Food and Agriculture Organization
of the United Nations

FAO Statistics Working Paper Series / 21-24

MEASURING PROGRESS TOWARDS SUSTAINABLE AGRICULTURE

FAO Statistics Working Paper Series

ESS/ 21-24

MEASURING PROGRESS TOWARDS SUSTAINABLE AGRICULTURE

Francesco N. Tubiello[1], Nathan Wanner[1], Lauren Asprooth[2,a] , Marc Mueller[2,b], Adriana Ignaciuk[2], Asfandiyar Arbab Khan[1] and José Rosero Moncayo[1]

[1] Statistics Division, FAO, Rome Italy
[2] Agri-Food Economic Division, FAO, Rome, Italy
[a] Currently at: University of California at Davis, Davis, CA, USA
[b] Currently at: Wageningen University and Research centre, Netherlands

Food and Agriculture Organization of the United Nations

Rome, 2021

Required citation: Tubiello, F.N., Wanner, N., Asprooth, L., Mueller, M, Ignaciuk, A., Khan, A. A. & Rosero Moncayo, J., 2021. *Measuring progress towards sustainable agriculture.* FAO Statistics Working Paper 21-24. Rome, FAO. https://doi.org/10.4060/cb4549en

ISBN 978-92-5-134364-7

Abstract

This paper presents a new methodological approach aimed at measuring progress towards sustainable agriculture in countries and across agri-food systems typologies, by measuring socio-economic and environmental dimensions with available national statistics, with sixteen indicators defined and constructed from FAOSTAT data. A trend analysis is carried out at country level over the time series 1961–2018, with country results aggregated by four agri-food systems typologies: traditional; land-intensive and capital-intensive mixed systems; and modern food systems. A traffic-light approach is implemented to grade sustainability performance in countries via a colour system (red, yellow and green), and a dashboard is used to aggregate country results by typology. The Progress Towards Sustainable Agriculture (PROSA) dashboard provides a visual overview of the sustainability status identifying sustainability hotspots and their evolution identified over time. The PROSA indicators extend conceptually the monitoring framework of indicator SDG 2.4.1 on "sustainable and productive agriculture", by changing the monitoring scope from farms to country level, and by complementing the eleven SDG sub-indicator that cover relevant socio-economic and environmental aspects of sustainability on the farm, with additional indicators of biodiversity and climate change, of importance beyond the farm gate. The analysis provides a novel framework for the analysis of progress in achieving sustainable agriculture by country and agri-food system type, which can be implemented effectively and allows for exploring solutions across development pathways.

Contents

Abstract .... **iii**

Acknowledgements .... **vi**

1. Introduction **1**

2. Methods **2**

2.1 PROSA Indicators *3*

2.2 PROSA Traffic Light Assessment and Dashboard *6*

3. Results **10**

3.1 Socio-economic indicators *10*

3.1.1 Steady progress in productivity and profitability across food systems 10

3.1.2 Credit, wages, diversification and food security are key limiting factors 12

3.2 Environmental indicators *16*

3.2.1 Efficient use of inputs is key to productivity and profitability 16

3.2.2 Agro-biodiversity and resilience are enhanced in traditional food systems 21

3.2.3 Low emissions and efficient land use pathways 24

4. Dashboard analysis **29**

5. Conclusions **33**

References **34**

Appendix I - Country typology groupings and list of countries **36**

Acknowledgements

The PROSA idea was developed with support from the FAO Strategic Programme 2 during the period 2016–2019. The authors are thankful to Clayton Campanhola, Jean-Marc Faurès, Amy Heyman, Kakoli Gosh and Mona Chaya for their continued support and feedback along the way. We gratefully acknowledge support provided by FAO staff throughout this effort and across many divisions, who attended several internal meetings and provided feedback and useful input over time. Special thanks go to the management, technical and support staff in the Statistical Division and the Agri-Food Economic Division of FAO for co-funding the PROSA efforts over several years and for unwavering support. We thank Xueyao Pan for support in drafting the final version of this manuscript. Very useful discussions and feedback from the Office of the Chief Statistician are also gratefully acknowledged; they helped improve the focus of this work in relation to FAO's ongoing SDG activities. We are furthermore thankful to the many internal and external expert reviewers from Institutions worldwide who provided insightful suggestions during two major peer-review efforts, undertaken respectively in the fall 2019 and spring 2020. This work describes the statistical component of the larger PROSA analysis. We are thankful to country experts and the ESS data collection team at FAO HQ in Rome for their contributions to FAOSTAT data processes, as well as to the regular support provided by member states to FAO's statistical work.

1. Introduction

Sustainable and productive agriculture is essential to nourish and sustain the well-being and health of people and the planet. These goals must be achieved in the face of a growing world population, limited natural resources and significant climate change challenges. Variations in endowments of land, labour, and capital will determine the most feasible and appropriate pathways towards sustainability in countries and globally.

Achieving progress towards sustainable agriculture is an integral part of the 2030 SDG Agenda. The vision for a sustainable agriculture is articulated in the SDG 2, Target 2.4: “By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.” SDG indicator 2.4.1 “proportion of agricultural area under productive and sustainable agriculture” addresses specific components of Target 2.4, with a focus on socio-economic and environmental dimensions of farms, monitored through a framework of eleven sub-indicators using a dashboard approach, meant to measure progress in farms across selected relevant themes and then aggregate results at national level (FAO, 2020).

It is well recognized, and initial data collection efforts confirm, that SDG 2.4.1 data collection, analysis and reporting of sufficient quality and quantity to enable global and regional monitoring will not materialize before 2025 as data is currently scarce and statistical systems at country level must be strengthen in order to produce the data needed for the compilation of the indicators. While these important efforts continue in coming years, it becomes therefore critically and equally important to explore complementary approaches for assessing progress towards sustainable agriculture. In particular, they must be built on data that is already available in countries, providing comparable, robust and transparent information in support of regional and global storylines. The food and agriculture statistics already regularly reported by member countries to FAO and disseminated in FAOSTAT offer precisely such an opportunity. In this study of Progress Towards Sustainable Agriculture (PROSA), a suite of indicators of agriculture productivity and sustainability are derived from FAOSTAT in order to monitor specific aspects of Target 2.4 in close but not exclusive alignment with the principles of SDG 2.4.1. In particular, rather than focusing on the farm, PROSA focuses on agricultural land, its management and relevant changes over time at the national level.

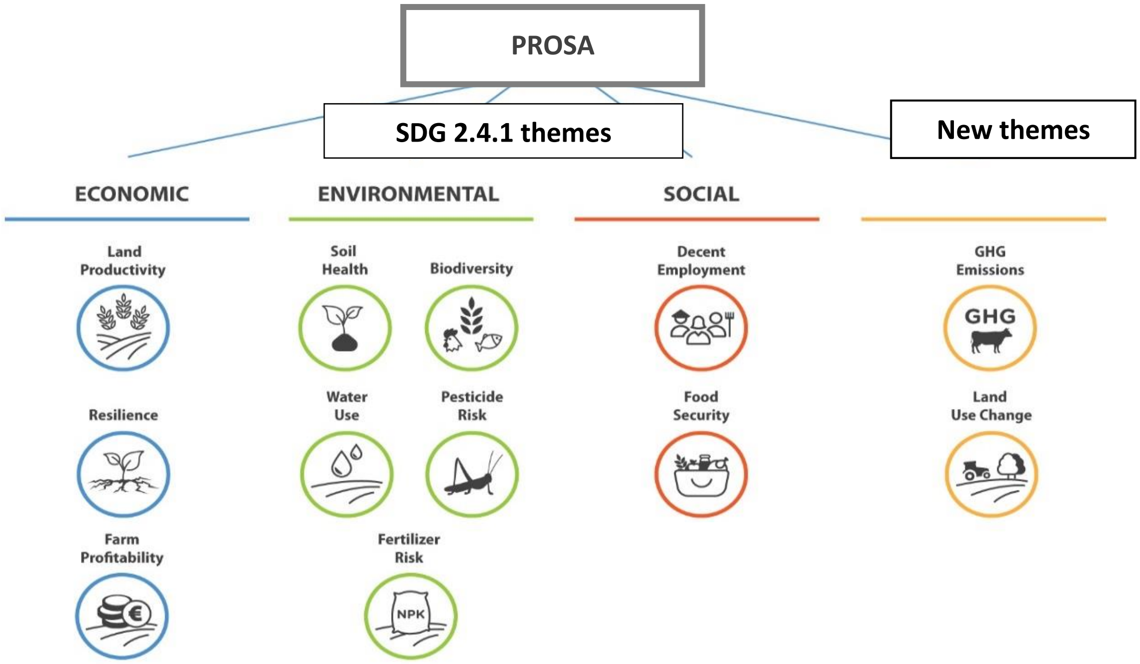
The outline of the next sections are as follows. Section 2 presents the methods underlying the selection of the PROSA indicators and their construction from national-level statistics. Methods for mapping four food systems typologies to countries are also presented. Section 3 presents results of each of the sixteen PROSA indicators, with time series over the period 1961–2018 (1990–2018 in some cases where only more recent data are available), with a discussion of the trends and their significance across the fours food systems groups used in the analysis. Section 4 introduces the traffic-light and dashboard methodology that allows to assign colours (red, yellow and green) to overall sustainability performance over time and by food system typology. Section 5 provides conclusions in terms of the significance of the efforts undertaken and recommendations for next steps in further strengthening monitoring of sustainable agriculture.

2. Methods

"Progress towards sustainable agriculture", PROSA, was developed as an indicators framework and dashboard analysis tool for assessing sustainability status of agriculture in countries, across relevant socio-economic and environmental dimensions. PROSA was developed in collaboration with internal and external experts and through a transparent and robust process of consultations that took place over the extended period 2018–2020. The approach chosen and implemented for PROSA from the very beginning was first and foremost one of integration of the extensive methodological and pilot-testing work that had been undertaken worldwide, under FAO coordination, for the development of the monitoring framework and dashboard approach of indicator SDG 2.4.1 on "proportion of agricultural area under productive and sustainable agriculture". SDG 2.4.1 aims at monitoring the relevant socio-economic and environmental dimensions of agriculture, across eleven themes, through eleven sub-indicators defined and monitored at the level of farms, with crop and livestock production systems being the monitoring scope of the SDG indicator (FAO, 2020). As pointed out in the introduction, the PROSA approach does not intend to replace the need to collect the SDG 2.4.1 indicators as defined in its methodological document. It intends to complement it by providing a first glance on the status of progress towards sustainable agriculture taking advantage of the range of statistics readily available at national level. In this sense, the measurement boundaries of PROSA were instead set directly at country level. Additionally, the scope of PROSA extended beyond the farm gate, to include dynamics of relevance to sustainability, but out of scope or not covered in SDG 2.4.1, such as land use change issues and climate change dimensions.

To this end, ten of the eleven sustainability themes tracked under SDG 2.4.1 were retained conceptually by PROSA, with two more added, to capture land use and climate change dimensions relevant to sustainability (Figure 1).

Figure 1. The multiple thematic dimensions of sustainable agriculture and agri-food systems in PROSA



Source: FAO, 2021.

2.1 PROSA Indicators

As a result of the above process, sixteen indicators were chosen for the PROSA framework for tracking sustainability in agriculture at national level, across thirteen themes. We next provide a detailed discussion of each indicator, including their FAOSTAT source and underlying data processes, with a mapping against the original SDG 2.4.1 framework and themes. The sixteen PROSA indicators fit within a traffic light and dashboard approach, discussed in the next section.

The *economic dimensions* were captured within the themes of l*and productivity*, *farm profitability* and *resilience*. Trends in productivity and profitability were monitored using the following indicators:

1. Land Productivity: Gross value of production per agricultural land (constant 2004–2006 I$/ha);
2. Farm Profitability: Gross value of production per worker (constant 2004–2006 I$/cap);
3. Resilience 1: Credit per rural population (USD/cap); and
4. Resilience 2: Value of production diversification index (%).

Land productivity was captured by the gross total value of crop and livestock production per unit land, representing in essence a yield expressed in monetary terms. At national level it was computed as the ratio of "gross index value for agriculture" from the FAOSTAT Production Indexes (http://www.fao.org/faostat/en/#data/QI, 1961–2018) to "agricultural land" area from the FAOSTAT Land Use domain (http://www.fao.org/faostat/en/#data/RL, 1961–2018). As discussed below with respect to the dashboard, PROSA interprets negative changes as an indication of poor sustainability.

Farm profitability was monitored via the gross total value of crop and livestock production per worker. At national level it was computed as the ratio of "gross index value for agriculture" defined above to "Employment in agriculture" numbers from the FAOSTAT Employment Indicators domain (http://www.fao.org/faostat/en/#data/OE, 1961–2018). Similarly to the above indicator, PROSA interprets negative changes as an indication of poor sustainability.

Limitations in both indicators above is the use of gross versus net production values, i.e. costs are not included. While this is not an issue for the productivity indicators, where monetary value is used merely as a straightforward way to aggregate physical yields of widely different commodities, it is a significant limitation in terms of profitability indicators, since the latter is clearly dependent on a balance between gross income and costs, which must be assumed to remain fairly proportional to income in order for the trends assessed to be meaningful.

Economic Resilience was monitored in terms of credit to agriculture per rural population and as an index of diversification of agricultural production.

Credit to agriculture per rural population was measured through the flow of financial capital in support of production. At national level it was computed as the ratio of "credit to agriculture" from the FAOSTAT Credit to Agriculture domain (http://www.fao.org/faostat/en/#data/IC, 1991–2018) to "Rural population" numbers from the FAOSTAT "Population" domain (http://www.fao.org/faostat/en/#data/OA, 1991–2018). PROSA interprets negative changes over time as an indication of poor sustainability.

The *Diversification Index* captures the risk of agricultural production arising from the basket of commodities produced. At national level it was computed as the Gini coefficient relative to the gross production value of all crop and livestock commodities in a country, taken from the FAOSTAT Production Indexes (http://www.fao.org/faostat/en/#data/QI; 1961–2018). PROSA interprets negative changes over time as an indication of poor sustainability.

The *social dimensions* were monitored via the themes of *decent employment* and *food security,* and monitored via the following indicators:

5. Decent employment: Value added per worker (constant 2005 USD/cap)
6. Food Security: Prevalence of undernourishment (%)

Decent employment was measured via average income, expressed as agricultural value added per worker. At national level it was computed as the ratio of "agriculture value added" from the FAOSTAT Macro Indicators domain (http://www.fao.org/faostat/en/#data/MK, 1970–2018) to "Employment in agriculture" numbers from the FAOSTAT Employment Indicators domain (http://www.fao.org/faostat/en/#data/OE, 1970–2018). Similarly to all previous cases, PROSA interprets negative changes as an indication of poor sustainability.

Food security was measured via the Prevalence of Undernourishment indicator (PoU), computed as a function of food availability against population caloric needs. At national level it was computed as the "PoU" indicator from the FAOSTAT Food Security Suite of Indicators domain (http://www.fao.org/faostat/en/#data/FS, 2000–2018). PROSA interprets zero to positive changes as an indication of sustainability.

The underlying concepts of the previous six indicators are that socio-economic sustainability can be positively linked to credit to local populations and diversification of crop and livestock production values, decent pay and food security.

