alexandratos and Bruinsma 2012). Developing countries account for approximately 40% of the irrigated production area, globally; half of the global irrigated area is located in India and China (127 million ha), supporting about 90% of global rice production. In total, the global water demand in agricultural production is projected to increase by 55% from 3'500 km^3 in 20 00 to 5'500 m^3 in 2050. Until 2050, India and China will account for the largest increase (+7 million ha) of the irrigated area (Alexandratos and Bruinsma 2012; OECD 2012b). Since the water demand from manufacturing (+400%), electricity production (+140%), and domestic use (+130%) is also going to increase significantly, increasing water use for irrigation seems limited. Such limitations will be even more severe under climate change (Strzepek and Boehlert 2010). Improved artificial water circulations, development of technologies improving irrigation efficiency as well as breeding strategies to increase plant water use efficiency are needed in order to constrain the upcoming water scarcity

(Walls 2006). The OECD summarized that such major improvements in water management need to be facilitated by policies encouraging efficient processes and techniques in order to decrease deterioration of water security. Moreover, improved water management, e.g., integrated water management, is supposed to reduce the increasing competition for water (OECD 2012b). Nevertheless, "business-as-usual"-scenarios project that 3.9 billion people or more than 40% of the world's population are likely to be under severe water stress within the next 40 years. By 2050, 45% of the global GDP will originate from regions that are under risk due to water stress (Mountford 2011; OECD 2012b; Ringler 2011), threatening food and nutrition security in these regions because water requirements for diets increase with GDP (FAO 2014e).

Water quality

Good water quality, mainly biological and chemical characteristics of drinking water, is as essential for human livelihoods as the availability and the access to water. In OECD countries, water quality is projected to further improve due to technology and efficiency improvements in the agricultural sector and due to waste water treatment. However, it is expected that these improvements will be poorly transmitted to other world regions, which will thus experience a continuing deterioration of surface water quality due to pollutants in surface waters (OECD 2012b). In 2050, 1.4 billion people are expected to still be without basic sanitation and still more than 240 million people are expected to have no access to improved water sources (OECD 2012c). Thus, major improvements will be particularly required in rural areas (Mountford 2011). In addition, using untreated wastewater for irrigation has raised concerns about health risks and food safety (e.g., in China), however, similar situations can be found in many developing countries.

4.1.5 Land

The Earth's surface area equals 51 billion ha, of which 71% are covered by ocean water. More than 60% of the terrestrial surface is already under direct use by humans, while 60.6 million ha are so-called unexploited forests, deserts, tundra or high mountain areas. However, also unexploited forests and remote areas are increasingly affected by human influences, such as atmospheric deposition of nutrients and pollutants, and by changing climatic conditions. Currently, ca. 38.6% of the water- and ice-free area (13.02 billion ha) are under agricultural use as pastoral (2.5-3.4 billion ha in 2000) and crop land (ca. 1.5-1.6 billion ha in 2000; Foley 2014; Lambin and Meyfroidt 2011). Another 15% (1.9 billion ha) are degraded (e.g., by soil erosion), covered by urban and rural settlements, managed by forestry or used for mining (Foley 2014). The availability, accessibility and usability of high-quality land are key prerequisites for agricultural food production, providing the basis for feeding 9 billion people by 2050. In theory, more land might be required to increase agricultural production, growing urban areas, for biodiversity conservation as well as for energy production, while at the same time quality of land suitable and available for agriculture will be increasingly threatened by degradation due to over-exploitation and indirect human impacts such as climate change (Hertel 2011). Overall, competition for land is steadily increasing (see also Chapter 4.3.3).

Land availability

While most of the past increase in productivity of agricultural systems was due to the improvement of yields per unit area, only 20% of the growth in productivity resulted from an increase in agricultural area. This spatial expansion took place primarily at the expense of tropical forests being converted to agricultural land, especially in South-America (Bruinsma 2003), a trend that is expected to continue under the pressure of population growth and increasing demand for food, feed and fuel, although with lower growth rates compared to previous decades (Figure 6; Chateau et al. 2011; FAO 2006; IAASTD 2009; MEA 2005; OECD 2012b).

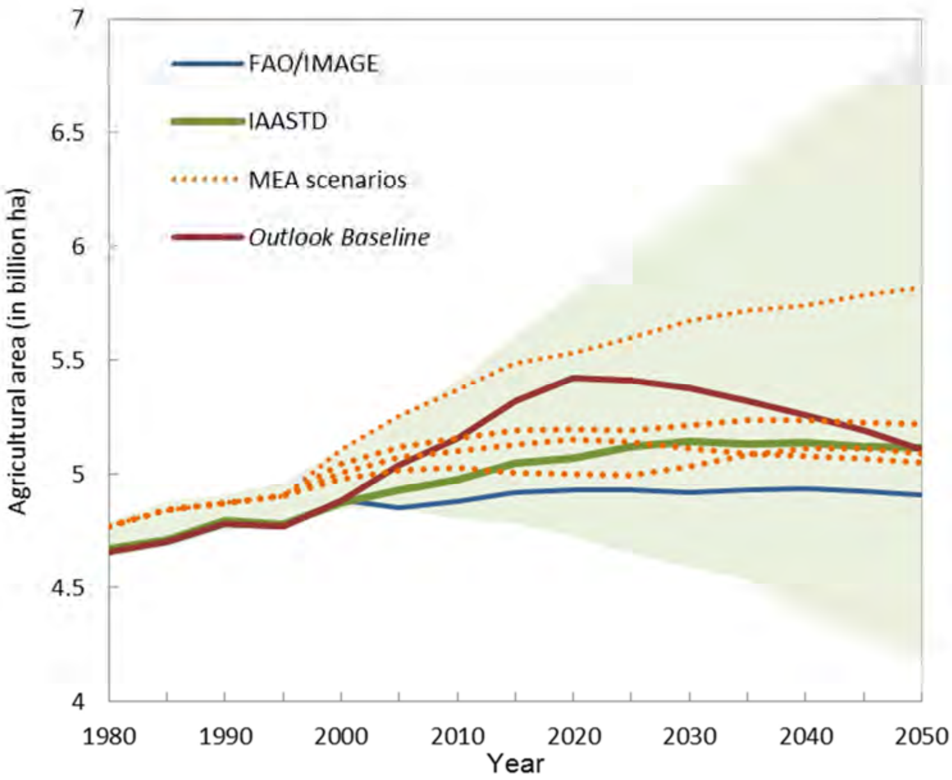

Figure 6: Past trends and projected developments of the global agricultural area from 1980 to 2050 based on multiple models and scenarios modified from OECD (2012b). The shading represents the spread between highest and lowest values assumed for the models.

This additional area needed to feed 9 billion people might amount up to 70 million ha (Bruinsma 2009), with an increase in 120 million ha in developing countries, predominantly in SSA and Latin America, counteracting a projected decline of 50 million ha in developed countries. In OECD and BRIICS countries, the area under agricultural use is expected to peak in 2030 and to decline afterwards, whereas in the rest of the world (i.e., excluding developed countries) further expansion is expected (OECD 2012b). Thus, both historical and projected trends in agricultural land-use differ tremendously across regions and land-use categories.

Land quality

The "Green Revolution" and the corresponding intensification of agricultural production resulted in the tremendous increase in agricultural productivity over the past five decades. However, it also had and still has negative impacts such as environmental pollution and degradation (Chapter 4.1.2), depletion of water reserves (Chapter 4.1.4), loss of biodiversity (Chapter 4.1.7), and public health problems. Particularly the loss of soils through conversion, degradation and erosion feeds back on climate (less/smaller soil carbon sinks) and disrupts biological cycles in agricultural systems (Kelley 1990; WMO 2005). Degraded land loses the capacity to fulfill important ecosystem functions, thereby causing the decrease/loss of yields, crop quality and incomes, while in turn increasing the demand for further input (i.e., water and fertilizers) to keep the respective land productive. Consequently, outcomes such as food and nutrition security, environmental quality, and social well-being are negatively affected and increasingly vulnerable. According to the United Nations Convention to Combat Desertification (2014), one third of all agricultural land is currently either moderately or highly degraded, leaving two options to the (mainly) small-holder famers “to flee or to fight”, illustrating the link to the social boundary conditions (e.g., migration; Chapter 3.2.5). Nevertheless, there are examples showing that there are alternatives to deteriorating land management practices (e.g., legume intercropping, crop rotation, mulching, no-till, precision agriculture, organic agriculture). reduction of land degradation is critically necessary to improve or even maintain food and nutrition security in areas heavily subjected to land degradation (e.g., Africa).

4.1.6 Plant and animal health

Plant animal pests (e.g., insects, mites, nematodes, gastropods, vertebrates), plant microbial pests (e.g., fungi, chromista, viruses, bacteria, phytoplasma), weeds (i.e., species competing for space and resources) as well as animal diseases caused by microbial infections (e.g., foot and mouth disease, bluetongue disease, avian influenza) are major threats to productivity, its projected growth as well as to safe and healthy food (Oerke 2006). Pests cause large damage in natural populations and managed ecosystems such as agricultural, livestock and fishery systems (Fisher et al. 2012). Moreover, pests occur along entire food value chains (Waterfield and Zilberman 2012). The occurrence of animal and microbial pests in production, processing and distribution facilities not only causes severe losses of raw materials and products, but potentially also severe health issues for humans (e.g., food-borne diseases). Moreover, the resistance to antibacterial drugs has become an increasing problem for both human and animal health, and can have strong negative effects on food production globally. Increased resistances are mainly driven by usage of antibiotics as well as the increasingly globalized transfer of people, plants, animals and food (WHO 2014a).

Dislocations, e.g., by human transportation or global trade, facilitate the increasing spread of “unwanted guests” and diseases in food systems throughout the world (Anderson et al. 2004). Local and global climatic conditions (weather conditions and climate change) are the second most important factor for the spreading of plant animal and microbial pests (Bebber et al. 2013; Gregory et al. 2009). However, the presence and distribution of diseases depend on multiple biophysical (e.g., perturbances of ecosystems) and socio-economic factors (e.g., increasing demand for animal-based products; Bebber et al. 2014; Lefrançois and Pineau 2014; Perry et al. 2013). Now and in the future, the detection, control and prevention of pests, pathogens and diseases to reduce losses and provide healthy food are a major challenge for food production, food value chains and, consequently, for entire food systems (Flood 2010; Maxmen 2013; OiE 2012).

Plant animal and microbial pests

Crop productivity has been and will continue to be highly threatened by the presence of animal and microbial pests detrimental to plants. Pests act during pre-harvest processes at the field, but also during post-harvest processes in storage facilities, during transport or at retailers. Today, plant pests, in particular animals and microbes, but also weeds still cause an average annual yield reduction in major crops of 10.8%, 14.5% and 8.5%, respectively (Dhaliwal et al. 2010; Maxmen 2013). In total, annual yield losses range from 26.4% (soybean) to 40.3% (potatoes; Oerke 2006). Within the past 20 years, a 1% increase of crop yield per hectare and year was significantly related to a 1.8% increase in pesticide use (Schreinemachers and Tipraqsa 2012). While only few developed countries have managed to reduce their pesticide use, especially insecticides, intermediate income countries such as Brazil or Mexico have increased their use tremendously (FAO 2014e). In the future, factors like decreasing availability of fertile land, water scarcity and increasing awareness about the climate impacts of land-use change (e.g., increasing greenhouse gas emissions) will limit the opportunity to expand land for agricultural use. Consequently, pesticides will still play a major – most likely increasing – role in the improvement of future crop yields to secure food availability (Savary et al. 2012), although the concept of threshold-based application together with appropriate crop and land management tools will be essential for a sustainable production (Oerke 2006).

Livestock pathogens and diseases

Diseases affecting livestock have severe impacts on animal health, growth and production, trade of animal products or live animals, quality of meat and animal products (leather, fibers), animal work power (transport, traction) and consequently also on human health and livelihoods. About 20% of food losses are linked to animal diseases in one way or another (OiE 2012). In addition, today, at least one new disease occurs every four months, of which three quarters can also infect humans (OiE 2012). Overall, livestock pathogens and diseases slow economic development, creating additional risks for food and nutrition security.

Aquaculture diseases

Since the 1980ies, aquacultures have expanded around the globe and have become highly intensified and diversified. Today, the production of food in aquaculture is one the fastest growing sectors globally (see Chapter 3.3.1). While aquacultures are major factors in successfully restoring natural ecosystems (i.e., by substitution of wild catch), supporting food and nutrition security (e.g., by providing sources of food and income), intensification and expansion are also major reasons for the introduction of pathogens and diseases to aquatic environments (Subasinghe 2014). Today, pathogens and diseases are the major constraints to quality and quantity of seafood production (OiE 2012). In 2010, the white spot disease caused the loss of nearly 100% of Mozambique's marine shrimp farming production, resulting in economic loss and unemployment (FAO 2012b).

4.1.7 Biodiversity and ecosystem services

Diverse ecosystems have the ability to maintain their structure and functions by being resilient to stress or disturbances (Constanza and Mageau 1999). Ecosystem functions and the services based upon them are intimately linked to biodiversity, providing the basis of any food value chain, i.e., the ecosystem function photosynthesis and consequently the ecosystem service plant yields (Mace et al. 2012). Diverse ecosystems are thus crucial for the productivity and the resilience of primary production systems such as agriculture and fishery (MEA 2005; Rockström et al. 2009). Nevertheless, the global demand for increasing yields led to a decline of biodiversity and ecosystem services during the past decades, which mainly affected the poor (Poppy et al. 2014). In 2008, the loss of natural resources due to depletion or pollution by human activities was estimated to 6.6 trillion USD (11% of the GDP in 2008; TEEB 2014). According to the Millennium Ecosystem Assessment, the growing demand for resources has already caused tremendous damage to ecosystems globally. If the destruction of ecosystems and related services will not be addressed sustainably, losses will be irreversible. Moreover, benefits from ecosystems might be lost completely (MEA 2005).

Biodiversity

Biodiversity, the biological variation within and among genes as well as the variation of species, ecosystems and landscapes, is a major prerequisite for food and nutrition security and social well-being. The value of biodiversity is multifold (Balvanera et al. 2006). Increased species richness in managed ecosystem has been found to increase and stabilize yields (Hector et al. 2010; Marquard et al. 2009; Proulx et al. 2010), increase resilience and resistance against weed pressure, pests and diseases (Lehmann and Tilman 2000; Roscher et al. 2009), but also to reduce vulnerability to climatic extreme events such as droughts (Kahmen et al. 2005). However, changes in land-use and management intensity, exploitation of ecosystems such as forests or the ocean, destruction and fragmentation of habitats, climatic changes as well as eutrophication, environmental pollution and the development of infrastructure have caused habitat and species loss (Secretariat of the Convention on Biological Diversity 2010). Also for the coming decades, increasing demand for food, feed and biofuels are projected to affect biodiversity and, consequently, humanity (Cardinale et al. 2012; Leadley et al. 2010; OECD 2012b; WWF 2010).

Biodiversity at all scales (from genes to landscapes) provides livelihoods (e.g., food, medicinal plants, etc.) to millions of people (Chappell and LaValle 2011). The large majority of today's crop cultivars and livestock breeds derive from genetic resources selected from wild relatives. These resources provided important sources for crop improvement and insurance for predicted changes in agriculture environments (e.g., climate change; Ford-Lloyd et al. 2011; Jarvis et al. 2008). Until today, the loss of breed diversity has been pushed by an increasing use of high-performance breeds such as Holstein-Friesian cattle, which are dominating in developed countries today (Secretariat of the Convention on Biological Diversity 2010). In China, the number of local rice varieties declined within the past 50 years from 45'000 to 1'000 due to agricultural intensification and socio-economic changes (Boettcher et al. 2010; Hammer and Teklu 2008; Reif et al. 2005). Thus, for the future, both, biodiversity conservation as well as ecological intensification of agriculture might be options for providing food and nutrition security, while preserving biodiversity (Adams 2012; Brussaard et al. 2010; Tscharntke et al. 2012). Nevertheless, well-informed regional and targeted solutions are still lacking (Tscharntke et al. 2012). Consequently, degradation of ecosystems and loss of biodiversity are projected to continue, most likely affecting human well-being, economic growth and food and nutrition security (Cardinale et al. 2012).

Ecosystem services

Ecosystem functions and services are highly relevant for human livelihoods, poverty alleviation, and food and nutrition security. Ecosystem services consist of four groups of benefits obtained from unmanaged and managed ecosystems: 1) supporting services such as soil formation, nutrient cycling, primary production or decomposition (also called ecosystem functions), 2) provisioning services such as food, fodder, timber and fiber, fresh water, bioenergy, fuel, medicine or genetic resources, 3) regulating services like climate, water and erosion regulation, water purification, waste decomposition, pollination, biological control (disease, pest and weed control), carbon sequestration and nitrogen fixation, and 4) cultural and social services such as recreation, tourism, and spiritual values (MEA 2005; WWF 2010).

On the one hand, agricultural systems are mainly managed to provide ecosystems services such as food, feed, fuel and fiber, but also carbon sequestration and recreation. On the other hand, these systems are themselves highly dependent on ecosystem functions/services such as the provision of water, nutrients and fertile soil or pollination. All of these ecosystem services are highly affected by activities throughout the global food systems (e.g., intensive production, transport, greenhouse gas emissions, etc.). Since food systems are major direct and indirect drivers affecting ecosystems and their services, the qualitative and quantitative analysis of relationships (e.g., trade-offs and synergies; Figure 1), interconnectedness as well as positive and negative feedbacks remain important challenge contexts for food systems (Power 2010; von Gunten and Cooper 2011).

While services such as the provision of crops for food, feed and fuel can be distinguished clearly and estimated precisely, other values such as important synergies and trade-offs are rarely priced (Gallai and Vaissière 2009; Klatt et al. 2014; OECD 2012b; WWF 2010). Consequently, an all-encompassing economic valuation of services and benefits from ecosystems is crucial (Costanza et al. 1998). The very first attempt to estimate the economic value of a range of ecosystem services resulted in the astronomically high number of 16 to 54 trillion USD p.a., compared to a global GDP of 18 trillion USD. Economic valuation or the pricing of services will provide a more efficient basis for the implementation, improvement and evaluation of financing, policy and management strategies (TEEB 2014). Moreover, estimates on the loss or degradation of ecosystem services are considered crucial to the implementation of their sustainable management (e.g., appropriate management practices) and protection (Power 2010).

4.2 Social boundary conditions

Social boundary conditions are partially set by demographic changes such as population growth and the increasing demand for food due to economic growth in all parts of the world. These socio-economic changes are accompanied by changing consumption and dietary patterns as well as migration, aging and urbanization patterns. Key trends and projections are presented in Chapters 3.1. and 3.2, the social aspects on the food system outcomes are addressed in Chapters 5.1 and 5.3. Further important social aspects, e.g., labor in food systems or social inequality, are not discussed in detail in this report.

4.3 Political boundary conditions

International and national policies (e.g., economic, agricultural, environmental, trade or development policies) affect the food systems across scales. Policies are believed to be highly relevant to establish and implement sustainable and healthy food systems which are spatially and temporally integrated into local and global markets and corresponding trade activities (Pisano et al. 2011). They are necessary to direct the transformation of food systems toward increased sustainability and resilience (Evans 2011). The overall aim of food system-related policies is to strengthen institutions and governance while considering private and public actors as well as the producers and consumers (IFPRI 2014). Policies not only need to address activities such as production, processing, trading, retailing, consumption or the direct outcomes of the system (i.e., food and nutrition security, environmental quality, and social well-being), but they also need to comprise multiple biophysical as well as socio-economic drivers within the food systems (Evans 2011; Margulis et al. 2013; McMichael 2011). Thus, the effect of policies and their implication are highly variable due to the complexity of food systems and, consequently, need to be revised continuously. However, a comprehensive understanding of the impact of subsidies, compensation schemes or mandates (e.g., mandated percentage of biofuels used in transport) on food systems and related processes and boundaries is still lacking (Lima and Gupta 2013). This section highlights major policy topics and trends, aside from agricultural policy, that are relevant to shaping the food system.

4.3.1 International trade policies

During the last decade trade barriers have been reduced both across industrial and developing countries. However, OECD countries still spend billions (201.2 billion euro in 2012) subsidizing their agricultural sector in order to maintain their competitive power in the global market (OECD 2013a). Subsidies and compensations account for a large share of farmers' incomes in countries such as Norway (63%), Switzerland (57%), Japan (56%) and Korea (54%). In other countries, this share is relatively low (Australia, Chile and New Zealand, <3%; OECD 2013a). Nevertheless, these payments are increasingly decoupled from production and are consequently less distortive to international trade than production-linked payments, market price support or import protection measures (OECD 2013a). Subsidies in developed countries often cause overproduction and therefore low prices for the products (OECD 2013a). However, small-scale farmers in countries without agricultural subsidies are not able to compete under such distorted conditions. They cannot enter foreign markets without changed policies and trade regulations (OECD 2013a). Further instruments protecting developed markets are quotas and tariffs but also sanitary and phytosanitary restrictions. Global trade is projected to increase in the future, but if protections of markets remain, global trade will remain uneven (Bruinsma 2003; IAASTD 2009; MEA 2005). Focusing on domestic support (e.g., subsidies, compensations), market access (e.g., import tariffs) and export competition (e.g., export refunds), the Doha Round aims at increasing the involvement of developing countries in global trade (EC 2014a). However, to foster trade of agricultural commodities, mitigate price volatility and provide entrance to markets for developing countries, long-term objectives of the Bali agreement such as the substantial progressive reductions in support and protection of markets in developed countries need to be fulfilled (IFPRI 2014).

In addition to the general decline of productivity growth (Chapter 3.3), decreasing food reserves are projected to result in higher pressure on the global cereal market and, consequently, on the worldwide food market. Moreover, scarcity of resources such as water and land (Chapter 4.1.2) as well as the projected impact of climate change will affect the already tense global market system (Hubert et al. 2010; IPCC 2013). Projections based on the IMPACT and GLOBE models indicated that a well-functioning global trade system is crucial for the reduction/avoidance of negative impacts arising from perturbations on the demand and supply sides of the world food system (Foresight 2011).

4.3.2 Environmental and climate policies

As outlined in Chapter 4.1, food systems are closely linked to environmental boundary conditions and thus to climate. Therefore national and international environmental policies, and in particular climate policies, are important instruments guiding the sustainable use of natural resources in food systems but also the reduction of negative impacts of food systems on the environment. Both at national as well as international levels (typically via the United Nations conventions, treaties, protocols and agreements), environmental policies have increased in number, participants and thus importance.

Building on the experiences of the Montreal Protocol on Substances that Deplete the Ozone Layer which entered into force already 1989, three highly relevant global conventions were negotiated at the Earth Summit in Rio de Janeiro in 1992, and later signed for ratification. These international agreements have spurred communications and discussions, global awareness and also actions in respect to the global environment and respective policies. While the UN Framework Convention on Climate Change (UNFCCC) has 196 parties, the Kyoto protocol has been ratified/signed by 83 parties (overall 192 parties), many of those with quantitative emission reduction commitments (relative to 1990, by 2013). The UN Convention on Biological Diversity (UNCBD) has 194 parties, of which 168 have signed the convention and agreed on the 20 Aichi Biodiversity Targets at the Conferences of the Parties (COP) in 2010. Both conventions, UNFCCC and UNCBD, have large scientific bodies (Intergovernmental Panel on Climate Change IPCC and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services IPBES, respectively), informing the policy-makers on scientific facts as well as issuing policy recommendations. On the other hand, although having the most signatories (more than 190 of the 195 parties), the UN Convention to Combat Desertification is not supported by a similar scientific body, and lacking a similar support of the international community. Nevertheless, all these conventions provide a political framework within which the nations have created and still develop and implement their own national policies.

However, necessary actions prescribed by national as well as international environmental policies might have counteracting effects on food systems. For example, the overall goal of reducing greenhouse gas emissions within the UNFCCC will have direct effects on agricultural/soil management practices, crop selection (e.g., rice) as well as livestock/husbandry, thus affecting entire food value chains, right to consumption patterns. On the other hand, several of the Millennium Development Goals (MDGs) to reduce hunger and poverty might counteract these emission reduction goals because more food will need to be produced for a growing world population (Chapter 3). Similar dilemmas are known for biodiversity conservation and protection of ecosystem services vs. increased/intensified land-use for food production, indirect land-use effects, fishing fleets in international waters or eutrophication due to fertilizer runoff (Conley 2012). A much discussed problem is the use of bioenergy: while biofuels might have the potential to mitigate climate change by replacing fossil fuels (although even this fact is heavily debated; WBGU 2009), the area needed clearly competes with land area, nutrient and water demands for food and feed production (Ingram and Hong 2011; Jones et al. 2013; Vermeulen et al. 2012). Thus, political prioritization or the development of win-win situations is one of the largest political challenges (EC 2011; IAASTD 2009). Although relevant at national level, this is becoming even more important considering political and economic decisions at/for the international level: decisions within one country or geopolitical region can cause tremendous effects on the environmental conditions within other regions, ranging from atmospheric transport to migration.

4.3.3 Biofuel/bioenergy policies

The demand for biofuels/bioenergy from feedstock and various biomass sources (e.g., waste, cascade use of harvest products) is currently increasing globally. The steady increase of crops used for bioenergy production is mainly driven by national biofuel targets, blending mandates and subsidies (Sorda et al. 2011). However, the supply of bioenergy is also tightly linked to developments in sectors outside the food system (e.g., technological development of engines, combustion, renewable energy, oil price). Moreover, the popularity of bioenergy has increased due to a growing consciousness of climate change (but see Chapter 4.3.2), "green innovation" and growing concerns about energy insecurity (Timilsina and Shrestha 2010). So far, most mandates on national bioenergy and biofuel targets are defined within the EU-27 states, where the share of renewable sources is supposed to be 20% by

2020. The share of biofuel used in transport is supposed to be 10% from renewable sources by 2020. In 2013, a proportion of 5-7.5% has been achieved (Lonza et al. 2011). Other countries which are targeting a comparable blending (15-20% by 2020-2022) based on biofuel mandates are the USA, China and Brazil (Lane 2013; Timilsina and Shrestha 2010). In total, biofuel mandates of various ranges have been set in more than 60 countries (Lane 2013). Thus, increasing demand for bioenergy and biofuels will directly affect land availability for food production, but also have far-reaching implications on commodity prices and price volatility on the global market.

The implementation of specific policies very often leads to a conflict of interests affecting local to global food systems. The development of commodity markets is very tightly linked to energy and non-energy commodity prices, competition for land, increasing demand of natural resources, economic development of developing countries, but also to changing environmental conditions such as climate change and their effects on agricultural productivity. The most prominent example representing such a conflict of interests within the world food system is related to policies concerning food, feed and fuel/energy.

