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Rural transformation and the future of cereal-based agri-food systems

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ABSTRACT

Rural transformation is an inevitable and fundamental process of development. However, the speed and dimensions of rural transformation can affect investments in major staples such as maize, wheat and rice, which continue to play an important role in agri-food systems around the globe. This paper investigates the impacts of rural transformation on the future of cereal-based agri-food systems which are not directly addressed in global agricultural assessment models such as IMPACT. In this study, we present several key cases of major cereal systems undergoing different changes as a result of rural transformation processes across the major cereal baskets. We place these case studies in the perspective of IMPACT model scenario study results. Our study shows that the rural transformations that are taking place in different regions are heterogeneous with different impacts on the investment requirements for research and development (R&D) in the major cereals. It is concluded that although results of global agricultural assessment models such as IMPACT show initial large-scale effects on food system interactions, an iterative approach with more focused analyses on the complexities of rural transformation is needed to fine-tune results and place them in perspective.

1. Introduction

Rural transformation is a process through which rural incomes grow, rural economies diversify, and linkages with urban and peri-urban areas evolve. Rural transformation is fundamental in understanding future food security and can be more formally defined as a long-term process of change in fundamental features of the way people in rural areas live and act economically, taking into consideration how they are embedded in societal and global dynamics. It is a complex phenomenon determined by a variety of interrelated political, economic, demographic, socio-cultural and environmental drivers (Berg et al., 2016; Carletto et al., 2017; de Brauw et al., 2014; Kelly, 2011).

Globally, wheat, maize, and rice, are major sources of dietary energy and protein, especially in developing countries (Bandumula, 2018; Shiferaw et al., 2013, 2011). These staple cereals provide the foundation for food security for most of the world's population. This cereal-based food security system has been evolving due to rural transformations (Beddington, 2010; Brooks and Place, 2019). With the expected increase in population from 7.6 billion in 2018 (World Bank, 2020a) to 8.9 to 10.6 billion by 2050 (United Nations, 2019), the total demand for cereals will rise to provide the caloric base of diets worldwide (Beddington, 2010; Godfray et al., 2010). With the increase in per capita GDP and lifestyle changes due to rapid urbanization, aggregate demand for food will not only increase, but the demand for high-quality food and value enriched cereals will also increase. As the ability to supply more food and particularly high-quality foods critically depends on the capacity of food supply from the rural areas, it is imperative to understand rural transformation to understand cereal-based food security in the future.

In this paper, we use foresight approaches to better understand the dynamics and consequences of rural transformation. Zooming in on

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several key cereal agri-food systems provides a new and clearer picture for evaluating policies and investments intended to raise agricultural productivity.

Foresight studies using quantitative methods offer insight into general developments in supply and demand (Brooks and Place, 2019; Hubert et al., 2010; Robinson et al., 2015; Tilman et al., 2011). One of these approaches is embodied in the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model of the global agricultural economy (Robinson et al., 2015). Using the IMPACT model, we consider several scenarios that look at different modes of agricultural research and what their effects on a wide range of indicators are likely to be (Wiebe et al., 2020). These scenarios do not capture rural transformation explicitly, as it is assumed that rural transformation is an implicit part of the overall development underlying the results. The speed of rural transformation is highly heterogeneous across regions and thereby requires different research and investment portfolios and policies. These will have different impacts on the development of rural landscapes in the target geographies and on how effective policies turn out to be. In our study, we consider recent results from IMPACT model scenarios (Rosegrant et al., 2017) in light of the broader context of rural transformation.

The study is organized as follows. Section 2 briefly presents the methods used in this study. Section 3 reviews major trends of staple cereals and drivers of those changes with a focus on major cereals: maize, rice and wheat. Section 4 captures the role of rural transformation in relation to major cereal-based agri-food systems in specific contexts and focus on how this links with the overall trends described in Section 3. Section 5 presents conclusions and policy implications emphasizing three major issues. Firstly, we shed light on the overall direction of agriculture and rural settings as a result of rural transformation. Secondly, we draw specific conclusions about each case study and what it means for other areas and crops. Finally, we assess the implications of the IMPACT scenario studies with special reference to what kinds of research investments would best support the changes that will