The *environmental dimensions* were monitored via themes on *soil health; water use; fertilizers risk*, *pesticides risk*, *biodiversity*, *GHG emissions* and *land use change*. These seven themes were captured by ten indicators, covering soil and water pressures, chemical inputs and biodiversity, aligned with the SDG 2.4.1 framework, plus indicators of land use change and greenhouse gas emissions, addressing components of SDG Target 4 (Goal 2) that were not covered by SDG 2.4.1. Trends is soil and water quality and pressure were monitored using indicators of soil nutrient balances per hectare, water productivity and fertilizer and pesticides application rates. Relevant biodiversity and climate change trends were monitored instead via indicators of crop and livestock species diversification, agricultural and forest land use change, and greenhouse gas emissions, the latter both in absolute terms as well as expressed as per unit production. The underlying concepts are that environmental sustainability can be positively correlated with low soil and water pressure, high crop and livestock diversity, low land use changes and a reduction in greenhouse gas emissions. The individual indicators are described in more detail below:

7. Soil health: Soil Nitrogen Balance (kg N/ha)
8. Water Use: Water productivity (constant 2004–2006 I$/m^3)
9. Fertilizers risk: Synthetic fertilizer use per area of cropland (kg N/ha)
10. Pesticides Risk: Pesticides use per area of cropland (kg/ha)
11. Biodiversity 1: Crop diversification index (area harvested) (%)
12. Biodiversity 2: Livestock diversification index (%)
13. GHG emissions: Emissions of agriculture per production value (kg CO_2eq/constant 2004–2006 I$)
14. Emissions intensity of beef (kg CO_2eq/kg meat)
15. Land use change: Agricultural land use change (ha yr^{-1})
16. Land use change: Forest land use change (ha yr^{-1})

Soil Health was captured by the so-called soil nitrogen load, representing the balance between amounts of nitrogen (synthetic and organic) added to and exported from the soil by crop and livestock production processes. At national level it was derived from the FAOSTAT Soil nutrient balance domain (http://www.fao.org/faostat/en/#data/ESB; 1961–2018). PROSA interprets changes away from an equilibrium reference level (defined in the next section) as an indication of poor sustainability.

Water Use was captured by an indicator of water productivity, evaluating crop production per unit irrigation water used. At national level it was taken directly as the water productivity (constant 2004–2006 I$/m^3) of the AQUASTAT database (http://www.fao.org/aquastat/statistics/query/results.html, 1990–2018). PROSA interprets positive changes as an indication of improved sustainability.

Fertilizers Risk was captured by fertilizer use intensity, computed at national level as the ratio of fertilizers use in agriculture per unit cropland and taken directly from the FAOSTAT Fertilizers Indicators domain (http://www.fao.org/faostat/en/#data/EF, 1961–2018). PROSA interprets shifts away from a reference equilibrium level (discussed below) as an indication of decreased sustainability.

Pesticides Risk was captured by pesticides use intensity, computed at national level as the ratio of total pesticides use in agriculture per unit cropland and taken directly from the FAOSTAT Fertilizers Indicators domain (http://www.fao.org/faostat/en/#data/EP, 1961–2018). PROSA interprets shifts away from a

reference equilibrium level (discussed in the dashboard section below) as an indication of decreased sustainability.

Biodiversity was captured in terms of crop and livestock diversification indexes, computed at national level as the Gini coefficients estimated from the distribution of harvested area by crop species and animal numbers by species, taken from the FAOSTAT Crop production domain (http://www.fao.org/faostat/en/#data/QC, 1961–2018) and livestock production domain (http://www.fao.org/faostat/en/#data/QA, 1961–2018), respectively. PROSA interprets positive changes as an indication of improved sustainability.

Climate Change impacts were captured in terms of GHG emission and land use change indexes., At national level, GHG indicators used for monitoring were: i) the GHG intensity of agriculture, defined as the ratio of total emissions from within the farm gate, taken from the FAOSTAT Emissions-Agriculture domain (http://www.fao.org/faostat/en/#data/GT, 1961–2018) to agriculture value added, taken from the FAOSTAT Macro Indicators domain (http://www.fao.org/faostat/en/#data/MK, 1970–2018); and ii) the GHG intensity of beef, defined as the ratio of total beef production, taken from the FAOSTAT Livestock Primary domain (http://www.fao.org/faostat/en/#data/QL, 1961–2018) to total emissions from cattle, taken from the FAOSTAT Emissions-Agriculture domain (http://www.fao.org/faostat/en/#data/GT, 1961–2018). PROSA marks decreases in both indicators as improved sustainability.

Finally, *Land Use Change,* a measure of both climate and biodiversity impacts, were captured in terms of agricultural and forest land use changes. At national level, the were computed as differences across times of agricultural land and forest land statistics, both taken from the FAOSTAT Land Use domain (http://www.fao.org/faostat/en/#data/RL, 1961–2018) PROSA marks decreases in forest land area and increased in agricultural land area as indicators of reduced sustainability.

2.2 PROSA Traffic Light Assessment and Dashboard

Each of the sixteen PROSA indicators was analysed in terms of their trends over time (in this work: 1961–2017). A traffic light and dashboard approach was implemented, directly applying the methodology of SDG 2.4.1 while making necessary modifications, as follow. First, for each country, we assigned qualitative parameters (i.e. the traffic-light colours: red, yellow and green) to each of the sixteen PROSA indicators. Traffic-light colours were assigned at national level based on indicator trends, as follows:

i. Gains (i.e. positive differences in indicator values between two time periods) were assigned yellow on the first time period; then green if maintained in the successive time period. Decreases between two successive periods were always assigned red.

ii. For three indicators with an assigned physical threshold (soil balance, fertilizers and pesticides), traffic light colour assignment was the same as above for indicator values below the threshold. It was however reversed for indicator values above it. Three specific bio-

physical thresholds were used, as follows: i) Soil N Balance = 5 kg N/ha;[1] ii) Fertilizers = 50 kg N/ha;[2] Pesticides = 1.25 kg active ingredient/ha[2]

The simple rules above were tested extensively against the outcomes of more sophisticated approaches. The latter included ranking indicator values and colour assignment depending on absolute value and growth rates of global and regional metrics, using either means or median and their trends; using standard deviations or quartiles distributions, as appropriate. Dashboard results generated with the more sophisticated methods were similar to those determined with the simple approach above (not shown). The simple rules method was therefore chosen for use in PROSA, having the added advantage that its outcome depended exclusively on within-country dynamics, rather than on regional and/or global trends.

In SDG 2.4.1, as discussed, the unit of measurement is the farm. Traffic light colours are assigned to each farm, with results aggregated at national level by using farm agricultural area as a scaling factor. The resulting colour distribution per indicator represents a national sustainability dashboard. Conversely in PROSA, the unit of measurement being the country, a dashboard can only be constructed at the level of regional aggregates, using national agricultural area as a scaling factor. Independently of the regional criteria chosen, it should be highlighted that while in SDG 2.4.1., the agricultural area of the farm may not sum up to total national agricultural area, since by construction it lacks common grazing areas (FAO, 2021), the advantage of using national level data in PROSA is that all of the national agricultural area is covered, and hence the underlying analysis of sustainability is consistent with the land use matrix of any given country as well as at regional and world level.

For regional aggregation, the PROSA methodology employs specifically derived country groups, based on the four agri-food systems typologies defined by the High Level Panel of Experts of the Committee on Food Security (HLPE, 2017): *traditional, land-intensive mixed, capital-intensive mixed, and modern agri-food systems*. While the HLPE provides only qualitative descriptions of these groups, substantial analytical work was undertaken by PROSA to associate countries against the four agri-food system categories. Countries are grouped based on factor productivities and relative intensities within agriculture – namely for land, labour and capital – to account for differences in agricultural production. Based on well-established quantitative methods using national data, four country groups emerge according to factor productivities and relative factor endowments, and these groups are the typologies referred to in this paper. In Figure 2, a map shows the country agri-food systems groups derived and used in PROSA.

With this mapping in place, the PROSA dashboard could thus be easily constructed by aggregating traffic-light colours by indicator and country, and scaling to the relevant agri-food system group by using country agricultural land area. In this way the dashboard approach of SDG 2.4.1 is applied to countries instead of to individual farms, but still using agricultural land area as scaling factor.

The statistical trend analysis of the PROSA indicators is the basis for quantified storylines that allows for a first understanding of how sustainability indicators may evolve over time, including how they may be

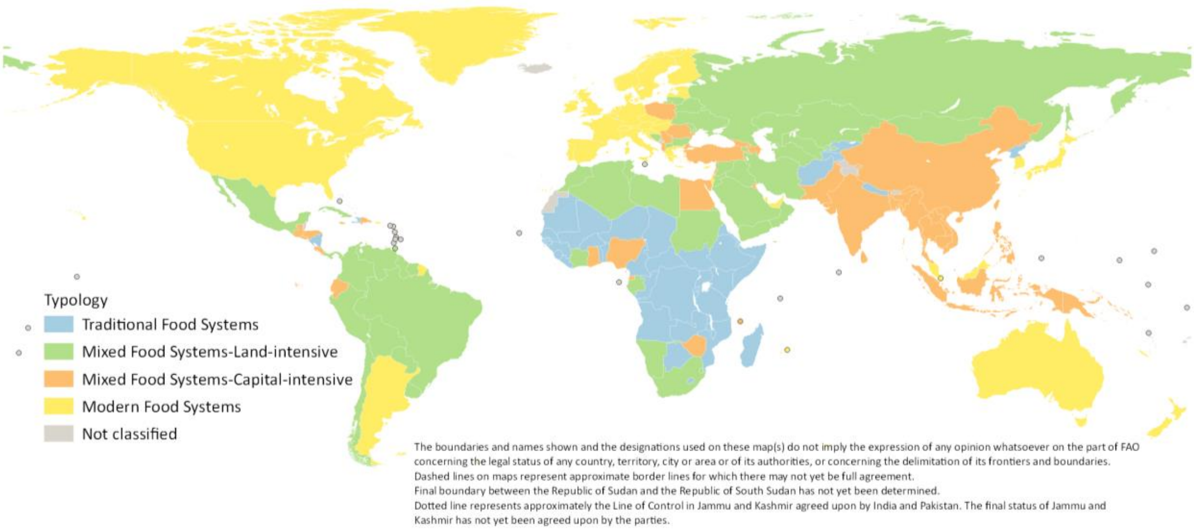
---

[1] Thresholds correspond to a zero balance on cropland soil nutrient inputs and outputs (e.g. chemical and organic applications, N exports in crop products), net of background atmospheric deposition rates (Zhang *et al*., 2021).

[2] Thresholds were based on global median application values per hectare of cropland. These values were consistent to those indicated as safe application thresholds in relevant literature (e.g. FAO, 2019a)

related to each other directly or through common drivers. The dashboard approach, though qualitative by its nature, further adds value by facilitating a first aggregate analysis of the indicators in terms of their contribution to sustainability, in other words by offering a "bird's eye" coherent view within and across agri-food systems typologies.

Figure 2. Country mapping to HLPE agri-food systems group derived and used in PROSA



Source: FAO, 2021.

Table 1. PROSA themes and indicators

Dimension	PROSA INDICATOR	FAOSTAT Source	Data Process
Economy	1. Gross value of production per agricultural land (constant 2004–2006 I$/ha)	Producer Prices Land Use	Official data/collected by FAO Official data/collected by FAO
	2. Gross value of production per worker (constant 2004–2006 I$/cap)	Macro-Indicators Employment Indicators	Official data/collected by UNSD/OECD/EUROSTAT Official data/collected by ILO
	3. Credit per rural population (USD/cap)	Credit to agriculture Population	Official data/collected by UNSD/OECD/EUROSTAT Official data/collected by World Bank
	4. Value of production diversification index (%)	Macro-Indicators	Official data/collected by UNSD/OECD/EUROSTAT
Social	5. Agriculture value added per worker (constant 2005 USD/cap)	Employment Indicators	Official data/collected by ILO
	6. Prevalence of undernourishment (%)	Food Security Indicators	Estimated by FAO. Based on official production and trade data collected by FAO and used as input into an internationally approved methodology – i.e. the Food Balance Sheets and Prevalence of Undernourishment calculations.
Environment	7. Soil Nitrogen Balance (kg N/ha)	Soil Nutrient Budget	Estimated by FAO. Based on official production and input data collected by FAO and used as input into an international methodology – i.e. OECD/EUROSTAT Guidelines on soil nutrient balances.
	8. Water productivity (constant 2004–2006 I$/$m^3$)	AQUASTAT (separate from FAOSTAT)	Official data/collected by FAO
	9. Synthetic fertilizer use per area of cropland (kg N/ha)	Fertilizers Indicators	Official data/collected by FAO
	10. Pesticides use per area of cropland (kg/ha)	Pesticides Indicators	Official data/collected by FAO
	11. Crop diversification index (area harvested) (%) 12. Livestock diversification index (%)	Production, Crops Production, Live Animals	Official data/collected by FAO Official data/collected by FAO
Climate Change Impacts	13. Emissions of agriculture per value of production (kg CO_2eq/constant 2004–2006 I$)	Emissions Agriculture Macro-Indicators	Estimated by FAO. Based on official production and land use data collected by FAO and used as input into an internationally approved methodology – i.e. the Guidelines of IPCC. Official data/collected by UNSD/OECD/EUROSTAT
	14. Emissions intensity of beef (kg CO_2eq/kg meat)	Emissions Intensities	Estimated by FAO. Based on official production and land use data collected by FAO and used as input into an internationally approved methodology – i.e. the Guidelines of the IPCC.
	15. Agricultural land use change (ha) 16. Forest land use change (ha)	Land Use	Official data/collected by FAO

Source: FAO, 2021.

3. Results

This section analyses and discusses progress towards sustainable agriculture across four food systems production typologies: Traditional, Land-intensive and Capital-intensive Mixed Systems, and Modern (HLPE, 2017). Progress is analysed in terms of the PROSA traffic-light dashboard, which helps to synthesize individual trends of sixteen sub-indicators spanning four themes across socio-economic and environmental pillars, including climate change. In the pages that follows, we first present detailed statistical trends of the main-sub-indicators that emerged as critical across the overall PROSA analysis, and then provide synthesis results through the PROSA Dashboard.

3.1 Socio-economic indicators

3.1.1 Steady progress in productivity and profitability across food systems

Land productivity and farm profitability measure, respectively, the biophysical and economic efficiency with which farmers take advantage of the agri-climatic endowment of their land, and maximize its output through appropriate use of inputs, labour and capital (Campanhola and Pandey, 2019). There are clear relationships between productivity and profitability with sustainability dimensions across a range of drivers, including mechanization and land size distribution, income and gender equality, which hold to varying degrees across the four food systems typologies considered herein. Accessibility to credit in agriculture also depends on many of these same drivers.