Food vs. fuel/energy

Crops cultivated for biofuel and bioenergy production make up a considerable share of agricultural production today. Instead of being used for food production for human nutrition, increasingly more land is used to produce bioenergy crops. In the future, increasing energy demands and increasing world market prices for bioenergy crops will amplify the competition between the different types of use (food vs. fuel/energy) as well as for land and further inputs of natural resources such as water and nutrients (FAO et al. 2011; Lima and Gupta 2013; Smith et al. 2010). Globally, EU and USA biofuel legislations have had the largest impacts on particularly the biofuel markets (Baier et al. 2009; Gerber et al. 2008). By 2050, the percentage of cereals, vegetable oils and sugar used for biofuel production is projected to at least double compared to today, amounting to 6.1%, 10.3% and 1.8% of the fuel produced, respectively (Alexandratos and Bruinsma 2012). An increasing biofuel production thus most likely reduces the amount of food produced for human consumption and thereby might provoke increasing food prices. This trend will strongly depend on the raw material used for biofuel production and the type of biofuel produced (1^{st}, 2^{nd} or 3^{rd} generation of biofuel). Today, 2^{nd} and 3^{rd} generations have almost no or only a very small impact on land competition, whereas 1^{st} generation biofuels have a very large impact (Ajanovic 2011; Gerber et al. 2008; Rathmann et al. 2010). Overall, the future demand and supply with bioenergy as well as the political and economic support of bioenergy will strongly depend on future oil prices. Highest projected oil prices will probably cause massive increases in bioenergy demand, while low oil prices will likely diminish the demand for bioenergy because investments shift elsewhere (Hertel 2011; Miranowski 2013; Tenenbaum 2008). Nevertheless, most bioenergy production plants would not be economically viable and thus competitive with food production without public financial support. Blending mandates, targets for biofuel shares and financial incentives for bioenergy production are much more important for the bioenergy amount supplied than rising energy prices.

Food vs. feed

The competition for land does not only arise from the increasing demand for bioenergy. Also the increasing demand for meat and dairy products generates increasing demands for animal feed and, at the same time, for space and resources to grow it. Moreover, the incidences of animal diseases such as the *bovine spongiform encephalopathy* (BSE) caused a change in animal feed from animal-based protein toward plant protein-based ingredients. Today, approximately half of the calories produced by crops are used to nourish people, while the second half is used for animal feed (Figure 7). In some countries, this share is much less balanced. In Brazil, more than 50% of the soy harvested is used as animal feed, whereas in China, which is the second largest producer of maize, approximately 77% of the maize harvest is used for livestock (Foley 2014). In contrast, in India, the largest proportion (89%) of harvested crops is still used for food (Figure 7).

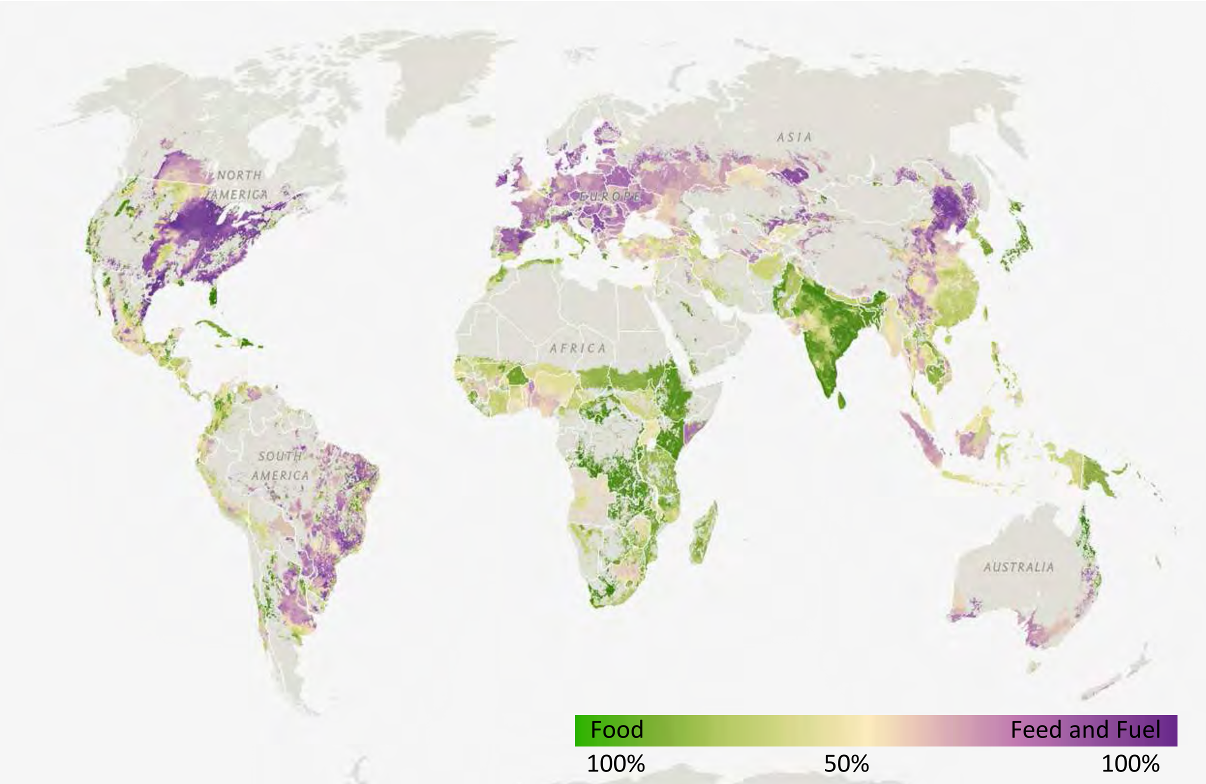

Figure 7: The nexus of food, feed and fuel – how planted crops are used, globally (Foley 2014).

In the future, the competition for land will increase if policies remain as they are today. A growing population with higher income will demand more animal-based food (see Chapter 3.2.7), while at the same time also increasing their energy demand, both strongly competing with food production (OECD 2013c).

4.3.4 Governance

Local to global food systems work within a formal framework of rules and institutions, which is determined by governmental, non-governmental, and private sector actors (Foresight 2011). Balanced and resilient food systems are the outcome of good governance (Evans 2011), which is based on equity, efficiency and sustainability (Behnassi et al. 2011). Governance is also a key element of a successful pathway of transition from a fragile to a stable state/nation, where governance needs to consider all interdependencies related to economy, environment and society (EC 2011; Ingram et al. 2010; McMichael 2011). Until today, global institutions which would be able to enforce decisions (e.g., regulating the climate, staying within planetary boundaries or reducing disruptive effects of trade) lack a clear mandate, but also credibility and enforcement authority (Foresight 2011). Global governance does not necessarily require central planning or management of processes, but should be based on common commitments, global democratic accountability, and key principles driving the decisions (Page 2013). Nevertheless, joined international efforts such as the Millennium Development Goals or the new process to develop Sustainable Development Goals (SDGs; Geoghegan 2013), initiated at the Rio+20 Conference on Sustainable Development, are globally coordinated steps, based on (global) governance, to ensure sustainable development and thus food and nutrition security globally.

4.3.5 Social and development policies

Funding and resources to specifically address food and nutrition insecurity at a national level may come from a variety of sources, including public expenditure, private funds and official development assistance from international donors (IFPRI 2014). Thus trends in development and humanitarian aid policy, and how they shape national social policies in terms of both structure and funding, can have a significant impact on the global status of food and nutrition insecurity.

National social and development policies aim at developing and establishing the right for social protection and food security in developing and developed countries (HLPE 2012). This includes reducing the vulnerability of individuals, households and societal groups, by providing income or food aid, by generating risk protection and social safety nets, by providing crop and livestock insurances or microcredits, and by enhancing the social status of poor or marginalized individuals, household or societal groups (HLPE 2012; UN 2010).

Commitments to food and nutrition security and agricultural development at the country level are supported and influenced internationally by official development assistance and through various global platforms (IFPRI 2014). In recent years, large scale global initiatives, such as the Global Nutrition for Growth Compact (which pledges 4.15 billion USD to promote nutrition sensitive investments), the New Alliance for Food Security and Nutrition (which mobilizes private investment and aid for agricultural and rural development and food and nutrition security in Africa) and the Scaling Up Nutrition (SUN) movement (which supports developing countries to prioritize nutrition related commitments) have raised awareness and commitments around these topics in donor and policy making communities (IFPRI 2014). The emergence of such platforms goes hand in hand with two new trends in development assistance: 1) the emergence of new actors as donors, in particular the private sector; and 2) the increasing impact globally of national food and nutrition policies in certain developing countries, namely China and India (IFPRI 2014).

Aside from broader development assistance, an important contributor to food security in crisis situations is humanitarian aid. During the past decades, humanitarian aid and food assistance activities have increased steadily however remain inadequate to address the challenge on hand (IFPRI 2014). During this time, food assistance policies, which address long- and short-term development, experienced three major changes. Firstly, many key donors such as UN agencies or non-governmental organizations changed from food aid to food assistance in order to support long-term development of the local population and to move from being instrument based to being problem based (Omamo et al. 2010). Secondly, the demand for food assistance increasingly arose from food, finance or fuel crises as well as from environmental hazards, in contrast to conflicts as was the case in earlier times. Thirdly, international food assistance was increasingly provided by non-OECD countries (Harvey et al. 2010; OCHA 2013).

A clear example of these changes can be witnessed in the World Food Program (WFP) and the US Agency for International Development (USAID). In 2010 USAID created the "Emergency Food Security Program" which enables the organization, and its partners such as the WFP, to expand the food assistance tool box to cash transfers, food vouchers and locally or regionally procured food items. In most cases this approach allows the purchase of food closer to the crisis location, getting it to those in need faster and more cost effectively than importing commodities from abroad (IFPRI 2014).

Since the year 2000, the Millennium Development Goals (MDGs) have influenced political discourse and shaped development agenda, though progress toward the targets that address hunger, child mortality, access to education, reproductive healthcare and sanitation has stalled or is lacking (IFPRI 2014). Given the expiration of the goals in 2015, attention is now shifting to the "post-2015" development agenda, where there is a push to develop Sustainable Development Goals (SDGs) to replace the MDGs. These goals should go beyond the MDGs to recognize the interactions and feedbacks between social, economic and environmental outcomes and drivers.

There is currently much debate surrounding how the SDGs will address sustainable agricultural intensification and food and nutrition security. The High Level Consultation on Hunger, Food Security and Nutrition that was carried out in 2013 and involved 1.3 million people, clearly identified that food and nutrition security is a basic human right that should be achieved globally within one generation (UN 2013). Furthermore, it recommends the formulation of a specific, stand-alone goal related to food and nutrition security, that addresses under- and over-nutrition simultaneously, puts focus on the "1'000 day window" for nutrition interventions, strengthens social protection and safety nets for vulnerable populations, eliminates wastes and losses, improves agricultural productivity and puts focus on inequality and human rights (UN 2013). However, ongoing debates and divergent views on a number of critical topics highlight that we are still far from a consensus, especially regarding what the goals should include, how the targets should be formulated and how progress can be monitored and measured (IFPRI 2014).

As international attention to the role of development and aid in addressing food and nutrition insecurity increases, there is also a shift in dialogue and programming toward the concept of resilience. Across the development and relief communities, there is consensus that building the resilience of vulnerable populations and food systems on the whole is of critical importance (IFPRI 2013b). Adopting a resilience framework is expected to link short-term shocks and long-term systemic changes and give a more complete view of what causes individuals to move into poverty and food and nutrition insecurity and how they can better absorb, adapt and transform in the face of shocks and stresses. This new approach requires systems approaches and collaboration across sectors, and in particular may serve as a means to mobilize better integration and coordination between the traditionally disparate relief and development sectors (IFPRI 2013b).

For the future, social and development policies need to increase the resilience of those in need by long-term strategies as well as considering other sectors' policies (e.g., biofuel or tax and trade policies) in order to contribute to lasting and sustainable food and nutrition security (UN 2010).

4.3.6 Knowledge, technology and innovation – Green economy

Knowledge, technology and innovation are elements of a transition pathway toward sustainable and resilient food systems (EC 2011; FAO 2009b). The development and thus availability of knowledge, technology and innovation for food systems at local to global scales is a never-ending challenge and highly depends on national and international political and economic strategies in all sectors, but also to economic incentives, if the big challenge (see Chapter 1) is to be met.

Biotechnology, nanotechnology, information and communication technology, to name a few, but also the consideration of agroecology are promising technologies and approaches to improve future agro-food systems by increasing productivity and efficiency along the value chains sustainably (COST 2009; EC 2011; Global Center for Food System Innovation 2013). Innovations range from precision farming practices on the production side, increased information technology used in storage and distribution systems, personalized and new alternative food on the consumers' side (Adamowicz 2011; ETP 2012; Frewer et al. 2011; FutureFood2050 2014; Kamen 2011). Thus, future knowledge, technology and innovation systems must go beyond addressing the (old) challenges of yield improvement or resource scarcity, however, without neglecting them, but rather use these new approaches to develop smarter solutions, which do not only apply to large-scale, commercial farming operations, but also to small-scale food system structures (FAO et al. 2011; IAASTD 2009). These initiatives are expected to yield best results when complemented by governmental strategies and policies fostering innovations.

One of these potential innovative pathways for sustainable development of the economy is the green economy. It aims at the economic prosperity and the eradication of poverty while reducing the use of resources and the negative impact on environmental quality (UN 2012). Its origins lie in a growing concern about economic instability (due to price volatility and increasingly scarce resources) and the impact of human activities on the environment and corresponding resources (EEA 2013). The concept of a green economy has been pushed to the political agenda internationally in 2012 at the UN Conference on Sustainable Development (Rio+20), and has been supported by the public, scientists, economists and politicians in order to change the way interactions between environmental interests and the economic sector are managed. How such a green economy could look like, is not clear yet. Measures suggested range from substitution of fossil fuels by biomass and its constituents, increases in resource efficiencies in general, fostering innovations to increasing global equity and improving governance.

4.4 Economic boundary conditions

4.4.1 Global markets

Global food markets are a sign of globalization and the result of changing policies (e.g., reducing trade barriers, decreasing costs of cross-border transfers of agricultural products and processed food) and increasing competition among multiple players (Anania 2006), aided by improved information and communication technologies (Anderson 2010). Agricultural products and processed food items are part of these global food markets, with both advantages and disadvantages (IAASTD 2009). Global markets facilitate trade and can modulate prices, but speculation with agricultural and food commodities also contribute to price volatility. Access to the global food market, particularly for small businesses and small economies, is often difficult and aggravated by high standards and regulations (e.g., quality, traceability and food safety). Therefore, De Schutter (2010) demanded that trade agreements need to promote food and nutrition security as a human right, and not push commercial interests over public interests.

4.4.2 Trade

Global trade has been and will continue to be a major driver of the world food system. Since many food commodities are highly tradable, they are strongly affected by changes in trade policies and trade flows. Overall, global food trade is expected to grow within the next decades, mainly due to population growth and increasing incomes (Chapter 3). Traditional exporters of wheat and coarse grains (North America, the EU and Australia) are projected to further increase their exports modestly, while new entrants of the export sector increase their shares of export sales on the global market (e.g., Russia, Ukraine). The global trade of agricultural and food commodities from and to developing countries is projected to expand continuously (Alexandratos and Bruinsma 2012), mainly due to emerging countries (OECD 2013c), although the great majority of the developing countries will stay net importers (compared to today, net import increase >200%). Nevertheless, within the next decades, more developing countries will strengthen their position as exporters (Alexandratos and Bruinsma 2012). Among different items, the global trade of grain and meat is projected to increase the most (IAASTD 2009): compared to 2010, trade of cereals will almost double, that of meat probably increase by a factor of four until 2050 (Hubert et al. 2010). High-income countries as well as Eastern Europe and Central Asia will thus be critical for meeting global food needs due to their role as food suppliers (Hubert et al. 2010).

4.4.3 Prices

The development of prices is a valuable indicator to predict the future of market systems. In general, rising prices indicate an imbalance of supply and demand. Moreover, they signal an increasing pressure of scarce resources on the market, which – in the case of the food market – is driven by a growing population demanding more food which is more energy- and resource-intensive (Nelson et al. 2010). Furthermore, food prices are highly linked to prices of other commodities such as energy or fertilizers. However, the major challenge for a well-functioning food system and thus food and nutrition security, especially for poorer countries or geopolitical regions, is the price or market volatility, increasing system vulnerability and decreasing predictability.

Food prices

The development of food prices, based on commodity supply and demand on markets as well as on the availability of food stocks and reserves, are of great interest to consumers, but also to authorities and governments (FAO 2012a; FAO 2014j; Gerber et al. 2008). Especially in low-income countries, food prices account for a large share of household expenditures, and therefore have a high impact on food and nutrition security (Willenbockel 2011). From 1960 to 2000, real agricultural commodity prices continuously declined and price peaks were only short-lived (FAO 2011b). However, since 2002, real prices of food and agricultural commodities as well as price volatility (see below) have increased dramatically (Figure 8), driven by demographic changes (population growth), but also related to energy prices, bad harvests, and low food stocks levels.

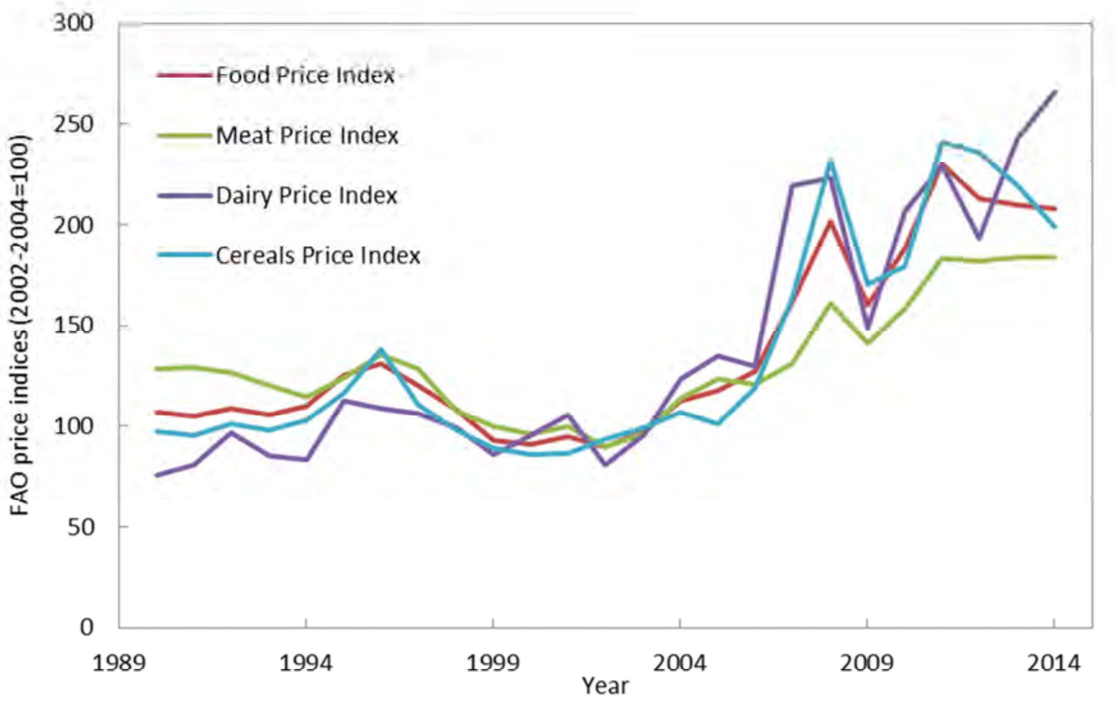

Figure 8: Price trends from 1990 to 2014 based on data from FAO (2014j).

This increase of real world market prices for food is projected to continue in the short-, medium- and long-term (FAO 2011c; Foresight 2011; OECD 2013c), as a result of increased pressures on resources such as land and water, demographic development such as population growth, the adverse impacts of climate change as well as rapidly rising incomes in most of Asia (Hubert et al. 2010). According to recent reports, international prices of agricultural commodities are projected to increase until 2050 (Foresight 2011; Willenbockel 2011). Greatest price rises are expected for grains such as maize (+30 to 50%). But also meat prices are projected to increase by about 20 to 30% compared to today (OECD 2013c; Willenbockel 2011). A slower population growth will clearly slow down the rise of food prices, but on the other hand, unmitigated climate change will cause rising food prices due to its negative impacts on yields (Foresight 2011; Nelson et al. 2010). Overall, prices of meat, fish and biofuel are projected to rise more strongly than that of primary agricultural products (OECD 2013c), due to different demands.

Price volatility

Price volatility results from high variations in agricultural prices over time, which cannot be anticipated, thus making medium- or long-term price predictions very difficult. This in turn causes large uncertainties, and increases economic risks along the whole value chains (FAO et al. 2011). The major determinants of price volatility are oil prices, low food stocks, globalization of markets, but also increasing speculation with agricultural commodities and climatic factors (EC 2011; FAO et al. 2011). Due to the higher share of their expenditures for food at overall lower income levels, poor consumers are most affected by higher price volatility. Since 1990, global price volatility has been shown to be largest in agricultural markets, particularly for major crops (FAO et al. 2011). In the future, the demand of a growing population for agricultural products will be closely linked to highly volatile and thus unpredictable prices (FAO 2015).

4.4.4 Fertilizer demand and prices

Within the past decades, increasing use of fertilizers such as nitrogen and phosphate has been the main factor for the increase in agricultural production. Today, most of the N and P fertilizers are used in developing countries (70%) and the share of these countries is projected to pass three quarters by 2050 (Alexandratos and Bruinsma 2012). Until 2050, the overall use of fertilizers will continue to grow. For example, the total quantity of N fertilizer use is projected to increase by 100 million tons (from now to 2050) and will reach 263 million tons p.a. in 2050. The relative shares of different fertilizers are expected to remain relatively constant (nitrogen (57%), phosphorous (25%) and potassium (18%); Heffer and Prud'homme 2013; Hernandez and Torero 2011).

Prices for rock phosphate increased from <50 USD per metric ton in 1998 to ca. 400 USD per metric ton due to this increasing demand and old processing units (Ulrich 2013). Since then, phosphate rock prices declined again by 200 USD, but have not yet reached previous (low) price levels again (FAO 2011a; Sutton et al. 2013; Ulrich 2013). Between 2003 and 2008, fertilizer prices peaked, following the prices of other commodities such as oil. Thus, depending on the price trend for oil in the future, also fertilizer prices will increase. If crude oil prices would increase by 75% until 2035, fertilizer prices are projected to increase between 85% and 162% (103% on average; Rosegrant et al. 2013). In addition, key inputs in fertilizer manufacturing are highly traded and therefore affected by various costs related to transportation, exchange rates, policy decisions and further uncontrollable factors (Rosegrant et al. 2013), again showing the tight relationships within all boundary conditions of the food system.

4.4.5 Energy demand and prices

Energy demand and supply are highly relevant for a globalized food system and, ultimately, food and nutrition security, not only due to the energy demand throughout the whole value chains, ranging from the production of fertilizers to waste management (Woods et al. 2010), but also due to the close link among different commodity prices. Thus, in the future, the affordability of energy and its price volatility will be of increasing relevance for all other sectors (FAO 2011c; van der Mensbrugghe et al. 2011).

Within the next decades, the global energy demand will increase and the structure of the energy supply will probably change tremendously. By 2050, the world economy that will be four times larger than today is projected to require 80% more energy than today (IEA 2013; OECD 2012b). The major energy demand will arise from emerging economies such as China and Southeast Asia (IEA 2013). Fossil fuels will remain the major energy source, although their overall share is projected to decline from 68% to 57% (IEA 2013; OECD 2012b; WEC 2013). Nevertheless, the annual growth rate of energy consumption is projected to increase by 0.5% for oil and 1.8% for coal and natural gas until 2050, according to the "business-as-usual" scenario of the OECD.

Although there is an increasing demand for energy in an increasingly resource-constraint world, energy price projections are very uncertain and range from approximately 75 USD to 204 USD per barrel crude oil (in 2012 USD) by 2040 (Figure 9; EIA 2013; EIA 2014).

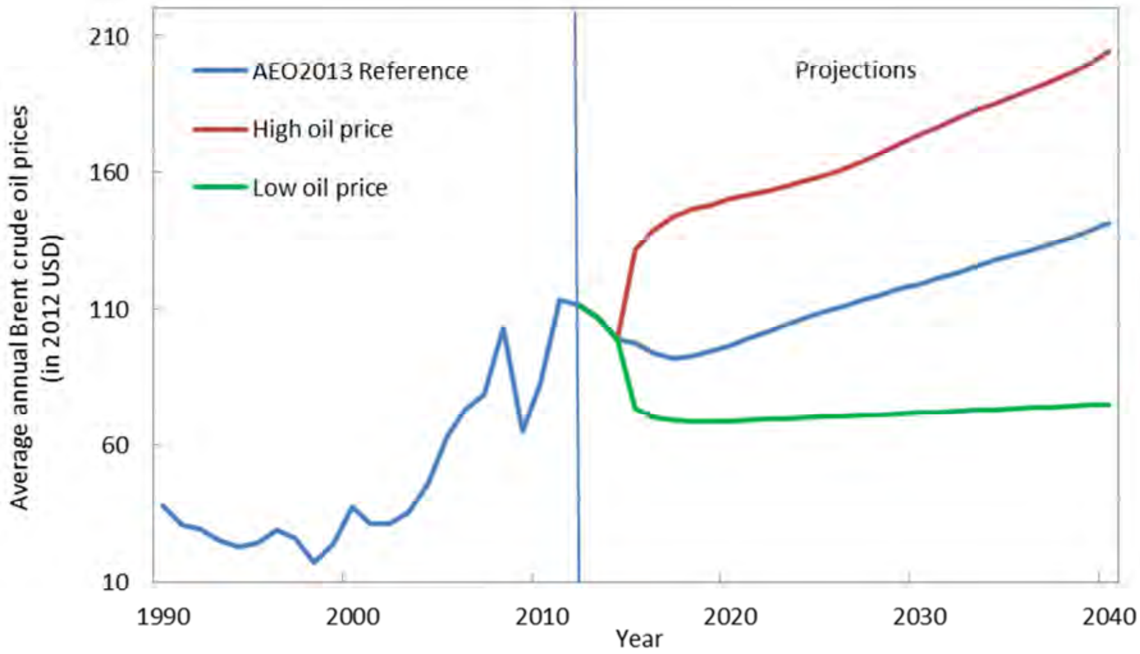

Figure 9: Average annual Brent crude oil prices under three scenarios between 1987 and 2040 (in 2012 USD) based on data from EIA (2014).

The peak of oil production will very likely push corresponding prices toward the upper range of the projections by the middle of the 21st century, while smaller changes are projected for natural gas or coal prices (Capros et al. 2013; OECD 2012b). The share of renewable energy will increase from 20% in 2011 to 31% in 2035, while the use of biofuels will triple during the same time (EEA 2013). Energy costs will thus remain a growing expenditure in many household budgets (IEA 2013; WEC 2013).

Overall, huge investments in electricity production will be needed in order to keep pace with increasing energy demand up to 2050. Projections of the World Energy Council indicated a range from 19 trillion USD ("Jazz scenario", focus on economic growth) to 26 trillion USD ("Symphony scenario", environmental sustainability) in 2050 (in 2010 USD; WEC 2013). In general, the energy demand will be highly affected by technological developments and improvements of energy efficiencies (EEA 2013; OECD 2012b), but also political stability (Hertel 2011).