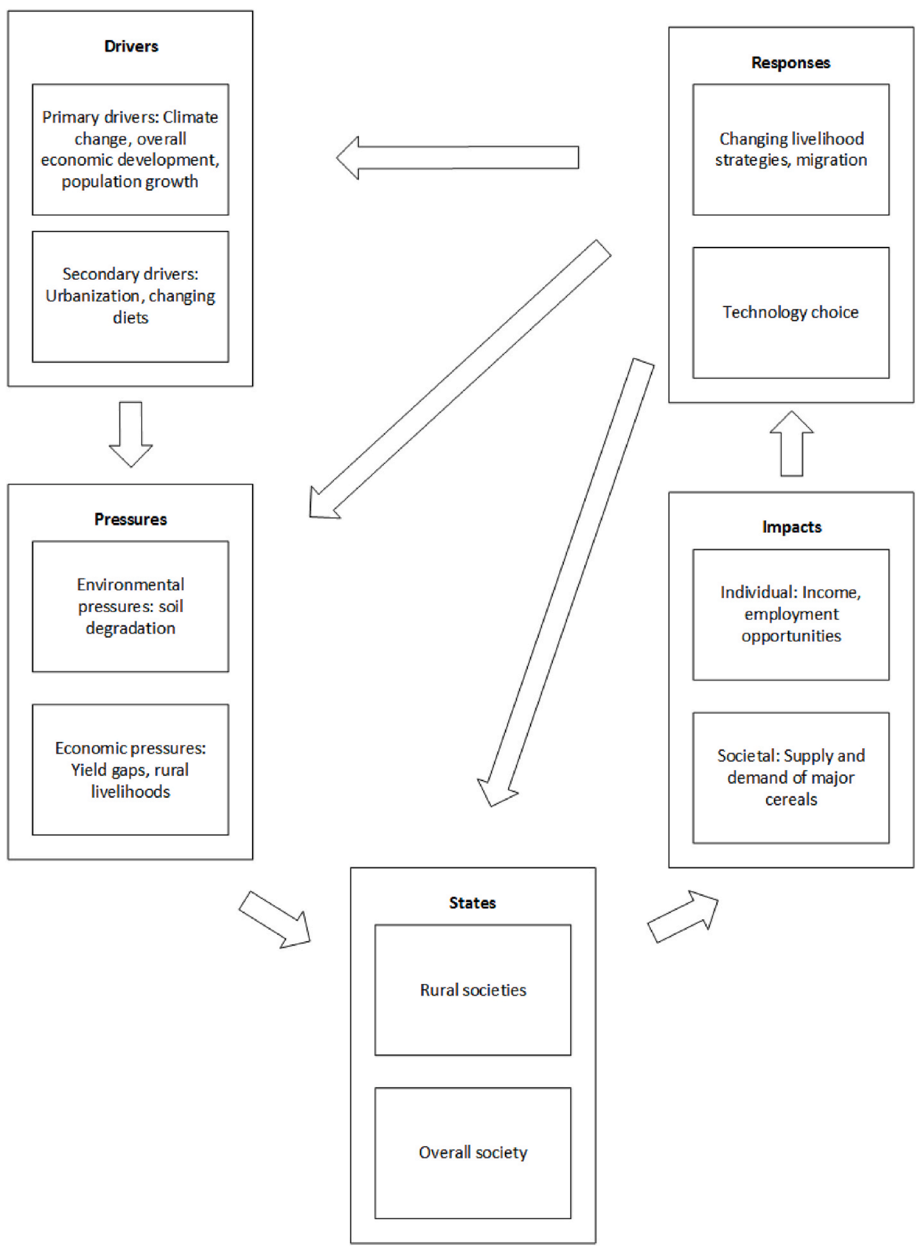

Fig. 1. The DPSIR approach applied to rural transformation.
Source: Authors' adapted from (Smeets and Weterings, 1999).

improve livelihoods of the poor.

2. Materials and methods

This study used the DPSIR (driving forces, pressure, state, impact, response) approach as a framework for analysis, which was developed in the late 1990s by the European Environmental Agency (Smeets and Weterings, 1999). The approach has been proven useful to understand the persistency of environmental problems and ways to address them. The approach is also useful to address other sustainable development issues, although to our knowledge this is the first time that the approach has been applied to understand cereal-based agri-food systems under the context of rural transformation. The DPSIR framework is shown in Fig. 1. The major drivers of climate change, population growth and general economic development cause pressures on cereal production and rural livelihoods. The drivers also create pressures in terms of pollution, erosion, land use change, and dietary change that reinforce the pressures on cereal production and rural livelihoods. These in turn influence both the state of the natural environment on which agricultural production depends, and the state of rural societies, all of which leads to impacts on key indicators such as income, employment opportunities, and supply and demand for agricultural commodities. These impacts induce responses from people in rural societies, which in turn influence drivers, pressures, impacts and the state of rural societies. This is the essence of rural transformation.

In this study, the DPSIR approach is applied to examine the findings of the foresight scenarios (Reardon et al., 2015) in the context of rural transformation. The Rosegrant et al., 2017 study used the IMPACT model to provide a quantitative assessment of the impacts of alternative investment options on key indicators regarding poverty, food and nutrition security, and natural resources and ecosystem services.

For this study, we used the scenarios presented in Table 1.

In this paper, we first describe the baseline scenario (REF_HGEM), which is a combination of the IPCC's Shared Socioeconomic Pathway 2 (SSP2) and Representative Concentration Pathway 8.5 (RCP8.5), which represents the business-*as*-usual climate scenario. RCP8.5 represents the scenario where the concentration of carbon contributing to global warming is at an average of 8.5 W m^{-2} across the planet with projected temperature increase of about 4.3 °C by 2100 relative to pre-industrial levels. According to the SSP2 scenario, the global population is likely to reach 9.2 billion by 2050, with an average income of USD 25,000 per person (Dellink et al., 2017; Jiang and O'Neill, 2015; Samir and Lutz, 2017). Whereas, RCP8.5 refers to the climate business-*as*-usual scenario, is simulated with the HadGEM general circulation model (a Hadley Global Environment Model developed by the UK Met Office) (van Vuuren et al. (van Vuuren et al., 2007), and IIASA (IIASA, 2015)). The detailed scenarios about both SSP and RCP with a comprehensive summary can be found in Rosegrant et al. (2017).