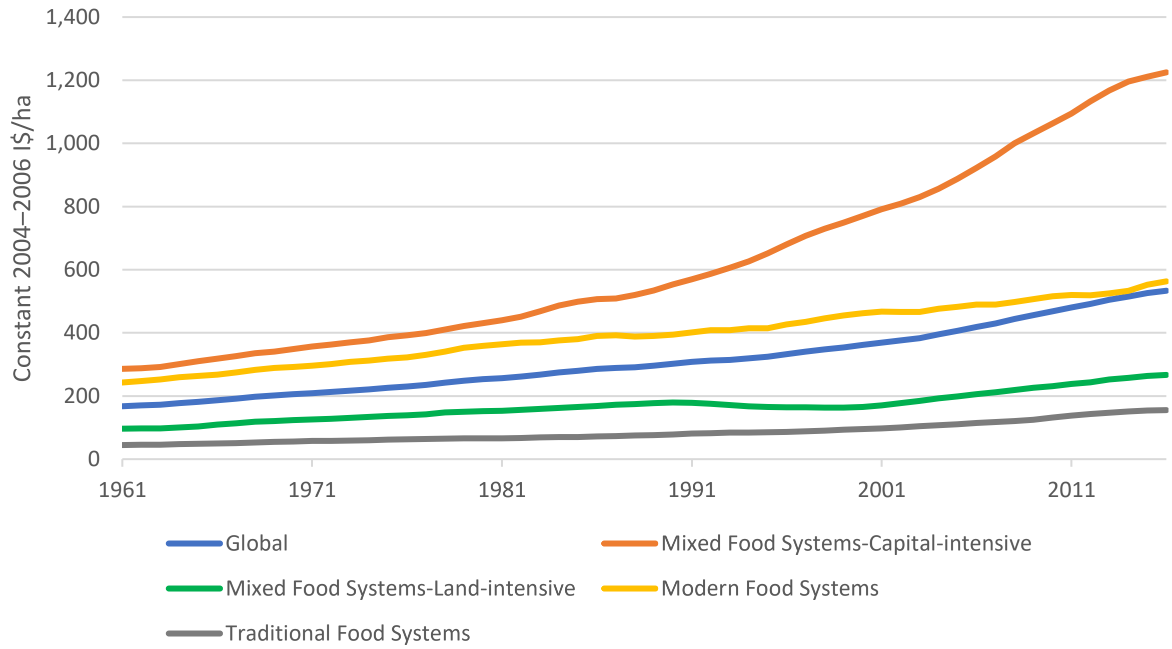
Low agricultural productivity may be associated with an unequal distribution of land and income.[3] In countries where a large share of the population derives a livelihood from agriculture, income inequality is in fact highly correlated with inequality in land size holdings. In turn, the size and level of mechanization of a farm influences land productivity, in addition to profitability and environmental impacts, depending on the technologies and inputs applied. At low levels of farm size, when most of the available agricultural land is held by a minority of landowners, land productivity is generally lower than in places of similar farm sizes where agricultural land is more evenly distributed.[4] Although large holdings tend to rely on low paid and temporary labour, the benefits of increased mechanization allow for increased labour profitability. At the same time, in countries with relatively smaller and more evenly distributed land size holdings, the use of family labour is more widespread, leading to lower supervision costs and higher incentives to produce.

Land productivity and profitability increased consistently over the period of study across all food systems typologies (Figure 3.1). Productivity increased nearly three-fold globally since the 1960s, from 190 to 520 constant 2004–2006 I$/ha, ranging between two and four-fold for the different typologies, with Capital-intensive mixed food systems and modern food systems representing the highest and the lowest growth in the range. With respect to the most recent decade, it grew at 1 percent per annum in modern food systems, and at 3 percent in Traditional food systems. For the latter group, productivity tripled since the 1960s, though it remains today still below the 1960 global mean. Indeed, the gap between traditional

[3] Dietrich Vollrath, Land Distribution and International Agricultural Productivity, *American Journal of Agricultural Economics*, Volume 89, Issue 1, February 2007, Pages 202–216, https://doi.org/10.1111/j.1467-8276.2007.00973.x
[4] Gollin, D. 2019. Farm size and productivity: Lessons from recent literature. IFAD Research Series, (34), 1-35.

systems and the other typologies increased over time, especially in comparison to capital-intensive mixed systems.

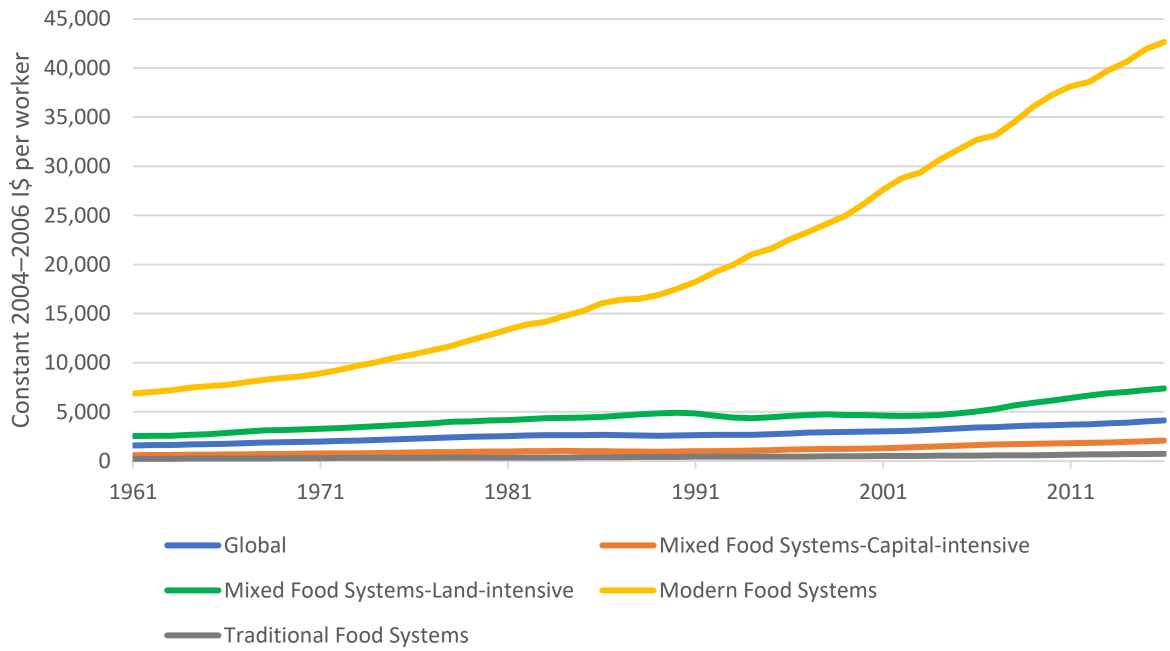
Figure 3.1. Land productivity – Gross production value per agricultural area



Source: FAOSTAT Employment indicators, 2019.

At the same time, farm profitability (Figure 3.2) more than doubled globally since the 1960s, from about 1 800 constant 2004–2006 I$/cap to nearly 4 000 constant 2004–2006 I$/cap of agricultural worker. Modern food systems showed the strongest trends and highest values (41 000 constant 2004–2006 I$/cap), reflecting trends in replacement of labour through mechanization and consistent improvements in technological inputs, leading to very high levels of farm profitability. Conversely, use of abundant labour, scarcity of capital and use of older technologies explained the wide gap observed between this group and the other typologies, for which profitability ranged from 700–7 000 constant 2004–2006 I$/cap in the most recent decade. Improvements in farm profitability will be an important component of improved sustainability in all other typologies. Indeed, and despite these differences, production efficiencies and profitability began to convergence over time, with growth rates in the last decade in the range 2–4 percent per annum across typologies, and highest in land-intensive mixed food systems.

Figure 3.2: Net production value per agricultural worker



Source: FAOSTAT Employment indicators, 2019.

The dashboard analysis (see last section of this report) shows that these sub-indicators progressed consistently across all food systems considered herein, with overall trends in economic growth in the last two decades impacting positively on land use efficiencies and farm incomes. In the time series analysed, they show continuous growth trends, with an increasing number of countries within each typology exhibiting growth sustained over the two most recent decades.

3.1.2 Credit, wages, diversification and food security are key limiting factors

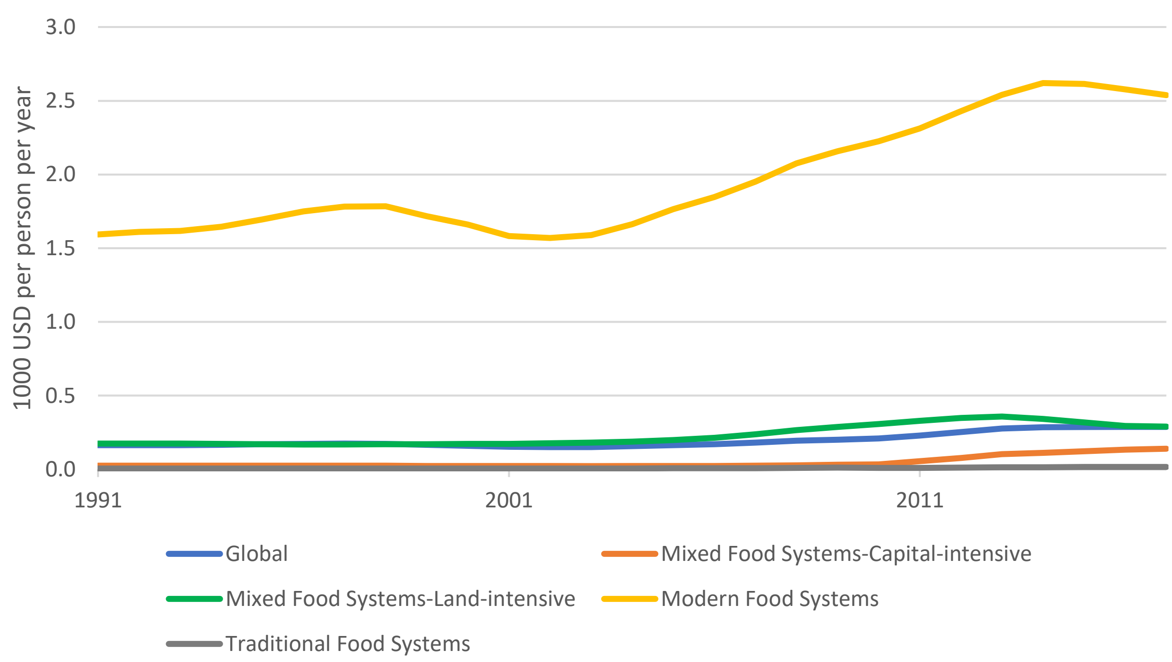
Agricultural credit is an important mechanism that facilitates the smooth running of agricultural holdings by allowing farmers to access the financial resources they need to grow their business. Used efficiently, credit can be used to secure the equipment and agricultural inputs (such as feed, seed, fertilizers, and pesticides) necessary to run a successful farm. It additionally serves as a safety net for farmers to buffer against loss of production and income linked to market or climatic events, for instance against hardships brought on by extreme events such as droughts and flooding. Although credit to agriculture, forestry and fishing has been on the decline since 1991 for most food system typologies as a share of total credit, it has largely increased on a per capita basis, with respect to the rural population.

Since the 1990s to present, credit to agriculture per worker (Figure 3.3) increased from 170–280 USD/cap, with values in the most recent decade highest in modern food systems (2 600 USD/cap) and lowest in traditional systems (20 USD/cap). These trends reflect our current understanding of the drivers of credit as a function of farm productions systems and depending on income and gender equality, land ownership dynamics and other critical factors (FAO, 2017). As for the other economic trends analysed earlier however, trends appear to converge in most recent decades, with the largest increase in credit per

worker, nearly five-fold since the 1990s, in Mixed Capital-intensive food systems. Significant though more moderate increases, e.g. ranging from 50 to 140 percent, were seen in the other food systems.

These trends highlight the need to secure additional sources of agricultural credit to close the disparity gap with respect to modern food systems and allow for the investments necessary to pursue the path towards increased sustainability. Closing the gaps requires addressing issues in unequal distribution of income and land in particular. In unequal societies, large shares of the population lack viable assets to use as collateral to access formal agricultural credit arrangements.

Figure 3.3. Credit to agriculture per capita of rural population

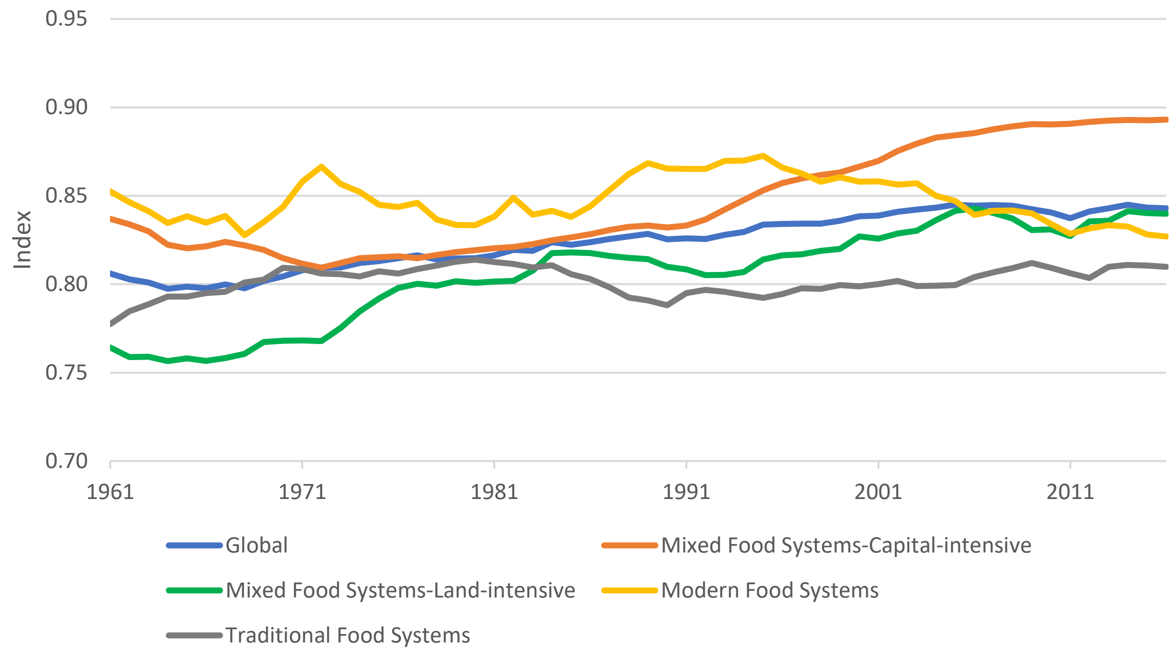


Source: FAOSTAT Credit to agriculture, 2019.

Gross output specialization measures the degree of diversification of farm incomes across crops and livestock commodities. High values (i.e. closer to unity) correspond to high market resilience, for instance in the face of price fluctuations. Conversely, low values indicate reliance on a smaller number of crops, hence potential exposure to fluctuations.

Gross output specialization (Figure 3.4) ranged 0.7–0.8 across food systems typologies over the period analysed. Both mixed food systems groups showed increases in recent decades, reflecting successful strategies to minimize impacts of market volatility while addressing growing demand for more diversified diets. Output value diversification remained rather stable in traditional food systems in most recent decades, whereas it decreased in modern food systems, signalling increasing reliance on large income volumes depending on few commodities. Farmers with large holdings tend to have agricultural production more oriented toward less diversified, commercial commodities significantly more than smaller farms, with increasing returns to scale.

Figure 3.4. Gross output specialization index

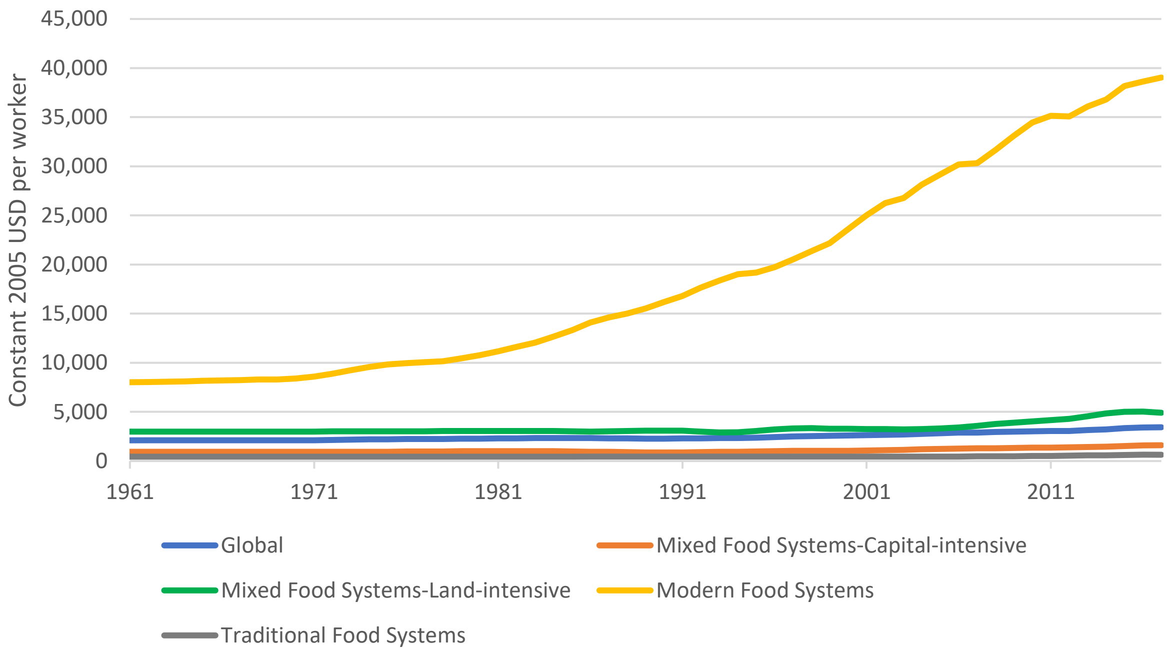


Source: FAOSTAT Value of agricultural production, 2019.