4.4.6 Concentration of market control

A further driver of global food markets is the concentration of market control. Agricultural markets and trade of agricultural and food products are increasingly organized in global value chains. Few large transnational businesses (trading companies, agri-food processors and producers) are key players, controlling the market by their decisions throughout the food system. A large concentration of power is seen within trading, processing and retailing (IAASTD 2009; Thompson et al. 2007). For example, the global seed industry is controlled by only five large biotech companies, the fertilizer industry (all major fertilizers) by five countries, holding a share of more than 50% of the world's production capacity (Hernandez and Torero 2011). The strategic position of both industries on the market (both providing crucial inputs for agricultural production) allows a strong market control, shown to restrict farmer's choices or access to seeds (Howard 2009; Then and Tippe 2009). Together with many other actors in the food systems, such as commodity buyers, processors and retailers, these companies and countries are creating dependencies and thus affecting prices and even consumption patterns (De Schutter 2010; Hernandez and Torero 2011).

4.4.7 Investments

National investments

Agricultural production and subsequent activities of food supply chains are major contributors to human livelihoods. Today, the agricultural sector alone provides livelihood to 1.3 billion people, i.e., 86% of rural populations (FAO et al. 2011). However, similar to investments into agricultural research, also private and public investments in agricultural production and downstream services such as storage and processing facilities have declined over the last decades (FAO 2009a; IAASTD 2009) and are projected to decrease even further, despite their high rates of return and their demonstrated contribution to poverty reduction, especially in rural and poor areas (Barilla Center for Food and Nutrition 2011; IAASTD 2009; OECD 2013c; Thompson et al. 2007). Until 2050, investments of approximately 1 billion USD are expected to be needed to produce enough food for 9 billion people and, at the same time, move toward sustainable production systems (IAASTD 2009).

Today, the range of opportunities to invest in food systems, sustainable food or agriculture, is as large and diverse as the pool of investors itself. Different kinds of future investments, primarily deriving from private sources, have been suggested by the High Level Panel of Experts on Food Security and Nutrition HLPE (HLPE 2011): 1) direct investments in agricultural research and development related to food systems as well as investments in sectors that support productivity growth (e.g., energy supply, irrigation, storage) and 2) non-agricultural investments in education, knowledge transfer or sanitation, which improve human well-being, stimulate productivity and efficiency, and reduce wastage. In general, investments in agricultural research, but also in education, infrastructure and input credits have proven to be the best options to increase agricultural productivity and thus food and nutrition security (EC 2011; IAASTD 2009).

Foreign direct investments in land and water rights

While investments in agricultural development have been declining, there is an increasing trend of financial investments in agricultural commodity-based derivatives as well as in land and water rights at the global scale (Rulli et al. 2013). The most prominent and heavily debated example is foreign direct investments in land, often also called "land grabbing" (Deininger et al. 2011). The reasons for investments in foreign land are thought to be global crises related to finances, increasing energy and food prices as well as the growing scarcity of resources and environmental destruction (De Schutter 2011; Murphy 2013). Powerful national and transnational actors, such as economic co-operations, governments or private equity funds, are increasingly investing in food and fuel production on foreign lands (Borras Jr. et al. 2011). The global area affected is difficult to quantify. In 2011, Oxfam International stated that 227 million ha were owned by foreign investors (Oxfam International 2011). In 2012, scientific articles revealed that a total of 32.7 to 82.2 million ha or 0.7-1.75% of the world's agricultural land were owned by foreign investors, depending on the stage of land-property transactions (Rulli et al. 2013). Other studies even indicate larger numbers up to 200 million ha in total by 2011 (Deininger et al. 2011; Oxfam International 2011; von Braun and Meinzen-Dick 2009). Overall, more than 50% (up to 70% according to the World Bank 2011) of these foreign direct investments are currently directed toward Africa (Figure 10; Deininger et al. 2011).

Figure 10: Scaled world map based on the relative amount of foreign direct investments in each country. Colors are only indicating the distinction between different countries (Giovannini 2012).

The reasons to participate in such land transactions are manifold: while some countries expect the improvement of local food and nutrition security as well as poverty alleviation, others are mainly interested in increasing profits, while yet others rather see the investment in foreign land as a short- or long-term win-win approach. Overall, critique on large-scale investments in foreign land addresses problems of lacking management capacities and legal transparency, questions the impact on poverty reduction, stresses the increasing dependency on foreign investors, and emphasizes possible risks of increasing land price volatility (De Schutter 2011; Shepard 2011).

5. Outcomes of the world food system

Local to global food systems are highly complex material flow and value chains, which contribute to human livelihoods while interacting with various other systems. Within multiple environmental, social, economic and political boundaries, food system processes (i.e., production, processing, distribution, retailing and consumption) contribute to certain outcomes. These outcomes can be conceptualized as societal goals which food systems interact with and contribute to, primarily: food and nutrition security, environmental quality, and social well-being (Figure 1). Explicitly including the outcomes as part of the food systems concept, and linking them to the different value chain activities, provides a basis to understand and analyze food and nutrition security, a principal goal of any food system (Ericksen 2008; ESF and COST 2009).

5.1 Food and nutrition security

Food and nutrition security can be considered the major outcome of a well-functioning food system, and refers to the situation when "*all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO 1996). Food (in)security is determined by four principal factors: availability, access, use and stability (FAO 2014f). Availability of food refers to what type of food and how much is available through local production, but also considers distribution and the exchange through trade or purchase (ESF and COST 2009). Accessibility of food not only represents how much affordable food is available, but also takes into account how this food is allocated (i.e., where and how food can be accessed) as well as whether social and cultural preferences can be met. In general, availability of food does not guarantee 1) universal access to food, or 2) access to safe, healthy and nutritious food. For example, although overall availability of food was adequate during 2012, 14.5% of US households (17.6 million households) experienced food insecurity at some time. Since 1995, this proportion has increased by 3% (USDA 2014). This insecurity very often reflects uneven distribution of food on different scales, which is highly related to poverty as well as social, political and economic inequality (Barrett 2010). The third determinant of food and nutrition security is use. Use refers to whether people are able to make appropriate use out of the food they have access to. It is related to factors such as the nutritional value of food, food safety, and social value. Overall, food and nutrition security is only achieved if availability, accessibility and utilization of food are stable over time (Zurek 2006) or resilient against any environmental, economic or political disturbance while allowing sustainable development of food systems (IFPRI 2013b). Thus, decreasing agricultural production, economic and political perturbations such as high price volatility within all aspects of food systems remain a big challenge for global food and nutrition security in the future (OECD 2013c).

5.1.1 Prevalence of hunger and malnutrition

Achieving food and nutrition security, especially in developing and poor countries or geopolitically unstable regions, will remain one of the greatest challenges of the world food system. The multitude of interacting contributing factors make this challenge difficult to overcome and, consequently, hunger, food insecurity, and undernourishment are predicted to persist in the 21th century (Smith 2013). Today, different forms of hunger are distinguished, according to the FAO's basic definitions of hunger (FAO 2014g): undernourishment or chronic hunger is defined as not reaching an average minimum of energy intake of 1’800 kcal per day for at least one year. Malnutrition is used for a broad range of conditions caused by inadequate and unbalanced food intake or poor nutrient uptake from food, resulting in protein, vitamin or micronutrient deficiencies. The main causes of chronic hunger are poverty, lack of access to resources, uneven distribution of incomes, conflicts, fragile and vulnerable economic and political systems as well as climate change (FAO 2011a; World Hunger Education Service 2014). Any form of hunger negatively affects growth in labor productivity and workforce, wage earnings as well as overall incomes (OECD 2013b).

From 1990-92 to 2011-13, the proportion of the world population that was undernourished declined from 19% to 12%. However, 842 million people still suffered from undernourishment/chronic hunger in 2013 (Alexandratos and Bruinsma 2012; FAO 2014e). Undernourishment is projected to remain highly variable among and within regions (Barrett 2010). This highlights that rapid and continuous economic growth in developing countries will not be enough to meet the World Food Summit target (FAO 2013d; OECD 2013c), even though progress toward the Millennium Development Goal Target 1C to ''*halve, between 1990 and 2015, the proportion of people who suffer from hunger*'' has been made in some regions (FAO 2013f, 2014f).

While approximately 1 billion people are undernourished, there are 2 billion suffering from “hidden hunger” caused by micronutrient deficiencies. Now and in the future, the deficiency of nutrients, vitamins and minerals remains a dominant factor causing diseases as well as a drawback of cognitive development (Müller and Krawinkel 2005; OECD 2013c). While in the year 2000, still 149 million malnourished children were counted, this number is projected to decrease to 99 million children in 2050. Nonetheless, projections vary between regions, and childhood malnutrition is projected to increase in certain regions of the world (e.g., SSA: +11%; Hubert et al. 2010). Hunger and malnutrition in early life, especially in the first 1’000 days from conception to age 2, leads to impaired cognitive and physical development and a long term impact on health outcomes later in life (Victora et al. 2008).

More often, it is not only undernourishment which affects human health. Over-nutrition, a form of malnutrition, is “*a chronic condition where intake of food is in excess of dietary energy requirements, resulting in overweight and or obesity*” (WHO 2006). Although associated with an overconsumption of certain foods and food components, it is often associated with an inadequate balance of micronutrients. Today, the widespread availability of low-cost, high-energy and nutrient-poor (convenience) food is one of the contributing factors to overweight and obesity and the associated diseases such as diabetes, stroke and heart disease (Traoré et al. 2012). However, there are a multitude of complex and interrelated causes. The prevalence of combined overweight and obesity in adults has risen in all world regions from 24% in 1980 to 34% in 2008 (FAO 2013e).

As a result of the various forms of malnutrition, billions of people around the world, representing a significant proportion of the global population, are now suffering from some form of diet-related health burden. This has led to the term “the double burden of malnutrition” being used to describe the current situation in the world, where we witness the co-existence and impacts of both under- and over-nutrition within countries, cities, villages and even households (WHO 2006).

5.1.2 Healthy, safe and nutritious food

Although the availability of food, clean water, sanitation and corresponding facilities as well as the access to health care have increased in many parts of the world, they are still not sufficient to assure health and nutrition security for all households and individuals (Pinstrup-Andersen 2012). Appropriate, available, nutritious and safe food is crucial for a healthy population. In developing countries, insufficient caloric energy intake, micronutrient deficiencies as well as the lack of clean water and sanitation facilities are still major reasons for health problems (Traoré et al. 2012), while access to improved water sources has tremendously progressed, the MDG drinking water target has been met by 2012. In contrast, in developed countries, health problems mainly result from a combination of overconsumption and lifestyle-related "diseases of civilization" such as obesity, coronary heart disease, cancer and diabetes (Via 2012).

Not only is the nutritional composition of food relevant for health, food also needs to be safe with regard to biological and chemical contaminants. Today, approximately 2.2 million people die each year from diarrhea caused mainly by microbial contamination of food and water. Now and in the future, chemical food contaminations are expected to cause an unpredictable amount of non-communicable diseases (WHO 2014b). Consequently, future progress toward healthy and safe food needs to consider that people need nutritious and safe food for healthy and safe diets. These can only be provided by well-functioning and sustainable food systems which not only produce enough food, but are coupled with education, access to sanitation as well as appropriate policies and governance.

As seen by the still large gap to reach the World Food Summit target, there is quite some progress to make to provide *"sufficient, safe and nutritious food"* to everybody all the time, starting with improvements in agricultural production along the value chains to the consumers to *"meet their dietary needs and food preferences"*, while also improving environmental, social, political as well as economic boundary conditions.

5.2 Environmental quality

Food systems are embedded in the environmental boundary conditions (Figure 1) and strongly dependent on services provided by intact and well-functioning ecosystems. Environmental conditions, their changes and feedbacks directly or indirectly affect all outcomes of food systems (Ingram et al. 2010). On the one hand, the impacts of food systems on the environment and natural resources are increasing, thus, sustainable solutions are needed, drawing on knowledge/science, technology and innovations as well as economic incentives to avoid negative impacts during agricultural and food production, processing, retailing and consumption. On the other hand, the impacts of the environment on food systems are increasing as well, thus increasing climate mitigation, biodiversity conservation, and improving efficient use of natural resources along all value chains are critical to limit or avoid negative impacts on food systems. At the same time, the awareness related to environmental changes through the impact of human activities is growing. Various national and international strategies and agreements, which are targeting environmental quality within the framework of food systems, have been agreed on. To various degrees, they also have been implemented (Baan et al. 2013; Ingram et al. 2010; Nelson et al. 2010). Avoiding soil degradation, dangerous climate change as well as further loss of biological diversity must be guiding principles to ensure resilience of food systems also in the future.

5.3 Social well-being

Food systems should contribute to social well-being outcomes by improving income, employment, and wealth as well as providing social, political and human capital, infrastructure and health (Ericksen 2008). Social well-being, i.e., human well-being and social security, is a key issue for development, since it comprises the provision of care at all ages (e.g., social, health, etc.), education, workforce and jobs, growth and, overall, livelihoods of individuals and households. The vulnerability of food systems with all their boundary conditions highly affects food and nutrition security and, consequently, social well-being, as the economic and social effects of the food price shocks in 2008 disclosed. However, social insecurity in turn also affects food systems, for example, when large numbers of people migrate from fragile states in search for peace, land, water, food and social well-being. Thus, particularly in less developed regions, the improvement of social well-being has become a key element in humanitarian policies, closely linked to activities ensuring food and nutrition security, particularly reaching out to the social, political and economic boundary conditions (Slater et al. 2013).

6. Research questions for the world food system

Based on a comprehensive literature review, Chapters 3 to 5 aimed to highlight the key trends and developments of relevance for the world food system in the coming years. The literature review and subsequent chapters were used in order to identify key questions that must be answered in order to build sustainable and resilient food systems that maximize the outcomes of food and nutrition security, environmental quality and social well-being. A total of five overarching questions were identified, which were structured around the food system outcomes and boundary conditions. The five overarching questions and associated sub-questions are outlined below. Addressing these questions, through interdisciplinary, solution oriented, multi-sector and multi-stakeholder research is critical to ensure the health of our planet and the global population for generations to come.

1. **How can sustainable food and nutrition security be assured for the global population?**
    - 1.1. How can the availability of diverse and quality food through agricultural production, processing, distribution and exchange be assured for all individuals in the face of changing boundary conditions?
    - 1.2. How can the physical and economic access to diverse and quality food be guaranteed?
    - 1.3. How can the capacity of individuals/households to safely prepare, store and use food be improved?
    - 1.4. How can sustainable and healthy diets be further developed and promoted?
    - 1.5. How can the resilience of food systems be improved?

2. **How can food systems contribute to social well-being?**
    - 2.1. How can social inequality (gender, ethnic, racial) and economic inequality (income, land tenure, water rights) be overcome for all actors across food systems?
    - 2.2. How can food systems create and ensure sustainable livelihoods for all actors, especially for vulnerable groups?

3. **How can the negative impacts of food systems on environmental quality be minimized and the positive impacts maximized?**
    - 3.1. How can food systems adapt to and mitigate environmental change, particularly climate change?
    - 3.2. How can the trade-offs and interactions between food systems and ecosystem services be estimated and managed?
    - 3.3. How can resource use efficiency be improved across food systems?
    - 3.4. How can waste and losses be eliminated from food systems?

4. **How can local, national and international policies and governance be directed to improve food system outcomes?**
    - 4.1. How can food and nutrition security be incorporated into a fair and functioning international trade regime?
    - 4.2. How can environmental and climate policies assist the provision of food system outcomes?
    - 4.3. How can policies manage trade-offs between production for food vs. feed vs. fuel?
    - 4.4. How can social and development policies build resilience against disturbances for short- and long-term food and nutrition security?

4.5. How can knowledge, technology and innovation be promoted and sustainably integrated into food systems?

5. How can economic systems be structured to support food system outcomes?

5.1. How can price volatility for input resources and food products be dampened in an increasingly globalized market?

5.2. How can the negative socio-economic consequences of increasing foreign direct investments and consolidation of market control in food value chains be avoided?

5.3. How can markets raise ethical and environmental standards and internalize externalities throughout the food system?

Steps toward a Sustainable Swiss Food System (Stage 2)

7. Trends and projections – Implications for Switzerland

7.1 Demographic changes

Demographic changes within the upcoming decades will be an important factor driving food systems globally and affecting the corresponding boundary conditions (Figure 1). Also in Switzerland, demographic changes such as the increasing Swiss population as well as migration, aging or urbanization will affect the Swiss food system. This will require a restructuring of health and social security sectors, but especially an adaptation of the food system to these new requirements in order to achieve a sustainable food supply and demand in Switzerland (BK 2011).

7.1.1 Population growth

Globally, the population has been steadily increasing and is projected to reach 11.1 billion people by 2050 (according to the UN "high fertility" scenario; United Nations Population Division 2013b). The Swiss population is also projected to continue growing until 2050, reaching between 7.2 and 8.9 million inhabitants depending on fertility rates (BFS 2010a; BFS 2010b). These scenarios are based on the assumption that current bilateral agreements such as free movement of work force within the European Union continues. As Switzerland depends on imports for roughly half of its food consumption, for many other foreign goods (e.g., seeds, fertilizers, etc.), all highly relevant for domestic food production, the global population growth trends might increase demand and, consequently, the competition for local vs. foreign food and feed products needed by the Swiss population.

7.1.2 Migration

Migration is projected to occur globally with increased frequency, both within and across national borders. Coupled with population growth trends, migration represents a large food system challenge as it is often prevalent in regions that already experience high food and nutrition insecurity. Projections on migration from/toward a specific country are difficult to make. Migration from/to Switzerland largely depends on factors such as the economic situation of migrants, the presence of work, family, education and application quota for asylum (BFS 2010a; Lowell 2009) as well as national politics. One example is the just recently accepted Swiss immigration referendum (public vote on 9 February 2014) and its potential implications. In Switzerland, immigration is strongly fluctuating since 1960 and reached its net total high in 2008 (BFS 2014d). Since then, the net total has been decreasing. More than 50% of the migrants in Switzerland originate from European countries such as Germany, Italy, France and Portugal (BFS 2014d). These nationalities also contributed to the largest share of emigrants. Until 2030, net migration to Switzerland is projected to decrease (BFS 2010b), and to stabilize later on. Low migration rates will affect the work force as well as the social security systems due to a shortage of skilled workers in working age in Switzerland and due to population aging. Moreover, impacts on the Swiss food system are to be expected since migrants often have different food preferences than the local population and are likely to create a new or different demand for imported food products.

7.1.3 Aging

Aging is an ongoing process that affects food systems at global and local scales. An increasing life expectancy and declining or low birth rates will lead to a continuously increasing share of the population being older than 65 years (i.e., aging of population; United Nations Population Division 2013a). Until 2050, demographic change such as aging of the Swiss population is projected to continue, comparable to other countries globally (BFS 2010a; BFS 2010b; United Nations Population Division 2013b). Similar to many other countries, aging in Switzerland will affect the demand for social services (health care, social security), the availability of work force, the demand for food and non-food consumables (BFS 2010a) as well as the productivity and economic growth. Moreover, an increasingly affluent demographic group is more inclined to seek out products that promote health and longevity, and/or address emerging health concerns in Switzerland.

7.1.4 Urbanization

Globally, urbanization is a major trend occurring in developed and developing countries due to structural changes in the economic sector as well as due to the thrive for economic success in prospering urban areas (Satterthwaite et al. 2010). Similarly, the trend has also been observed and will continue in Switzerland (BFS 2013a). Until the mid of the 20^{th} century, urbanization in Switzerland was very slow (BFS 2013a; Kübler 2005). This changed drastically and today, ca. 75% of the Swiss inhabitants are living in cities or urban areas (Kübler 2005). Increased wealth and urbanization are already causing changes in lifestyles and daily routines, which require less physical activity. This is projected to cause negative health effects and will amplify the occurrence of non-transmissible diseases such as obesity, cardiovascular diseases or diabetes mellitus type 2. Consequently, there will be an increasing demand for innovative food products, which need to be adapted to the urban life style as well as to the needs that arise from less physical activity, also in Switzerland.

Economic growth concentrates in urban regions. There, secondary, tertiary and quaternary sectors will provide an increasing share of jobs for the urban, suburban and rural population. The distribution, processing and retail of food and non-food products will benefit from better, centralized infrastructure and trading areas as well as from larger gatherings of consumers (Satterthwaite et al. 2010). Urbanization and the increase of settlements will put increasing pressure on ecosystems in urban areas (Satterthwaite et al. 2010). Typical rural or cultural landscapes will be lost due to the increase of settlements, including fertile land suitable for agricultural production (7.4.5), but also land, which provides other ecosystem services such as recreation and purification of urban air. Further problems are related to noise and odor nuisance due to livestock production, manure applications or biogas production in increasingly urbanized areas. Many of these consequences of urbanization are already visible in Switzerland (Keck et al. 2011).

7.2 Trends in food demand

7.2.1 Demand through economic growth

Both, per capita income and purchase power are important factors determining and directing the consumption of food, feed and fuel of any population (van der Mensbrugghe et al. 2011). Switzerland is projected to follow international economic trends of developed or high-income countries, which means an economic growth of approximately 2% per year (Alexandratos and Bruinsma 2012).

Gross Domestic Product

The global GPD has increased fourfold during the past forty decades and is projected to continue increasing until 2050 at around 3.5% per year (OECD 2012a). In 2013, the Swiss GDP was 650 billion USD (current USD), which is comparable to the economic growth rates of Norway or the Netherlands (Trading Economics 2015a). The Swiss GDP is projected to triple (annual growth rate of 2%) and will reach 1’551 billion USD by 2050 (Trading Economics 2015b). These projections of economic growth, the potential outcome sand components will be similar to those of other high-income countries such as Austria, Belgium, France, Germany as well as USA or Japan (The World Bank 2013; Trading Economics 2015c). While economic growth is a major driver of food demand in developing countries, this correlation is less important in Switzerland or in other developed countries. Here, a high level of food demand has already been reached (BFS 2013b), and economic growth at national, enterprise and individual scales can be a driving force for increasing investments.

Share of economic growth among nations

Within the next decades, the economic balance among nations is predicted to change rapidly (Dadush and Stancil 2010). The economic growth of emerging countries and their increasing share of the global economic growth might cause a shift of economic power at the world market (Dadush and Stancil 2010; OECD 2012a). For all other nations, including Switzerland, these countries and their increasingly successful economies might become strong competitors on the global market (WEF 2014). However, Switzerland is thought to be able to find its space within these changing markets. In 2014, Switzerland again resided at the top of the global competitiveness ranking for the sixth year in a row (WEF 2014). Top academic institutions, a strong collaboration between academia and business, infrastructure and connectivity as well as high spending on research and development are just e few parameters allowing Switzerland to be highly innovative and, consequently, competitive in a global market (WEF 2014). Competiveness due to increasing demand for Swiss products, for example from emerging markets, might raise the Swiss economy additionally.

Per capita income

In the past decades, average per capita incomes increased globally (OECD 2012a). However, the levels of increase as well as the range of per capita income remain highly variable among regions. As a consequence of economic success, incomes (nominal wages) in Switzerland have constantly increased during the past decades and are among the highest incomes globally. Between 1980 and 2013, GDP per capita at current prices increased from 18’000 to 80’000 USD per year. By 2018, the gross domestic product per capita at current prices is projected to increase up to 91’000 USD (IMF 2014). In contrary, while income per capita was increasing during the past century, the share of household expenditures for food in total expenditures was constantly decreasing, from 38.8% in 1921 to 6.8% in 2011 (BFS 2014c; ICONOMIX 2013), partly caused by lower prices due to increasing productivity and technological progress, but mainly due to a rise in income. According to the scenarios provided by the Federal Office for Agriculture (FOAG), purchase power will continue to increase (scenarios 1 and 2) or stagnate (scenario 3) despite increasing prices within the food sector (BLW 2010). Overall, it will rather be the increase of the total population than the increase of food consumption causing an increasing demand for food in Switzerland. In contrast to developing countries, where household expenditures for food are relatively high, further increase of per capita income in Switzerland will not increase the per capita demand for food in general. The stagnation of consumers demand for food might be satiety point in per capita food consumption, which has been reached in

Switzerland. Consequently, an extraordinary growth of per capita food demand cannot be expected. Nevertheless, there might be an increasing demand for high quality food (e.g., food from premium lines) as well as social and environmental responsibility associated to the food value chain.

Structural change in the economic sectors

In the future, a continuing structural shift within the economic sectors toward the industry and the service sector is projected at global scale. Also in Switzerland, a similar trend will probably be seen, with a decreasing agricultural sector (-17%) and increasing industry (+15%) and service sectors (+24%) until 2030 (Ecoplan 2011), thus, toward a highly technologized industry and service community. While developments of technologies and innovations as well as the employment rate in the food sector will remain stable until 2030, the health sector is projected to increase above-average due to changing demographic structures and increasing incomes (Ecoplan 2011). If structural changes continue as projected, then there is a potential that rural areas lose their economic viability, e.g., jobs might get lost in the agricultural sector, and inhabitants might either become urban dwellers (Chapter 7.1.4) or commute to their work in the cities. This might not only reduce the livelihood of these persons, but also increase the pressure on infrastructure and on the environment. Moreover, agriculture might need to become more intensive and more centralized in order to stay competitive, leading to increased farm sizes and further job being lost.

7.2.2 Demand through changing per capita food consumption

Over the last decades, per capita food consumption increased continuously from 2’373 kcal per capita and day to 2’772 kcal per capita and day (1969-2007), due to economic growth and increasing per capita income worldwide (Alexandratos and Bruinsma 2012). The average per capita food consumption per day of the Swiss population was much higher than the global average and changed only little from 3’576 kcal in 1962 to 3’487 kcal in 2011 (FAO 2014c). Studies on Swiss food consumption indicate little changes in the total amount of food consumed since 1980 (BFS 2014b). Even if per capita consumption for some food items might decrease, the population growth in Switzerland might compensate these declines (BFS 2010a; Zoss and Becker 2012). Thus, any increasing demand for food and food production in Switzerland as well as for imported goods will rather be the result of total population growth than of increasing per capita food consumption (BFS 2014b).

7.2.3 Demand through dietary changes

Globally, diets are projected to change toward meat and dairy-based foods. Especially in developing countries, increasing income and purchase power will change diets. In Switzerland, only single groups of food (i.e., milk and dairy products, fruits, vegetables, cereals, meat, potatoes, wine, etc.) experienced slight changes in average annual per capita consumption (BAG 2012b). On one hand, the average per capita consumption of animal fats (-40.4%), fruits (-24.2%), wine (-21.4%), meat (-15.9%) and potatoes (-8.2%) declined between 1980 and 2008. On the other hand, the average per capita consumption of fish (46.6%), plant fats (+20.0%) or vegetables (+15.6%) increase at the same time (BAG 2012a). These changes might arise from changing life style of the Swiss society, but also from changing demographic structures (migration, aging, etc.), causing changes in production and processing, and also in demand for imported food.