Table 1
Descriptions of productivity enhancement scenarios.

Scenario	Scenario descriptions
REF_HGEM (baseline)	SSP2 with RCP8.5 future climate using HadGEM GCM
MED	Medium increase in R&D investment across the CGIAR portfolio
HIGH	High increase in R&D investment across the CGIAR portfolio
HIGH + NARS	High increase in R&D investment across the CGIAR portfolio plus complementary NARS investments
HIGH + RE	High increase in R&D investment across the CGIAR portfolio plus increased research efficiency
REGION	Regionally-focused high increase in CGIAR R&D investments Targets the highest increases to South Asia and Sub-Saharan Africa with medium levels of increase in Latin America and East Asia

Source: Adopted from Rosegrant et al. (2017).

3. Major trends of staple cereals as related to selected drivers of change: brief review

3.1. The major drivers of rural transformation

In high-income countries, rural transformation, driven by increased incomes and urbanization, has resulted in a rural exodus with larger scale farm enterprises increasingly relying on science and technology-based production systems (Peter, 1988). Migration and urbanization are important in many low and middle-income countries where agriculture still accounts for a large portion of GDP, however, agriculture is not only still a major economic sector, but also a fallback option or safety net when employment opportunities in the migration destinations do not materialize (Kelly, 2011).

Global drivers of change such as economic development, population growth and climate change affect the three major cereals, both in terms of supply and demand. This interplay of drivers and their effects on specific commodities is an integral part of agricultural assessment models, such as IMPACT. Explicitly defined sets of these drivers form the underlying assumptions used by the models.

3.2. Trends in cereals related to drivers of change

While a large overall increase in cereal consumption is evident, cereal consumption patterns are expected to change in relation to time and space. In 2017, excluding beer, the total cereal consumption in the world was 1.3 billion Metric ton (MT) (FAO, 2019a). The IMPACT scenario analyses show that by 2050, the total cereal consumption for the entire globe will range from 2.9 to 3.9 billion MT (Reardon et al., 2015). Within that broad context will be regional variations.

Assuming moderate growth across world economies for the drivers of population and income, global maize consumption would nearly double between 2010 and 2050 (Fig. 2). Maize utilization (the food versus animal feed) would also change. In South Asia, the bulk of the maize consumed in 2050 would be allocated to livestock feed, increasing from 34% in 2010 to 72% in 2050. The shift away from human consumption and toward animal feed will take place in the former Soviet Union, Latin America, Sub-Saharan Africa, the Middle East and North Africa.

Adding climate change on top of population and income changes gives dramatically different results. Under climate change as modeled by HadGEM climate with RCP8.5, global maize production would only increase by 36% between 2010 and 2050 (as opposed to 72% with a steady climate). Europe and North America would experience no change in production. Concomitantly, maize consumption would also decrease globally compared with no climate change, although maize utilization patterns in 2050 would remain almost the same with and without climate change,.

While maize is likely to be hit much harder than other crops by climate change, demand is expected to rise strongly. Maize is the preferred food of low-income consumers in large parts of Africa and Latin America and is an important feed-stock for livestock production that is expected to increase with growing incomes.

Positioning the major cereals relative to the drivers of change is important to understand their role in the scenarios described above. We first describe their role in a general sense before looking at their role in rural transformation. The demand for wheat is probably the most sensitive to income growth, but also likely to be the least negatively affected by climate change. For example, without climate change, we would expect to see consumption of 876 million MT in 2050, while with climate change REF_HGEM, consumption could actually increase, coming in higher at 910 million MT (Table 2). Interestingly, under many of the IMPACT scenario simulations (Reardon et al., 2015), the global area under wheat cultivation would be lower in 2050 than in the base period. This implies that increased wheat production would mainly come from enhanced yield in the future.