Mean national farm wages were estimated as agricultural value added per worker (Figure 3.5). Globally, farm wages grew over the 1961–2017 period considered, from 2 100 constant 2005 USD/cap to 3 300 constant 2005 USD/cap, at an average rate of 1.5 percent per annum. In line with trends in the economic indicators, wages in modern food systems were significantly larger and grew the fastest among food systems typologies, having increased nearly five-fold since the 1960s and reaching about 40 000 constant 2005 USD/cap. Wages were one order of magnitude lower in other food systems, with the highest wages in land-intensive systems (about 5 000 constant 2005 USD/cap) and the stronger growth (a doubling since the 1960s) in capital-intensive systems. Finally, though average wages increased very strongly in the most recent decade in Traditional systems, indicating similarly to other indicators a convergence across food systems groups, it remained at values well below the global average wages of the 1960s, indicating that much needs to be achieved to bridge the gap with modern systems.

The marked disparities in these statistics are known in the literature and reflect important differences in underlying drivers. For instance, the advances in mechanization on larger farms require less farm labour, leading to higher productivity, hence total farm output and wages per worker (Sims, Hilmi and Kienzle, 2016).

Figure 3.5. Agricultural value added per agricultural worker

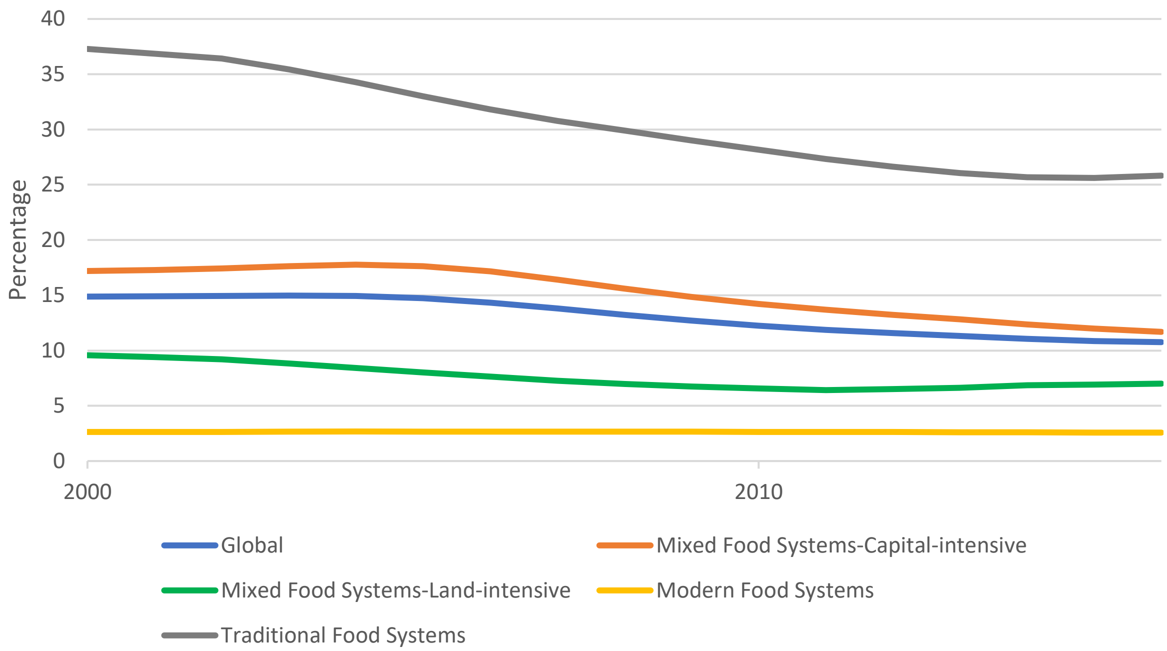


Source: FAOSTAT Employment indicators, 2019.

Statistics on the prevalence of undernourishment (PoU) indicate the share of the population at risk of hunger and malnutrition (FAO, IFAD, UNICEF, WFP and WHO, 2019). Globally, the PoU decreased by 20 percent from the 2000s to present (Figure 3.6), from 0.14 to 0.11. In the most recent decade, modern food systems had the lowest PoU (3 percent), followed by land-intensive mixed food systems (7 percent) and capital-intensive mixed systems (12 percent). Traditional food systems had the highest value (26 percent). While significant progress was made in recent decades, recent analyses have shown a slight increase in most recent years.[5] Addressing food security should be a key priority in order to make progress towards sustainability. Additionally, the analysis of these and the other socio-economic indicators show that food security is linked to improved productivity, including through increased use of agricultural inputs, increased credit to support technology improvements and farm profitability, and output diversification in both value and species, to manage risks from natural disasters and market volatility.

[5] See The State of Food Security and Nutrition in the World, http://www.fao.org/state-of-food-security-nutrition

Figure 3.6. Prevalence of Undernourishment



Source: FAOSTAT Suite of food security indicators, 2019.

3.2 Environmental indicators

3.2.1 Efficient use of inputs is key to productivity and profitability

Soil nitrogen balances (kg N ha^{-1}) provide information on the pressure that agriculture exerts on the environment, expressed as the balance between inputs (chemical and mineral fertilizers; livestock manure; green manure including crop residues and biological N fixation, plus atmospheric N deposition) and outputs (N exported in grains, vegetables and fruits) (Wang *et al.,* 2019). An excess in the balance drives nitrogen losses to the environment, including nitrates leaching to soils and water bodies, emissions of ammonia and greenhouse gases into the atmosphere (Hanqin *et al*., 2019). The dynamics of these pressure fluxes are complex, depending on the specific agro-climatic conditions prevailing in the country, and critically on specific spatiotemporal details within each country including weather, land management, etc. The soil nitrogen balance (SNB) is thus a simple proxy, which nonetheless allows for a first-order assessment of possible problems at national scale.

In terms of assessing this indicator, both its absolute value terms and growth patterns can be analysed. It is widely thought that a small positive balance is indicative of good soil health, since some of the inputs considered would also be present under natural, undisturbed conditions. A background balance of 5 kg N ha^{-1} is assumed herein, to represent known natural background deposition rates (Zhu *et al.,* 2019). Variations below or above this background can then be assessed as positive (moving towards the background) or negative (away from it).

The global mean SNB increased since the 1960s to present (Figure 2.7), from virtually 0 kg N ha^{-1} to about 9 kg N ha^{-1} at present. It passed the background balance in the mid-1980s and has remained above it since.

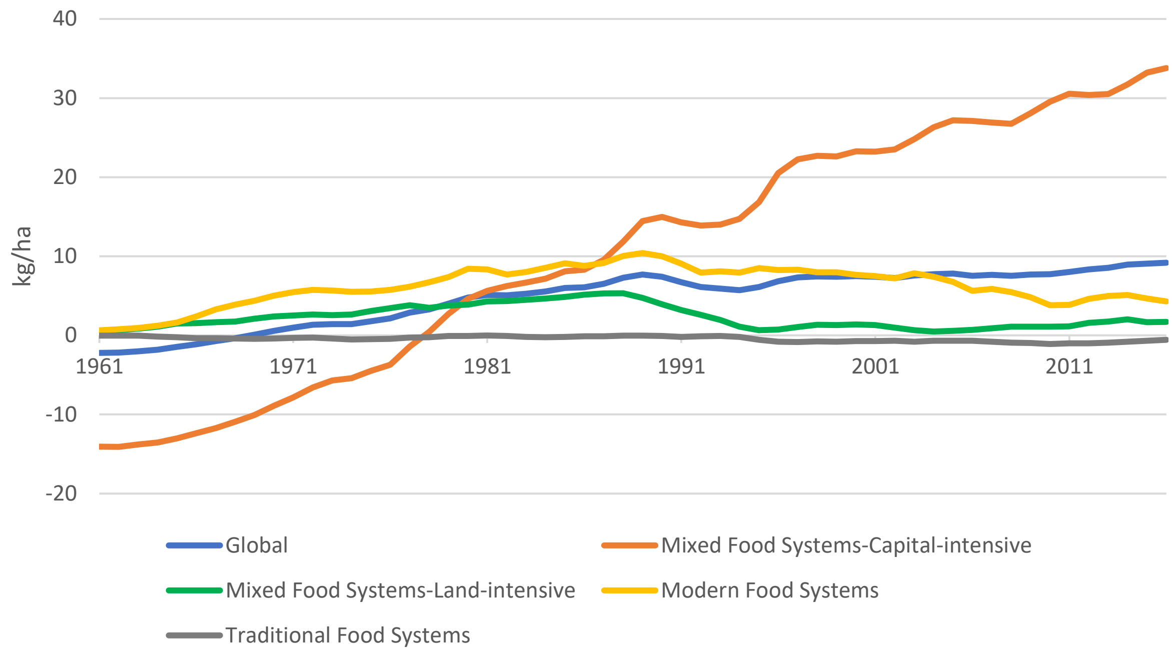
Increases in N pollution in soils and waters, as well as concomitant increases in greenhouse gas emissions from agricultural soils, are a testimony to the associated negative environmental impacts.

The largest value of SNB currently was observed in Mixed Food Systems-Capital-intensive countries, which also are characterized by the largest relative growth from the 1960s to present, i.e. from about -12 to 32 kg N ha^{-1}, with an increase since the 1970s of over 100-fold. This trend is consistent with the increased use of improved cultivars and synthetic fertilizers that characterized the green revolution, and which took place largely in the Asian countries that contribute to this food system typology. SNB balances in this country group were well above optimal levels starting in the 1980s and kept increasing away from it in following decades (negative performance). The high values computed for this group are consistent with its typology, especially considering that synthetic N applications constitute a significant feature of capital-intensive food systems.

Conversely, Mixed Food Systems-Land-intensive countries exhibit low levels of the SNB indicator, ranging 1–2 kg N ha^{-1} since the 1990s and growing between 2000s and the present decade (negative absolute values, slightly positive performance). It should be noticed that SNB values in this group were higher in previous decades (1960–1980), growing progressively until reaching 5 kg N ha^{-1} in the 1980s. The overall SNB dropped to less than half in the 1990s. A probable cause is the breakdown of the agricultural system in former USSR countries, which saw sharp reductions in fertilizer and manure use after 1992. The low values computed for this group are also consistent with the underlying typology, for which large areas of agricultural land are the most important component of the N balance.
Modern food systems countries exhibited a balance near the background, still higher than the values in the 1960s but importantly, half what they were in the 1980s (positive performance). The environmental performance of the last decade is positive, i.e. from about 6 to 5 kg N ha^{-1} from the 2000s to present. It can be noted that trends in SNB in this group were largely driven by trends in N inputs, and that the decrease towards more positive patterns observed is consistent with nitrogen regulations put in place in some regions starting in the 1990s, notably in the EU countries (Tubiello, 2019).

Finally, SNB values in Traditional Food Systems countries were very low, near 0 kg N ha^{-1} in all decades, indicating applications insufficient to sustain production trends. The countries in this group were characterized by low overall nitrogen application rates in general, and very low chemical and mineral fertilizers application rates in particular. In fact, SNB values at present were lower than in the earlier decades from 1960s to 1980s (negative performance). The negative values for the N balance in the Traditional systems is directly connected to insufficient applications of fertilizers inputs, especially synthetic fertilizers, needed to replace N loss from agricultural production.

Figure 3.7. Soil nutrient balance



Source: FAOSTAT Soil nutrient budget, 2019.

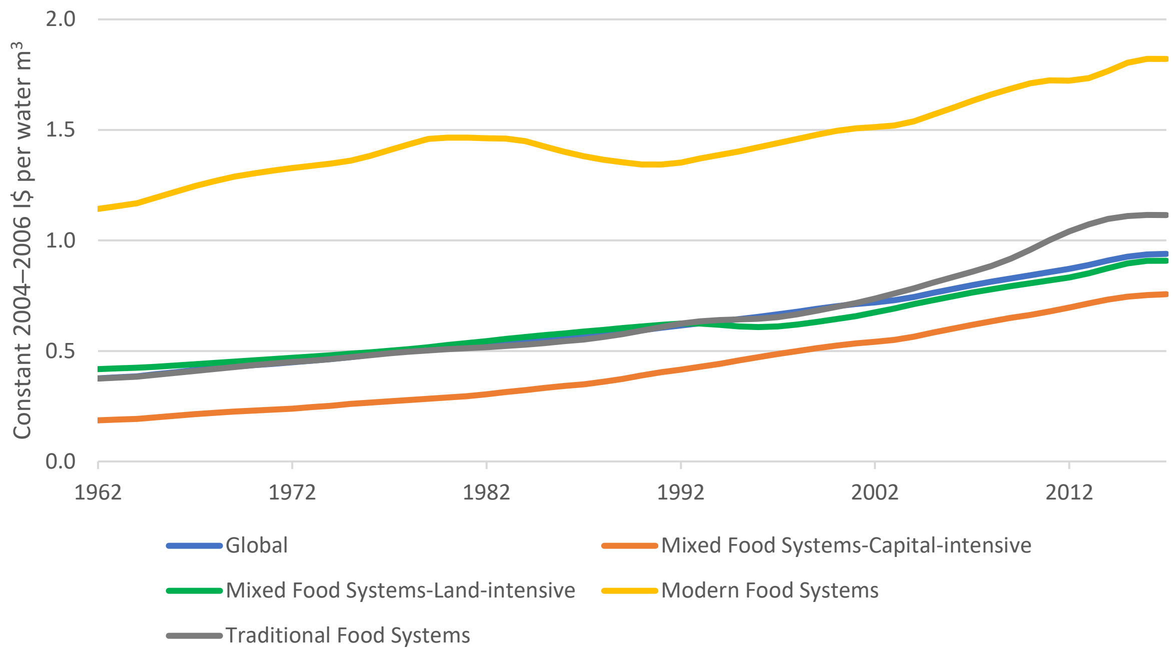
Agriculture is the largest water user in most countries, responsible for withdrawals of about 75 percent of available freshwater resources globally (FAO, 2011; Campanhola and Pandey, 2019). This is because water is a fundamental input for intensive crop production; irrigated fields provide currently about half of the global cereal grain production, on a mere 10 percent of cropland (FAO, 2019b, IPCC, 2019). As a result of past and current water use, water resources worldwide are being increasingly tapped, and irrigated field areas expanded, to keep up with ever-growing agricultural demands, with critical reservoirs becoming depleted in key production regions (FAO, 2011). In addition, water use increases leaching and runoff of nitrogen and other chemicals, as well as causes salinization in some areas, threatening soil and water quality, including in rivers and oceans, as well in reservoirs. Water use, both in terms of efficiency and quality, is an important aspect of sustainable agriculture. This analysis focuses on measures of economic water productivity, which track water use in agriculture in relation to income. While statistics on physical water flows and quality are needed to complement an analysis of progress based on this measure, data availability prevented their inclusion at this stage.

We thus consider herein progress towards sustainability based on water productivity, as the ratio of gross production value to water withdrawal for agriculture (constant 2004–2006 I$/m^3).