Cereals

Globally, cereal staples such as maize, rice, and wheat are the most important source of calories in total food consumption providing an average of 50 to 60% or ca. 158 kg per capita to the annual human caloric energy intake (Alexandratos and Bruinsma 2012; IAASTD 2009). In developed countries, cereals are of increasing importance in biofuel production, but the projections for the future are highly dependent on policies (e.g., bio-based fuel production) related to agriculture (Alexandratos and Bruinsma 2012; Kearney 2010). In Switzerland, the per capita consumption of cereals contribute ca. 15% of the total of 980 kg (2011) per capita consumption per year (BFS 2014b). Although the annual demand for cereals (+27 kg), since 1980 (BFS 2014b), the per capita demand for cereals is projected to remain stable in Switzerland. However, population growth is expected to cause an increasing demand for cereals, which will increasingly put pressure on a declining share of Swiss arable land (BFS 2013a). The currently high ratio of locally vs. globally produced cereals (e.g., wheat) will decrease and thus increase the dependency on imports. Moreover, if livestock production increases to fulfill the higher demand for meat and dairy products by increasing number of people in Switzerland, there might be an increasing food or feed conflict in terms of resource competition at local scale, but much more at global scale.

Animal proteins

Economic growth and population welfare drive the increasing demand for animal proteins, particularly in rapidly growing developing countries (Alexandratos and Bruinsma 2012). The annual consumption of meat is projected to increase from 38.7 kg per capita in 2005/2007 to 49.4 kg per capita in 2050, at the global scale (Alexandratos and Bruinsma 2012). In Switzerland, the consumption of meat (kg/capita/a) has slightly declined since 1999 (51 kg in 2012), whereas the consumption of dairy products increased constantly (BFS 2014b). While meat contributed ca. 5% to the total per capita consumption per year, dairy products alone had a share of 26% in 2012 (BFS 2014b). Overall, the per capita consumption of meat is projected to be 10% lower by 2050, which might reduce the environmental impact of livestock in Switzerland, but also increase the demand for increasingly imported, plant-based products.

Proteins from fisheries and aquaculture are important contributors to human nutrition, globally (WWF 2010). Since 1960, world fish consumption has grown dramatically (3.2% p.a.), from per capita seafood consumption of 9.9 kg per capita p.a. (live weight equivalent) to >18.4 kg per capita p.a. (FAO 2012b; FAO 2013b). In Switzerland, fish and sea food consumption is increasing steadily (three quarters are from marine sources), but is still below the global average. In 2012, almost 8 kg seafood per capita were consumed per year (BFS 2013d). At the same time, increasing demand and decreasing local production due to overfishing caused in Swiss lakes cause high dependency on imports and high negative impact in foreign countries despite a growing share of fair trade initiatives and sustainability labeling (Allsopp et al. 2008; BFS 2013d).

Consumptions trends in developed countries

Despite the increasing demand for food by growing populations in developing countries and the increasing demand for more meat and dairy-based food, there are many more specific trends and consumption patterns (EC 2007; EC 2011). First, food and consumption of food has become more diverse due to increasing trade and market activities, changes of social or demographic structures (e.g., migration, aging, etc.) as well as technological development, while regional differences in food purchase and preparation have been declining within Europe (EC 2011; Hauser et al. 2013). The trend of diversification of food can also be observed for Switzerland. This may cause an increasing production of diverse food products as well as the demand for foreign products which are supplied by increasing imports, shopping abroad (i.e., shopping tourism) or online (Feubli et al. 2013). Secondly, diets comprise an increasing share of convenience food, which is caused by changing life style, the changing role of women as well as changes of household structures, incomes and availability of enriched food in Swiss society (Hauser 2012; Hauser et al. 2013; Hauser et al. 2011). Since the 1990s, the demand for industrial food, pre-packaged meals, convenience or functional food has increased constantly in Switzerland and neighboring countries (Hauser 2012; Hauser et al. 2013; Zoss and Becker 2012). This trend requires a continuous adaptation of products as well as innovative capacity and product developments, which will cover life style, health and the society's demand for socially fair and environment-friendly food products. However, compared to countries such as USA or Germany, food consumption away from home did not increase significantly yet (Okrent and Alston 2012; Oltersdorf 2003). The third trend is related to diet-related diseases, which are projected to continue increasing. Consequently, lowering the per capita food consumption per day as well as the generation and transfer of knowledge on healthy food and diets remain highly critical. Moreover, an increasing demand for novel and specialist foods, for example vegetarian or organic products, as well as foods for special health requirements such as allergies can be observed in Switzerland and other developed countries (Hauser 2012). These demands will be drivers for new niche markets at national and international scale and for new and innovative food products.

7.3 Trends in food supply

Functioning food value chains, i.e., production, processing, distribution, retail, consumption and physiological responses, are crucial for a sustainable local, national or global food supply. Overall, global agricultural production and processing have changed considerably over the last decades (Prax 2011). At global scale, smallholders and family farms are of major importance in food production since they produce ca. 70% of the global food supply on less than 25% of the world's farmland (Prax 2011). Nowadays, 500 million farms are still family owned and are responsible for 56% of the global agricultural production (FAO 2014h, 2014i). In Switzerland, the number of farms decreased from 111'302 in 1975 to 55'207 in 2013; in contrast, the share of farms with > 10 ha increased from 38.4% to 64.2% (BFS 2013c). Since 1970/1975, the number of fishermen and farmers in Switzerland decreased by ca. 50% (BLW 2014), although most Swiss farms are still family farms (SBV 2013).

7.3.1 Agricultural production

Agricultural production until 2050 needs to grow by 0.8% p.a. in order to feed a growing global population (FAO 2014e). This means, if the global relations of production, consumption as well as losses and waste remain constant, global food production in 2050 needs to be approximately 50-60% higher than today (Alexandratos and Bruinsma 2012; van der Mensbrugghe et al. 2011). Since 1990, food production in Switzerland has increased and reached 23'529 terajoules in 2012 (BFS 2014a). Excluding the share, which has been produced from imported feed, 20'892 terajoules were produced in Switzerland (BFS 2014a). In other terms, 63.5% of all food and agricultural products consumed in Switzerland originated from Swiss agriculture (47.5% plant-based, 100.4% animal-based) in 2011, while the remains needed to be imported, creating a dependence on food imports for an increasing

Swiss population (BLW 2014). Considering the "Business-As-Usual" projection of the REDES project ("Ressourceneffizienz im Dienste der Ernährungssicherheit"; Kopainsky et al. 2013), clearly indicated that it is necessary to increase efficiency and agricultural productivity as well as to improve the efforts to multilateral trade agreements in order to assure food security in Switzerland (Zoss and Becker 2012).

Crop yields

In the past decades, global crop yields have tripled, whereas the harvested area increased by only 10 million ha within the same time (215'489'485 ha in 2012; FAO 2014e). Food demand from a rising population size, diet shifts and increasing biofuel consumption are projected to require an additional 1 billion tons of cereals p.a. to meet the food and feed demands by 2050 (Alexandratos and Bruinsma 2012). In Switzerland, the area for cereal as well as root and tuber (potato) production decreased over the past 20 years (-50'000 ha and -5'000 ha, respectively; BFS 2014e; FAO 2014b), while the areal coverage of fodder production or permanent crops did not change, and that of oil seeds and other crops increased (BFS 2014e; FAO 2014b). This trend is projected to continue at least until 2025. The increase of crop yields is stagnating (e.g., in Europe or Switzerland), while the focus of breeding strategies increasingly is on adaptation to scarce resources such as water or nutrients as well as aiming at the reduction of agricultural inputs (Walter et al. 2014). Thus, Switzerland might become increasingly dependent on imports due to an increasing demand for foreign plant-based products (SGPV 2011).

Livestock production

Currently, livestock production is the largest land-use sector globally and one of the fastest growing agricultural sectors, with an asset value of 1.4 trillion USD (Herrero and Thornton 2013; Thornton 2010). Assuming current consumption patterns and population growth at medium level, an additional meat production of approximately 200 million tons will be required in 2050 (Alexandratos and Bruinsma 2012). Livestock production in Switzerland has increased continuously since 2001 (FAO 2014b), with largest increases for chicken, followed by pig and cattle (BFS 2013e). In theory, Switzerland covers its meat and dairy demand by domestic production (BLW 2014). However, this production is still highly dependent on foreign feed sources such as soy imports (BLW 2014), which increased between 1990 and 2012 by the factor of 10 (250'000 tons in 2012), due to an increasing demand for animal feed and the prohibition of animal-based feed for ruminants (Baur 2011). Consequently, Switzerland will remain highly dependent on foreign fodder production as well as on the availability of GMO-free feed (e.g., soy), which today is only available by imports from Brazil and China (Baur 2011).

Fisheries and aquaculture

In 2012, global capture fisheries and aquacultures provided 156.2 million tons of fish (93 million from capture, 63 million from aquaculture), an important source of high-quality food with a total value of 258 billion USD (FAO 2013b). In the future, major growth in fish and sea food production will result from aquacultures as natural stocks are overexploited (FAO 2013b). Since 1984, the production of fish (tons per year) from fish farms and wild stocks is constantly decreasing in Switzerland (BFS 2013d). While the export has decreased from 3'785 tons per year to 583 tons per year (2013), the import grew constantly, reaching 73'928 tons in 2013 (BFS 2013d). Today, 90% of the consumed fish are imported and a large share still originates from critical sources (i.e., unsustainably managed sources, large by-catch; water pollution by excrements and pharmaceuticals, etc.(Bostock et al. 2010; EC 2011; FAO 2012b; FAO 2013b; Garcia and Rosenberg 2010; Godfray et al. 2010). Most likely, there will be an increasing dependency on imports also in the future.

7.3.2 Processing, distribution and retailing

In the future, food system areas such as processing, distribution and retailing will change, partly due to changes in consumer behavior, but also due to economic reasons. Globally as well as in Switzerland, a higher demand for processed food is projected within the next decades (Hauser 2012). Along the food value chain, large food and beverage processors, distributors as well as retailers will play an increasing role due to concentration of markets (Satterthwaite et al. 2010). But these actors will also provide a growing proportion of employment related to transport, food processing, retailing and vending rather than agricultural production (Cohen and Garrett 2009). At the same time, the food and beverage sector will be affected by a consolidation of markets driven by major global players, increasing national and global competition.

Processing

In Western societies, the majority of food is processed at industrial scale (ESF and COST 2009). Between 80 and 90% of the food has undergone some processing, which ranges from very simple to very complex procedures (ESF and COST 2009). Sustainability, nutritional value and food safety aspects are going to present major issues of food processing in the future. Besides traditional food processing, the future focus of the processing sector will be the development of a wide range of food products such as healthy and convenient food with balanced nutrition, while increasing shelf life, valorizing or minimizing waste, and improving product screening and monitoring, globally as well as in Switzerland (Dainelli et al. 2008; ESF and COST 2009; Hubert et al. 2010; Mahalik and Nambiar 2010). Progress in food processing technologies and up-to date food products based on consumer demands present important fields for Swiss food industry to achieve science- and knowledge-based developments and to improve their positioning in the global market. Moreover, the competitive access of Swiss food industries to high-quality raw materials and ingredients will also be affected by the development of national trade and standard agreements.

Distribution (transport and packaging)

The distribution, packaging and storage of food and food products experienced large changes in the past decades due to globalization and geographical shifts of markets (ESF and COST 2009). The increasing trade of food and related raw materials tremendously affected global and local markets as well as transport and logistics of food. Globally, increased distances are travelled for the transport of food and related goods (ESF and COST 2009). The same trends are observable for the Swiss food system. The amount of goods transported (t per km) is projected to increase until 2050 (BFE 2013b; Schweizerischer Bundesrat et al. 2012). This trend will not only increase pressure on infrastructure such as roads or rails, but will also have negative ecological and social impacts such as increasing greenhouse gas emissions, noise or landscape fragmentation due to (new) infrastructure. In addition, the transport of food within as well as to or from Switzerland will be increasingly incorporated into global trading networks.

The packaging industry became a truly global business (Duriez 2009). The food sector holds a share of 60% in the global packaging industry due to the demand for increasing quality and food safety standards, shelf life extension, increasing demand for convenience food and for information about food products (e.g., nutritive value, presence of allergens, advertisement; Duriez 2009). Packaging solutions for an increasingly globalized market are highly variable, consider innovative technologies and integrate concepts from chemistry, microbiology, and engineering (Mahalik and Nambiar 2010; Robertson 2012). Past trends in packaging address light-weighting, material reductions, recycling and waste reduction initiatives. The packaging market in the year 2020 is most likely influenced to a large extent by techno-economic trends, while previous trends remain (Farmer et al. 2013). Switzerland is probably following the trend to more innovative packaging for an increasing demand for packed but fresh as well as convenient food for safety and quality reasons. Innovative packaging materials and concepts might be able to reduce waste and losses, and, consequently, resources used for food products as well as greenhouse gas emissions (Marsh and Bugusu 2007). Life Cycle Assessments (LCA) considering packaging will be a major approach to improve packaging materials and concepts within food systems (Farmer et al. 2013).

Retailing

In the past, the growth of supermarkets was the prevailing trend in food and beverage retail (Ellickson 2011; Fernie 1997). Until 2020, retail will undergo further changes. In the EU, choices for consumers have increased and diversified since 2004 (EC 2014c). Future challenges for the European market will be the increasing demand for transparency and traceability of raw materials, food products and associated social aspects such as fair trade (ESF and COST 2009). In Switzerland, these overall trends are observable as well. The turnover in food retail is projected to increase further, due to increasing purchase power in Switzerland (Feubli et al. 2013). Compared to neighboring countries, the food price levels will likely remain at a high level in Switzerland (37% higher), which causes a persistent “shopping tourism” and, consequently, economic losses for Swiss retailers. In order to be competitive in global and local markets, also Swiss retailers will have to increase operational efficiency, e.g., by using new information technologies such as Quick Response-codes (QR) as well as smart phones to connected and inform consumers. The growth of online shopping, which includes “click-and-buy”, home delivery and monitoring of sales, is projected to become an important driver of changes in the retail sector (Mansour and Zocchi 2012).

7.3.3 Waste and losses

Today, the consideration of food losses and waste in food systems is of major importance in terms of resource efficiency in a resource-constraint world. Approximately one third (1.3 billion tons) of the food produced for human consumption is lost every year (Gustavsson et al. 2013; Gustavsson et al. 2011). With 1/3 or approximately 2.3 million tons of food lost within the Swiss food system, food waste is also a major problem in Switzerland. 48% of total calories produced (edible crop yields at harvest time and animal products, including slaughter waste) are lost across the whole food value chain (Beretta et al. 2013). Comparable to other developed countries, food safety standards cause major losses and waste early in the value chain, actually before the food even reaches the consumer. In addition, approximately 45% of all avoidable losses along the food value chain occur in households, where they also have negative economic impacts (Beretta et al. 2013). Every year, 500-1’000 CHF per person are spent for food that is wasted by the consumer in Switzerland. Thus, losses and waste of food in Switzerland cause indirect overexploitation of natural resources, including energy that has been used throughout the food value chain as well as GHG emissions and pollution of the environment. These problems and damages are caused locally as well as abroad from where more than 50% of the Swiss food and energy is imported (Jungbluth et al. 2011).

7.4 Food system boundaries – Environment

Globally and locally, food systems of any complexity affect the environment and natural resources, which are crucial for the production of food. However, effects can be local but also in other regions or countries where food system inputs are coming from or where food products produced for consumers in Switzerland. For example, major impacts of products consumed in Switzerland are indeed located in foreign countries (73%, Frischknecht et al. (2014), 60%, Jungbluth et al. (2011)).

7.4.1 Climate change

Globally, a warming trend due to anthropogenic greenhouse gas emissions has been observed, where average global surface temperatures increased by around 0.85 °C from 1880 to 2012. Further signs of global climate change are increased ocean temperatures, decreases in snow and ice masses, rising sea levels, and more frequent extreme events, such as heat waves and droughts (IPCC 2013).

In Northern Europe, changing climatic conditions are projected to have a primarily positive effect on agricultural production, with longer growing seasons, growth potentials for new cultures and slightly higher photosynthesis rates (CO_2-fertilization; Iglesias et al. 2012; Lavalle et al. 2009). In contrary, in Southern Europe, agricultural production will increasingly suffer from water shortages and changing patterns of pests and diseases (Fritsche-Neto and Borém 2012; Iglesias et al. 2012). In both cases, further negative impacts have been reported, e.g., reduced nutritional values in plants and loss of biodiversity (IPCC 2013; Müller et al. 2014).

In Switzerland, average temperatures during the entire year are projected to rise, summer precipitation to decrease and winter precipitation to slightly increase (as rain, not as snow) and to become more variable (BAFU 2014; Bösch et al. 2011; CH2011 2011). The consequences expected within the current century are multifold and range from a shift of productive land, increased demand for irrigation (water), changing cultures (e.g., less maize, more sorghum), increased productivity of meadows or arable land (e.g., longer growing seasons, cultures with higher yield potential), to reduced productivity per ha in drier areas (Western parts), increasing problems with pests and diseases as well as invasive species, increase in livestock diseases and heat stress during summer and damages through hail or late frosts (BAFU 2012a; BAFU 2014; Finger and Schmid 2008; Klein et al. 2013; Lehmann et al. 2013a; Lehmann et al. 2013b). The damage potential of floods, mudflows and landslides result from direct consequences of run-off and soil erosion, transfer of pollutants (e.g., fertilizer, heavy metals) and subsequent eutrophication of water bodies as well as from negative impacts on soil and water quality (BAFU 2012a; BAFU 2014). Declining water reserves and increasing demand for water for agricultural production will increasingly cause conflicts in land use (OcCC and SCNAT 2007). These conflicts are not only projected to arise among different uses (such as environmental protection vs. agricultural production), but also among different sectors (such as energy vs. food production; Chapter 7.7.5). Furthermore, the implications of changing climatic conditions on biodiversity and ecosystem services are poorly understood, both at local and at global scales.

At the global scale, climate change might increase volatility of prices such as for agricultural commodities, food and feed (Tran et al. 2012). The projected increase of droughts and the increasing withdrawal of water from natural sources will potentially raise global food prices and increase local, national and international competition for land and water. As a consequence, markets might become more volatile and populations might become more food insecure, increasing the risks for social conflicts or political riots. In Switzerland, there will be higher economic risks for domestic production (see above) as well as for purchasing of imported products. However, at a national level, direct payments make Swiss farmers less vulnerable to climate variability, since these payments make up 30% of total farm revenue in Switzerland which (Finger and Schmid 2008; Lehmann et al. 2013a).

Changing climatic conditions and the consequences at global and local scales might also affect further areas/sectors of food value chains. Increasing temperatures might cause higher demand for cooling facilities in distribution, processing, retail and in consumer households. In the future, this might increase the pressure on product and food safety, e.g., by increasing contamination and pathogen growth rates or increasing food-borne diseases (Portier et al. 2010).

7.4.2 Natural resources (nutrients, water, land)

Natural resources are the key factor for food production. Their availability and quality are essential for food security and the provision of healthy and nutritious food. Globally as well as in Switzerland, their sustainable use, protection and restoration are fundamental for a competitive economy, for environmental quality, and social well-being (BAKBASEL und Global Footprint Network 2014).

7.4.3 Nutrients (nitrogen, phosphorous)

Macro-nutrients such as nitrogen (N), phosphorous (P) and potassium (K) are crucial for agricultural production and, consequently, food supply. Although the global use of fertilizer has increased tremendously over the last decades, the lack of nutrients is still limiting agricultural productivity and, consequently, food and nutrition security in many regions of the world (Dawson and Hilton 2011). On the other hand, in intensively managed areas with high fertilizer use, high loads of nutrients threaten ecosystem quality and stability (Mountford 2011; Sutton et al. 2013). In Switzerland, on-farm nutrient management of N has been improved after different regulations entered into force and new or integrated management practices were established (BAFU and BLW 2008). Nevertheless, in 2010, Swiss farms produced an on-farm budget surplus of almost 120’000 tons of N, due to mineral fertilizer use, manure and slurry, N deposition, and N_2 fixing legumes (BAFU and BLW 2008; BLW 2013; BLW 2014). Consequently, negative impacts on the environment and human health by emitted nitrogen oxides and ammonia as well as on national and international water bodies (e.g., North Sea) by the release of nitrate still persist (BLW 2013; BLW 2014). Compared to N use efficiency (increased by app. 30%), P use efficiency in agricultural production has improved tremendously (by about 60%). P inputs from agriculture also have been reduced by 10 to 30% compared to 1990, but are still too high in areas with very high livestock density. General improvements in waste water treatment (e.g., in settlements) additionally reduced release and leaching of P to natural habitats and related negative impacts (BAFU 2009b). Furthermore, the destruction of natural habitats, changing climatic conditions and inadequate management practices (e.g., open soils) can cause erosion and run-off from arable land, thus nutrient loss that in turn pollutes water resources, causes loss of water and soil quality as well as loss of biodiversity in Switzerland (BAFU and BLW 2008).

7.4.4 Water

Food systems are major users of water resources, with the production of food (agriculture only, without processing) using 70% of the world's annual freshwater (2'703 km^3 in 2012), compared to 20% by industries and 10% by cities (de Fraiture and Wichelns 2010; FAO 2014a). Increasing demand for water, its pollution but also climate change will limit its availability in the future at the global scale. Switzerland has a large, natural and relatively stable supply of water (Ernst Basler und Partner AG 2007). While the per capita use of drinking water has been decreasing (170 l/a, 2010) (Ernst Basler und Partner AG 2007; Leitungsgruppe NFP 61 2015), the total water use in Switzerland is still 2.2 km^3 per year (25% households, 20% agriculture and 55% industry). However, local water quality has been increasing due to positive impacts of technological and management improvements in the water sector (Leitungsgruppe NFP 61 2015). Currently, the Swiss water economy spends 7 billion CHF per year for maintenance and construction of water facilities, which also comprise hydro power plants, domestic water supply and treatment as well as flood protection (Leitungsgruppe NFP 61 2015). Overall, Switzerland is strongly involved in virtual water trade, mainly due to large food and other product imports, affecting food and water security elsewhere.

In the future, climate change will affect local water availability and the variability of water levels in some Swiss regions (Klein et al. 2013), although the major impacts on high-quality water supply will probably still be related to socio-economic aspects, less to climate change (Leitungsgruppe NFP 61 2015). Until 2100, 90% of the current glaciers are expected to be gone (Leitungsgruppe NFP 61 2015). Consequently, the water supply by glaciers will decline over time, which might cause conflicts among competing uses of water: for energy production (hydro-power), for irrigation in agricultural production, and for conservation of natural habitats (BAFU 2012a).

7.4.5 Land

Currently, 38.6% of the water- and ice-free area (13.02 billion ha) are under agricultural use as pastoral (2.5-3.4 billion ha in 2000) and crop lands (ca. 1.5-1.6 billion ha in 2000) globally (Foley 2014; Lambin and Meyfroidt 2011). In the future, an increasing world population will need to be supplied with food, while at the same time area and quality of land suitable and available for agriculture will decrease (Hertel 2011). Globally, competition for land will be steadily increasing, similar to the situation in Switzerland (BFS 2013a). Here, urbanization (Chapter 7.1.4) is the major reason for land competition, i.e., transformation of agricultural land into land for settlements or infrastructure, with the result that fertile land originally used for agricultural purposes has been declining since decades (-32'000 ha since 1996, -2'000 ha per year) (BFS 2013a). Further socio-economic drivers of land competition in Switzerland include the number of people moving or commuting to cities, the increasing demand for larger living space per person, and a tendency towards more one-family houses due to increasing income and economic welfare (Schweizerischer Bundesrat et al. 2012). In 2013, already 60% of all settlement area originated from pastures and arable land (BFS 2013a). Moreover, fertile land is lost due to the increase in sealing of soils (Straumann et al. 2012). Today, a sustainable land use planning and regulation seems highly necessary in order to protect fertile land (BAFU and BLW 2008; Schweizerischer Bundesrat et al. 2012). With healthy and fertile land becoming an increasingly scarce resource, agricultural production competes not only for land with settlement expansion but also with nature conservation (SNF 2013).

7.4.6 Plant and animal health

Plant animal and microbial pests, weeds as well as animal diseases caused by microbial infections but resistance to antibacterial drugs are major threats to agricultural productivity, its projected growth as well as to safe and healthy food (Oerke 2006; Fisher et al. 2012; BAG et al. 2014; WHO 2014a). Pests occur along entire food value chains (Waterfield and Zilberman 2012), where they cause losses and severe health issues for humans. Dislocations, global trade, and changes in climatic conditions are important drivers for spreading of pests and diseases (Bebber et al. 2013; Gregory et al. 2009), also to and in Switzerland. In the future, climate change will increase the probability of the occurrence of natural vectors, which enable pests, pathogens as well as invasive species to invade new territories, potentially affecting agricultural production (BAFU 2014). Since Switzerland imports a large share of its commodities, detection, control and prevention of pests, pathogens and diseases will be a perquisite to reduce losses and to provide safe and healthy agricultural products as well as food (FOPH 2012), also in regard to national and international regulations and cooperation.

Another aspect to consider when addressing food systems is the consumers' perception. Although the efficient use of, for example, antibiotics can increase the health of livestock in many of today's production systems, the consumers in Switzerland increasingly demand high quality products to be free of any kind of residues, to originate from sustainable production and/or to come from healthy animals treated as little as possible (BAG et al. 2014).

7.4.7 Biodiversity and ecosystem services

The global demand for increasing yields led to a decline of biodiversity and ecosystem services during the past decades (Poppy et al. 2014). Increasing demands for food, feed and biofuels are projected to affect biodiversity and most likely affecting human well-being, economic growth, and food and nutrition security in the coming decades (Cardinale et al. 2012; Leadley et al. 2010; OECD 2012b; WWF 2010). These changes in biodiversity affect food value chains, either due to genetic erosion such as the loss of crop varieties and livestock breeds on farms, or due to invasive species affecting agricultural production and subsequent processing. Today, only few, highly efficient varieties and breeds are used by farmers in industrialized states such as Switzerland (Last et al. 2014), also causing the loss of cultural heritage as the fundamental base of diverse food, but also of ecosystem services such as genetic resources for future crop improvement, pollinator attraction, natural pest control and yield stability in disturbed systems (Hajjar et al. 2008).

In Switzerland, efforts to support biodiversity are showing first signs of success (e.g., in forests). Drastic losses, which occurred between 1900 and 1990, could be slowed down after 1990. Nevertheless, halting the general loss of biodiversity as an overarching goal could not be achieved until today. Major causes for biodiversity loss are expanding settlements due to urbanization and infrastructures, intensification of agriculture, expansion of activities (tourism, leisure time), pressure on ecosystems and ecosystem fragmentation caused by activities mentioned previously. Since 1900, 23 animal species (out of 715 species and 9 investigated groups) disappeared (Lachat et al. 2010). The reversal of biodiversity loss has to consider all levels of diversity and requires a substantial commitment to conservation and sustainable development (BAFU 2012b; Lachat et al. 2010).

However, while native species disappeared, new species could establish, including invasive species. These species crossed natural borders by migration into new suitable habitats (e.g., due to changed climatic conditions) or were brought in by humans, could establish and spread. In Switzerland, 107 species are classified as invasive; they all have the potential to cause ecological or economic harm and negative health effects (Lachat et al. 2010).