Rice is the cereal most closely associated with irrigation water use

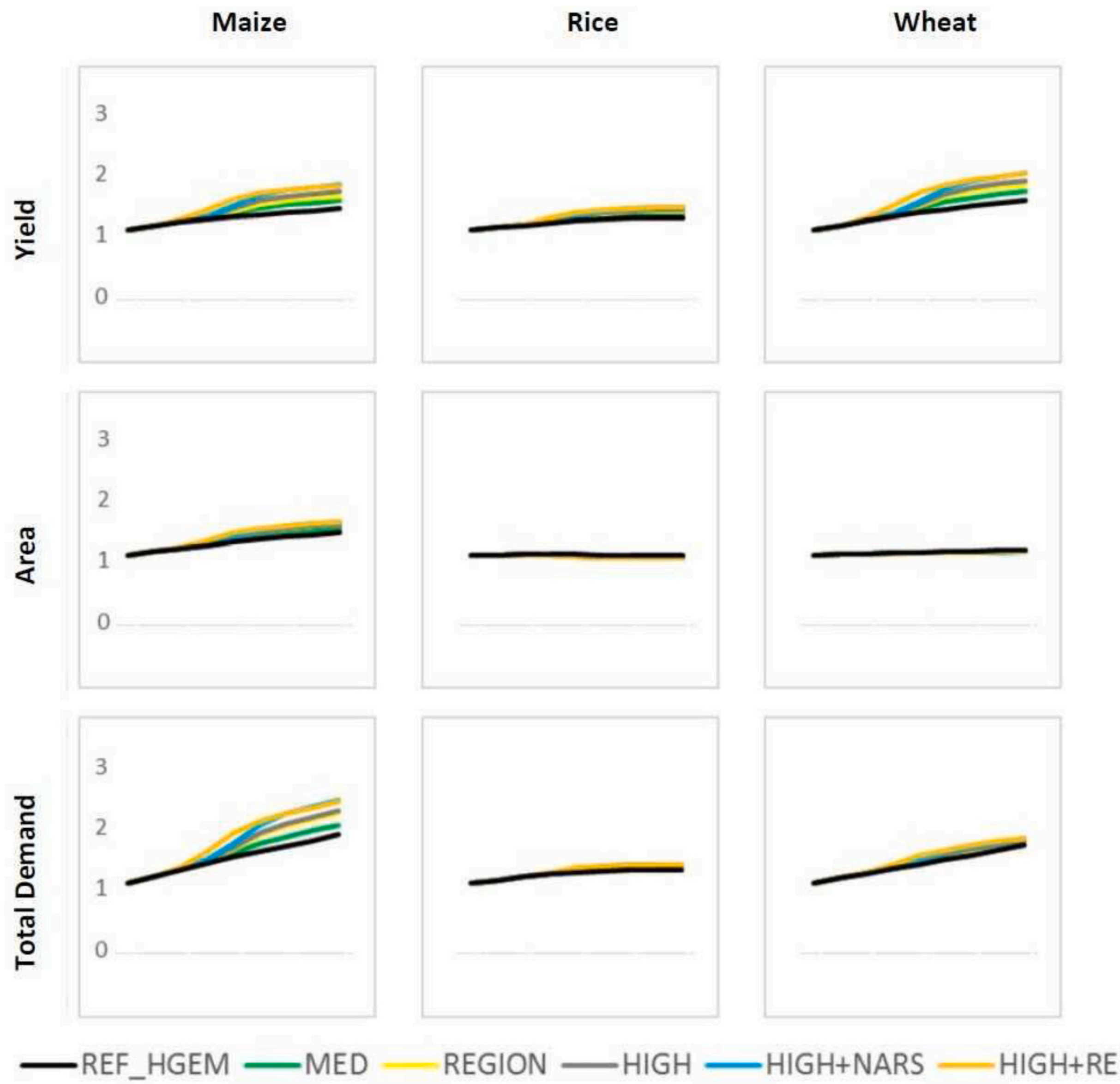

Fig. 2. Trend for yield, area, and total demand between 2010 and 2050. Values indexed to 2010. Major cereals under the productivity scenarios (MED = Medium increase in investment across the CGIAR portfolio; REGION = Regionally-focused high increase in CGIAR investments. Targets the highest investments to South Asia and Sub-Saharan Africa with medium levels of investment increase in Latin America, and East Asia; HIGH = High increase investment across the CGIAR portfolio; HIGH + NARS = High increase in investment across the CGIAR portfolio plus complementary NARS investments; HIGH + RE = High increase in investment across the CGIAR portfolio plus increased research efficiency) and baseline (REF_HGEM = international agricultural R&D continuing along current trajectory)
Source: Authors' based on (Rosegrant et al., 2017).

(although plenty is grown in rainfed systems). As such, it can be susceptible to flooding and drought-induced shortage of irrigation water. Climate change is expected to have a severe impact on the global rice sector by altering the patterns of droughts and floods and spreading more pests and diseases. The climate change could decrease global rice production by approximately 5% (Fig. 2). The decrease in supply would be associated with about an 18 or 24% higher price (Reardon et al., 2015), indicating a greater challenge in securing rice production than is currently felt.

From these figures it becomes clear that major cereals play a dominant role in both the supply and demand side of agri-food systems. This role is further molded by rural transformation processes.

3.3. *The rural transformation perspective*

Rural transformation is inevitable due to large, slow moving pressures with implications for both urban and rural areas. The forms that it takes will come about due to choices made by individual actors as well as policy choices made (or not made) by governments and institutions. Rural transformation fits into the socio-economic scenarios used in the IMPACT model through the economic drivers.

A key driver changing rural areas is population growth along with urbanization. Population growth around 2050 will likely result in a doubling of the population in Africa and an increase of about 25% in South Asia (United Nations, 2014). The interactions between these drivers in turn lead to migration and further urbanization. In some cases, like South Asia, it is likely that urbanization will outpace population growth leading to partial depopulation of rural areas (Swerts et al., 2014). However, in Africa, the opposite may be true with rural areas becoming more densely populated (Racki et al., 2014).