Trends in the indicator show that water productivity more than doubled globally since the 1960s (Figure 3.8), due to improvements achieved across all food system typologies. The largest gains were seen in capital-intensive and traditional food systems (nearly 3.5 and 2.5-fold increases, respectively). Land-intensive food systems showed more than a doubling in terms of efficiency, while modern food systems were characterized by more moderate increases.

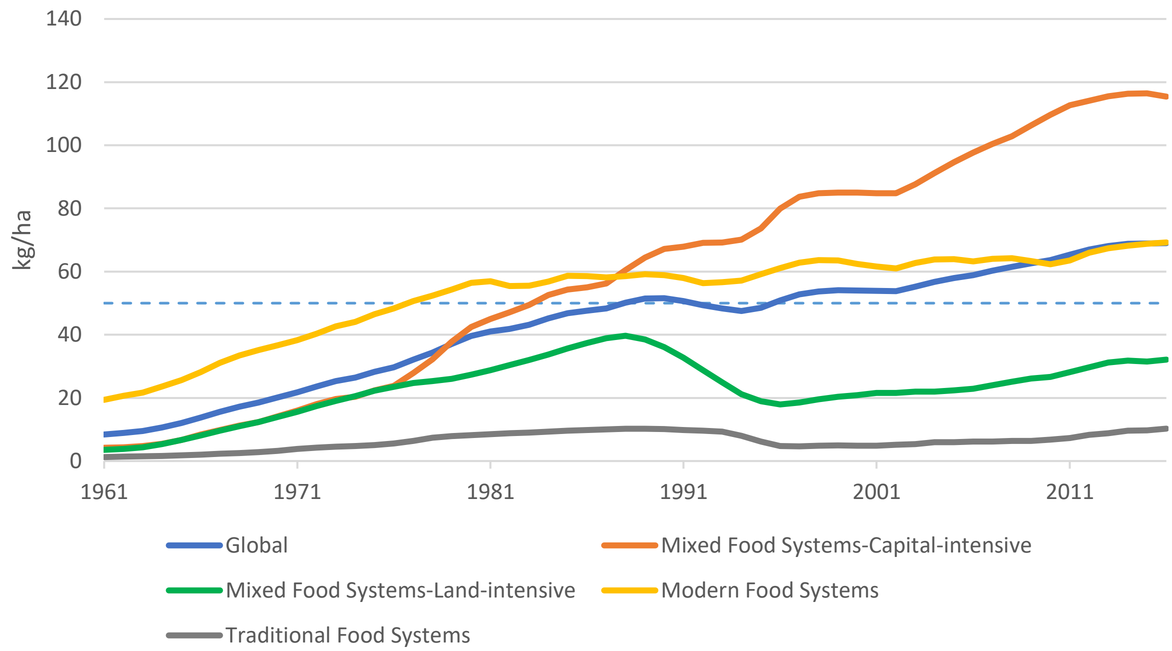
In the most recent decade, modern and traditional food systems exhibited the highest water productivities, above 1 constant 2004–2006 I$/m^3, compared to the other typologies. The high values achieved in modern systems can be related to similar trends in land productivity, for example they are the result of economies of scales due to advanced mechanization on large holdings. At the same time, the high water productivity in traditional systems may be related to locally adapted water use and conservation practices driven by water scarcity and a lack of access to irrigation water facilities, aimed at maximizing water use across a variety of landscapes and agro-climatic zones. There has been an increase in crop yield potential coupled with small changes in crop water uptake to increase water productivity of most grain crops (Sadras, Grassini and Steduto, 2012) - building on past documented trends in improved water use (FAO, 2011), further increases in recent decades were possible due to the land productivity increases seen in previous sections.

Figure 3.8. Water productivity



Source: AQUASTAT, 2019.

Figure 3.9. Synthetic nitrogen use per hectare of cropland



Source: FAOSTAT Fertilizers indicators, 2019.

While an analysis based on SNB assesses soil health in relation to sustainable use of fertilizer inputs within a given production system, pollution risks may be expressed in terms of use of synthetic fertilizer on cropland (kg N ha^{-1}) (FAO, 2019a). Recognizing that fertilizer application levels depend on agri-environmental conditions and cropping systems adopted, this study nonetheless adopted a benchmark value (50 kg N ha^{-1}), obtained as the global median of national-level application rates in the most recent decade.

Fertilizer N use per cropland area (Figure 3.9) increased nearly 5-fold globally since the 1960s, from 15 to 69 kg N ha^{-1}. It grew fastest, by over twelve-fold, in capital-intensive mixed systems, reaching values well above the reference benchmark, to above 110 kg N ha^{-1} in the most recent decade. As already observed, significant use of synthetic fertilizers in capital-intensive mixed food systems reflects trends linked to the green revolution and the use of improved (and N demanding) crop cultivars in many Asian countries since the 1970s. Also, in modern food systems the use of synthetic fertilizers was above the reference benchmark, to nearly 70 kg N ha^{-1}, reflecting practices usually adopted in intensive, highly mechanized and poorly diversified production systems. Conversely, while increases in synthetic N rates were also strong in the other two food systems typologies (2–4-fold), the values in both traditional and land-intensive food systems were below the reference benchmark, indicating low pollution risk. The fastest growth, roughly 5.5 percent per annum, was observed in traditional food systems, albeit starting from a very low base, and currently at 10 kg N ha^{-1}, still below the global average levels of the 1960s. It is relevant to note that current synthetic N use in agriculture in traditional food systems countries, currently largely located in Africa, is at the same level that characterized capital-intensive, mixed food systems countries – largely located in Asia – in the 1960s, i.e. just prior to their development under the green revolution. The data in this analysis then support the view that renewed efforts towards adoption of improved cultivars,

coupled with increased and more efficient use of fertilizers, are needed in those countries, in order to spur progress towards sustainable agriculture.

3.2.2 Agro-biodiversity and resilience are enhanced in traditional food systems

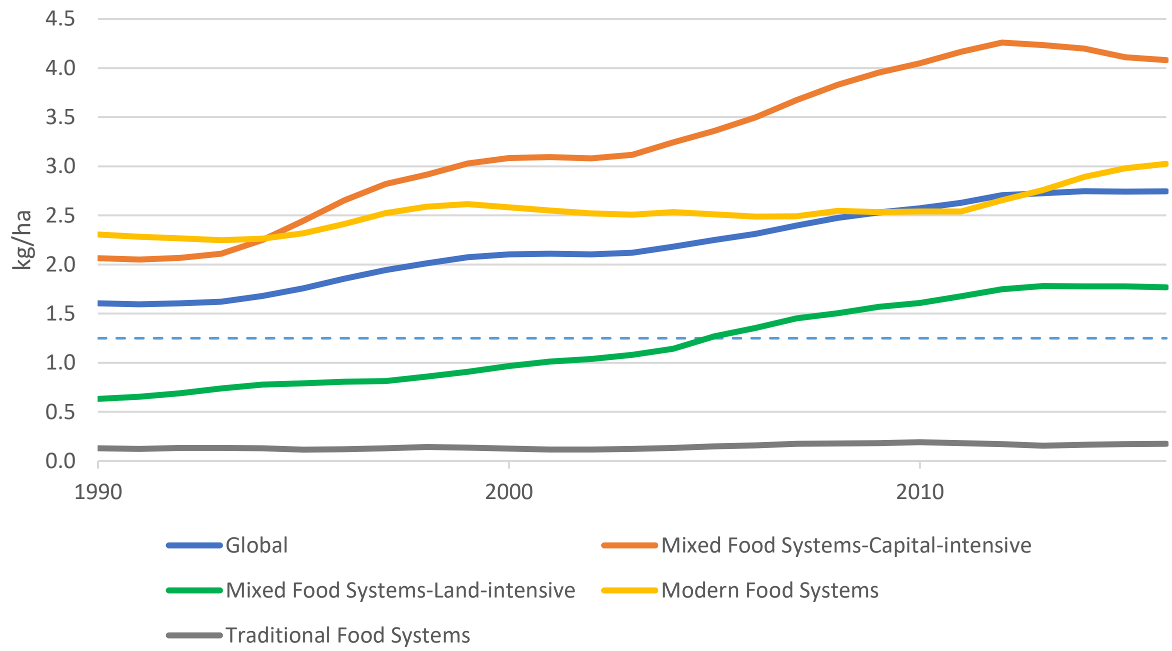
Pesticide risk, in relation to the impacts that chemically active ingredients may have on ecosystems, animal and human health is a complex issue that requires detailed analysis at farm and landscape level. Nonetheless, statistics of national-level total pesticides use in agriculture per cropland area (kg active ingredient ha^{-1}), can provide a useful proxy when the required more detailed information is lacking, enabling a first-order analysis including cross country or country-groups comparisons. As in the previous case of synthetic fertilizer N application, a reference benchmark level was introduced (1.25 kg ha^{-1}), based on the global median of the distribution of national values in the most recent decade.

This analysis indicates that global applications of pesticides per area of cropland (Figure 3.10) were already above the risk benchmark in the 1990s, and further increased to the most recent decade, from 1.9 to 2.7 kg active ingredients ha^{-1}.

Across food systems typologies, in the most recent decade, the largest application rates were in capital-intensive mixed food systems (4.2 kg ha^{-1}), well above the risk benchmark, double the rate characterizing land-intensive food systems, and nearly thirty times the rate in traditional food systems. Modern food systems, despite slow recent growth, had the second largest application rate (2.9 kg ha^{-1}). Application rates grew fastest in land-intensive mixed food systems, nearly doubling currently with respect to the 1990s, and slowest in modern food systems (+20 percent).

This analysis suggests close monitoring of pesticide use especially in land-intensive mixed food systems, considering that they apply pesticides over large holdings, and despite the fact that they currently exhibit the second lowest application rate among food system typologies. In these as well as in modern food systems, where application levels are above the risk threshold considered herein, progress towards sustainability will require use of integrated pest control management systems alongside more efficient use of chemicals, with a view to reduce the total amounts applied. Conversely, the extremely low levels (less than twenty times the risk thresholds) characterizing production in traditional food systems suggest that there is room for targeted increases in pesticides use. This could bridge the significant gap with other food systems typologies, while easily remaining well below the risk thresholds considered and thus maintaining the already good standings in this area of sustainability.

Figure 3.10. Pesticides use per ha of cropland



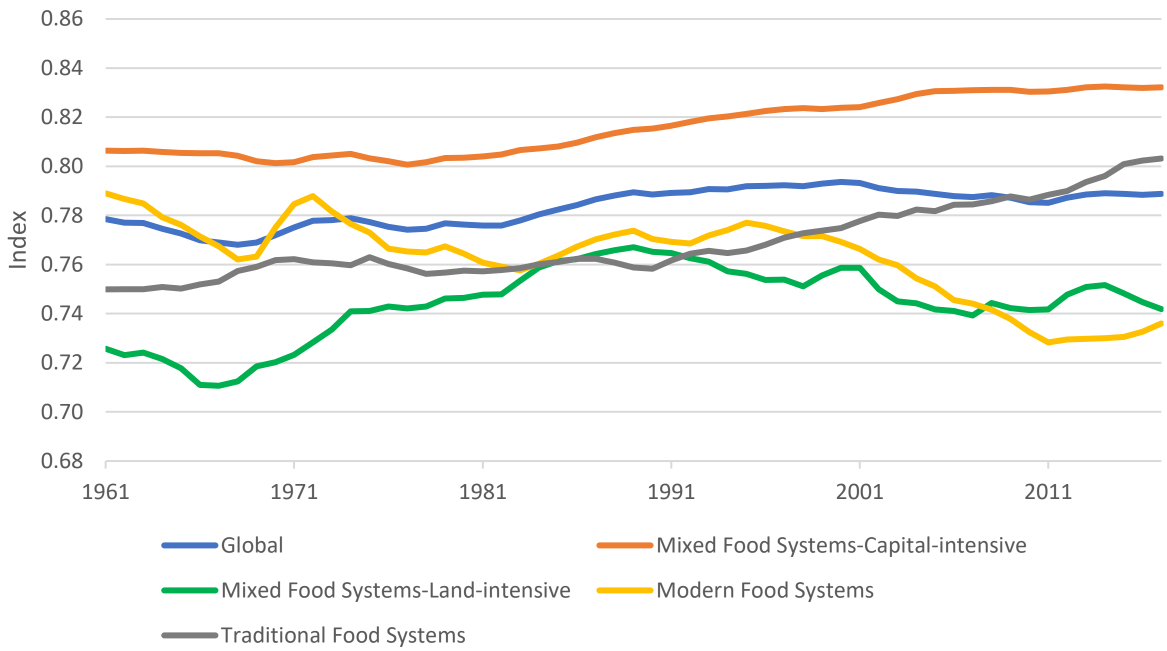
Source: FAOSTAT Pesticides indicators, 2019.

Crop and livestock species diversification increase resilience to climate extremes such as flooding and droughts, or to pest infestations and disease (Rosenzweig *et al*., 2019).

Globally, crop and livestock diversification slightly increased over time (Figure 3.11 and Figure 3.12), for instance for crops from about 77 percent to 79 percent. Capital-intensive mixed and traditional food systems exhibited the highest diversification levels. The former typology, having also high values of gross output specialization, showed in this analysis high resilience to both natural and market fluctuations. Traditional food systems were however characterized by low output specialization, suggesting that they produce many different crops, but that overall output value is skewed towards very few commodities, making these systems resilient to climate fluctuations but more exposed to market fluctuations. Increased access to credit, building on the agri-environmental resilience characterizing these systems, is one of the possible instruments to be considered in order to reduce market risks.

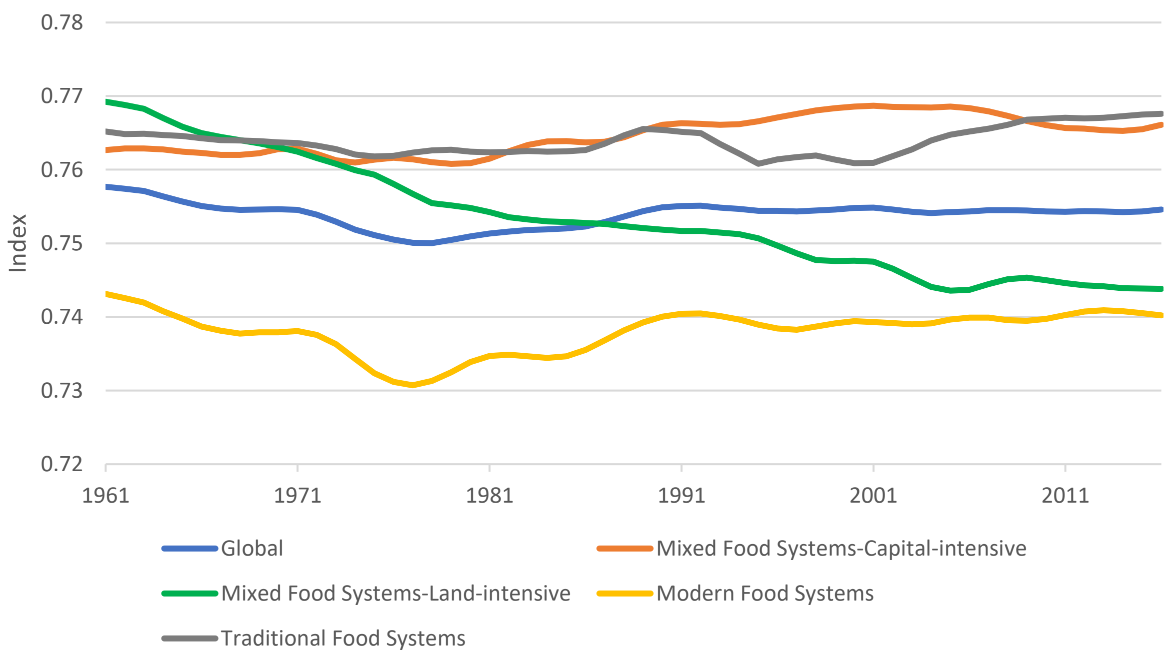
Land-intensive and modern food systems had lower diversification values, with declines in most recent decades. The low values indicate reliance on fewer crop species compared to the other groups. Coupled with moderate levels of gross output specialization, this analysis suggests high exposure to climate risks, possibly moderated by lower market exposure. Indeed, the cropland landscape in both systems s generally characterized by large holdings planted with a few dominant commodity crops of importance to global markets. Similarly, these systems saw progressive concentration of production on fewer livestock species, typically cattle. Progress towards sustainability in these food systems typologies will require increases in crop and livestock species used on the farm.