Swiss food system not only affects local biodiversity in Switzerland, but reaches much farther. The import and export of consumables, their production abroad as well as investments in a global food system also have impacts on biodiversity elsewhere. For example, importing more than 200’000 tons of soy meal per year, Swiss meat production and, consequently, consumption has an impact on biodiversity loss in the exporting countries such as Brazil, the US or Argentina (Baur 2011).

Biodiversity and ecosystems services such as nutrient cycling, water purification, soil fertility, biological pest, weed and disease control, pollination, etc. are of indispensable value for the agricultural production and the provision of healthy and safe food now and in future. Consequently, protection of ecosystem services and their maintenance have become serious considerations in Swiss political strategies (BAFU 2011; BAFU 2012b).

7.5 Food system boundaries – Social aspects

Social boundary conditions are basically set by demographic changes such as population growth and the increasing demand for food due to economic growth. These socio-economic changes are accompanied by changing consumption and dietary patterns as well as migration, aging and urbanization patterns. Key trends and projections are presented in Chapter 7.1 to 7.3.

7.6 Food system boundaries – Politics and policies

Although Swiss policies might have comparably little effect on foreign policy development, international policy developments build an important framework for Switzerland, for example the adjustments to or the integration of EU policies as well as international trade agreements. Similarly, traffic, energy and communication networks are continuously growing together across borders (BFE 2013b). Furthermore, emerging countries are increasing their share on global markets and will thus arise as increasingly competitive players. This might cause a shift of power and power relations in terms of market relevance and strength, requiring new international efforts, cooperation and governance.

7.6.1 International trade policies

During the past decades, political efforts addressed the reduction of trade barriers such as customs and quotas as well as the regulations for products and admissions among trade partners globally (Anderson 2010; Hawksworth and Chan 2013). Reducing and stabilizing prices for agricultural products and food, increasing competiveness in agricultural and tourism sectors (economic growth) or improving foreign market entrance (international economics) are just a few envisaged outcomes of establishing and improving international trade agreements (Bösch et al. 2011). These agreements aim at a multi-lateral market access liberalization, for example, through the Doha round by the World Trade Organization (WTO) or at bilateral trade agreements, for example, free trade agreements with the European Union (Schluep Campo and Jörin 2008).

However, liberalized trade will increase pressure on local producers since prices will have to decrease to become adapted to EU level (Bösch et al. 2011). In order to remain competitive a change of focus and the restructuring of the Swiss food system and related policies are necessary. A focus on quality, Swissness, or export as well as the adaptation of direct payment or investment systems is required to remain a competitive partner at European or global level (Keller and Kurzen 2012). Liberalizing of bilateral (“Freihandelsabkommen Schweiz-EU im Agrar- und Lebensmittelbereich” (FHAL)) or multilateral trade (Doha Development Agenda (DDA)) of agricultural products and food would cause a decrease of prices of meat and, consequently increase the consumption (increasing the impact on climate change; Schluep2008a). Moreover, the currently strong Swiss franc will lower the demand from domestic sales markets, which will have negative economic impacts (Keller and Kurzen 2012). The producer prices are under pressure due to cheaper production abroad. Export might decrease due to comparably high costs of goods and services, which might experience a declining demand if prices are high (Keller and Kurzen 2012).

7.6.2 Environmental and climate policies

The United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol provide a major, but very basic framework fighting the drivers and impacts of global greenhouse gas emissions. Global leaders had agreed on a common goal, which aimed at keeping the increase of average global temperature at 2°C compared to pre-industrial times. While national commitments have been shown difficult to implement, these global negotiations play a major role in developing strategies and laws reducing global warming and its impacts. The Swiss climate policy (2013-2020) aims at the reduction of national greenhouse gas (GHG) emissions by 20% compared to 1990 (FOEN 2014). Instruments include the regulation of GHG release, emission trade systems, promotion of energy efficiency (e.g., houses, appliances, cars), compensation schemes for emissions, education and knowledge transfer, and credits for innovative companies. The Swiss CO_2 Act has been implemented as the most important component of the Swiss climate policy. The act aims at directing and reducing the use of fossil energy sources, while promoting renewable energy sources. Although the targets for thermal and motor fuels defined in the CO_2 Act were missed, the stabilization of GHG emissions relative to 1990 was successful due to climate, energy and transport policy measures (FOEN 2014). Furthermore, climate policy is tightly linked to energy policy and the corresponding strategies (“Energy Strategy 2050”) that are going to set the direction of Swiss energy demand and supply until 2050, coherent with European strategies. Since reducing fossil energy use, per capita use of energy, and GHG emissions by 2050 are instruments to meet these national and international commitments, forest and agricultural policies can have an important role in reducing the Swiss contribution to global climate change.

Production and consumption of food cause approximately 30% of the negative impacts on the environment in Switzerland (Jungbluth et al. 2011), due to the demand for resource intensive foods such as meat as well as waste and loss of food within the food system. In general, federal acts such as the Environmental Protection Act (EPA) or the Waters Protection Act (WPA) are the major tools for regulating and protecting natural resources, crucial for a sustainable Swiss food system and the provision of healthy, safe and nutritious food. A strategy such as the “Green Economy” is supposed to reduce the use of natural resources to a level, which is accepted economically and environmentally (BAFU 2013).

7.6.3 Biofuel/bioenergy policies

Many agricultural products can be used for either food, feed or bioenergy. This competition can be dealt with economically or politically. The development of agricultural commodity markets is and will be very tightly linked to all other commodity markets (e.g., crude oil), to increasing demands for natural resources, and the economic development of developing countries, but also to changing environmental conditions (e.g., climate change) and their effects on agricultural productivity. Thus, to direct these developments, national policies set in, for example to make sure that food production on remaining agricultural land has first priority. Also in the future, biofuel or bioenergy production will probably still be based on biogenic by-products from food value chains and bio-based third generation biofuels such as from algae might be reconsidered an option in Switzerland if technology has further improved in terms of ecological, economic and social viability (BAFU 2009a; BAFU et al. 2009).

Food vs. feed vs. energy

The development of commodity markets is and will be very tightly linked to all commodity prices, competition for land, increasing demand for natural resources, economic development of developing countries, but also to changing environmental conditions (e.g., climate change) and their effects on agricultural productivity. In Switzerland, these conflicts could become a problem, too. However, considering European experiences, first and second generation biofuel production will not receive any financial incentive in order to make sure that food production on remaining agricultural land is the first priority. In the future, biofuel or bioenergy production will still be based on biogenic by-products from the food value chain and the bio-based third generation biofuels such as from algae might be reconsidered if technology has further improved in terms of ecological, economic and social viability (BAFU 2009a; BAFU et al. 2009).

7.6.4 Governance

Local to global food systems work within a formal framework of rules and institutions, which is determined by governmental, non-governmental, and private sector actors (Foresight 2011). Balanced and resilient food systems are the outcome of good governance (Evans 2011), which is based on equity, efficiency and sustainability (Behnassi et al. 2011). The parliamentary system in Switzerland ensures stable political boundary conditions, on which a food system and its actors can rely. Moreover, even agricultural and food security at the global scale is in the focus of federal offices. For example, the Swiss Agency for Development and Cooperation addresses access to food by vulnerable groups of the population and the governance of land at global scale (SDC 2015).

7.6.5 Social and development policies

International attention to the role of development and aid has been increasing when addressing food and nutrition insecurity. The concept of resilience is now in the focus of dialogue and programming (IFPRI 2013a). Applying this concept to social and development policies means that short-term shocks and long-term systemic changes are considered together to identify drivers and find solutions against poverty and food and nutrition insecurity (IFPRI 2013a). Although poverty and hunger are not a concern of local Swiss authorities, Switzerland contributed to reach the (now expired) UN Millennium Development Goals (MDGs), and is currently taking responsibility to develop the so-called Sustainable Development Goals (SDGs) for the post-2015 agenda.

7.6.6 Knowledge, technology and innovation – Green economy

Globally, there is a growing concern about economic instability and the impact of human activities on the environment and corresponding resources. Thus, knowledge, technology and innovation are indispensable to perform a transition from a fossil-based, fossil product dependent and unsustainable society towards a society that achieves economic wealth and social well-being by maintaining natural resources as the fundament for future livelihood at all (BAFU 2013; BBT 2011). Strategies, such as the European Bioeconomy Strategy, therefore clearly affects also sustainability and resilience of food systems (EC 2011; FAO 2009b).

7.7 Food system boundaries – Economy

7.7.1 Global markets

Global food markets are a sign of globalization and the result of changing policies (e.g., reducing trade barriers, decreasing costs of cross-border transfers of agricultural products and processed food) and increasing competition among multiple players (Anania 2006), aided by improved information and communication technologies (Anderson 2010). Agricultural products and processed food items are part of these global food markets, with both advantages and disadvantages (IAASTD 2009). For Switzerland, global markets are of great importance for the export of Swiss products and, consequently, for national economic growth. Moreover, global markets provide more that 50% of the goods required for the Swiss food supply (BLW 2014), thusbeing indispensable for food security and social well-being in Switzerland.

7.7.2 Trade

Global trade of agricultural and food commodities is expected to grow within the next decades and will continue to be a major driver of the world food system (ESF and COST 2009). The major growth of agricultural productivity is projected to be by driven by developing countries. Consequently, trade from and to developing countries is projected to expand continuously (Alexandratos and Bruinsma 2012). However, the EU will remain Switzerland's largest trade partner for agricultural products (56% export, 75% import, all goods considered). Thus, well-functioning trade partnerships with Switzerland are crucial for the supply of agricultural commodities and food products (Chapter 7.6.1).

7.7.3 Prices

The development of prices is affected by the imbalance of supply and demand, which is driven by an increasing pressure of scarce resources on the market, by a growing population demanding more energy- and resource-intensive food as well as related commodities such as fertilizers, energy or other raw materials (Nelson et al. 2010).

Food prices

Food prices are of high relevance for food security in low-income countries, where they account for a large share of household expenditures (Nelson et al. 2010; Willenbockel 2011). In Switzerland, food prices or the expenditures for food and beverage constitute only a small share (6.8%) of household costs (BFS 2014c). Although food prices are high compared to other developed countries, local and global implications for Swiss households are expected to remain relatively stable until 2025.

Price volatility

Low prices of agricultural commodities and food on the world market (in the 90s) have recovered and settled on a high level in 2008, where they are projected to remain (FAO 2011b). From this perspective, no pressure on Swiss food prices and thus households is expected. Globally, only short-term price increases are expected due to extreme price peaks on the world market. Although gaps between Swiss and EU prices have become smaller, the difference for agricultural commodities and food still remains high (and will continue to stay high if trade barriers remain). The remaining variable customs allow the absorption of the effects of global price volatility, which results in local price stability now and in medium-terms. In general, global food price volatility is expected to cause only moderate effects on prices in Switzerland since the cost for food makes up only 6.8% of the Swiss households' budget (BFS 2014c; BFS 2014d). Also costs for producers are projected to stay higher compared to other countries, albeit with general and ecological direct payments functioning as a buffer. However, the cost for and support of agricultural production were stable during the last decade (3.4 billion CHF in 2014) and make up a large percentage of the agricultural income in Switzerland today (BLW 2014). The amount of money spent for both types of payments has increased, while payments for production and sales quantity have decreased (BLW 2014). Those payments make Swiss agricultural production systems less vulnerable to market volatility as long they remain (Lehmann 2013b).

7.7.4 Fertilizer demand and prices

Macro-nutrients (i.e., N, P and K) are crucial for the supply of food. The use of fertilizers was and will be closely linked to the increasing demand for food, while production is restricted to only a handful of countries, based on finite natural reserves, no substitutable or requiring large amounts of energy such as fossil fuels (Sutton et al. 2013; Ulrich 2013; Ulrich and Frossard 2013). Consequently, fertilizer use as well as the corresponding prices of fertilizer raw materials and production costs have increased tremendously over the last decades (Sutton et al. 2013). In general, Switzerland is a net importer of fertilizers such as phosphate and its dependence on foreign resources for fertilizers will remain high (BAFU 2009b), although the demand for phosphate and nitrogen was relatively stable during the last two decades (i.e., P: 10'000 t/a, N: 50'000 t/a). Since prices for imports of P in mineral fertilizers are projected to triple by 2023, Switzerland sees great potential in recycling of P from manure, slurry, sewage sludge and animal waste (AWEL 2008). Together with political and technological progress toward resources-use efficiency, the implications of increasing global demand for fertilizers and the impact of corresponding prices (and volatility) can be reduced on medium and long-term (Ulrich and Frossard 2013).

7.7.5 Energy demand and prices

Energy demand and supply are highly linked to global food systems due to the energy required throughout the whole value chains, but also due to the close link among different commodity prices (Klepper 2011). In the future, the affordability of energy and its price volatility will be of increasing relevance for all other sectors, since the global energy demand is projected to increase (+80%; FAO 2011c; van der Mensbrugghe et al. 2011). Nevertheless, energy price projections are very uncertain and range from approximately 75 USD to 204 USD per barrel crude oil (in 2012 USD) by 2040 (EIA 2013; EIA 2014).

In Switzerland, final energy consumption was 896’000 terajoules (TJ) in 2013 (BFE 2013c). While the population is projected to grow, the “Energy Strategy 2050” aims at reducing the per capita energy demand in order to keep the current total energy consumption constant. The total energy consumption has been increasing since 1950, but the share of energy sources changed (BFE 2013c). Since 1945, fuels gained increasing importance in total energy use and make up the largest share in energy use today (33.5%), followed by electricity (23.8%) and petroleum fuels (18.8%). In general, the shift toward increasing demand for electricity is projected to continue (BFE 2013c). The largest demand for energy results from the transport sector (35%) and from households (29%). While industry (18.4%) and services (16.7%) both account for around one sixth of the energy consumption, the contribution of agriculture is smaller than 1%. Until 2030, attainments for public transport will increase by 50% and for individual mobility by 17% (UVEK 2012). This trend is not only projected to cause an increasing energy demand in general, but will also require more land for infrastructure.

Although the production of energy from primary sources such as wood, water, waste, gas and other renewable sources has more than doubled since 1970, there is an increasing dependency on foreign energy (import: 77.6% or 797’170 TJ, without nuclear energy, 2013; BFE 2013c).

In the future, changing climatic conditions and the unbalanced and seasonal supply of water (Chapter 7.4.4) might cause emerging supply gaps (BAFU 2014). Climate change is projected to reduce the water-based energy production (by 7% until 2050) due to variable and low water levels (BAFU 2014). However, a reliable energy production based on hydropower requires a certain level and constant amount of water in rivers (BAFU 2014; Leitungsgruppe NFP 61 2015).

The withdrawal from the use of nuclear energy on a step-by-step basis due to national and international political decisions as well as projected changes on the global energy market clearly demand a restructuring within the Swiss energy sector in order to maintain energy security and, consequently, food security, in Switzerland (BFE 2013a).

7.7.6 Concentration of market control

Along food value chains, only few large transnational businesses (trading companies, agri-food processors and producers) are key players controlling the market (De Schutter 2010; IAASTD 2009; Thompson et al. 2007). On the one hand, only few companies cover major activities of the food system, thereby dictating the position of producers and consumers (e.g., prices). This is called horizontal concentration of markets. In Switzerland, the two largest retailers Coop and Migros control approximately two thirds of the market (Economiesuisse 2013). On the other hand, single companies can control multiple parts of the whole food value chain through the provision of feed, fuel, pesticides or fertilizers at once (e.g., Syngenta, Monsanto). This is called vertical integration and causes a high risk of increasing prices and price volatility during market shocks (EvB 2014a; EvB 2014b). Horizontal concentration and vertical integration in food value chains are both becoming more frequent. Swiss companies such as Nestlé and Syngenta are holding large shares within single or multiple food system activities, which allows them market control at national and global scales. Moreover, the Swiss food system is also affected by the increasing use of GMO material in agricultural production at global scale (ETC Group 2011; EvB 2014a; EvB 2014b). The availability of GMO-free feed as well as GMO-free seeds will get increasingly problematic for crop and livestock production systems in Switzerland.

The decision on the continuation or the cessation of the moratorium for genetically modified organism after 2017 will have important impacts on Swiss agricultural research and also on agriculture in the future.

7.7.7 Investments

National investments

Globally, agricultural production and subsequent activities of food value chains are major contributors to human livelihoods and to reduction of poverty (FAO 2011c; Nelson et al. 2010). Nevertheless, investments into agricultural research and also private and public investments in agricultural production and downstream services such as storage and processing facilities have declined over the last decades (FAO 2009a; Nelson et al. 2010). In Switzerland, the national budget spent on the agricultural sector remained relatively stable within the last decade (ca. 3.5 billion CHF)(BLW 2014). However, the proportions of money spend on direct payments and social measures have increased steadily since 2008 (78% in 2013; BLW 2014).

Foreign direct investments in land and water rights

There is an increasing trend of financial investments in agricultural commodity-based derivatives as well as in land and water rights called “land and water grabbing” at the global scale (Rulli et al. 2013). The spatial quantification of those investments is difficult, management capacities and legal transparency are lacking and the impact on poverty reduction as well as social well-being is still questioned (De Schutter 2011; Rulli et al. 2013). However, investments in production sites abroad are projected to increase (Alliance Sud 2010). Switzerland itself does not invest in foreign land and water resources in order to assure national food security. However, Swiss companies, banks and financial funds do perform such financial investments (Alliance Sud 2010). These pathways of investments are highly complex and interrelated within and across societal, economic and political boundaries (FIAN 2014). Since foreign direct investments have the potential to improve the situation and progress in developing countries, Switzerland as well as all other developed countries that invest in foreign land, is responsible for a sustainable development of those investments. They should not intervene, reduce or deteriorate land rights for the local population and smallholder farmers. Moreover, standards and regulations for the qualitative as well as quantitative estimation and implementation of responsible investments in foreign resources are required at national and international scales (Graf 2011).

7.8 Outcomes of the Swiss food system

7.8.1 Food and nutrition security

Prevalence of hunger and malnutrition

Food and nutrition security for all people on this planet will remain one of the major challenges throughout the 21th century (Smith 2013). We are not only obliged to fight chronic hunger and “hidden hunger” in the developing world, but also the increasing occurrence of overnutrition and malnutrition in developed countries (FAO 2014g).

Switzerland, is ranked as highly food secure based on the Global Food Security Index (Rank 6/109; The Economist Intelligence Unit 2014). The three major factors or strengths, which this international ranking was based on, were 1) the proportion of the population below the poverty line, 2) the presence of safety net programs, and 3) the access to financing for farmers (The Economist Intelligence Unit 2014). The average food supply in Switzerland was 3’487 kcal/capita/day in 2011, which did not indicate any prevalence of hunger (FAO 2014d). However, obesity and food-related diseases such as type 2-diabetes, hypertension, osteoarthritis and cancer due to overconsumption or malnutrition are an increasing problem in developed countries like Switzerland (Schneider et al. 2009). They are expected to increase the pressure on health and security systems in a population that gets increasingly older (BAG 2012b; Schneider et al. 2009).

Healthy, safe and nutritious food

Problems with regard to healthy, safe and nutritious food have different predominant causes in developing and developed countries. While insufficient caloric energy intake, micronutrient deficiencies or the lack of clean water cause health problems in developing countries (Traoré et al. 2012), overconsumption and lifestyle-related “diseases of civilization” such as obesity, coronary heart disease, cancer and diabetes threaten the health of human beings in developed countries (Via 2012). However, the occurrence of obesity is also increasing in poor countries.

The level of food and drinking water safety is very high in Switzerland (FOPH 2012). The number of outbreaks of foodborne diseases has decreased constantly within the last decades. Considerable commitments to hygiene along food value chains were the main reason for this decline. Today, negative economic and medicinal impacts caused by diet-related diseases are seen as a much greater and more difficult socio-economic challenge than food safety issues. In the future, costs of diet-related diseases will continue to surpass costs of foodborne outbreaks of disease (FOPH 2012).

7.8.2 Environmental quality

Food systems affect and are affected by the environmental boundary conditions (Figure 1) and strongly depend on services provided by intact and well-functioning ecosystems. Environmental conditions, their changes and feedbacks directly or indirectly affect all outcomes of food systems (Ingram et al. 2010). Also the Swiss food system, which is linked to the global food system in multiple ways and to various extents, affects the environment and natural resources at national and global scale while passing planetary boundaries, on one hand (Rockström et al. 2009). On the other hand, the Swiss food system is affected by changes in the environment and increasingly scarce resources. At local scale, the impact of climate change or the loss of biodiversity and ecosystem services might be less obvious than the continuous loss of arable land in Switzerland. However, since the majority of the Swiss consumables as well as relevant goods for food production such as fertilizers and fuels are imported, the impact if climate change and the degradation of the environment abroad can have an impact on Swiss food supply as well. Consequently, the protection of the environment and natural resources, the mitigation of climate change and the prevention from losing biodiversity are crucial at national and global scales. The resilience and the stability of food systems highly depend on good environmental quality, which each food system stakeholder has to take responsibility for – in Switzerland and abroad.

7.8.3 Social well-being

Food systems should contribute to social well-being outcomes by improving income, employment, and wealth as well as providing social, political and human capital, infrastructure and health (Ericksen 2008). In Switzerland, social well-being, i.e., human well-being and social security, is at a high level compared to most countries, where households are much more vulnerable to changes of any boundary condition. The consumption and life style of the Swiss population might be an indirect driver for different changes such as caused by increasing demand for foreign land, foreign water rights or the degradation of natural resources and, consequently, can cause unpredictable changes and social insecurity. As a privileged country, Switzerland has to contribute to social well-being by taking responsibility for improving food system outcomes such as social well-being in developing countries.

8. A sustainable Swiss food system – Challenges, policies and barriers

8.1 Challenges based on the interviews

The eight interviewees identified a wide range of topics as current and future challenges related to the Swiss food system (Table 5).

Table 5: Topics and challenges discussed in eight interviews with representatives of Swiss federal offices. Number of interviews (N) indicates the number of interviews (out of eight) in which the respective topic or challenge was mentioned or discussed.

Topics and Challenges (Global and National)	Number of Interviews (N)
Scarce resources	8
Climate change (incl. water) Competitiveness Demographic changes Standards and labeling Food security and food sovereignty (Switzerland)	7
Land (availability and quality) International trade agreements/Legal security Food security – Global responsibility Prices (food and agricultural commodities) Swiss market protection Economic/financial strength of Switzerland	6
Transparency and traceability Food quality Energy supply (security) Conflicts of interest/Trade-offs Soil (quality) Biotechnology	5
Urban farming Productivity in agricultural production Political instability/stability Plant protection Participatory approach and knowledge transfer Resources – Global responsibility Food waste and losses Employment – Jobs Education and outreach Consumption pattern Competition for resources Biodiversity	4

Table 5 (continued)

Topics and Challenges (Global and National)	Number of Interviews (N)
Shopping tourism (Swiss border) Resistance to antibiotics Policy coherence Human health and nutrition Green economy (Switzerland) Food value chains Diet-related diseases	3
Structural change Land grabbing Initiatives related to food Food safety	2
Resilience Livestock health Invasive species Global vs. local food Fortification, Biofortification Ecological degradation Nanotechnology	1

The setting of new standards and labels is one of the challenges which food systems are going to increasingly face (seven out of eight interviews). According to the interviewees, these standards and labels are going to strengthen the position and competitiveness of Swiss products and services on global and national markets. For example, standards and labels function as a guarantee for fairness, quality or safety along food value chains. The interviewees agreed that these products might stand for environmental and social responsibilities which are increasingly demanded by the consumers. However, three of eight interviewees stated that standards and labels can also have massive impacts on food systems in developing countries as well as on legal frameworks of food systems among countries. The interviewees also indicated that setting standards and labels holds great potential for conflict, if Switzerland sets them outside of an international legal framework.

„Wir sind eine in die Weltwirtschaft integrierte Volkswirtschaft, die abhängig ist von einem internationalen Regelwerk." (Source: Interview)

In general, food security or food sovereignty at national and global scale were stated as challenges by seven of the eight interviewees. Here, one major point discussed was food security within the context of hunger and poverty in developing countries for which Switzerland and other wealthier countries have to take responsibility (six out of eight interviews). Moreover, food security was discussed at national scale. Here, the capability of Switzerland to produce half of the consumed calories within the country was seen as a success considering national structures and available resources. One interviewee indicated that a challenge in the future will be to keep a certain degree of food sovereignty in order to assure food security.

„… ein kleiner Beitrag an die Welternährung, wenn die Schweiz sich als immer noch souveräner Staat sagt, wir haben noch Land für die Hälfte der Versorgung. … die Hälfte der Kalorien. Singapur hat praktisch Null." (Source: Interview)

Overall, challenges related to the changing and increasingly globalized food and commodity markets were stated as being important by six of the eight interviewees. These include potential implications of new trade agreements such as the Transatlantic Trade and Investment Partnership (TTIP) that is currently being negotiated or a free trade agreement with the European Union, which are increasingly complex. One interviewee indicated that these increasingly complex trading and cooperation systems require a framework of legal security.

Six out of eight interviewees highlighted the very privileged position of Switzerland due to high purchasing power, economic stability and financial strength. These aspects were seen as important factors that will assure food security through the economic access of the Swiss population. However, six out of eight interviewees agreed that a sustainable food system should not consider any political borders. On one hand, the food supply in Switzerland is highly integrated in a global food system. On the other hand, Switzerland as a wealthy country obtains resources such as food and water (i.e., virtual water) from all over the world and, consequently, needs to take responsibility for the negative impact abroad.

„… dann übernimmt sie [die Schweiz] eine globale Verantwortung und kann sich nicht mehr nur an ihren politischen Grenzen orientieren, sondern die Grenzen sind die „Planetary boundaries" (Source: Interview)

Half of the respondents (four out of eight interviewees) were of the opinion that comparable to other countries Switzerland is already doing a lot for the conservation of biological diversity which was indicated as an important natural resource. Two interviewees stated this has never been neglected totally from Swiss political agendas and that is why it contributes to the character of the Swiss agricultural landscape. On the one hand interviewees said that there is acknowledgment by, for example, the public of the importance of biodiversity although this is not perceived by everyone. On the other hand, the interviewees agreed that current efforts with regard to the protection of biodiversity are not adequately accounting for the importance of biodiversity per se and corresponding ecosystem services. Biological diversity, including genetic resources and species diversity is one of the basic resources for a sustainable production of diverse food.

„… das ist naturnah, das ist nachhaltig, das ist ökologisch, da hat man auf die Biodiversität geachtet. Das wird immer mehr noch an Bedeutung gewinnen. Und die Schweiz kann sich eigentlich als Hochpreisland nur im Markt positionieren, wenn sie das wirklich ernst nimmt." (Source: Interview)

The interviewees named numerous trends and challenges expected to have more or less impacts on the Swiss food system. Topics such as food waste and losses, competition for resources were mentioned by four out of eight interviewees.