Additionally, the interrelated drivers of general economic development (partially realized as urbanization) and climate change will

Table 2
Projected production and consumption of major cereals across various regions in 2050 based on the reference scenario (REF_HGEM).

Cereals	Rice				Wheat				Maize			
Year	2010	2030	2050	% change (2010–2050)	2010	2030	2050	% change (2010–2050)	2010	2030	2050	% change (2010–2050)
Production (million metrics tons)												
World	435	495	511	18	647	788	924	43	752	914	1023	36
Asia	390	436	439	12	284	362	426	50	208	285	351	69
Africa	15	25	36	134	26	30	32	22	52	73	82	59
MENA	7	8	10	45	70	92	105	51	14	17	20	39
SSA	11	21	32	189	7	10	13	91	45	65	72	61
LAC	19	22	21	12	27	36	44	60	98	151	197	100
Consumption (million metric tons)												
World	429	490	505	18	633	774	910	44	736	899	1007	37
Asia	379	423	427	13	318	405	454	43	241	310	369	53
Africa	22	35	47	109	53	76	95	77	67	105	146	117
MENA	12	16	19	62	90	120	141	56	32	46	60	83
SSA	18	30	41	124	20	33	45	125	50	80	112	123
LAC	19	22	22	14	36	48	108	201	104	148	178	71

Notes: MENA = Middle East and North Africa, SSA = Sub-Saharan Africa. LAC = Latin American and the Caribbean.
Source: Authors' calculation based on Rosegrant et al. (2017).

strongly influence rural areas. The complex nature of rural transformation makes capturing it in global foresight studies difficult. Some studies that capture parts of the rural transformation process include the Mage model and, Agrimonde (Fouré et al., 2013). All models, including the IMPACT model used here, capture a portion of the processes, but never all. Rural transformation is implicit in scenarios that are primarily built around other concepts.

Interpretation of model results needs to consider how the large market-based trends will be felt at the ground level in rural areas. Important aspects for consideration are rural-urban linkages, migration, and technology development and transfer. Permanent migration to cities feeds population density but more transitory commutes and marketing channels facilitate the movement of labor, natural resources, and raw materials from the rural areas to support the urban population. Similarly, these linkages allow urban innovations to make their way to rural areas. If those links are absent, new technologies will not take hold, undermining the incentive for developing them in the first place.

Employment and migration patterns often differ by gender. Female participation in paid employment is expected to change over time due to improved access to education with two effects: better education leads to greater female participation in the workforce, but higher education also leads to delayed entry of women in the workforce (Fouré et al., 2013). Another aspect is the differential effect of migration on the rural workforce. Temporary employment elsewhere tends to be male dominated, leaving women to tend the farms and fields.

Such rural-urban linkages have consequences for agricultural decision making and hence productivity (Ruben et al., 2006). Yield gaps between current farm yields and potentially attainable yields exist for a variety of reasons. But there is empirical evidence that yield gaps become smaller when markets, infrastructure and technology transfers are of a high standard (Edmeades et al., 2010). This indicates that the effect of migration depends on whether ties are severed or maintained, and whether there are other mechanisms allowing for exchange of resources and ideas.

4. Case studies of specific agri-food systems

In this section we apply the DPSIR approach in a foresight framework using IMPACT model scenario results to five specific case studies to understand how rural transformation will play a key role in development in different geographies with different major cereal-based agri-food.

Table 2 presents the projected production and consumption of the world's leading cereals (rice, wheat, and maize) from the baseline scenario in Rosegrant et al. (2017) with climate change as modeled by HadGEM and RCP8.5. From this table, we can find three critical insights. First, both the production and consumption of major cereals will increase worldwide, which is mainly due to population growth. Second, Asia will remain the world's leading food bank. The highest growths are observed in the production of maize (69% increase), followed by wheat (50%), and rice (12%) in 2050 compared to that in 2010. Finally, consumers in Africa, especially in Sub-Saharan Africa (SSA), will demand more than double all of the three cereals in 2050 compared to 2010 consumption. However, in terms of absolute demand for all cereals, Asia will be leading the pack in 2050. In the rest of the paper, these baseline results are compared with the other scenarios described in Table 2.

Total cropped cereal area will increase globally (Table 3), albeit with regional differences per crop. Importantly, since per capita availability of land, estimated dividing cropped areas by population, will decline almost everywhere (Table 3), policies should focus on farm size and farmland distribution worldwide (Lowder et al., 2016). The rest of the paper compares results from this baseline with various scenarios described in Table 1.

4.1. Rice in Asia

Most Asian economies have gone through major structural transformations induced by rapid urbanization, industrialization and globalization, affecting entire agri-food value chains in those economies (Otsuka, 2013; Reardon et al., 2015; Reardon and Timmer, 2014; Tschirley et al., 2014). Here, we will only discuss rural transformation in terms of changes in farm size, rural wage, and rice production and processing technology in Asia. Together with price policy reforms (Laborde et al., 2018), these are the primary drivers that are likely to affect production systems and, thus, rural communities.