Figure 3.11. Crops diversification index



Source: FAOSTAT Crops, 2019.

Figure 3.12. Livestock diversification index



Source: FAOSTAT Livestock patterns, 2019.

3.2.3 Low emissions and efficient land use pathways

Crop and livestock production within the farm gate are a significant source of greenhouse gas (GHG) emissions, resulting in over 6 Gt CO_2eq annually, or 9–15 percent of total anthropogenic emissions (IPCC, 2019). These farm-gate emissions are dominated (about two-thirds of the total) by livestock, in the form of methane produced by ruminants and nitrous oxide from the decomposition of manure applied to or left on agricultural soils (Tubiello, 2019). Additional emissions are generated by the use of mineral and chemical fertilizers and by paddy rice cultivation. Finally, food related emissions may also be generated outside the farm gate in some countries. These emissions, which add approximately another 5 Gt CO_2eq annually to those within the farm gate, are linked to land use change activities, such as deforestation and peatland drainage, needed to clear land for crops and livestock (FAO, 2014).

GHG emissions from agriculture per gross output value of production (kg CO_2eq/constant 2004–2006 I$) is a useful indicator relating emissions to the underlying food production. Decreases over time indicate progress towards sustainability, as they are typically linked to increased efficiencies of production and economies of scale in the underlying commodities, and/or may arise from a shift to commodities that generate lower emissions.

Globally, emission intensity of agriculture decreased by 40 percent since 1960s (Figure 3.13), from 3.5 to 2.1 kg CO_2eq/constant 2004–2006 I$. This result underlines that the emission intensity of agriculture is currently double the emission intensity of the energy sector, which is roughly 1 kg CO_2eq/constant 2004–2006 I$. At the same time, absolute farm-gate emissions increased globally nearly 75 percent, indicating that increases in agricultural production significantly outstripped the emission efficiency gains implied by the decreased intensity.

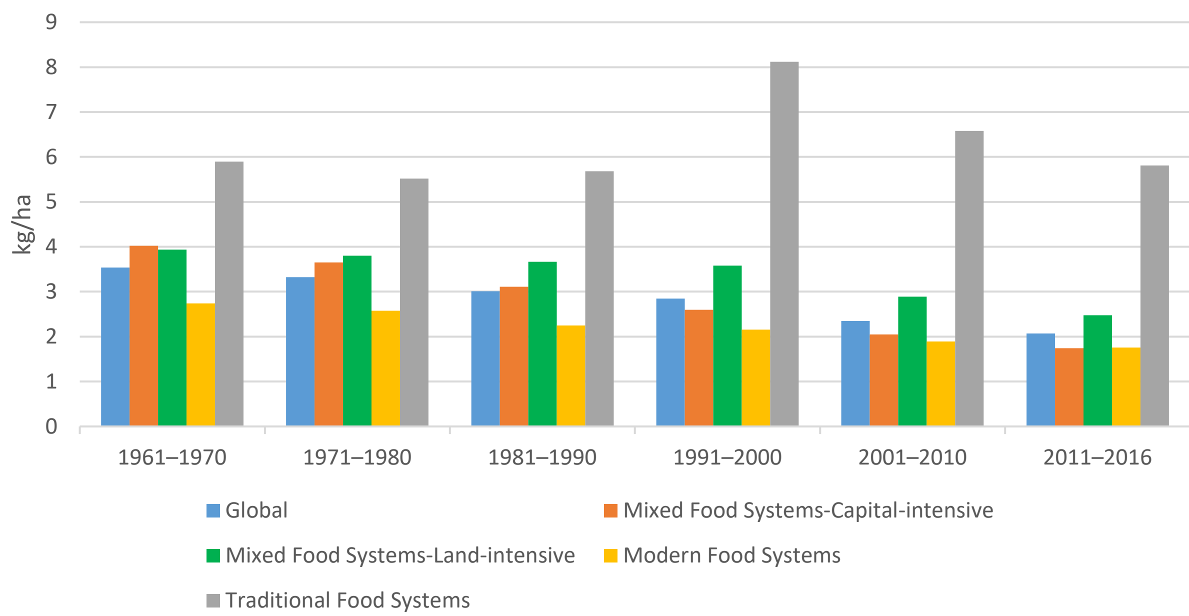
The emission intensity of agriculture decreased in all food systems typologies except in traditional food systems by 30–60 percent, with the largest gains in capital-intensive mixed food systems. The lowest values in the most recent decade were seen in capital-intensive and modern food systems, about 1.75 kg CO_2eq/constant 2004–2006 I$. While these results are well aligned with progress in these two groups being associated to the efficiency that comes from increased mechanization and economies of scales, it should be noted that additional improvements in emission intensity will become more difficult in coming decades, as additional productivity gains become harder to achieve (Smith *et al*., 2014). Conversely, the emission intensity of traditional food systems, at nearly 6 kg CO_2eq/constant 2004–2006 I$, was much higher than in other food systems and well above the global mean value in the 1960s. This is of course not related to levels of absolute emissions, which remain very low in these systems, but rather reflects the low productivity levels in these systems and inefficient use of inputs.

It is important to note that trends in emission intensities, while indicating progress towards sustainability of different production systems, should nonetheless be complemented by monitoring of national emissions levels. Despite current trends indicating continuous increases (Figure 3.14), they would in fact need to decrease over time to achieve planetary sustainability, i.e. if the Paris Agreement targets are to be met in coming decades. In this context, additional analyses showed that modern food systems were the only typology were, since the 1990s, both emissions intensities and total emissions decreased.

Progress towards sustainability in this area requires specific strategies aimed in general at productivity improvements, complemented by improved crop and livestock management, and a shift towards less emitting commodities. These efforts nonetheless should be complemented by mitigation measures aimed

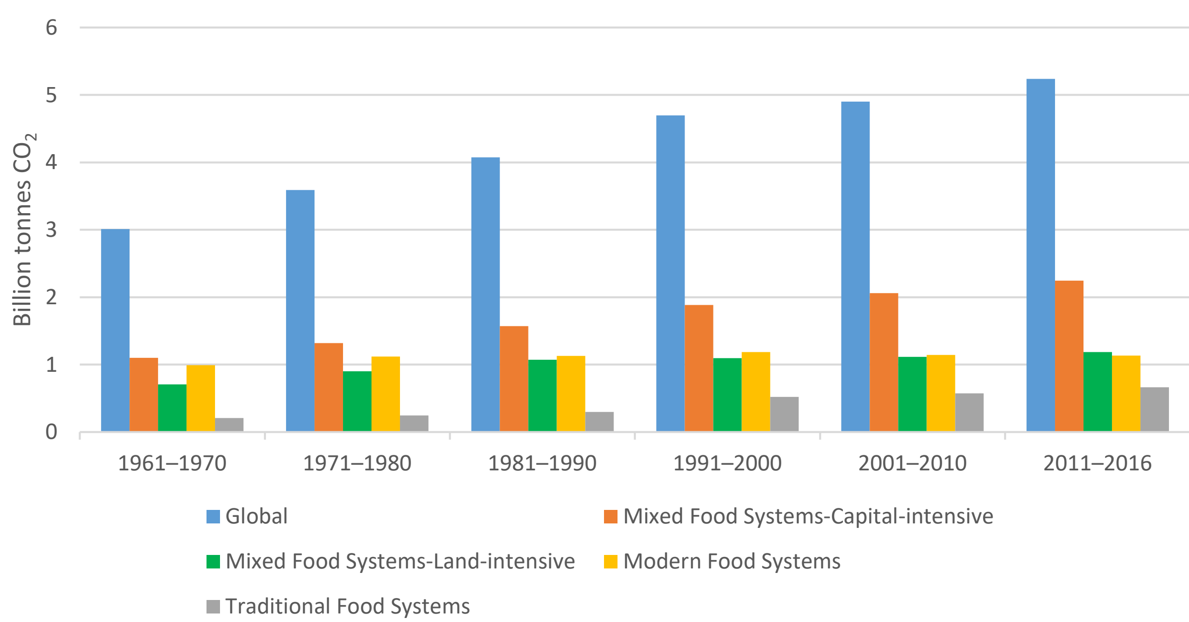
at real reductions in total emissions (IPCC, 2019). The path towards improved sustainability in traditional food systems appears to be significant, provided that productivity improvements and increased input use are taken up swiftly to close the gaps with the other food systems analysed herein.

Figure 3.13. Emissions per value of agriculture



Source: FAOSTAT Emissions-agriculture 2019 and FAOSTAT Value of agricultural production, 2019.

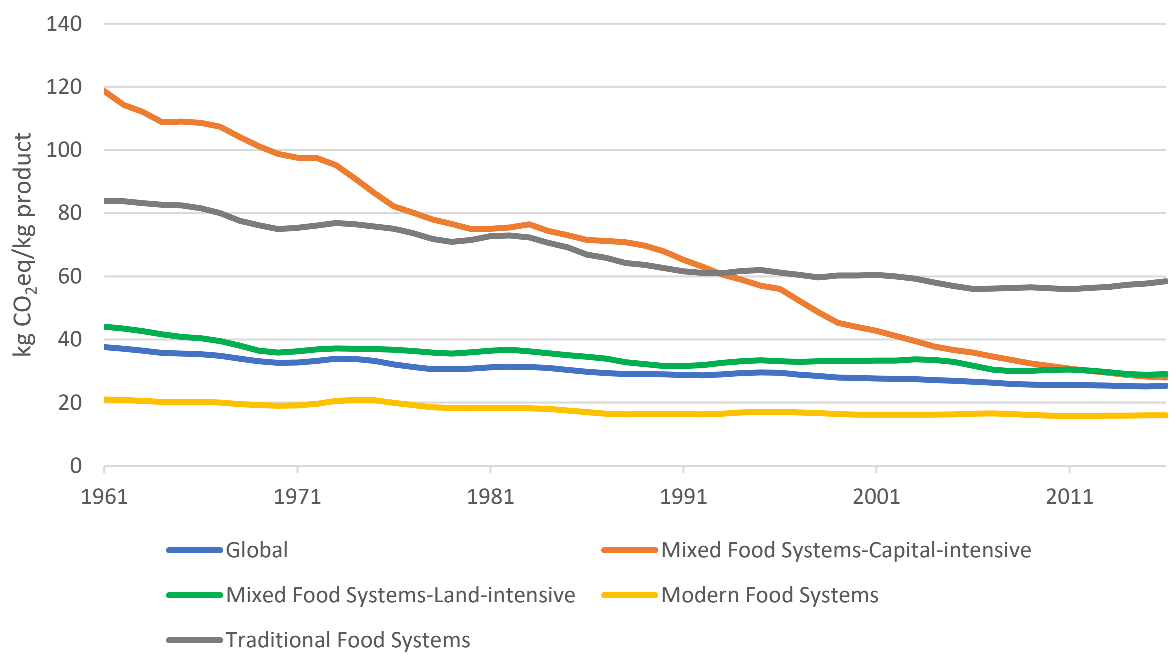
Figure 3.14. Total emissions from agriculture



Source: FAOSTAT Emissions-agriculture, 2019.

Because livestock, and in particular cattle production, dominates emissions from the farm gate, we also report on emission intensity of beef. Globally, it decreased by 30 percent, from 35 to 25 kg CO_2eq kg^{-1}. In the most recent decade, modern food systems exhibited the lowest value, 15 kg CO_2eq kg^{-1}, traditional food systems the largest, at 60 kg CO_2eq kg^{-1}, while mixed food systems had intermediate values of 30 kg CO_2eq kg^{-1}. Capital-intensive food systems showed the most marked decrease over time and in recent decades. Decreases in emissions intensity do not necessarily correspond to increased overall sustainability, unless they begin affecting trends in absolute emissions as well.[6] To this end, modern food systems were the only one characterized by decreases in both total emissions and emission intensity.

Figure 3.15. GHG emissions intensity for cattle meat



Source: FAOSTAT Emissions intensities, 2019.

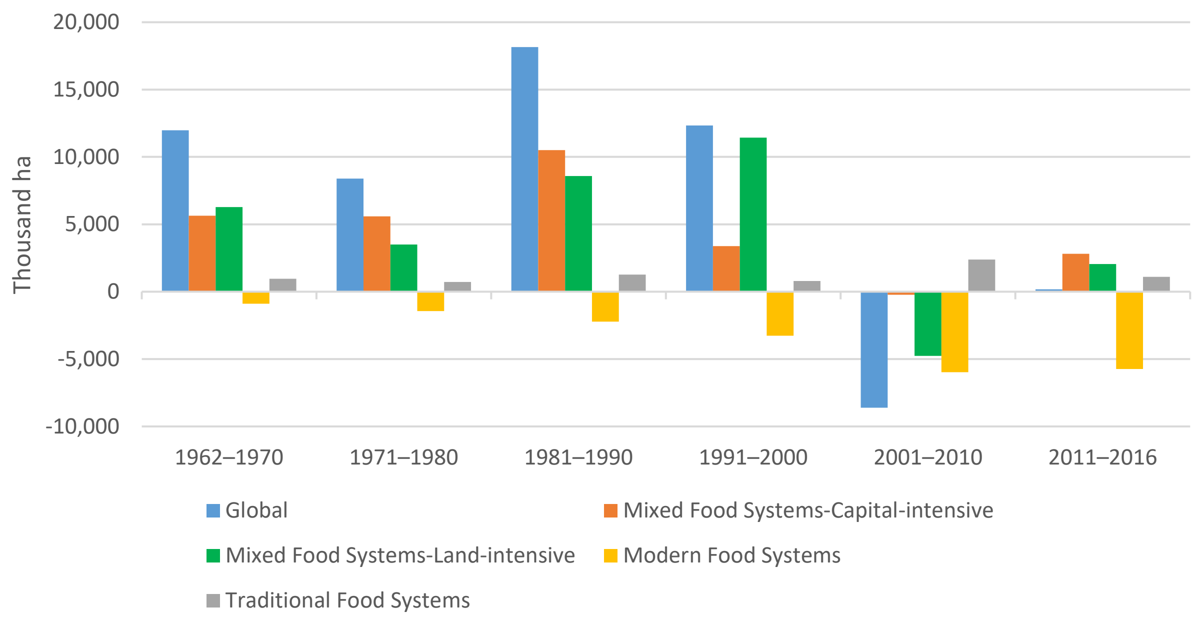
Land use change trends are relevant to conservation of ecosystems services, biodiversity and carbon sequestration goals (IPBES, 2019). They are robustly linked to trends in productivity and profitability, and the underlying drivers underpinning mechanization and input use efficiency, including income and land distribution among the rural population.