Although topics such as urban farming, policy coherence, diet-related diseases, and many other trends were not mentioned by all of the interviewees, they cannot be seen as less important or a less severe challenges for food systems in the future. Diet-related diseases, for example, affect the health of human beings and health security systems already today. One interviewee stated that in developed and industrialized countries such as Switzerland, they already have a greater negative economic impact on societies than food safety issues.

„… die ökonomischen Konsequenzen von Krankheiten, die durch schlechte Lebensmittelsicherheit ausgelöst werden, sind in unseren Ländern viel kleiner als die, die durch die „Burden of disease", also durch Fehl- und Mangelernährung, ausgelöst werden." (Source: Interview)

8.2 Challenges based on the online survey

All 1078 entries of challenges the Swiss food system will be confronted with over the next 20 years were recoded into 162 challenges to facilitate further analysis. These challenges addressed all different activities and actors within the Swiss food system, not concentrating on only one activity, actor or sector (Table 6; Appendix 2). Competiveness was stated most frequently, i.e., 55 times out of 1078, combining 5.1% of all answers, closely followed by loss of land, climate change and food quality. Overall, the 17 challenges most frequently mentioned represented 50% of all answers to this question. The top 30 challenges represented 66% of the answers. Among these top 30 challenges were many cross-cutting challenges, i.e., concerning the entire food system and the food value chain, such as competitiveness, food waste, resource-use efficiency, sustainability, conflicts of interests, to name a few.

8.3 Consistency between interviews and online survey

8.3.1 Challenges of the Swiss food system

The question about challenges the Swiss food system would be facing in the next 20 years was asked in the interviews with eight representatives from federal offices as well as in the online survey with Swiss food system stakeholders. Both groups provided very similar answers: Competitiveness, loss of land and climate change were the three challenges most frequently mentioned in the online survey (by 35%; Table 6), also given by the majority of the interviewees (between five and seven out of eight interviewees; Table 5). Resource scarcity was even mentioned most often in the interviews (eight out of eight). Also diet-related diseases and food waste were challenges mentioned by both (by about 17% of the survey respondents as well as by three and four out of the eight interviewees, respectively). Furthermore, a majority of the interviewees (six out of eight) as well as a large share of survey respondents highlighted challenges that result from prices of food and agricultural commodities, from increasing and changing international trade agreements or from increasingly liberalized markets (6-7%). Moreover, the majority of the interviewees highlighted the capability of producing enough food at global (six out of eight) and national (seven out of eight) levels as major challenges for the future Swiss food system, supported by about 5% of the survey respondents in respect to the national level, but by less on the global scale (less than 1%). Further differences between the semi-structured interviews and the online survey were, for example, challenges with respect to standards and labels along food value chains, which were mentioned by seven out of eight interviewees, but were only given seven times (standards) or even only once (labels) by the survey respondents. Food quality was mentioned often in the online survey, but was not cited explicitly in the interviews.

Table 6: The 30 most stated challenges (out of 162) that the Swiss food system will be confronted with over the next 20 years according to the online survey respondents. The full list of challenges given in question 3 of the online survey is available in the Appendix 2.

No.	Challenge	Challenges mentioned	
		[N]	[%; out of 1078]
1	Competitiveness	55	5.10
2	Loss of land	48	4.45
3	Climate change	47	4.36
4	Food quality	44	4.08
5	Diet-related diseases	38	3.53
6	Food waste	33	3.06
7	Self-sufficiency	32	2.97
8	Sustainable production	32	2.97
9	Prices	31	2.88
10	Liberal markets	27	2.50
11	Consumption pattern	26	2.41
12	Resource-use efficiency	26	2.41
13	Education (nutrition)	23	2.13
14	Food security	21	1.95
15	GMOs	20	1.86
16	Environmental protection	17	1.58
17	Food safety	17	1.58
18	Resource scarcity	17	1.58
19	Sustainability	17	1.58
20	Conflict of interests	16	1.48
21	Structural change	16	1.48
22	Resistance to antibiotics	15	1.39
23	Healthy food	14	1.30
24	Local markets and products	14	1.30
25	Ecological production	13	1.21
26	Population growth	13	1.21
27	Biodiversity loss	12	1.11
28	Traceability	12	1.11
29	Productivity	11	1.02
30	Resource degradation	11	1.02

8.3.2 Trade-offs

The interview and the online survey analyses also revealed conflicts of interests that can pose large challenges to the Swiss food system, both already on-going but also continuously changing. While some responses stated "conflicts of interest" as challenge without further specifications (3.7% of the survey respondents and five out of eight interviewees), some conflicts of interests were directly mentioned and discussed, particularly by the interviewees, such as the often opposing challenges of agricultural production vs. biodiversity (*"Brot oder Blumen",* Source: Interview) or potentially upcoming international conflicts of interest (*"…, dass sich doch internationale Interessenkonflikte jetzt verstärken …"*, Source: Interview). Another conspicuous conflict of interest was the notion of the privileged financial position of Switzerland compared to other countries (mentioned by six out of eight interviewees) vs. the challenge of shopping tourism across borders (mentioned by three out of eight interviewees). Others were less obvious such as the trade-off of being competitive on markets (mentioned by seven out of eight interviewees) vs. the protection of the environment and natural resources (mentioned by four out of eight interviewees) or the trade-off between the responsibility of Swiss food system stakeholders to conserve and restore global resources while heavily competing for them at the same time (mentioned by four out of eight interviewees, respectively).

8.4 Key policies and instruments for a sustainable Swiss food system

The interviews were used to identify policies and policy instruments such as national laws, ordinance, action plans or strategies currently in place or under way at different federal offices in Switzerland (Table 7).

Table 7: Policies, strategies and laws currently in place or underway to address food system challenges in Switzerland. Answers are based on eight semi-structured interviews with representatives of Swiss Federal Offices.

Policies, national laws, ordinances, etc.	
Agrarpolitik (AP)	
Bundesgesetz über die Raumplanung (RPG)	
Bundesgesetz über die Reduktion der CO_2-Emissionen (CO_2-Gesetz)	
Bundesgesetz über den Umweltschutz (USG)	
"Swissness"-Gesetzesvorlage (in Vernehmlassung)	
Pflanzenschutzverordnung (PSV)	
Current strategies	**Federal Offices participating or contributing**
Strategie Nachhaltige Entwicklung	ARE
Raumkonzept Schweiz	ARE
Sachplan Fruchtfolgeflächen (SP FFF)	ARE
Strategie zur Anpassung an die Klimaänderung	ARE, FOEN, FOAG, FOPH, FSVO, FOCP
Klimastrategie Landwirtschaft	FOAG
Strategie Biodiversität Schweiz	FOEN, FOAG
Grüne Wirtschaft	FOEN, FOAG
Umweltziele Landwirtschaft	FOEN, FOAG
Nationales Programm Ernährung und Bewegung	FOPH
Schweizer Ernährungsstrategie	FOPH
Salzstrategie	FOPH
Strategie gegen Antibiotikaresistenzen (StAR)	FOPH, FSVO, FOAG
Energiestrategie 2050	SFOE
Masterplan Cleantech	SFOE, FOEN, SERI, SECO
Tiergesundheitsstrategie Schweiz 2010+	FSVO

Most interviewees mentioned several policies and instruments being relevant for addressing the challenges the Swiss food system is and will be facing, however, often related to their specific office. These office-specific strategies and action plans are typically either related to one of the food system areas or outcomes such as agricultural production (i.e., “Agrarpolitik”), health and nutrition (i.e., “Salzstrategie”) and environmental health (e.g. “Strategie Biodiversität Schweiz”) or indirectly related to the food system or food value chains. For example, federal laws such as the Environmental Protection Act (“Umweltschutzgesetz”) impact food system outcomes such as environmental quality. The Energy Strategy 2050 (“Energiestrategie 2050”) will clearly affect the food system since energy is a major prerequisite of food production along food value chains.

None of these existing policies, laws, strategies or action plans explicitly aims at developing a sustainable Swiss food system or has “food security” among its objectives. However, the recent initiative “Food security” of the Swiss Farmer’s Union (SFU) and the corresponding alternative proposal of the federal council were mentioned in one of the interviews. Moreover, there is no common strategy in place or underway which brings together the competences of all critical federal offices relating to a sustainable Swiss food system. The lack of such a common strategy has been highlighted explicitly by one interviewee. This person reflected on the necessary components of a common strategy that would aim at the establishment of a sustainable Swiss food system in the future, i.e., conservation and promotion of biodiversity (i.e., genetic resources), promotion of sustainable land use (both in terms of quality and quantity of land and soil) as well as outreach and education.

„Alles, was Strategie genannt wird, ist sozusagen fokussiert auf die Aufgabenerfüllung der Bundesämter. Die sitzen zwar zusammen, aber es gibt nicht eine Strategie, sozusagen vom Boden bis in den Mund.“ (Source: Interview)

8.5 Barriers and gaps for a sustainable Swiss food system

The interviewees identified multiple aspects that act as barriers and gaps hindering the progress toward improved food system outcomes. Answers ranged from global to national aspects as well as from personal to worldwide economical and societal barriers and gaps.

Overall, the food system was not the focus of any of the federal offices and thus was not explicitly mentioned in any of the interviews. Most of the interviewees limited the discussion to single aspects of the food system, such as agricultural production or environmental quality, topics highly relevant to or in the portfolio of the corresponding federal offices. Nevertheless, one interviewee discussed multiple areas and also boundaries of the food system, such as innovation in agricultural production, processing, changes in trading systems or the environmental impact of food in general. Another interviewee discussed the aspect of food safety along food value chains. Thus, the interviews reflected the lack of a common approach presented in Chapter 8.1.

Nevertheless, several barriers and gaps were mentioned in the semi-structured interviews. An important obstacle toward the development of sustainable food systems seems finding a consensus on common decisions that satisfy the large number of actors along food value chains and participants within any food system. One interviewee highlighted that there are more and increasingly powerful countries, geopolitical regions as well as trading partners that want to assert their interests. This interviewee considered the disability of parties or countries to have common and multilateral agreements that fit everyone's demands and requests in a globalized world as the major barrier for approaching food system challenges. In particular, changing national polices and the stagnating progress of trade agreements, both crucial for a sustainable food system at national and global scales, is thought to limit the development toward sustainable food systems.

„Ich denke, eine der wichtigsten Barrieren ist hier die Unfähigkeit, sich [Anm.: auf globaler Ebene], multilateral auf neue Wege einigen zu können. Das ist ein System, das eigentlich in der Vergangenheit stets konsensorientiert funktioniert hat. Es war wichtig, dass es konsensorientiert funktioniert, weil - sobald ich von diesem Prinzip abweiche – fühlt sich niemand mehr verpflichtet …" (Source: Interview)

This was also seen as a barrier at the national level, for example for Switzerland. One of the eight interviewees indicated that national actors and stakeholders of the Swiss food system are predominantly interested in keeping their own political and economic interests rather than being resource-use efficient in order to increase economic competitiveness of agricultural products.

„Der ganze Geschäftsbereich für dieses Zusatzmaterial [Anm.: Pestizide und Dünger] schrumpft natürlich und dementsprechend sind sie natürlich gar nicht interessiert, dass es in diese Richtung geht. Die Abhängigkeit von dieser Politik und Wirtschaft, wie sie hier zusammenspielt, ist natürlich massiv." (Source: Interview)

Two of the eight interviewees indicated that lacking willingness to reform the Swiss agricultural policy (AP) is one barrier toward a change. Further progress in reforming AP 2014-2017, which is supposed to lead to more competitiveness of agricultural production and products on global and national markets, seems required. One interviewee indicated that increased pressure on Swiss agricultural production or production and consumer prices, for example by the development of free trade agreements with the European Union, seems to be lacking.

„Man kann auch sagen, es ist der fehlende Druck von aussen [Anm.: z. B. durch den Abschluss der DOHA-Runde und Freihandelsabkommen mit Europa]. Das ist ein wichtiges Element. … Also da fehlt der wichtigste Motor." (Source: Interview)

Moreover, one of the eight interviewees stressed the fact that Swiss agricultural policy had not yet contributed to a comparable competitiveness of Swiss products on a global market or to the full potential of an economic optimization and efficient use of inputs. Due to market protection and direct payments, the majority of Swiss farmers do not seem to be at the same level of competition as foreign producers.

„… durch den Schutz, den es noch gibt, haben sie [Anm.: die Bauern] noch ein Stück weit weniger Wettbewerb als wenn man den Markt ganz offen hätte." (Source: Interview)

„… dort [Anm.: im europäischen Ausland] hat man in den letzten Jahren die Qualität der Lebensmittel massiv gesteigert. Sie sind zur Schweiz konkurrenzfähig, aber das ist noch nicht in die Köpfe der Schweizer gedrungen, weil die Bauern auf ein „weiches Bett" fallen. Diese Konkurrenz ist noch nicht so spürbar." (Source: Interview)

Overall, the privileged economic situation of Switzerland as well as the stakeholders along the food value chains, which had been highlighted by seven out of eight interviewees, can also be seen as barrier for the establishment of a sustainable Swiss food system. On the one hand, according to one interviewee, economic strength assures food security, since Switzerland is able to import the goods its population is demanding for. On the other hand, lack of competition due to large financial support, e.g., in the agricultural production, hinders the reduction of inefficiencies and their negative effects on the environment. Moreover, two interviewees highlighted the fact that the lack of competition might limit innovations, which are very often driven by less favorable market conditions.

„… im Vergleich zu Ostdeutschland, wo man wirklich jeden Euro pro ha rechnen muss, damit man wirtschaftlich bleibt, kann man hier [Anm.: in der Schweiz] sagen, dass man zur Sicherheit ein bisschen mehr spritzt. Dieses Versicherungsdenken, bei der Produktion von etwas Schönem und Grossen, kann man sich leisten." (Source: Interview)

„Der [Anm.: Schweizer] Bund hat das Geld weggenommen, die Grenze etwas offen und da … mussten sie eine Innovation machen. … Es gab sogar eine Agrarzeitung, die den Titel beinhaltete „Aus der Not wurde Wettbewerbsfähigkeit"." (Source: Interview)

In general, a complex system such as the food system requires contributions and participation of various stakeholders. This includes a wide variety of research areas, various federal offices and many other stakeholders. Thus, three out of the eight participating federal offices mentioned that more efforts are required for the coordination and development of a holistic strategy, which aims at achieving a sustainable Swiss food system. However, one interviewee also mentioned that the office-specific task accomplishment is still of highest priority.

„Alles, was Strategie genannt wird, ist sozusagen fokussiert auf die Aufgabenerfüllung der Bundesämter." (Source: Interview)

Moreover, one interviewee mentioned that there are also communication challenges (i.e., different federal offices "speak" different languages). Thus, a common understanding with regard to this highly transdisciplinary and trans-sectorial topic seems to be lacking. This also includes possible roles and responsibilities in cross-sectorial collaboration.

„Man hat zuerst einmal Mühe, sich zu verstehen und sich auf eine gemeinsame Sicht zu einigen. Viele sehen ihren Schnitt und wie sie die Welt darum bauen. Man baut nicht ein Ganzes zusammen." (Source: Interview)

All interviewees were aware of the complexity of food systems and the problems related to the food system which can hardly be addressed by a single federal office alone. Various projects and collaborations already tried to cope with different aspects of the food system. Two interviewees stated that the complexity of the food system as well as the complexity of stakeholder interactions are the reasons for highlighting the demand for a leading person or a lead institution. According to these interviewees, this leadership is required to guide legates from all the different federal offices and institutes. According to the opinion of two interviewees, this would include not only to lead, guide or direct stakeholders, but also to improve the coordination and the distribution of knowledge, which seems still lacking.

„Was wir haben, ist gutes Wissen, das man für eine Strategie benötigen würde, aber niemand übernimmt hier wirklich die Führung." (Source: Interview)

„Keine systematischen Verteiler über Wissen …" (Source: Interview)

Another major barrier reducing progress toward the implementation of successful measures for a sustainable Swiss food system seems a lack of urgency, mentioned by four out of eight interviewees, framing different aspects of the food system. According to these interviewees, most of the food system stakeholders do not see or directly experience the implications of scarce resources such as the increasing loss of arable land in Switzerland. In the interviewees' perception, the stakeholders do not see the urgency to conserve these resources and, consequently, the pressure on political or economic systems to change something is currently quite low.

„… wir haben nicht diese Krise vor der Haustür, wo man völlig anders denken würde. Wo man diese Knappheit spüren würde. Wo man spüren würde, bei jedem Quadratmeter Land, der verloren geht, da verlieren wir etwas. Diese Situation haben wir nicht. Darum ist natürlich auch nicht die Dringlichkeit da und auch nicht die Meinungsbildung. Für ein Gesetz muss ich auch wirklich eine Meinungsbildung haben." (Source: Interview)

9. A sustainable Swiss food system – Research topics

9.1 Respondents of the online survey

In total, 485 stakeholders of the Swiss food system completed the online survey. Since a response was not mandatory for all questions, the total number of respondents for each question varied. The majority of respondents were German-speaking (73%), male (63%), between the age of 25 and 64 (96%), had a graduate degree (BSc, MSc or doctoral degree, 94%) and were of Swiss nationality (83%; for further details, see Appendix 2).

Overall, the survey respondents covered all areas and sectors of the food system. While the majority of respondents worked within the area of research, most respondents assigned the majority of their work to the sectors of agriculture as well as human health and nutrition (Figure 11, or see Appendix 2).

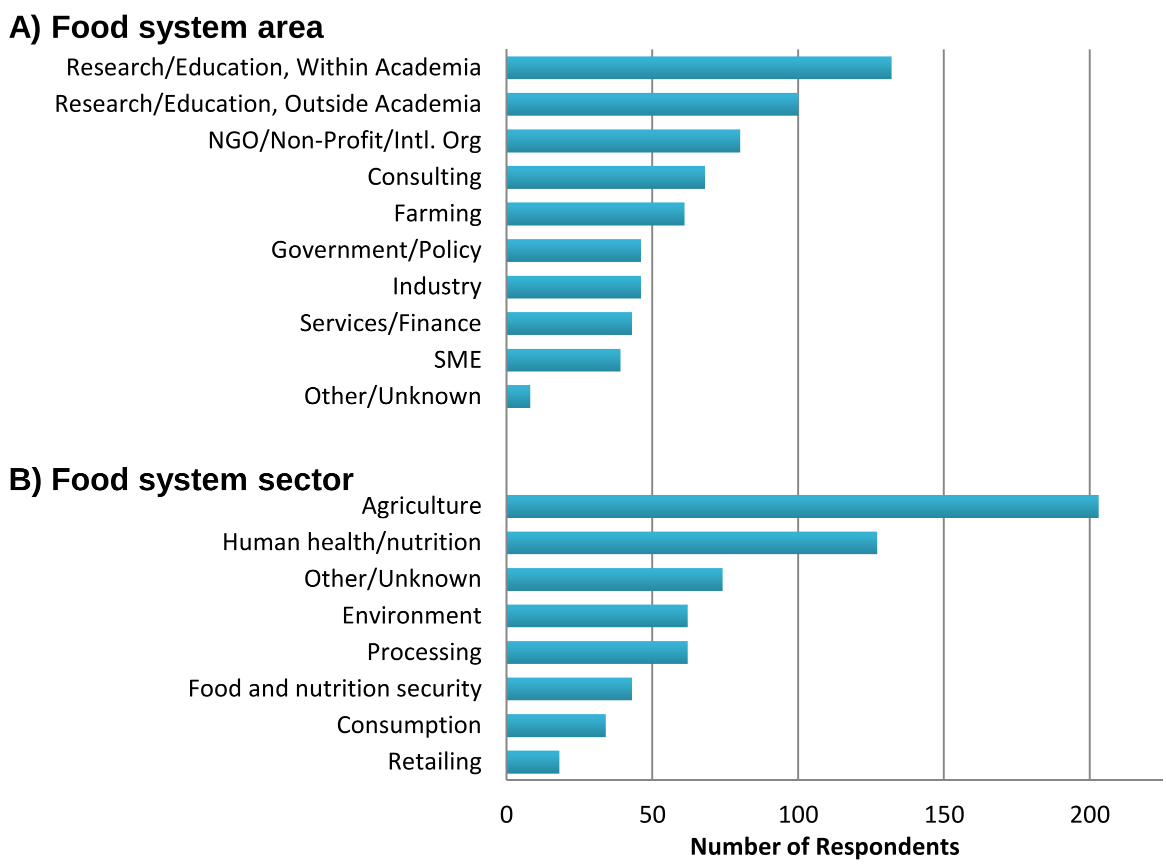

Figure 11: Number of respondents per A) food system area and B) food system sector.

9.2 Importance of research topics

On average, 490 respondents evaluated the 88 research topics (Table 8), giving scores between 1 and 6. The average score for the research topics ranged from 5.15 ("Soil health and fertility in agricultural production systems" (position after scoring: 1)) to 2.92 ("Gender and equality in farming in Switzerland" (88); Table 8). Most of the ten highest and the ten lowest scored topics address the whole food system rather than focusing on single food system areas (Table 8).

Table 8: Mean scores and corresponding standard deviation of the 88 research topics (ordered from highest to lowest). Scores are based on a scale of 1 to 6, with 1 = not critical and 6 = very critical.

Position	Research Topic	Mean Score	Std Dev
1	Soil health and fertility in agricultural production systems.	5.15	1.09
2	Resistance to antibiotics.	5.09	1.19
3	Energy-use efficiency along food value chains.	4.99	1.09
4	Reducing food waste.	4.97	1.27
5	Sustainable diets.	4.96	1.28
6	Impact assessment of local vs. global food production.	4.90	1.16
7	Nutrient-use efficiency along food value chains.	4.90	1.13
8	Reducing losses in food value chains.	4.88	1.24
9	Nutrient cycling in agricultural production systems.	4.80	1.13
10	Policy development for sustainable food systems.	4.76	1.30
11	Waste and by-product valorization in food processing.	4.72	1.12
12	Biodiversity in agricultural production systems.	4.71	1.30
13	Trade-offs between ecosystem services and agricultural production.	4.70	1.23
14	Water-use efficiency along food value chains.	4.69	1.32
15	Sustainability assessment of food value chains.	4.67	1.24
16	Efficient use of materials along food value chains.	4.64	1.13
17	Diet, nutrition and chronic diseases (including obesity, type 2 diabetes, cardio-vascular diseases, cancer).	4.62	1.39
18	Closing resource and material cycles in food systems.	4.62	1.23
19	Design and processing of healthy food products.	4.59	1.24
20	Strategies for the development of regional value chains.	4.58	1.34
21	International trade agreements and impact on Swiss food system.	4.57	1.32
22	Traceability in food value chains.	4.56	1.26
23	Quality and safety along food and feed value chains.	4.54	1.17
24	Plant protection (including pests, pathogens, and weeds).	4.53	1.15
25	Effectiveness of education on nutrition and health.	4.53	1.43
26	Livestock nutrition, health and welfare.	4.51	1.32
27	Impact of policies on food systems.	4.50	1.33
28	Sustainable intensification in agricultural production systems.	4.49	1.35
29	Certification and labeling for sustainable food value chains.	4.49	1.38
30	Adaptation of food value chains to anthropogenic climate change.	4.49	1.28
31	Design and management of agroecological systems.	4.48	1.33

Table 8 (continued)

Position	Research Topic	Mean	Std Dev
32	Plant breeding.	4.46	1.30
33	Alternative protein sources for animal feed.	4.45	1.41
34	Food system externalities (costs imposed on others or benefits received for free).	4.45	1.29
35	Water resource management in agricultural production systems.	4.43	1.34
36	Food processing technologies for optimized resource use.	4.38	1.22
37	Organic agriculture and food.	4.36	1.57
38	Genetic resources in agricultural production systems (including estimation, conservation, and optimized use).	4.33	1.30
39	Life cycle assessment of food products.	4.33	1.33
40	Incentives to protect ecosystem services in agricultural production systems.	4.33	1.34
41	Mitigation of anthropogenic climate change through food value chains.	4.32	1.35
42	Impact of land use and zoning on food system activities.	4.32	1.34
43	Socio-economic viability of farms and farming systems.	4.30	1.40
44	Socio-economic impact of diet-related disease (including malnutrition, obesity, and micronutrient deficiency).	4.27	1.47
45	Technology and knowledge exchange with developing countries.	4.25	1.39
46	Impact and risk assessment of genetically modified organisms (GMOs) in food value chains.	4.21	1.56
47	Food toxicology and health.	4.18	1.31
48	Drivers of consumption patterns.	4.18	1.39
49	Standards for imports of food into Switzerland.	4.17	1.46
50	Systems for consumer information about food products.	4.16	1.44
51	Pollination services in agricultural production systems.	4.15	1.36
52	Resilience assessment of food value chains.	4.13	1.31
53	Food prices.	4.10	1.44
54	Alternative protein sources for human consumption.	4.09	1.52
55	Impact and risk assessment of genetically modified organisms (GMOs) in feed value chains.	4.08	1.56
56	Legislation concerning food (including labelling and ingredients).	4.07	1.43
57	Socio-economic analysis of ecosystem services in agricultural production systems.	4.06	1.36
58	Nutritional value of food products and components.	3.99	1.37
59	Nutritional status of the population.	3.94	1.47
60	Food storage technologies and systems.	3.93	1.32
61	Drivers of consumer perception and acceptance of food products and compounds.	3.93	1.39
62	Protection of domestic food markets.	3.92	1.61
63	Livestock breeding.	3.89	1.34
64	Subsidies in the context of free trade regimes.	3.88	1.48
65	Food preservation and product shelf life.	3.84	1.37

Table 8 (continued)

Position	Research Topic	Mean	Std Dev
66	Labor in food value chains.	3.82	1.35
67	Access to food.	3.79	1.60
68	Consolidation in food systems (including vertical and horizontal integration).	3.79	1.32
69	Logistics in food distribution and storage.	3.77	1.43
70	Biotechnology for agricultural production.	3.76	1.50
71	Bioactive compounds in food.	3.75	1.42
72	Rules and practices for institutional food purchase.	3.73	1.45
73	Increase the nutritional value of food by breeding and/or agronomic management (biofortification).	3.71	1.40
74	Succession in farming in Switzerland.	3.71	1.53
75	Nano-materials in food.	3.70	1.50
76	Plant physiology.	3.69	1.31
77	On-farm decision making.	3.64	1.44
78	Precision farming.	3.59	1.47
79	Packaging technologies for food quality and safety.	3.50	1.43
80	Animal physiology.	3.48	1.32
81	Design and processing of food for special dietary needs (including functional foods).	3.41	1.49
82	Domestic fish and seafood production (including aquaponics and aquaculture).	3.39	1.57
83	Packaging technologies for convenience.	3.32	1.45
84	Human physiology.	3.21	1.42
85	Technologies for food purchasing and planning.	3.16	1.43
86	Agricultural insurance schemes.	3.08	1.31
87	Design and processing of convenience food products.	3.05	1.47
88	Gender and equality in farming in Switzerland.	2.92	1.54

Research topics, which were among the Top 10 according to their scores, already covered all areas of the food system scheme. Production-related topics such as “Soil health and fertility in agricultural production systems” (1)and “Nutrient cycling in agricultural production systems” (9) were as present as consumption-related topics such as “Sustainable diets” (5) or topics covering aspects all along the food value chain such as “Energy-use efficiency along food value chains” (3) or “Reducing losses in food value chains” (3). The same accounted for the ten research topic at the bottom of the list (Lowest 10). Here, all areas of the food system were covered as well. Research topics related to production such as “Gender and equality in farming in Switzerland” (88) were as present as topics related to processing of food “Design and processing of food for special dietary needs (including functional foods” (81).