The share of Rice in agricultural GDP, employment, food calories and food expenditures has been declining in many Asian countries (Mohanty et al., 2017). More than 90% of the global 500 million MT of rice are produced and consumed in Asia (FAO, 2019b), which is produced from 30% of the total arable land of this region. However, Asia is undergoing declining trends in women fertility, child mortality, family size, population growth, the proportion of the agricultural population, and involvement of youth in agriculture. On the other hand, rural out-migration, aging of the farming population, and urbanization show increasing trends (Bhandari and Mishra, 2018). Per capita availability of arable land (average farm size) has been declining rapidly in many Asian countries in the last decades (Hazell et al., 2010; Lowder et al., 2016), possibly due to succession across several generations, expansion of plantation crops, aquaculture farming, and urbanization (Bren Bren d'Amour et al., 2016; Pandey and Seto, 2015).

In Asia, the rural wage increased substantially during the last two decades (Otsuka, 2013) potentially caused by the development of

Table 3
Projected per capita availability of cropped land (ha/person) of major cereals across various regions in 2050 based on the reference scenario (REF_HGEM).

Cereals	Rice				Wheat				Maize			
Year	2010	2030	2050	% change (2010–2050)	2010	2030	2050	% change (2010–2050)	2010	2030	2050	% change (2010–2050)
Cropped land (million ha)												
World	152.73	153.74	152.45	−0.18	218.15	221.64	226.79	3.96	149.57	171.26	186.06	24.40
Asia	135.31	134.47	131.51	−2.81	98.38	100.88	103.90	5.61	47.62	55.76	62.23	30.68
Africa	9.01	10.99	12.86	42.65	10.46	10.76	10.92	4.35	28.66	32.83	34.52	20.44
MENA					27.97	29.13	28.78	2.88	2.19	2.50	2.83	29.39
SSA	8.36	10.39	12.25	46.60	3.11	3.51	4.18	34.37	27.63	31.65	33.19	20.12
LAC	6.42	6.22	5.79	−9.85	9.98	10.75	11.87	18.94	28.12	35.32	42.19	50.01
Per capita land availability (ha/person)												
World	0.022	0.019	0.017	−25.25	0.032	0.027	0.025	−22.15	0.022	0.021	0.020	−6.85
Asia	0.033	0.028	0.026	−21.70	0.024	0.021	0.020	−14.92	0.011	0.012	0.012	5.27
Africa	0.009	0.007	0.006	−27.58	0.010	0.007	0.005	−47.02	0.028	0.021	0.017	−38.86
MENA					0.061	0.048	0.040	−34.26	0.005	0.004	0.004	−17.33
SSA	0.010	0.008	0.007	−29.39	0.004	0.003	0.002	−35.28	0.032	0.024	0.019	−42.14
LAC	0.011	0.009	0.008	−28.91	0.017	0.016	0.016	−6.21	0.048	0.051	0.057	18.29

Notes: MENA = Middle East and North Africa, SSA = Sub-Saharan Africa. LAC = Latin American and the Caribbean.
Source: Authors' calculation based on Rosegrant et al. (2017).

non-farm sectors and the close proximity to urban areas as well as an increasingly active land market in most Asian countries (McGee, 2008; Turok and McGranahan, 2013; UNCTAD, 2015), creating high-income job opportunities (McGee, 2008; Turok and McGranahan, 2013). Due to the labor shortage in the farm sector, agricultural labor productivity (the price of labor) rose in many Asian countries, as did the production costs (Moya et al., 2004). Finally, even though green revolution technologies in the food sector had a significant impact on food and nutritional security as well as on alleviating poverty, particularly in developing countries, these technologies are reaching their limits (Pingali, 2012) and there are concerns about the sustainability of production in these input-intensive systems.

4.2. Rice in Africa

Based on the scenarios (Reardon et al., 2015), per capita availability of land will decline from 28 to 47% in Africa, and from 30 to 42% in SSA (Table 3). However, we found that the cropped areas under all three cereals will increase significantly, mostly in SSA (Table 3), due to significant increase in cereal demands (Table 2). The highest demand increase is observed for rice (47%). One of the main reasons for this is Africa's diet transformation, where rice is becoming a luxury good for many wealthy consumers, unlike in Asia, where demand has shifted to other foods. The scenarios (Reardon et al., 2015) project that African consumers will demand 20–40 million MT more rice by 2050 than in 2010 (Table 2).

At present, the critical challenges facing the African rice sector are to enhance production, processing, and marketing to enable the growing demand to be turned into an opportunity for the economy and rice value chain actors (Demont, 2013; Seck et al., 2010; Wopereis et al., 2013). Nonetheless, by 2050, rice productivity could increase between 40 and 42% under increased investment in international and national agricultural research in SSA (scenarios HIGH + NARS, HIGH + RE and REGION). Increasing production across these investment scenarios would push down rice prices between 20 and 27% (Reardon et al., 2015).

Farm size is larger in most African countries compared to Asia, therefore, instead of consolidation policies, formalization of land rights policies can help intensification of farming systems with corresponding yield increases (Otsuka and Place, 2015; van Oort et al., 2015). During the last decade, Africa's rice sector witnessed a significant boost in yield, mostly in SSA, comparable to the GR growth rates in Asia. Thus, this sector has the potential for the enhancement of rural incomes and food security in African countries (Otsuka and Larson, 2016). This requires a regional approach to agricultural R&D because rice productivity in Africa and Asia are not on par.