Globally, agricultural land area grew until the 2000s, adding between 8–18 Mha yr^{-1}, with the highest values in the 1980s (Figure 3.16). It decreased afterwards, by about 9 Mha yr^{-1} in the 2000s while stabilizing in the current decade. The decreasing trend was most pronounced in modern food systems, where it decreased in each decade analysed, and with the largest decrease in the two most recent decades, with losses of about 6 Mha yr^{-1}. In mixed food systems, agricultural land increased significantly up to the 2000s, at rates between 6–12 Mha yr^{-1}. The most pronounced increases happened in the 1990s in land-intensive mixed food systems, mirroring a maximum in deforestation rates observed in the same

[6] See, e.g. IPCC 2019. Special Report on Land and Climate change, Food Security Chapter. Executive Summary https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SRCCL-Chapter-5.pdf

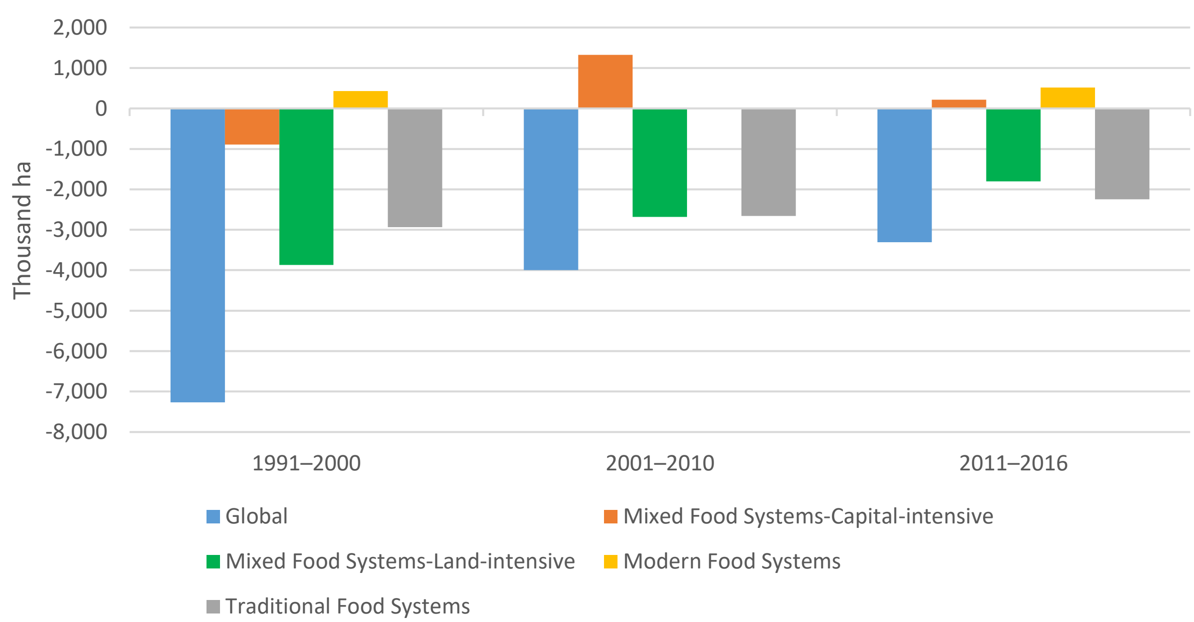
period. The two most recent decades exhibited contrasting trends, with decreases in the 2000s (up to 5 Mha yr^{-1}) and expansion in the most recent decades (2–3 Mha yr^{-1}). Conversely, agricultural land continued to expand in traditional food systems countries, at rates between 1–2 Mha yr^{-1}.

Figure 3.16. Agricultural land use change



Source: FAOSTAT Land use, 2019.

Figure 3.17. Forest land use change



Source: FAOSTAT Land use, 2019.

Since the 1990s, forest land area decreased globally (Figure 3.17), albeit at progressively diminishing rates. Forest area loss ranged from 7 Mha yr^{-1} in the 1990s to 3 Mha yr^{-1} more recently. These trends mirror somewhat those seen for agricultural land area, particularly in the 1990s, when forest area loss represented about 70 percent of the agricultural land area gain.

In terms of food system typologies, forest area loss was similar in land-intensive mixed and traditional food systems ranging about 2 to 4 Mha yr^{-1}, and decelerating over time as seen in the global statistics. Trends in forest area loss in both groups mirrored those in agricultural area gains.

By contrast, in capital-intensive mixed and modern food systems, forest land area did not exhibit a clear trend in the period considered, i.e. ranging -1 and 1 Mha yr^{-1} in the former and 0–0.5 Mha yr^{-1} in the latter.

4. Dashboard analysis

Available national-level statistics allowed for a first yet complete analysis of progress towards sustainability, in both qualitative and quantitative fashion. The dashboard allowed to identify “sustainability hotspots” across the sixteen sub-indictors provided, for each food systems typology, i.e. by pinpointing graphically as well as numerically which subset of PROSA indicators represented most limiting factors within the dashboard analysis, by food system typology and over time. Results of this analysis re-enforce the trend analysis provided in previous sections, by adding critical details to specific storylines highlighting key relationships between underlying socio-economic trends and environmental impacts. Progress over time was seen across most sub-indicators and food system typologies, with important differences.

The analysis showed continuous progress over time in all food systems typologies, but also detailed how new criticalities emerge over time, reflecting the evolution of underlying drivers and their interactions. In the discussion below and in Figures 4.1 – 4.4, we refer the results of the dashboard analysis against trends in the sixteen PROSA indicators discussed in the previous section, specifically: 1) production value per hectare; 2) production value per worker; 3) credit per capita; 4) gross value diversification; 5) value added per capita; 6) prevalence of undernourishment; 7) soil nutrient balance; 8) water productivity; 9) fertilizers per hectare; 10) pesticides per hectare; 11) crop diversification; 12) livestock diversification; 13) GHG intensity; 14) beef GHG intensity; 15) agricultural land use; and 16) forest land use.

Progress towards sustainability along socio-economic dimensions was strong over the 1961–2018 period, with trends in gross value diversification representing the most limiting factor to progress towards sustainability in most food systems. In modern food systems, reliance on a limited range of crops and livestock commodities became over time the most limiting factor overall to continued progress towards sustainability, in the face of the improvements achieved in all other sub-indicators. Risk of exposure to price commodity fluctuations – indicated by low values in this indicator – was an important limiting factor to sustainability also in traditional and land-intensive mixed food systems, alongside other, mostly environmental factors, but not in capital-intensive systems, where environmental factors were significantly more limiting progress towards sustainability.

Land use change was a critical issue where agricultural land expanded at the detriment of natural ecosystems, in particular forests. This was particularly true in traditional food systems, where land use change was the most limiting factor to agriculture sustainability, possibly in relation to low land productivity coupled with increased inequality and population growth rates. As production systems moved to more intensive production and to modern food systems, land pressures were progressively reduced, especially on forests. Agricultural land expansion, along with its links to reduced biodiversity and carbon losses, remained nonetheless a critical limiting factor to sustainability in both land-intensive and capital-intensive systems, despite continuous progress. Only in modern food systems land use issues were no longer a limiting factor. This was consistent with the high land productivities indicated through the gross value per hectare indicator and economies of scale, which allowed for sufficient production without need for further land expansion.

The analysis showed that albeit crops and livestock diversification is key to climate resilience, in moving from traditional to modern food systems this did not coincide with market resilience (measured via value diversification) and vice-versa. This is because traditional food systems rely on the largest range of crops

and livestock species for production, yet farm income depends on fewer commodities, exposing these systems to market fluctuations, reducing the overall capacity to cope of the farm. As production systems became more intensive, species diversification began to decrease, though income diversification strengthened. In land-intensive and capital-intensive mixed food systems, livestock species diversification decreased, likely linked to a progressively larger reliance on cattle at the detriment of other, perhaps less efficient livestock species. At the same time, income diversification, i.e. from more crops and livestock species, strengthened over time, signalling reliance on a basket of commodities perhaps commanding better market prices, to the point that it no longer represented a factor limiting sustainability in either capital-intensive or modern food systems. The latter typology was the one where crop species diversification decreased to the point that it became a critical sustainability factor. Hence, in our analysis development along the trajectory from traditional to modern systems appeared to shift risk exposures from market to biodiversity issues.

The dashboard analysis indicated that soil nutrient balance and pesticides remained significant limiting factors to agriculture sustainability in all food systems typologies, at both low levels and high levels of inputs. In traditional systems, low input levels represented critical limiting factors to sustainability in most decades analysed, though showing significant progress over time, to the point that soil nutrient balances no longer limited sustainability in these systems in recent decades. As systems intensified production, increased pesticides use became an even more pronounced limiting factor, while nutrient balances improved in land-intensive food systems, remaining a critical factor in capital-intensive systems. Ultimately, and closing a cycle that marks the trajectory from under to overuse, fertilizers balance became the most limiting factor for sustainability in modern systems, while pesticides use decreased its critical role, perhaps due to the increased role of niche markets requiring less use of chemicals in production. In particular, production trends in the capital-intensive systems led to important trade-offs between socio-economic progress and natural resource use, for instance improved efficiencies in input use led to much higher water productivity, while criticality of synthetic fertilizers use worsened.

Finally, and importantly, sustainability and climate change dimensions were significantly linked on the farm and beyond to surrounding landscapes. The improvements seen in most systems over time in crop and livestock diversification can be interpreted as leading to improved resilience to climate change, yet remaining a critical issue in modern food systems where such diversity remains low. This would imply the need for more focused climate changed adaptation through better diversification of crop species, as a means towards safeguarding current productivity levels in coming decades in modern systems. Among needed climate responses in this area, improvements in water use efficiency across all production typologies will be needed to bolster capacity to adaptation to high temperature events and droughts. Finally, land-based mitigation will need to be promoted by policies that couple sustainability and climate change. Such policies should promote improved farm production efficiencies while setting absolute pollution reduction targets, to ensure that the decreased emission intensities that typically accompany modernization trends lead to real reductions in absolute emissions. This can only be obtained by linking policies that promote improved production efficiencies on the farm alongside agricultural land conservation and to reduced deforestation.

Figure 4.1. PROSA dashboard for traditional food systems

Source: FAOSTAT and AQUASTAT, 2019.

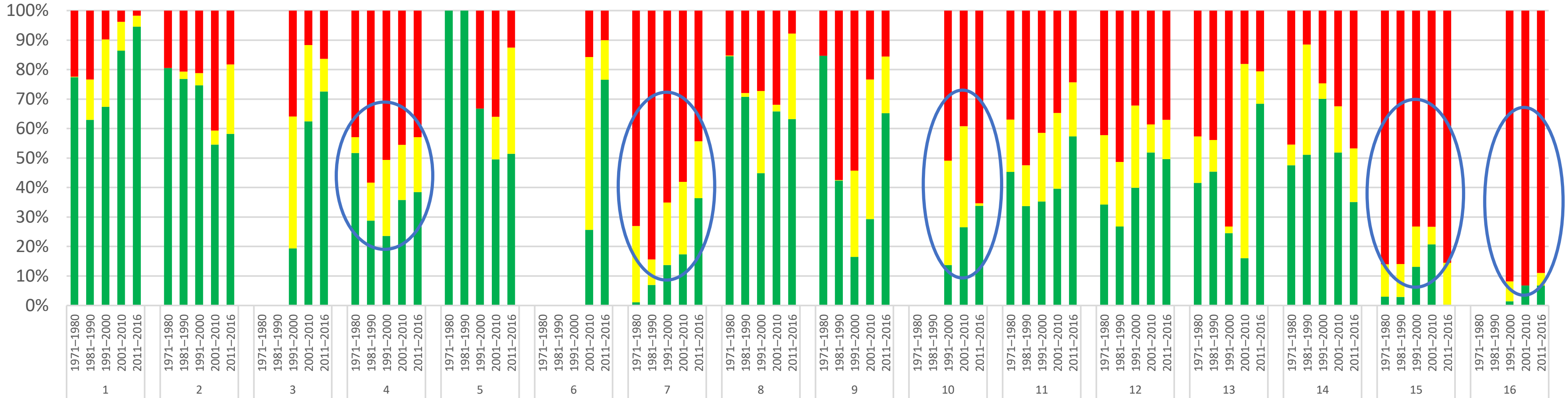


Figure 4.2. PROSA dashboard for land-intensive mixed food systems

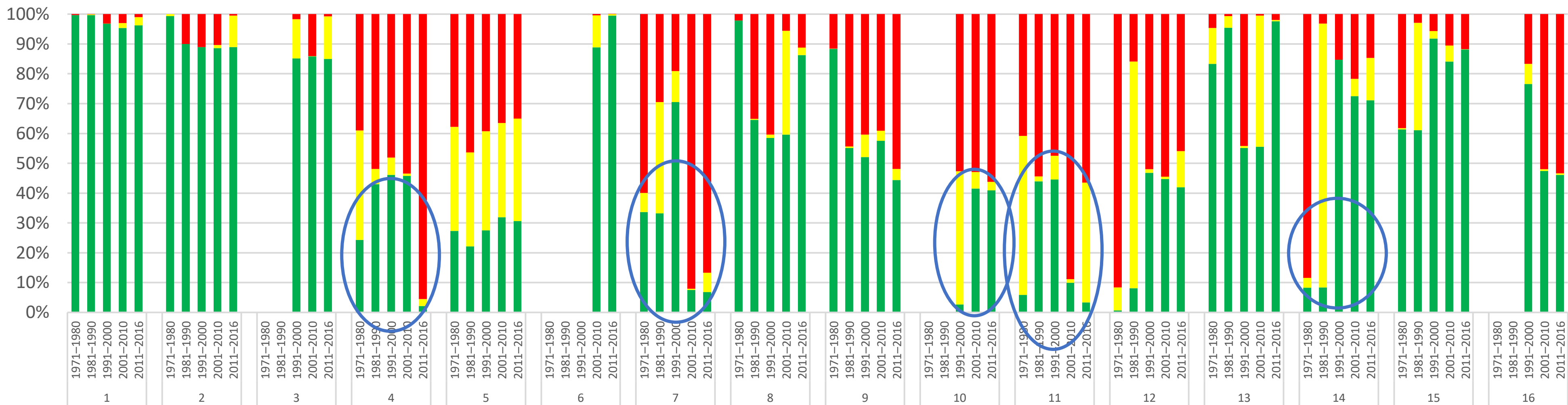
Source: FAOSTAT and AQUASTAT, 2019.

Figure 4.3. PROSA dashboard for capital-intensive mixed food systems

Source: FAOSTAT and AQUASTAT, 2019.

Figure 4.4. PROSA dashboard for modern food systems

Source: FAOSTAT and AQUASTAT, 2019.



5. Conclusions

This paper reported results of a novel statistical trends and dashboard analysis, conducted in support of the growing demand for monitoring country progress towards sustainable agriculture (PROSA). Increased attention and demand for better information and data in this area of work is needed in support of the 2030 Sustainable Development Agenda, helping countries to monitor and assess their progress towards sustainability in all relevant sectors of society, economy and the environment.

Within this context, this work leverages on FAO existing 'statistical muscle', i.e. the significant amount of national statistics regularly collected from member states and disseminated in FAOSTAT. As a complement with ongoing efforts under the 2030 Sustainable Development Agenda, and mindful of the significant progress that must be undergone to help countries collect and report more detailed data, PROSA provides a simplified framework of national statistics, useful to assess progress at country level, as well as across the different food systems typologies, facilitating the regional and global analysis of sustainability while capturing in sufficient detail the different development stages of agriculture around the world.

The PROSA analysis shows and helps quantify how different food systems typologies may face different challenges in coming decades, in the face of threats to food security, socio-economic fairness, biodiversity and climate change, among several key issues. The sustainability hotspots identified in this paper can help to inform the ongoing pivotal discussion on agricultural best practices and the way forward towards achieving sustainable and productive agriculture.

References

Barbier E.B. & Hochard J.P. 2016**.** Does Land Degradation Increase Poverty in Developing Countries? PLoS ONE 11(5): e0152973. https://doi.org/10.1371/journal.pone.0152973

Campanhola, C., & Pandey, S., eds. 2019. *Sustainable Food and Agriculture: An Integrated Approach*. FAO. Rome.

Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, M., Kirilenko, A., Morton, J., Soussana, J.F., Schmidhuber, S. & Tubiello, F.N. 2007: Food, fibre and forest products. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, Eds. Cambridge University Press, pp. 273-313.Rockström *et al*., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2): 32.

FAO. 2020. *SDG indicator 2.4.1. Proportion of agricultural area under productive and sustainable agriculture. Methodological note.* Tenth revision - July 2020. Rome. Available at: http://www.fao.org/3/ca7154en/ca7154en.pdf

FAO. 2019a. *SDG Indicator 2.4.1 Proportion of agricultural area under productive and sustainable agriculture*. Methodological note. Available at: http://www.fao.org/3/CA2639EN/ca2639en.pdf.

FAO. 2019b. FAOSTAT Database, Land Use. Available at http://www.fao.org/faostat/en/#data/rl.

FAO. 2019c. *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction.* Rome.

FAO, IFAD, UNICEF, WFP & WHO. 2019. *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns*. FAO, Rome.

FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome.

FAO. 2018a. *Transforming Food and Agriculture to Achieve the SDGs: 20 interconnected actions to guide decision-makers*. Rome.

FAO. 2017. *The State of Food and Agriculture 2017*. Rome.

FAO. 2014a. *Building a Common Vision for Sustainable Food and Agriculture, Principles and Approaches*. Rome.

FAO. 2014b. *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by: 1990–2011 Analysis*. FAO Statistical Working Paper Series 14/02. FAO, Rome.

FAO. 2012. *The State of Food and Agriculture 2012. Investing in agriculture for a better future.* Rome.

FAO. 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) - Managing systems at risk*. FAO, Rome and Earthscan, London.

Federici. S., Tubiello, F.N., Salvatore, M., Jacobs, H. & Schmidhuber, J., 2015. New estimates of CO_2 forest emissions and removals: 1990-2015. Forest Ecol Manag. 352:89-98.

HLPE. 2017*. Nutrition and food systems*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. *et al*. (eds.). IPBES secretariat, Bonn, Germany.

IPCC. 2019. Summary for Policy Makers. Arneth et al., 2019. IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. IPCC, Cambridge, UK.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. Stuart, Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K. Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen P. & Foley, J.A. 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2): 32.

Rosenzweig, C., Mbow, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E.T., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., Xu, Y., Mencos Contreras, E. & Portugal-Pereira, J. 2020. Climate change responses benefit from a global food system approach. Nat. Food, 1, no. 2, 94-97, doi: 10.1038/s43016-020-0031-z.

Sadras, V. O., Grassini, P. & Steduto, P. 2012. Status of water use efficiency of main crops: SOLAW Background Thematic Report-TR07. FAO, Rome.

Sims, B. G., Hilmi, M. & Kienzle, J. 2016. Agricultural mechanization: a key input for sub-Saharan Africa smallholders. Integrated Crop Management (FAO) eng v. 23 (2016).

Smith P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N.H., Rice, C.W., Robledo Abad, C., Romanovskaya, A., Sperling, F. & Tubiello, F.N. 2014. Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Tubiello, F.N. 2018. Get more out of FAO statistics, *Nature* (7729) 35-35.

Tubiello, F.N. 2019. Greenhouse Gas Emissions Due to Agriculture. In: Ferranti, P., Berry, E.M., Anderson, J.R. (Eds.), Encyclopedia of Food Security and Sustainability, vol. 1, pp. 196–205. Elsevier.

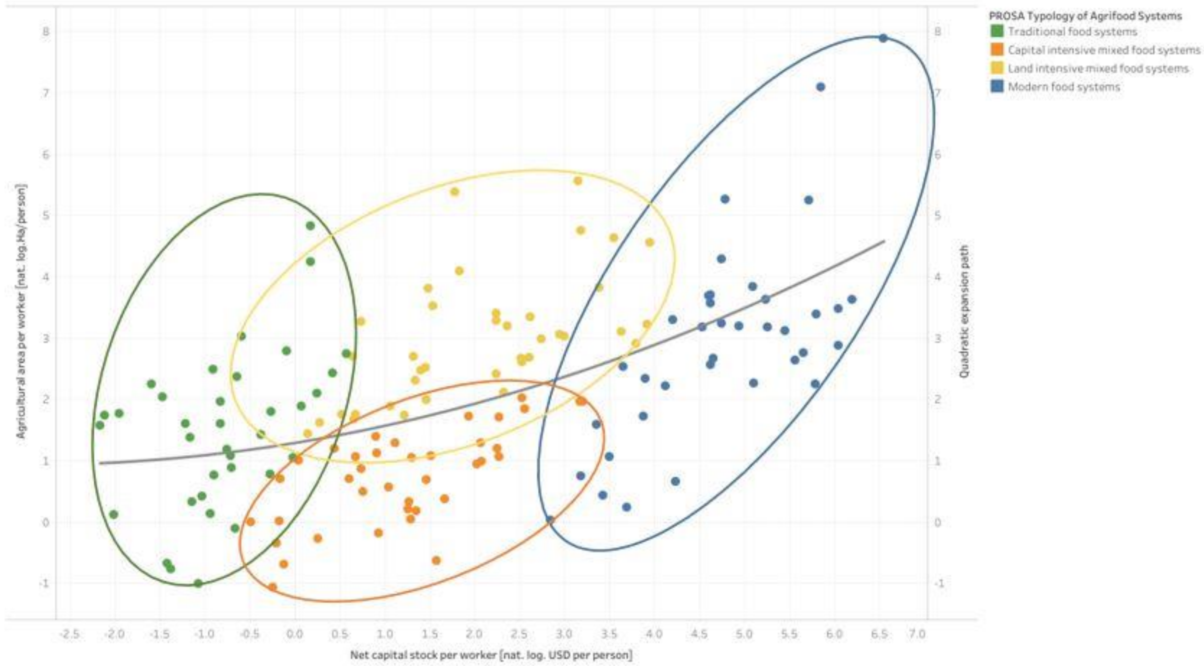
Wang, Q., Zhou, F., Shang, Z., Ciais, P., Winiwarter, W., Jackson, R.B., Tubiello, F.N., Janssens-Maenhout, G., Tian, H., Cui, X., Canadell, J.G., Piao, S. &Tao, S. 2019. Data-driven estimates of global nitrous oxide emissions from croplands. National Science Review, doi.org/10.1093/nsr/nwz087.

Appendix I - Country typology groupings and list of countries

There are several country-level typologies that have been developed within FAO and beyond. These include the Food System typology used by the High-level Panel of Experts on Food Security and Nutrition (HLPE 2017), the per capita income groupings used by the World Bank, the UNDP human development level, the UN/DESA country classification, and the FAO Low-Income Food-Deficit Countries (LIFDC) list. These typologies provide useful insights into the social and economic conditions of countries, as well as broader insights into agricultural supply chains and nutritional outcomes in the case of the HLPE food system typology. However, they are not explicitly focused on agricultural production side factors, which are critical for an assessment of sustainable agriculture.

The typology proposed in this report follows the typology of agri-food systems developed in Campanhola and Pandey (2019) by focusing on agricultural sector factor endowments applied to the country-level. Countries are grouped based on factor productivities and relative intensities within agriculture – namely for land, labour and capital – to account for differences in agricultural production. The typology incorporates other recognized typologies as a second-tier evaluation criteria for a country's classification. Based on well-established quantitative methods using national data, four country groups emerge according to factor productivities and relative factor endowments, illustrated in Figure A- provides the detailed methodology used to group countries. These groups overlap well with the typology groups developed by the HLPE (2017): traditional food systems, mixed food systems, and modern food systems. The PROSA typology makes a distinction between the mixed food systems groups based on differences found in capital and land intensities.

Figure A-1. Grouping of countries by capital and land intensities (log scale) per worker



Source: FAO, 2021.

Countries within each of the resulting four groups share the following broad characteristics:

Traditional food systems countries (green) are characterized by low labour and land productivity and low capital stocks. Within this country group, the majority of people farm for a living, yet the marginal productivity of agriculture workers is low due to an abundance of labour and severe capital constraints. These constraints are reflected in lower land productivity than in capital-intensive mixed food systems and modern food systems countries and lower agriculture value added with relatively little increase over time. This group includes countries such as Afghanistan, Nicaragua, and Niger. Many of these countries are also categorized as low-income food deficit countries according to FAO, and require increases in agricultural productivity and investment in degrading agricultural soils to meet growing food needs.

Capital-intensive mixed food systems countries (orange) are characterized by higher land productivity and agriculture value added due to higher levels of capital endowment per worker compared to traditional food systems countries. The broader economy is diversifying into services and industry resulting in a lowering agriculture share of GDP and employment. In these countries, growth is based primarily on capital-intensive agriculture, often substituting for labour. Countries in this group include Ecuador, Ghana, and Thailand.

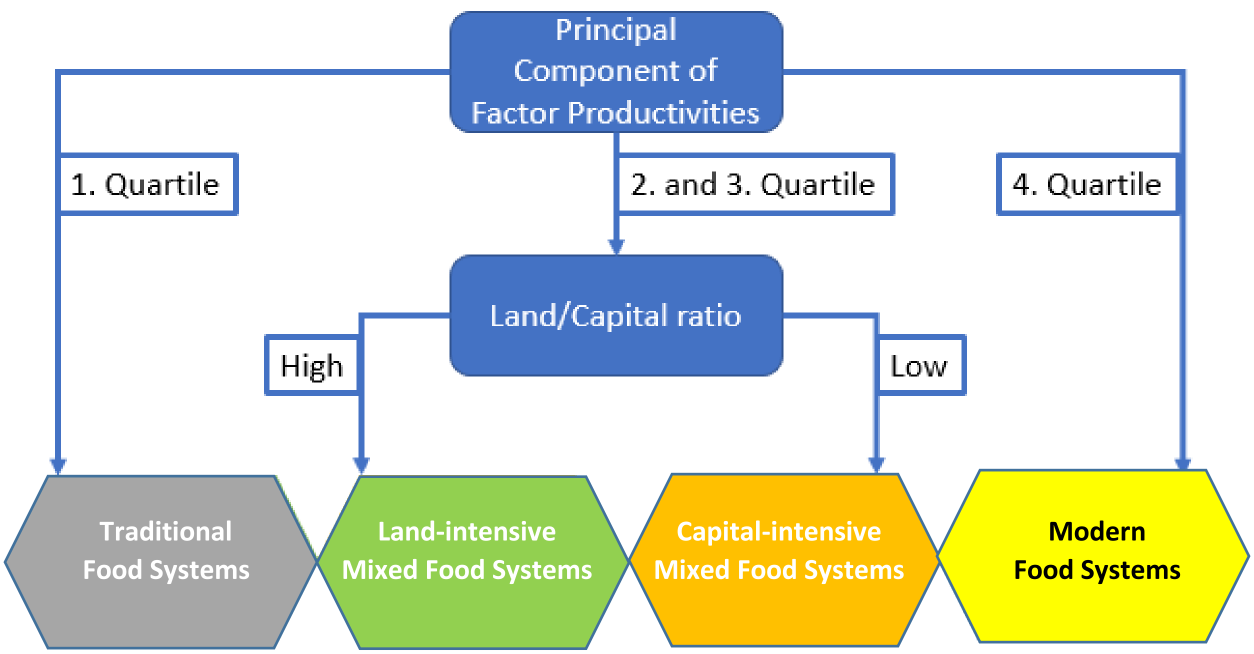
Land-intensive mixed food systems countries (yellow) are also characterized by higher productivity compared to the traditional group, chiefly due to larger land areas available to the agriculturally active population. Agriculture's contribution to the GDP and employment are lowering due to diversification of the economy as a whole, however land productivity is lower and increasing at a slower rate compared to capital-intensive mixed food systems countries. Agricultural growth in this group is based on higher land

use intensities than capital intensities due to a greater abundance of land leading to more extensive farming systems. Brazil, Russia, South Africa are examples of land-intensive mixed food system countries.

Modern food systems countries (blue) are capital-intensive with high land or labour productivities. Due to mechanization and access to modern technologies, agriculture is highly competitive, creating a strong agricultural export market. The countries in this group typically have a higher agriculture value added, but the overall contribution of agriculture to the diversified economy is smaller. Examples of modern food systems countries are Australia, Argentina, and Japan. In most of these countries, agricultural productivity is high and food insecurity is low, shifting the priority to ensuring that agriculture is increasingly environmentally sustainable and socially just.

This applied typology of agri-food systems aims to enhance understanding country-level differences in terms of the trends of sustainable agriculture and the assessment of suitable strategies towards more sustainable systems.

Figure A-2. Decision tree for PROSA country groups



Source: FAO, 2021.

Table 2. List of countries used in the PROSA analysis, grouped by agri-food system typology

Traditional Food Systems	Land-intensive Mixed Food Systems	Capital-intensive Mixed Food Systems	Modern Food Systems
Afghanistan	Algeria	Albania	Argentina
Angola	Armenia	Azerbaijan	Australia
Benin	Belarus	Bangladesh	Austria
Botswana	Bolivia (Plurinational State of)	Cambodia	Bahrain
Burkina Faso	Bosnia and Herzegovina	China	Belgium
Burundi	Brazil	Comoros	Canada
Cameroon	Bulgaria	Costa Rica	Croatia
Central African Republic	Chile	Dominican Republic	Cyprus
Chad	Colombia	Ecuador	Czech Republic
Congo	Côte d'Ivoire	Egypt	Denmark
Democratic People's Republic of Korea	Cuba	El Salvador	Estonia
Democratic Republic of the Congo	Gabon	Equatorial Guinea	Finland
Djibouti	Guyana	Georgia	France
Eritrea	Iran (Islamic Republic of)	Ghana	Germany
Ethiopia	Iraq	Guatemala	Greece
Gambia	Jordan	Honduras	Hungary
Guinea	Kazakhstan	India	Ireland
Guinea-Bissau	Libya	Indonesia	Israel
Haiti	Lithuania	Jamaica	Italy
Kenya	Mexico	Kuwait	Japan
Kyrgyzstan	Mongolia	Lao People's Democratic Republic	Latvia
Lesotho	Morocco	Lebanon	Malaysia
Liberia	Namibia	Myanmar	Mauritius
Madagascar	Oman	Nigeria	Netherlands
Malawi	Panama	Pakistan	New Zealand
Mali	Paraguay	Papua New Guinea	Norway
Mauritania	Peru	Philippines	Portugal
Mozambique	Republic of Moldova	Poland	Puerto Rico
Nepal	Russian Federation	Romania	Qatar
Nicaragua	Saudi Arabia	Serbia	Republic of Korea
Niger	South Africa	Solomon Islands	Singapore
Rwanda	Sudan	Sri Lanka	Slovakia
Senegal	Swaziland	Palestine	Slovenia
Sierra Leone	Syrian Arab Republic	Thailand	Spain
Somalia	The former Yugoslav Republic of Macedonia	Timor-Leste	Suriname
South Sudan	Trinidad and Tobago	Turkey	Sweden
Tajikistan	Tunisia	Viet Nam	Switzerland
Togo	Turkmenistan	Zimbabwe	United Arab Emirates
Uganda	Ukraine		United Kingdom of Great Britain and Northern Ireland
United Republic of Tanzania	Uruguay		United States of America
Zambia	Uzbekistan		
	Venezuela (Bolivarian Republic of)		
	Yemen		

Source: FAO, 2021.

Contact:

Statistics Division – Economic and Social Development
www.fao.org/food-agriculture-statistics/resources/publications/working-papers/en/
FAO-statistics@fao.org
francesco.tubiello@fao.org

Food and Agriculture Organization of the United Nations
Rome, Italy

ISBN 978-92-5-134364-7

9 789251 343647

CB4549EN/1/05.21