Interestingly, research on new technologies such as GMO (46, 55), biotechnology (70) or technologies at different stages along the value chain, e.g., technologies for packaging improvement (78) or nano-technology (75), were considered less critical by the participating food system stakeholders than those on organic agriculture and food (37). Thus, research on the conservation and the efficient use of resources such as energy (3), nutrients (7), water (14, 35) and materials (16) were seen more critical than the development and application of new and innovative technologies along food value chains.

Since Switzerland is the so-called "water castle" of Europe due to its large water reservoirs, research on water scarcity might seem less critical than on constantly declining fertile, arable land for agricultural production. This might be the reason why research topics such as "Water-use efficiency along food value chains" (14), "Water resource management in agricultural production systems" (35) as well as climate change-related topics such as "Adaptation of food value chains to anthropogenic climate change" (30) and "Mitigation of anthropogenic climate change through food value chains" (41) received lower scores than soil-related topics such as "Soil health and fertility in agricultural production systems" (1).

Furthermore, one might assume that research related to food was considered more critical than research on feed, e.g., for controversial topics such as GMOs and alternative proteins like insects. However, while research on the "Impact and risk assessment of genetically modified organisms (GMOs) in food value chains" (46) was seen as more critical than in feed value chains (53), research on alternative proteins sources was considered more critical for feed (33) than for human nutrition (54).

9.3 Effect of stakeholder affiliation

The evaluation of research topics by different stakeholders (Table 9, see Appendix 2) was consistent among all stakeholder groups from different food system areas and sectors. Overall, respondents did not focus on their own area or sector (Table 9, Table 10), but were critical across all topics for a sustainable Swiss food system, as stakeholders' evaluations and their affiliations (i.e., area and sectors) were not linked.

Researchers, the largest respondent group (N = 232), scored 22 out of 88 research topics significantly different than the other respondents (Table 11). However, the ten highest scored research topics were very similar for researchers and non-researchers (Table 11). Differences were present for the topic "Diet, nutrition and chronic diseases" (overall, 17), which was scored higher by the non-researchers (within Top 10) than by the researchers (scored within second quartile) and for the topic "Policy development for sustainable food systems" (overall, 10), which was also scored higher by the non-researchers (within Top 10) than by the researchers (scored within first quartile). On the other hand, the topic "Waste and by-product valorization in food processing" (overall, 11) was scored within the Top 10 by researchers, but only within the first quartile by non-researchers.

Overall, there was a disagreement between researchers and non-researchers with regard to one quarter of the 88 research topics. While the majority of these differences resulted from non-researchers evaluating certain research topics as slightly more critical than researchers, three research topics were more critical from the perspective of the researchers. These topics included "Genetic resources" (overall, 38) and "Precision farming" (overall, 78) and "Technology and knowledge exchange with developing countries" (overall, 45).

Table 9: Research topics with highest scores related to the food system sector of the respondents. The presence (i.e., shaded box) or absence (i.e., empty box) of the five highest scored research topics among respondents of the different food system sectors in the overall top ten scored research topics.

Pos.	Research Topic	Industry	Research / Education, Outside Academia	Services / Finance	Consulting	Farming	Research / Education, Within Academia	NGO / Non-Profit / Inter. Organizations	SME (small and medium enterprises)	Government / Policy	Other / Unknown
1.	Soil health and fertility in agricultural production systems.	■	■	■	■	■	■	■			
2.	Resistance to antibiotics.	■	■	■	■	■			■	■	
3.	Energy-use efficiency along food value chains.	■	■						■	■	
4.	Reducing food waste.			■	■		■	■			
5.	Sustainable diets.						■	■			■
6.	Nutrient-use efficiency along food value chains.	■	■								
7.	Impact assessment of local vs. global food production.			■		■					■
8.	Reducing losses in food value chains.	■					■			■	
9.	Nutrient cycling in agricultural production systems.		■			■					
10.	Policy development for sustainable food systems.							■	■		

Table 10: Research topics with highest scores related to the food system area of the respondents. The presence (i.e., shaded box) or absence (i.e., empty box) of the five highest scored research topics among respondents from the different food system areas in the overall top ten scored research topics.

Pos.	Research Topic	Other / Unknown	Agriculture	Environment	Consumption	Food and nutrition security	Processing	Retailing	Human health / nutrition
1.	Soil health and fertility in agricultural production systems.	■	■	■	■	■			
2.	Resistance to antibiotics.	■	■				■	■	
3.	Energy-use efficiency along food value chains.	■	■	■			■		
4.	Reducing food waste.	■			■				■
5.	Sustainable diets.			■	■				■
6.	Nutrient-use efficiency along food value chains.		■	■			■		
7.	Impact assessment of local vs. global food production.		■		■			■	
8.	Reducing losses in food value chains.	■				■	■		
9.	Nutrient cycling in agricultural production systems.								
10.	Policy development for sustainable food systems.				■			■	

Table 11: The ten highest scored research topics of researchers and non-researchers. The asterix (*) indicates that this topic was the 11th in the ranking for non-researchers.

Research Topics	Non-Researchers	Researchers
Resistance to antibiotics.	✓	✓
Diet, nutrition and chronic diseases (including obesity, type 2 diabetes, cardiovascular diseases, cancer).	✓	
Energy-use efficiency along food value chains.	✓	✓
Reducing food waste.	✓	✓
Impact assessment of local vs. global food production.	✓	✓
Reducing losses in food value chains.	✓	✓
Nutrient cycling in agricultural production systems.	✓*	✓
Nutrient-use efficiency along food value chains.	✓	✓
Policy development for sustainable food systems.	✓	
Soil health and fertility in agricultural production systems.	✓	✓
Sustainable diets.	✓	✓
Waste and by-product valorization in food processing.		✓

9.4 Research topics added by respondents

After assessing the 88 research topics, the respondents were asked to provide additional research topics thought to be critical to build a sustainable Swiss food system (question 5). More than 600 individual responses were given by the respondents (n = 220 for this question), which could be consolidated to 183 additional research topics. However, more than 50% of these additional research topics (317 out of 608) were explicitly or implicitly already covered by 65 of the 88 original research topics provided in the survey (question 4). Two thirds of the 183 additional research topics were only stated once or twice, clearly illustrating the broad range of the additional topics provided. On the other hand, the four research topics stated most often – although two of them were already part of the original list – were “Effectiveness of education on nutrition and health” (32 times), “Design and management of agricultural production in urban areas” (20 times), “Strategies for the development of regional value chains” and “Design and management of systems for reduced and more sustainable production of meat” (both 17 times; see Appendix 2). In most cases, the additional research topics were tailored to very specific questions and thus represented a more detailed level compared with the original survey questions.

The top 22 additional topics combined 266 (44%) of all answers (see Appendix 2). About two thirds of these 22 additional research topics (each stated seven or more times) were already included in the original survey list (see Appendix 2), while about one third was truly additional. These true additions included topics related to agricultural production in urban areas (e.g., urban farming; 20 times) or options for more sustainable production of meat (e.g., less grain in animal feed; 17 times), among other topics like the relationships of nutrition and health (15 times), management of knowledge or the international consequences and connections of actions in the Swiss food system (each 9 times) and strategies for increased valuation of agriculture (7 times).

9.5 Content analysis of Swiss online media coverage

The media content analysis covered the period one week before the online survey opened until it closed. It revealed that only five of the scored Top 10 research topics, five of those ten with critical scores (positions 40 to 49) and three of the ten research topics with lowest scores were covered in Swiss online media published in German (Figure 12 A). The number of articles that mentioned one of the 30 research topics varied considerably, ranging from zero to maximum ten articles per topic. However, the three groups (Top 10, Mid 10, Low 10) did not differ significantly from each other (Figure 12 B).

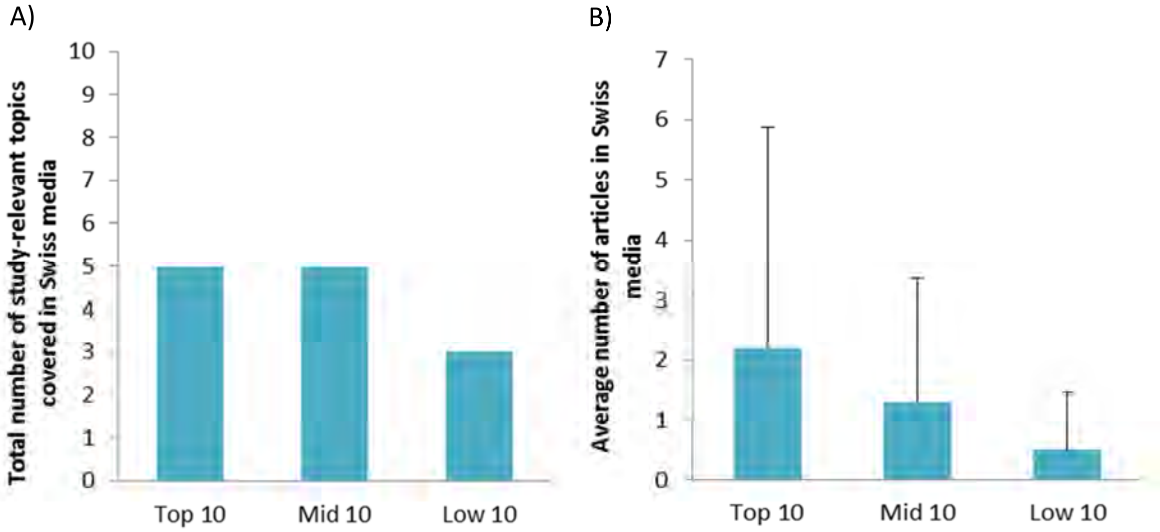

Figure 12: A) Total number of research topics per group (Top 10, Middle 10, Lowest 10) covered by articles in Swiss online media, and B) Average number of articles in Swiss online media covering one of the ten research topics in each group. Only media in German were considered. Media analysis covered the period of 8 December, 2014 to 6 January, 2015, i.e., one week before the survey opened until it closed. Top 10 represents the ten research topics with highest scores, Mid 10 represents the ten topics at positions 40 to 49, and Low 10 indicates the ten research topics with the lowest scores. Bars show standard deviations.

9.6 Research approaches, education and outreach

Respondents considered all six research approaches as well as outreach and education as critical to very critical for Swiss research (average scores between 4.4 and 5.4). The assessment by researchers (the largest group of respondents) and non-researchers did not differ significantly. The applied research approach was the only exception. Here, the support was considered significantly more critical by researchers than by non-researchers (Figure 13).

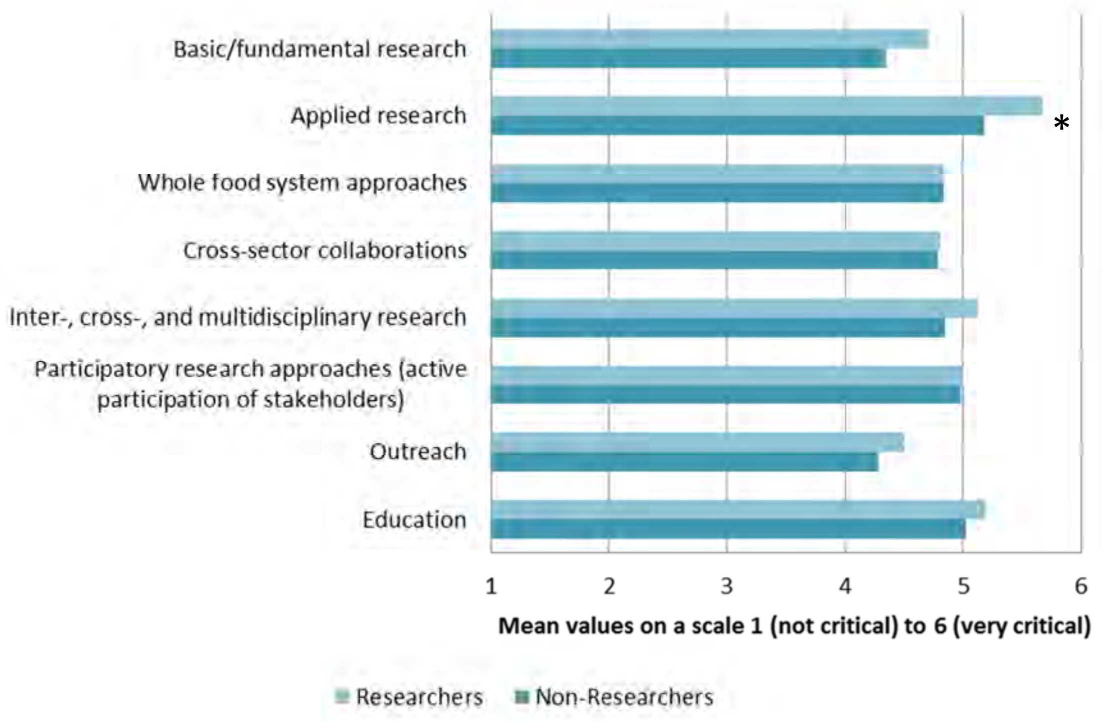

Figure 13: The overall mean values for all respondents, researchers and non-researchers for support for different research and communication approaches on a scale of 1 (not critical) to 6 (very critical). The asterix (*) indicates a significant difference between researchers and non-researchers ($p < 0.05$).

10. Discussion

10.1 Closing current policy gaps

Currently, many Swiss policies addressing parts of or framing the Swiss food system are in place. Challenges such as climate change, loss of arable land and biodiversity, or degradation of natural resources such as water are addressed by laws, strategies or action plans, which already entered into force (Chapter 4.1). Most often, they aim at reducing negative impacts of human activities on the environment or focus on activities related to agricultural production and/or economic growth, for example on export or trade agreements. Many of these food system related aspects are thus addressed by the agricultural policy, although this misses many aspects of the (more diverse and thus more complex) Swiss food system, as mentioned explicitly by the interviewees.

A major challenge for the future is the establishment of a sustainable Swiss food system with food products that are competitive at national and global scales. Competiveness is a driving force for many political measures. Nevertheless, according to the most recent OECD report (2015), current agricultural policy still causes a major barrier toward a competitive agriculture and food sector in Switzerland. The current system of market protection and direct payments in Switzerland has been assessed as distortion of prices and market signals on which competitive decisions of producers should be based. Moreover, corresponding political measures are thought to inhibit structural changes within the agro-food sector and to shield the Swiss agro-food sector from competitive forces, while preventing successful participation in global value chains, development and innovation (OECD 2015).

In addition, achievement of food safety and health will stay a major challenge of the Swiss food system in the future. On the one hand, food safety along Swiss food value chains is extremely high today, mainly due to governmental measures and strict regulations; while on the other hand, health in relation to food and nutrition is far more difficult to deal with by state regulations and political measures. An appropriate balance between regulation via public governance vs. self-responsibility of individuals has not been achieved yet, making diet-related diseases and their increasingly negative impacts on social security and health systems hot topics for political (and scientific) debates (Chapter 7.6). Overall, a wide range of individual laws, policies and strategies successfully address selected aspects of the Swiss food system and corresponding outcomes. Nevertheless, they do not address the food system as an entity nor consider a food systems approach, representing the major gap of current policies in regard to the Swiss food system.

Consequently, a coordinated, multi-stakeholder strategy is lacking to address these system challenges at the national level, partly due to sectorial policy priorities, partly due to the lack of political and societal pressure and urgency. However, it is exactly such a common strategy with a common goal that was not only asked for by the interviewees but is clearly mandatory to overcome barriers and gaps that prevent building and maintaining a sustainable Swiss food system. In fact, Switzerland could take leadership in this respect, since in other countries such a strategy seems to lack as well. The complexity of tasks and challenges will require the involvement of a wide range of food system stakeholders to develop such a common strategy toward a sustainable Swiss food system. Thus, a joint agreement needs to be reached what a sustainable Swiss food system actually is, what it includes, and how it should develop in the future. This will require theoretical as well as very practical considerations, ranging from definitions to indicators of success. Moreover, a leading house has to be determined early on by the food system stakeholders and their corresponding institutions. This leading house needs to assure that all relevant aspects of a sustainable Swiss food system are addressed, that different perspectives are considered and decisions implemented. Moreover, this leading house will not only need to coordinate the process, but also has the difficult task to integrate the interests of the various stakeholders into a common strategy.

Jointly building and developing a Swiss food system, while also considering the environmental, economic, political and social boundary conditions, will probably require targeted research that crosses these boundaries and provides a comprehensive basis of knowledge and the development of effective communication pathways. Consequently, financial support for the development and implementation of a strategy leading toward a sustainable Swiss food system is indispensable. Effective communication will be a prerequisite in successfully addressing the complexity of food systems without wasting resources (e.g., finances) and potential capacities (e.g., human resources). Additionally, communication among all stakeholders provides not only a platform, but also a basic reservoir of and access to knowledge and networks in order to identify overall research gaps and implement smart solutions. To date, no such communication and knowledge platform for the Swiss food system is available, although many networks, centers, alliances, etc. exist in Switzerland.

10.2 Identifying main research areas

The online survey was completed by almost 500 stakeholders of the Swiss food system. The 88 research topics, which had to be scored by the participants, represented a wide range of aspects, including both long-standing topics (e.g., soil fertility) as well as those which only came up rather recently (e.g., food waste and losses). The backgrounds of the respondents covered all areas and sectors of the Swiss food system, and although the majority of the survey respondents worked in research, the Top 10 research topics scored very similar between this group and a “non-research” group. Concerns that the scoring of research topics – especially those with the highest scores – were influenced by abundant media coverage during the time of the survey could be rebutted. Although media reported about issues related to food systems, the media coverage did not focus on the Top 10 research topics, but also applied to topics scoring in the middle (between position 40 to 49) and at the very low end (positions 79 to 88). Thus, the results based on the online survey are considered very solid and reliable.

Interestingly, research on topics highly relevant at the global scale, but currently underrepresented in Swiss research, such as on aquaculture or precision faming, were considered less critical than expected for the development of a sustainable Swiss food system. In this study, “Precision farming” (78) as well as “Domestic fish and seafood production (including aquaponics and aquaculture)” (82) were among the 11 research topics with the lowest scores. A comparably good economic situation of Swiss farmers and the small size of farms might reduce the demand for new technologies like precision farming in Switzerland. The lack of local traditions in fish farming, as they exist in Norway or in many Asian countries, the large imports of fish and seafood, and no access to the sea might explain the low score of this specific research topic for Switzerland, thus at the national scale.

The survey also revealed different perspectives on how to translate major challenges of the Swiss food system to the importance of research topics. Two examples might illustrate this. Example 1: Although “Loss of land” was mentioned by a large share of interviewees and survey respondents as one of the major challenges for the Swiss food system and the loss of arable land in Switzerland is recognized broadly (e.g., Soil as a Resource – NFP 68), the research topic on “Soil health and fertility” (1) received the highest score overall, while research on the “Impact of land use and zoning on food system activities” (42) was not considered to be very critical. Example 2: The reduction of “Food waste and losses along food value chains” was mentioned as a big challenge by interviewees and survey respondents alike, and was also clearly reflected in the scores of related research topics. For example, research topics addressing “Reduction of food waste” (4), “Reduction of food losses along food value chains” (8) and “Waste and by-product valorization in food processing” (11) were considered very critical for building a sustainable Swiss food system, and scored among the 11 research topics with the highest scores in the online survey. Nevertheless, other research topics also clearly related and able to contribute to reducing food waste and losses, e.g., “Packaging technologies for food quality and safety” (79) or “Food preservation and product shelf life” (65) were not considered very critical, maybe reflecting the overall low scores of topics related to development and application of new and innovative technologies along food value chains.

Overall, this foresight study clearly demonstrated that the research topics considered to be most critical to build a sustainable Swiss food system addressed all aspects of the food system. They ranged from research focusing on single food system areas/components such as “Soil health and fertility in agricultural production systems” (1) to cross-cutting activities relevant within the entire food system such as “Energy-use efficiency along food value chains” (3; Figure 14). This conclusion is supported by the fact that none of the research topics had an average score smaller than 2.9, i.e., all research topics were thought to be somewhat to very critical for building a sustainable Swiss food system.

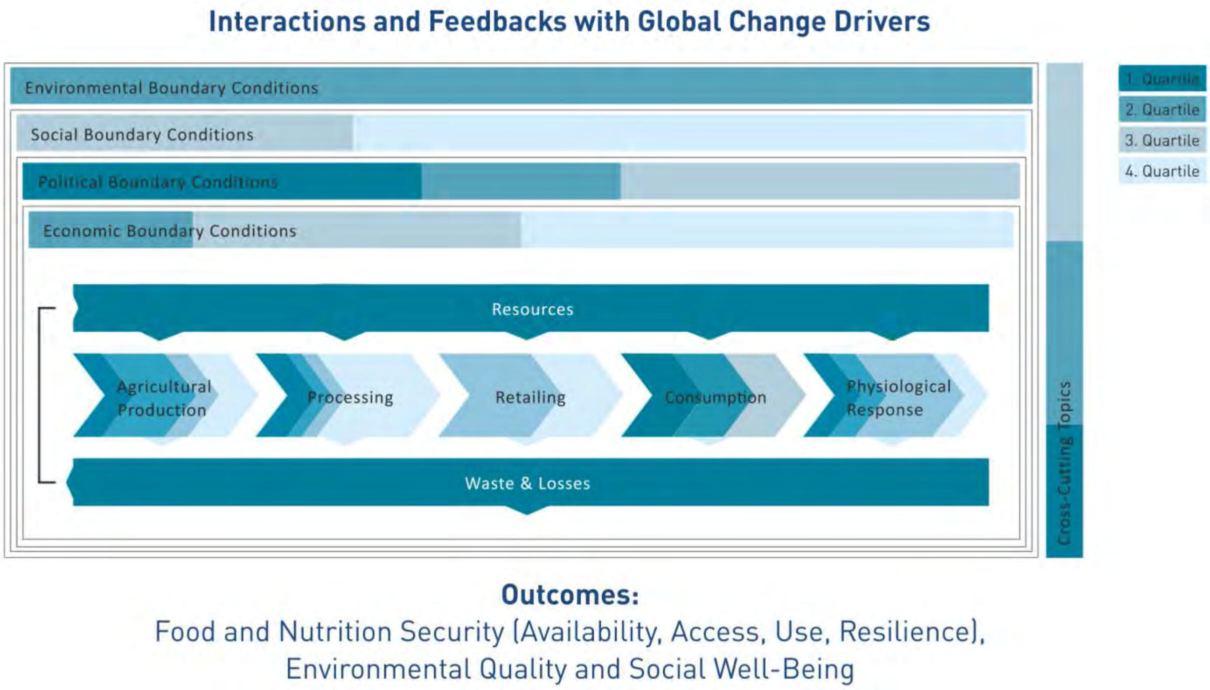

Figure 14: Representation of how critical the 88 research topics are to build a sustainable Swiss food system, related to the corresponding food system areas and boundaries (original scheme: World Food System Center). Different colors indicate how many research topics related to each area and boundary were within the 1st (position 1-22), 2nd (position 23-44), 3rd (position 45-66) or 4th quartile (position 67-88) of all scored research topics. The share of coloration in each field represents the relative contribution of each quartile.

Although in the public perception, the food system (similarly to food security) is often reduced to agricultural production, the results of the survey did not point to a research focus on this early step in the food value chain. Instead, the survey revealed that the majority of research topics, that addressed the entire food value chain (i.e., cross-cutting), received very high scores, which in turn placed them predominantly within the first two quartiles of all 88 research topics. These positions, based on the stakeholder assessments, clearly indicate how critical systems approaches are today, and that a paradigm change is needed toward cross-sectorial, multidisciplinary and participatory research approaches, without neglecting disciplinary research. This will require additional efforts, since in the past, food systems approaches occurred rather coincidental or were addressed only partially. Particularly for multi-stakeholder, inter/transdisciplinary projects, one needs to recognize that reaching specific goals will take longer than in disciplinary projects since trust, a common language and a common understanding of the research need to be achieved first. Projects should thus rather be tailored to post-doctoral researchers than to doctoral students. Moreover, adequate and dedicated funding for management and coordination support as well as for the translation and communication of findings to target audiences are crucial. Thus, the need for a food systems approach, already identified in the interviews to be highly critical to close the current policy gaps, was acknowledged by the survey participants as well, but here in the context of highly critical research topics toward a sustainable Swiss food system.

Considering the results of the online assessments of all research topics leads to the following four main research areas that are highly critical to build a sustainable Swiss food system:

- Research on efficient use of natural resources such as land, soil, water, nutrients and biodiversity at all levels (ecosystems, species, genetic resources) as well as their conservation, recycling and restoration. Here, efficient use of energy and materials, which are often produced from natural resources, as well as waste and losses of resources are included.

- Research on a coherent policy framework that aims at national policies such as (but not exclusively) the agricultural policy, but also at international policies such as trade policies, which are strongly linked to the food system as well as to the food system boundary conditions.

- Research on sustainable diets, not only considering environmental aspects, but also linking to nutrition, health and diseases as well as consumption patterns.

- Research on cross-cutting issues within the entire Swiss food system, addressing their drivers, mechanisms and impacts along all stages and across the food value chains.

11. Conclusions and recommendations

This foresight study showed that policy-makers as well as stakeholders of the Swiss food system have a very comparable understanding of the challenges the Swiss food system will be facing in the next 20 years. Thus, the momentum to develop a coordinated, multi-stakeholder strategy to address these systems challenges at the national level seems optimal.

Future challenges identified by federal office representatives and food system stakeholders closely align with the desirable outcomes of any food system, i.e., food and nutrition security, environmental quality and social well-being. For Switzerland, these challenges include food self-sufficiency/ sovereignty and the global responsibility of Switzerland as well as dealing with resource efficiencies/scarce resources and climate change. At the same time, the challenges how to ensure sustainable production, environmental protection and the reduction of food waste and losses need to be addressed. Furthermore, demographic changes with changing consumptions patterns, the trade-offs financial strength vs. prices, international trade agreements vs. Swiss market protection need to be dealt with, but also food safety and quality issues as well as diet-related diseases. Thus, policy and research need to be designed, supported and implemented for and in the entire Swiss food system to achieve the desirable outcomes of a sustainable Swiss food system, not only now but also in the future.

Moreover, competitiveness was mentioned as another major challenge, considered very crucial by the interviewees and mentioned most frequently in the online survey. However, this term is not well defined, despite being used in various contexts (albeit very differently). Any assignment of research topics identified as critical for the Swiss food system to the challenge *competitiveness* is highly arbitrary. Three examples might illustrate this: increasing resource-efficiencies for energy, nutrients and water within the Swiss food system (all ranked as highly critical in the survey) do clearly increase the system's competitiveness since inputs can be reduced and outputs produced more efficiently. But similarly, mitigating anthropogenic climate change or understanding drivers of consumption pattern (both ranking only in the middle of all research topics) will also increase competitiveness, by making the food system more resilient and opening new market segments. Finally, understanding human, animal or plant physiology as well as developing new packaging technologies will equally contribute to increasing competitiveness in the long-run, since understanding basic physiological processes related to product quality and human health will improve product qualities, while new technologies can increase shelf life and thus increase profits. Thus, the rather vague term *competitiveness* does not seem very useful in the discussion about a sustainable Swiss food system, unless it is clearly defined in the context of interest.