4.3. Wheat in MENA region

The Middle East and North Africa is one of the world's most rapidly transforming regions, politically, economically, demographically, and environmentally (McKee et al., 2017), and it is expected to continue facing these major issues. Pressures such as land degradation (including desertification and erosion), water shortage (with the highly expected impact of climate change) and driver-induced trends towards urbanization will de determining factors shaping the future of the region.

Urban areas will generate around 90% of total population growth across MENA countries by 2050. When including net rural–urban migration, some 70% of the region's populations will be living in cities by 2050 (McKee et al., 2017) with some regional variation. Food demand patterns in urban agglomerations will have a significant impact on the wheat value chain, with more reliance on diversified market products, which will also offer opportunities for further development of this value chain. From a political perspective, most governments in the MENA have been using direct protection instruments to safeguard both local production and consumption. MENA is among the largest global basic foodstuff importer, representing around 30% of total food imports. The region is collectively a net importer of 58 million MT of cereal (Wright and Cafiero, 2011). Wheat production systems in the region have for a long time been shaped by the political economy and social dynamics (Ahmed et al., 2013).

Rapid urbanization and off-farm opportunities are likely to increase the pressure on agriculture as the main component of rural livelihoods. Moreover, climate change and related increases in temperature will make wheat production more difficult in many of the current breadbaskets of the region. Increasing production as projected by IMPACT scenarios (see Fig. 2, Table 2) will tend to drive down wheat prices somewhat, leading to improved terms of trade for net wheat importing countries.

4.4. Maize in Sub-Saharan Africa

SSA is urbanizing very rapidly (Tacoli and Agergaard, 2017; Tschirley et al., 2014), and most of its population will live in urban areas by 2035 (World Bank, 2020b). Urbanization springing from the synergistic relationship between agriculture and small cities and towns, therefore, has a potential to transform rural areas and result in a more inclusive growth because of: (i) the transformational power of rural towns, (ii) increased access to markets, (iii) lifestyle and food system changes, (iv) farming system transformations, and (v) increased labor and cash flows.

Maize is a staple food in SSA (Shiferaw et al., 2020). Based on

Rosegrant et al. (2017), future maize demand in SSA is projected to nearly double by 2050 compared to 2010 (Table 2), whereas cultivated land per capita is projected to decrease over the same period (Table 3). Hence, the gaps between maize demand and supply will reach 40 million MT in 2050, more than seven times compared to that of 2010 (Table 2). Rising food demand presents an opportunity for inclusive rural transformation across SSA.

Intensifying land scarcity should increase rural-rural migration to areas where land is still available and should put greater pressure on non-farm sectors to absorb rural labor in densely populated areas (Jayne et al., 2014). Climate change encourages migration into better farming environments (Simelane, 1995), or urban informal workers returning when weather conditions permit This shows that the distinct relations between migration, agricultural change, and the environment are mediated in varying degrees by flows of remittances, loss of labor, socioeconomic stratification, gender dynamics, and cultural factors (Greiner and Sakdapolrak, 2013).

Clearly, access to markets is a necessary condition for rural transformation in SSA. The paved road network in SSA has significantly expanded in the last few decades (Berg et al., 2016), creating opportunities for the establishment of rural towns next to rural roads to stimulating smallholder market participation and the growth of the nonagricultural sector (Barrett, 2008; Damania et al., 2017; Houssou et al., 2018; Jacoby and Minten, 2009; Minten et al., 2013).

Market access also allows the diversification of livelihoods out of agriculture and has a strong connection to migration, where complex relationships are expected to emerge with positive (Gibson and Gurmu, 2012) and negative effects (Cris, 2010) and leading to for instance circular migration (Jayne et al., 2014).

4.5. Maize in Latin America

The agrarian transformation has been a key issue in Latin American agricultural development as a response to drivers and pressures on rural society. Across the continent, different parallel agricultural systems developed within the cereal-based systems. Modern agricultural enterprises produce for domestic and/or international markets, alongside small to medium scale farms that tend to produce for local and domestic markets, and smallholder farms producing for own-consumption and relying primarily on off-farm and/or non-farm income for their livelihood. Along this spectrum, many different farm types exist, in both lower middle-income as well as higher middle-income countries. Early development processes in Latin America were biased toward industrialization, with only limited agrarian reform followed by a wave of incomplete liberalization that ultimately formed the backbone of much agricultural policy throughout the region (Gwynne and Kay, 2004). Policies to address inequalities between large-scale enterprises and smallholder systems across the region have not yielded major results (Vergara-Camus and Kay, 2017) and the differences are not likely to change over the coming decades.

With extant structural inequality, a large number of smallholder farms will continue producing for own consumption or the local markets, albeit in livelihood strategies in which agriculture is only one of the pillars. On the other end of the spectrum, large-scale agricultural enterprises operating for export and/or industrialized domestic processing value chains will generate an important part of agricultural GDP. Options for local sourcing of raw material for the processing industry or more value-added products will offer scope for consolidating both large scale agricultural enterprises and possibly small to medium scale farms. An additional prospect is the production of maize for animal feed. In Mexico, for instance, currently, the vast majority of maize for animal feed is imported, while maize for food is domestically produced.