According to the OECD (2015), competitiveness is defined as "*… the ability to successfully face competition. In this sense, competitiveness is the ability to sell products that meet demand requirements (price, quality, quantity) and, at the same time, ensure profits over time that enable the firm to thrive*." It is assessed using different indicators and typically selected countries or firms are used as a benchmark. However, ultimately, this definition is reflecting the three pillars of sustainable development, i.e., society, economy and ecology (Brundtland and WCED 1987), since *"… meeting requirements … such as quality and quantity of products …"*, "*… prices … ensuring profits …*" and "*… ensuring … over time …*" reflects nothing else than realizing and further developing a sustainable food system. In other words, to become and stay competitive, sustainable development of a food system needs to be achieved. To keep a sustainable food system in balance and therefore make it resilient against challenges, all three aspects of sustainability need to be balanced. To develop a sustainable food system over time and to keep it "on track", i.e., providing the desirable food system outcomes and to stay competitive also in the future, policies and research need to address the challenges a food system will be facing over time. It is thus highly recommended to take these aspects into consideration when discussing and deciding on future policy and research priorities for the Swiss food system.

Further recommendations for the policy realm include:

- to develop and implement a coordinated, multi-stakeholder strategy addressing the entire Swiss food system,
- to identify a leading house for such a strategy process,
- to establish a knowledge and communication platform, and
- to set up targeted research toward a sustainable Swiss food system.

Recommendations for research that is critical to achieve a sustainable Swiss food system are:

- to apply multiple research and communication approaches,
- to include stakeholders in targeted research for a sustainable Swiss food system,
- to carry out research using a systems approach, in particular the following four main research areas:
    - research on efficient use of natural resources such as land, soil, water, nutrients and biodiversity at all levels (ecosystems, species, genetic resources) as well as their conservation, recycling and restoration. Here, efficient use of energy and materials, which are often produced from natural resources, as well as waste and losses of resources are included.
    - research on a coherent policy framework that aims at national policies such as (but not exclusively) the agricultural policy, but also at international policies such as trade policies, which are strongly linked to the food system as well as to the food system boundary conditions,
    - research on sustainable diets, not only considering environmental aspects, but also linking to nutrition, health and diseases as well as consumption patterns, and
    - research on cross-cutting issues within the entire Swiss food system, addressing their drivers, mechanisms and impacts along all stages and across the food value chains.

Based on these recommendations, we conclude that Switzerland can best respond to the future challenges at national and international levels when consciously developing a sustainable Swiss food system together with all actors and stakeholders, enabling the system to stay competitive and to ensure food and nutrition security, environmental quality as well as social well-being now and in the future.

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Appendices

1. Contributing experts

Name	Institute/Center, Group
Prof. Mark Adams	University of Sydney, Faculty of Agriculture and Environment
Dr. Maria Andersson	ETH Zurich, Institute of Food, Nutrition and Health, Human Nutrition
Claudio Beretta	ETH Zurich, Institute for Environmental Engineering, Ecological Systems Design
Dr. Raushan Bokusheva	ETH Zurich, Institute for Environmental Decisions, Agricultural Economics
Prof. Emmanuel Frossard	ETH Zurich, Institute of Agricultural Sciences, Plant Nutrition
Prof. Jaboury Ghazoul	ETH Zurich, Institute of Terrestrial Ecosystems, Ecosystem Management
Dr. Delia Grace	International Livestock Research Institute (ILRI), Food Safety and Zoonoses
Dr. Kenneth Harttgen	ETH Zurich, Centre for Development and Cooperation
Dr. Robert Jörin	ETH Zurich, Institute for Environmental Decisions, Agricultural Economics
Prof. Michael Kreuzer	ETH Zurich, Institute of Agricultural Sciences, Animal Nutrition
Prof. Leo Meile	ETH Zurich, Institute of Food, Nutrition and Health, Food Biotechnology
Prof. Pierre Mérel	ETH Zurich, Institute for Environmental Decisions, Agricultural Economics
Dr. Ueli Merz	ETH Zurich, Institute of Integrative Biology (IBZ), Plant Pathology
Dr. Diego Moretti	ETH Zurich, Institute of Food, Nutrition and Health, Human Nutrition
Prof. Anthony Patt	ETH Zurich, Institute for Environmental Decisions, Human-Environment Systems
Dr. Simon Peter	ETH Zurich, Institute for Environmental Decisions, Agricultural Economics
Dr. Christian Schaffner	ETH Zurich, Energy Science Center (ESC)
Prof. Rainer Schulin	ETH Zurich, Institute of Terrestrial Ecosystems, Soil Protection
Prof. Michael Siegrist	ETH Zurich, Institute for Environmental Decisions, Consumer Behavior
Prof. Johan Six	ETH Zurich, Institute of Agricultural Sciences, Sustainable Agroecosystems
Prof. Achim Walter	ETH Zurich, Institute of Agricultural Sciences, Crop Sciences
Prof. Hong Yang	Eawag, System Analysis, Integrated Assessment and Modelling, Water, Environment and Food Security

2. Topline results of the online survey

The following tables contain information gathered from the online survey in the original order. All numbers presented here refer to percent of valid responses unless stated otherwise.

Language Selection

Please select the language in which you wish to proceed.	
Deutsch	73.2
Français	20.2
Italiano	2.2
Engish	4.3

Introduction

Q1. In which area of the food system would you say the majority of your professional work activities fall?	
Resources and agricultural inputs (e.g., fertilizers, seeds, etc.)	4.0
Agricultural production	25.5
Processing	9.6
Retailing	2.9
Consumption	5.1
Human health / nutrition	18.1
Waste and losses	.6
Food and nutrition security	6.9
Environment	9.8
Social services	.8
Other (Please specify.)	16.5

Q2. Please select the sector that best characterizes the area into which the majority of your professional work activities fall.	
Industry	6.9
SME (small-medium enterprise)	6.3
Government (national, cantonal, local)	6.1
Policy (non-government)	1.0
Non-governmental organization	4.0
Non-profit organization	7.9
Research / Education (outside academia)	16.1
Research / Education (within academia)	21.2
Farming	9.1
Service	4.3
Finance / Banking	.5
Consulting	10.9
International organization	1.0
Other	4.8

Challenges

Note: Numbers give position (fist and fourth column) and counts of challenges (third and last column).

Q3. In your opinion, what are the three most important challenges that the Swiss food system will be confronted with over the next 20 years? (Most frequently mentioned challenges)					
1	Competitiveness	55	16	Environmental protection	17
2	Loss of land	48	17	Food safety	17
3	Climate change	47	18	Resource scarcity	17
4	Food quality	44	19	Sustainability	17
5	Diet-related diseases	38	20	Conflict of interests	16
6	Food waste	33	21	Structural change	16
7	Self-sufficiency	32	22	Resistance to antibiotics	15
8	Sustainable production	32	23	Healthy food	14
9	Prices	31	24	Local markets and products	14
10	Liberal markets	27	25	Ecological production	13
11	Consumption pattern	26	26	Population growth	13
12	Resource-use efficiency	26	27	Biodiversity loss	12
13	Education (nutrition)	23	28	Traceability	12
14	Food security	21	29	Productivity	11
15	GMOs	20	30	Resource degradation	11

Research topics

On the following five pages, you will be asked to evaluate the relative importance of a series of 88 research topics that concern the food system. The topics will appear in no particular order. We are interested in the opinion of all stakeholders about all topics.

This set of topics has been derived from consultation with food system researchers and a review of the most recent research strategies, programs, and concepts of more than 20 Swiss and European research institutes, organizations, federal offices, universities, and the food system industry.

As the list of topics is not exhaustive, there will be places at the end of the section to provide additional research topics that you think should be factored into the analysis.

Swiss Food System Definition

Note: For the purposes of this research, the „Swiss food system“ concerns food produced and consumed in Switzerland as well as national stakeholders and national boundary conditions.

Research Topics 1 of 5

Q4a. On a scale of 1 (not critical) to 6 (very critical), please rate how critical you think the following research topics are for building a sustainable Swiss food system in the next 20 years?							
	Not critical					**Very critical**	**No Opinion**
Topic	**1**	**2**	**3**	**4**	**5**	**6**	
Certification and labeling for sustainable food value chains.	3.5	6.6	12.8	18.4	28.7	28.0	1.9
Resilience assessment of food value chains.	3.1	7.0	15	23.4	23.2	13.3	14.8
Sustainable diets.	2.3	3.9	7.6	12.8	26.9	45.2	1.4
Biodiversity in agricultural production systems.	2.0	4.9	10.7	19.9	25.8	35.5	1.2
Food storage technologies and systems.	3.5	11.0	21.4	27.3	22.0	12.7	2.2

Plant breeding.	2.0	5.3	15.9	21.5	25.2	25.6	4.5
Reducing losses in food value chains.	2.1	3.7	7.4	16.0	30.5	38.9	1.4
Access to food.	9.7	14.0	17.9	20.3	16.6	19.1	2.4
Food system externalities (costs imposed on others or benefits received for free).	0.8	5.7	14.8	19.9	20.7	22.8	15.4
Diet, nutrition and chronic diseases (including obesity, type 2 diabetes, cardiovascular diseases, cancer).	2.7	6.9	11.0	19.4	22.5	35.5	2.0
Plant protection (including pests, pathogens, and weeds).	0.6	4.7	12.0	27.3	30.1	22.2	3.1
Livestock breeding.	3.6	12.3	22.4	24.2	21.6	12.5	3.4
Impact and risk assessment of genetically modified organisms (GMOs) in feed value chains.	7.2	10.4	16.8	19.4	19.8	23.9	2.5
Impact and risk assessment of genetically modified organisms (GMOs) in food value chains.	6.8	9.6	14.1	19.2	21.5	26.2	2.5
Technologies for food purchasing and planning.	12.4	23.4	22.0	20.9	11.0	6.9	3.3
Resistance to antibiotics.	1.8	2.2	7.0	12.5	24.1	48.7	3.7
Domestic fish and seafood production (including aquaponics and aquaculture).	12.7	20.8	18.3	19.2	15.5	11.5	2.0
Nutrient cycling in agricultural production systems.	0.4	2.9	9.4	22.2	28	32.4	4.7
Increase the nutritional value of food by breeding and/or agronomic management (biofortification).	7.6	12.2	20.5	26.3	20.5	9.6	3.2
Impact of land use and zoning on food system activities.	1.8	8.2	16.3	20.3	25.1	21.3	7.0
Pollination services in agricultural production systems.	4.2	6.0	17.6	24.4	21.2	17.2	9.2

Research Topics 2 of 5

Q4b. On a scale of 1 (not critical) to 6 (very critical), please rate how critical you think the following research topics are for building a sustainable Swiss food system in the next 20 years?

	Not critical					**Very critical**	**No Opinion**
Topic	**1**	**2**	**3**	**4**	**5**	**6**	
Nano-materials in food.	8.4	12.9	19.1	18.5	20.7	11.2	9.2
Sustainability assessment of food value chains.	1.4	4.3	11.2	20.7	27.6	30.2	4.7
Agricultural insurance schemes.	10.5	19.0	26.2	17.3	9.5	3.6	13.9
Socio-economic viability of farms and farming systems.	3.2	8.7	13.7	22.0	23.6	22.8	6.0
Policy development for sustainable food systems.	1.8	6.0	7.9	17.7	27.4	35.9	3.2
Alternative protein sources for human consumption.	6.4	11.2	16.0	21	21.8	22.2	1.2
Alternative protein sources for animal feed.	4.4	6.0	13.1	19.7	27.2	27.8	1.8
Logistics in food distribution and storage.	6.7	12.5	21.8	25.2	17.3	13.5	3.0
Traceability in food value chains.	2.2	5.8	9.3	25.2	29.8	26.6	1.2
Drivers of consumer perception and acceptance of food products and compounds.	4.4	10.9	22.0	21.6	21.6	14.3	5.2
Drivers of consumption patterns.	3.8	8.1	18.4	23.1	23.1	20.0	3.4
Subsidies in the context of free trade regimes.	6.1	11.3	17.0	21.7	16.8	15.2	11.9
Impact assessment of local vs. global food production.	1.0	3.6	7.6	16.1	31.7	36.9	3.0
Organic agriculture and food.	5.7	9.5	14.2	15.4	20.6	32.6	2.0
Nutritional value of food products and components.	4.0	10.9	20.4	24.6	22.8	15.4	1.8

Research Topics 3 of 5

Q4c. On a scale of 1 (not critical) to 6 (very critical), please rate how critical you think the following research topics are for building a sustainable Swiss food system in the next 20 years?							
	Not critical					**Very critical**	**No Opinion**
Topic	**1**	**2**	**3**	**4**	**5**	**6**	
Trade-offs between ecosystem services and agricultural production.	1.4	3.7	10.7	21.8	26.5	31.2	4.7
Waste and by-product valorization in food processing.	1.0	2.5	9.9	23.3	33.7	27.6	2.1
Adaptation of food value chains to anthropogenic climate change.	2.1	5.8	11.3	23.5	26.4	23.9	7.0
Mitigation of anthropogenic climate change through food value chains.	3.1	4.9	16.5	20.6	22.9	20.6	11.3
Labor in food value chains.	3.5	13.8	20	24.7	19.5	11.1	7.4
Nutritional status of the population.	3.5	16.1	20.6	20.8	18.8	19.4	0.8
Plant physiology.	3.7	14.5	21.5	25.2	17.4	8.3	9.5
Food toxicology and health.	1.4	9.9	19.8	22.3	25.8	17.7	3.1
Socio-economic impact of diet-related disease (including malnutrition, obesity, and micronutrient deficiency).	3.3	12.1	14.1	18.6	23.2	25.4	3.3
Animal physiology.	4.7	19.5	22.4	23.0	15.2	6.6	8.4
Life cycle assessment of food products.	3.3	6.4	16.5	22.5	29.1	21.2	1.0
Consolidation in food systems (including vertical and horizontal integration).	2.9	9.2	15.8	18.5	14.6	6.9	32.1
Biotechnology for agricultural production.	8.7	13	15.5	24.4	19.6	12.6	6.2
Impact of policies on food systems.	1.9	8.0	11.8	19.8	28.5	26.4	3.7
Food prices.	4.5	10.5	17.1	23	22.2	19.8	2.9
Water-use efficiency along food value chains.	2.3	5.1	10.5	18.3	27	33.5	3.3
Energy-use efficiency along food value chains.	0.6	2.1	7.0	17.3	29.5	39.4	4.1
Nutrient-use efficiency along food value chains.	1.0	2.9	6.8	18.5	31.2	34.9	4.7
Efficient use of materials along food value chains.	0.8	2.7	11.2	24.2	29.8	24.6	6.6

Research Topics 4 of 5

Q4d. On a scale of 1 (not critical) to 6 (very critical), please rate how critical you think the following research topics are for building a sustainable Swiss food system in the next 20 years?							
	Not critical					**Very critical**	**No Opinion**
Topic	**1**	**2**	**3**	**4**	**5**	**6**	
Design and processing of convenience food products.	15.8	22.3	17.9	19.2	11.5	5.4	7.9
Technology and knowledge exchange with developing countries.	3.5	9.2	14.2	25.3	23.0	22.3	2.5
Gender and equality in farming in Switzerland.	20.4	23.1	18.5	15.8	9.4	7.3	5.4
Legislation concerning food (including labelling and ingredients).	4.4	11.9	17.7	22	24.1	18.5	1.5
Strategies for the development of regional value chains.	2.5	7.1	10.4	19.1	29.3	29.9	1.7
Water resource management in agricultural production systems.	2.5	7.5	12.1	22.7	26.7	24.4	4.2
Socio-economic analysis of ecosystem services in agricultural production systems.	3.2	10.1	15.6	21.7	23.4	13.7	12.4
Incentives to protect ecosystem services in agricultural production systems.	2.9	6.7	13.7	22.1	26.3	19.7	8.6
Genetic resources in agricultural production systems (including estimation, conservation, and optimized use).	1.9	7.7	12.8	24.3	25.3	19.5	8.6
Closing resource and material cycles in food systems.	0.8	5	11.1	18.4	28.5	24.9	11.3
Protection of domestic food markets.	8.1	14.8	14.8	16.5	21.9	19.6	4.2
Soil health and fertility in agricultural production systems.	0.4	2.5	6.9	12.1	26.7	49.4	2.1

Reducing food waste.	2.1	4.8	6.5	12.7	27.7	45.2	1.0
Design and processing of food for special dietary needs (including functional foods).	11.1	18.3	20.0	21.4	15.5	9.0	4.6
Precision farming.	7.7	12.8	16.7	18	17.4	7.7	19.7
Food preservation and product shelf life.	4.8	13	19.9	24.9	23.1	11.1	3.1

Research Topics 5 of 5

Q4e. On a scale of 1 (not critical) to 6 (very critical), please rate how critical you think the following research topics are for building a sustainable Swiss food system in the next 20 years?

	Not critical					**Very critical**	**No Opinion**
Topic	**1**	**2**	**3**	**4**	**5**	**6**	
Design and processing of healthy food products.	1.7	4.6	12.3	20.7	30.9	26.5	3.3
Succession in farming in Switzerland.	7.5	16.3	15.1	18.4	19.5	12.3	10.9
Bioactive compounds in food.	5.5	13	20.3	19.7	18.9	10.7	11.9
Packaging technologies for convenience.	10.7	21.4	17.4	21.8	16.6	6.1	6.1
Systems for consumer information about food products.	4.4	10.3	17.2	20.5	25.2	21.0	1.5
Effectiveness of education on nutrition and health.	4.2	6.5	12.3	16.7	26.8	31.4	2.1
Food processing technologies for optimized resource use.	1.7	5.7	15.2	23.8	31.6	18.1	3.8
Standards for imports of food into Switzerland.	4.8	10.7	14	19.2	26.4	19.7	5.2
Quality and safety along food and feed value chains.	0.8	4.4	12.4	25.3	29.7	22.7	4.6
Sustainable intensification in agricultural production systems.	3.6	4.4	12.8	20.1	26.8	25.8	6.5
On-farm decision making.	7.6	13.7	17.3	21.7	18.4	8.6	12.7
Human physiology.	10.9	17.9	22.7	18.1	11.2	5.9	13.3
Packaging technologies for food quality and safety.	8.8	17.4	20.1	23.2	17.6	8.2	4.8
Design and management of agroecological systems.	1.9	7.6	11.1	20.6	26.3	24.8	7.8
Livestock nutrition, health and welfare.	2.1	6.5	12.6	21.8	26.2	27.7	3.1
International trade agreements and impact on Swiss food system.	2.7	5.6	10.5	20.9	28.2	28	4.0
Rules and practices for institutional food purchase.	6.5	12.3	16.9	20.7	18.4	10	15.1

Additional Questions

Note: Numbers give position (first and fourth column) and number of times each research topic was stated (third and last column). Truly additional research topics (not covered in Q4) are highlighted in bold.

Q5. Are there additional research topics that you think are very critical for building a sustainable Swiss food system in the next 20 years? Please include up to five additional topics, in no particular order.					
1	Effectiveness of education on nutrition and health.	32	12	Livestock nutrition, health and welfare.	10
2	**Design and management of agricultural production in urban areas (including urban farming, private gardens, community supported agriculture).**	**20**	13	Soil health and fertility in agricultural production systems.	9
3	Strategies for the development of regional value chains.	17	**14**	**Knowledge management and transfer in the Swiss food system**	**9**
4	**Design and management of systems for reduced and more sustainable production of meat (including grass-based animal husbandry, domestic feed).**	**17**	**15**	**Integration and connection of the Swiss food system to foreign food systems (including consequences of domestic consumption elsewhere).**	**9**
5	Design and management of agroecological systems.	15	16	Biotechnology for agricultural production.	8
6	Plant breeding.	15	17	Food prices.	8
7	**Diet, nutrition and health in all age classes.**	**15**	18	Alternative protein sources for animal feed.	7
8	Plant protection (including pests, pathogens, and weeds).	14	19	Food system externalities (costs imposed on others or benefits received for free).	7
9	Biodiversity in agricultural production systems.	13	20	Organic agriculture and food.	7
10	Genetic resources in agricultural production systems (including estimation, conservation, and optimized use).	10	21	Policy development for sustainable food systems.	7
11	Impact of land use and zoning on food system activities.	10	**22**	**Strategies to increase the valuation of farmers, agricultural production and consumption.**	**7**

Q6. On a scale of 1 (not critical) to 6 (very critical), how critical is it that food system researchers in Switzerland have support for the following?	**Not critical**					**Very critical**	**No Opinion**
	1	**2**	**3**	**4**	**5**	**6**	
Basic / fundamental research.	2.3	5.9	12.9	25	21.7	28.7	3.5
Applied research.	0.8	0.6	2.7	10.5	25.2	58.4	1.8
Whole food system approaches.	3.1	4.1	8.2	12.7	30.5	37.9	3.5
Cross-sector collaborations.	1.8	2.3	9.6	18.4	31.4	32	4.5
Inter-, cross-, and multidisciplinary research.	1.4	3.7	5.5	17.4	25.4	42	4.5
Participatory research approaches (active participation of stakeholders).	1.4	2	7.8	16.6	24.2	43.2	4.7
Outreach.	3.3	6.8	15	22.7	25.4	24.6	2.3
Education.	1.2	1.6	7.4	13.5	27.9	46.9	1.4

Q7. What is your gender?	
Female	36.5
Male	62.5
Decline to answer	1

Q8. What is your age?	
16 to 24 years	1.2
25 to 34 years	21.4
35 to 44 years	25.2
45 to 54 years	30.5
55 to 64 years	18.4
65 years or older	3.3

Q9. What is the highest level of education you have completed?	
Mandatory Primary / Secondary School	0.4
Apprenticeship	1.6
Secondary or High School Diploma	1.4
Bachelor's Degree	15.1
Master's Degree	36.9
Doctorate / PhD / Habilitation	39.2
Other	5.4

Q10. What is your nationality?	
Swiss	82.7
French	1.4
Austrian	1.0
German	10.5
Italian	0.6
Other	2.5

3. Keywords for media content analysis

Position_Rank	Research topic	Keywords (as entered in google news search)
Top 10_1	Soil health and fertility in agricultural production systems.	gesunder Boden, fruchtbarer Boden location:Schweiz
Top 10_2	Resistance to antibiotics.	Antibiotikaresistenz OR resistente Keime location:Schweiz
Top 10_3	Energy-use efficiency along food value chains.	Energieeffizienz Lebensmittel, OR Wertschöpfungskette location:Schweiz
Top 10_4	Reducing food waste.	Food waste, OR Lebensmittelverschwendung, OR Lebensmittelabfälle, OR Nahrungsverschwendung, OR Nahrungsmittelabfälle, OR Nahrungsmittelverschwendung location:Schweiz
Top 10_5	Sustainable diets.	"nachhaltige Ernährung" location:Schweiz
Top 10_6	Impact assessment of local vs. global food production.	Auswirkungen Lebensmittelproduktion, lokal, OR global location:Schweiz
Top 10_7	Nutrient-use efficiency along food value chains.	Nährstoffeffizienz, OR Nährstoff Nutzungseffizienz Nährstoffeffizienz, OR Nährstoff Nutzungseffizienz, "effiziente Nährstoff Nutzung, effizienter Nährstoff Nutzung" location:Schweiz
Top 10_8	Reducing losses in food value chains.	Food loss, OR Lebensmittelverlust, OR Nahrungsmittelverlust location:Schweiz
Top 10_9	Nutrient cycling in agricultural production systems.	Nährstoff Kreisläufe Landwirtschaft location:Schweiz
Top 10_10	Policy development for sustainable food systems.	Politik, OR Strategie, OR Entwicklung "nachhaltiges Ernährungssystem" location:Schweiz
Mid_10_40	Incentives to protect ecosystem services in agricultural production systems.	Ökosystemleistungen location:Schweiz
Mid_10_41	Mitigation of anthropogenic climate change through food value chains.	Klimawandel, Reduktion Emissionen, Nahrung location:Schweiz
Mid_10_42	Impact of land use and zoning on food system activities.	Landumnutzung, OR Landwirtschaftsland, OR Agrarland, OR Kulturland, OR Verlust von Agrarland, OR Verlust Kulturland location:Schweiz
Mid_10_43	Socio-economic viability of farms and farming systems.	landwirtschaft Betriebe Wirtschaftlichkeit location:Schweiz
Mid_10_44	Socio-economic impact of diet-related disease (including malnutrition, obesity, and micronutrient deficiency).	"ernährungsbedingte Krankheiten" Kosten, OR Übergewicht, OR Diabetes location:Schweiz
Mid_10_45	Technology and knowledge exchange with developing countries.	Entwicklungsländer, Austausch, Wissen, OR Austausch, OR Transfer location:Schweiz
Mid_10_46	Impact and risk assessment of genetically modified organisms (GMOs) in food value chains.	Risiken, Lebensmittel UND GMO, OR GVO, OR genetisch verändert location:Schweiz
Mid_10_47	Food toxicology and health.	Lebensmittel, AND toxisch, OR gesundheitsgefährdende location:Schweiz
Mid_10_48	Drivers of consumption patterns.	Konsumverhalten, UND Lebensmittel, OR Nahrungsmittel location:Schweiz
Mid_10_49	Standards for imports of food into Switzerland.	Lebensmittel Import Standards location:Schweiz
Low_10_79	Packaging technologies for food quality and safety.	Lebensmittel Verpackung Qualität, OR Sicherheit, location:Schweiz
Low_10_80	Animal physiology.	Ernährung, Stoffwechsel, Tier, OR Tierphysiologie location:Schweiz

Low_10_81	Design and processing of food for special dietary needs (including functional foods).	Functional food, probiotische Lebensmittel location:Schweiz
Low_10_82	Domestic fish and seafood production (including aquaponics and aquaculture).	Aquakultur, Aquaponic location:Schweiz
Low_10_83	Packaging technologies for convenience.	Lebensmittel Verpackung Design, OR Technologie, OR Convenience, location:Schweiz
Low _10_84	Human physiology.	Ernährung, Stoffwechsel, menschlich, OR Humanphysiologie location:Schweiz
Low _10_85	Technologies for food purchasing and planning.	Technologie, Lebensmittel Einkauf, OR Planung location:Schweiz
Low _10_86	Agricultural insurance schemes.	Landwirtschaftsversicherung, OR Landwirtschaft AND Versicherung location:Schweiz
Low _10_87	Design and processing of convenience food products.	Lebensmittel, Design, Convenience, OR verbraucherfreundlich, OR Fertiggerichte location:Schweiz
Low _10_88	Gender and equality in farming in Switzerland.	Landwirtschaft Gleichstellung, OR Frau, OR Gleichberechtigung, OR Geschlechtergleichstellung location:Schweiz