The foresight scenarios (Reardon et al., 2015) project (Table 2) a higher increase in production than consumption, implying a shift is use towards the feed industry that is currently reliant on imports. The increase in production can be attributed primarily to shifts in land use, such that more land is cropped with maize (Table 3).

5. Conclusions and policy implications: possibilities and challenges of major cereals

In this paper, we use foresight approaches to better understand the dynamics and consequences of rural transformation. Simulation models project large increases in demand, but meeting this demand will require attention to aspects of rural transformation that are not fully captured in simulation models (at least at present). Zooming in on cereal-based agrifood systems of key regions, this study indicates that cereal-based food system will remain dominant. Thus, it is imperative to invest in agricultural productivity to enhance cereal supply considering rural transformation.

The challenge is to support rural and agricultural transformation with its benefits of poverty alleviation and employment creation, while maintaining agricultural diversity. The challenge for major cereals is to meet the increased demand brought about by urbanization and dietary change without displacing other nutritious crops and livestock from rural landscapes. To date, global agricultural assessment models are unable to adequately address these concerns.

Major drivers of change that influence rural transformation are climate change, migration patterns and social and economic structures in rural areas. Population growth and economic opportunities in non-agricultural sectors also drive urbanization. Finally, natural resource scarcity both in quantitative and qualitative terms places pressure on agriculture and rural communities. In all regions changes in rural lifestyle and pressure on farmland will also induce changes. These can be positive changes on the adoption of new varieties of seeds, farm inputs, and labor-saving innovations. These can also lead to more pressure on food systems when productivity and demand do not develop at the same pace, as in the MENA region. Improved access to markets opens new opportunities for rural households, relieving pressure from sole reliance on agriculture for livelihoods. Considering the importance of balanced diets to combat malnutrition and disease, there is a call to invest in non-cereal crops, such as lentils and vegetables, by reducing investment in cereals (Pingali, 2007; Pingali et al., 2019). However, our study stressed that the staples maize, wheat and rice, will continue to play an important role in supplying most of the daily caloric intake around the globe.

Based on region-specific case studies, higher production costs might discourage rice farming because of the reduction in rice's competitiveness in Asian rice-based systems. However, labor productivity of women in Asia is still low and not yet fully realized in agricultural activities. Empowering women in agriculture could reduce cost of rice production. Smallholder rice production systems in Asia are under pressure due to natural resource constraints. With these pressures, rural transformation in Asia is diversifying out of rice production and into high value commodities and non-farm employment. This is opposite to the situation in Africa, where smallholder rice production has growth potential as part of the rural transformation process.

Rural transformation in MENA will certainly result in more pressure on the wheat sector; both in terms of demand and supply. However, the IMPACT model results also show that investments in productivity enhancement could result in significant increase of wheat supply. More value chain opportunities would also be expected with growing urbanization, market development and diversification.

In Africa, besides rural transformation factors, the production and supply of major crops such as maize is influenced by environmental factors. Rain-fed maize systems in Africa will be hit hardest by climate change (Reardon et al., 2015; Tesfaye et al., 2015). To off-set these pressures, while considering the continuing rural transformation processes, investments are needed that allow farmers to take advantage of unexploited agricultural potential in maize-based systems. This requires investment in infrastructure, markets and service provision to increase market access. As food systems evolve, desired traits for maize varieties will also evolve. For example, the need for yellow maize is expected to increase in SSA due to the emerging cattle fattening and poultry production business that is following the expansion of towns and cities. These and other emerging needs require accelerated variety substitution to meet evolving reality. This requires investment in both international agricultural research and national agricultural research systems (NARS) to tailor varieties and associated technologies to local circumstances.

In Latin America, economic development and rapid urbanization will lead to a decreased growth in demand for the major cereals as food consumed directly, but a continued growth of animal-based food products that depend critically on maize for feed. Maize for food and feed are different varieties with different physiological and agronomic characteristics, hence shifts between food and feed are not automatic and require investments in both variety development as well as innovative systems to assist the transformation.

The novelty of this study is that it used the IMPACT model findings (Reardon et al., 2015) on future global R&D scenarios and looked at the limitations through the lens of rural transformation analysis across regions. The study argues that rural transformation is a complex phenomenon hinging on agro-climatic conditions, population dynamics and overall economic developments including market access. IMPACT and other global economic models do capture regional, national and even some subnational variation, but they don't generally capture the nuances of rural transformation that this paper has argued are important. So limited conclusions can be drawn from the IMPACT model results alone regarding what kinds of research investments would best support the changes that will improve livelihoods of the poor in the studied target geographies. Therefore, an iterative approach with more focused analyses on the complexities of rural transformation is needed to fine-tune results and place them in perspective. Supplementing the IMPACT model results with rural transformation analysis, however, shows that the evolving needs in different regions and development domains in those regions require different R&D investment strategies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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