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# Adaptation and development pathways for different types of farmers

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ABSTRACT

One of the greatest challenges humanity faces is feeding the world's human population in a sustainable, nutritious, equitable and ethical way under a changing climate. Urgent transformations are needed that allow farmers to adapt and develop while also being climate resilient and contributing minimal emissions. This paper identifies several illustrative adaptation and development pathways, recognising the variety of starting points of different types of farmers and the ways their activities intersect with global trends, such as population growth, climate change, rapid urbanisation dietary changes, competing land uses and the emergence of new technologies. The feasibility of some pathways depends on factors such as farm size and land consolidation. For other pathways, particular infrastructure, technology, access to credit and market access or collective action are required. The most viable pathway for some farmers may be to exit agriculture altogether, which itself requires careful management and planning. While technology offers hope and opportunity, as a disruptor, it also risks maladaptations and can create tradeoffs and exacerbate inequalities, especially in the context of an uncertain future. For both the Sustainable Development Goals and the 2015 Paris Agreement to be achieved, a mix of levers that combine policy, technology, education and awareness-raising, dietary shifts and financial/economic mechanisms is required, attending to multiple time dimensions, to assist farmers along different pathways. Vulnerable groups such as women and the youth must not be left behind. Overall, strong good governance is needed at multiple levels, combining top-down and bottom-up processes.

## 1. Introduction

There is increasing consensus that the global food system needs to be transformed if it is to deliver safe and nutritious food for all, whilst keeping within the Earth's limits (Willett et al., 2019). Future trends place the food system in an even more vulnerable position than it is at present. Global demand for food is expected to grow by 70% from 2009 levels by 2050 (Foley et al., 2011). At the same time, projected climate change impacts threaten to make food more difficult and more expensive to produce and distribute (Foley et al., 2011), while huge amounts go to waste (KC et al., 2016). The burden of these challenges will fall disproportionately on the poorest and most vulnerable farmers, many of whom already suffer from hunger (Holt-Giménez et al., 2012; Gregory et al., 2005). 'Business as usual' agriculture is not an option for meeting basic human needs on a planet with 2 billion more people compared to 2018 by 2040, and intensifying climate change impacts (KC et al., 2018). To keep the planet's mean annual temperature within 1.5 °C of pre-industrial times, agriculture's carbon intensity must be radically and urgently reduced, as food production is already contributing significantly towards the overstepping of planetary boundaries in many locations around the world (IPCC, 2019; Gordon et al., 2017). Changes are required against the backdrop of global trends in population growth, rapid urbanization, dietary changes, the emergence of new technologies and pressures from competing (non-food) land uses. Impacts of these trends are unequally distributed between the global north and the global south, affecting different types of farmers in different ways.

If countries' commitments under the 2015 Paris Agreement and the Sustainable Development Goals (SDGs) are to be achieved, transformation becomes vital. Transformative change towards a future in which food security, climate change and livelihood aspirations are met through multi-functional landscapes requires radical, systemic shifts in

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values and beliefs, patterns of social behaviour, and governance (Olsson et al., 2014). Haberl et al. (2011) estimate the magnitude of transformation required is akin to that from hunter-gatherer societies to agrarian and then industrial societies, constituting nothing less than the "fourth industrial revolution" (World Economic Forum, 2016). No single transformation pathway will be appropriate in all situations, and it is difficult to generalize from one farmer to another (Fraser et al., 2006; Stringer et al., 2006; Scoones et al., 2018). As such, many argue that multi-disciplinary and multi-stakeholder interventions are needed to help leverage progress along different pathways and address the needs and aspirations of the farmers themselves if they are to pursue a meaningful livelihood (Fraser et al., 2016; Hebinck et al., 2018; Pereira et al., 2018a, 2018b). Pathways further need to ensure that environmental, economic and social-cultural benefits are not compromised, now or into the future.

This paper explores possible pathways for different types of farmers, considering where they might be in the future, beyond 2030 and the era of the SDGs. It outlines some of the necessary interventions, risks and trade-offs associated with these different pathways, for farmers operating in a variety of agricultural systems globally, including cropping, livestock and tree (silvopasture) systems. It also considers the impacts of different disruption scenarios that could radically alter anticipated pathways and offers a range of possible interventions. Investigating possible pathways for different farmers allows us to better identify necessary levers for transformation.

## 2. Adaptation and sustainable development pathways for different types of farmers

Different types of farmers need different adaptation and sustainable development pathways as they are starting from different points and are affected by global trends in different ways. In some cases, farm size is important in shaping decisions and options; in others, possible pathways might have consequences such as reducing agricultural income within overall livelihood portfolios. Other types of farmer might require greater action to address environmental concerns, and for some farmers an exit from farming might be necessary. In light of this complexity, and with an awareness of Agenda 2030 and the 2015 Paris Agreement, we employ the three classic pillars of sustainable development (WCED, 1986), as a conceptual anchor to inform the identification of adaptation and development pathways for different kinds of farmers. In doing so, our analysis reveals that some farmers will need to pay more attention to environmental considerations; other types of farmers will need to place more emphasis on economic or social-cultural imperatives. In Fig. 1 we have imagined four types of farmer and illustrated that while each may have different pathways, all must end up balancing the various dimensions of sustainability. Using this broad-brush typology, we can explore how at an aggregate level, a global transformation of the agricultural system can help to keep climate change below 1.5$^0$C while also achieving food security.

While the concept of food sovereignty is gaining international traction beyond social movements like La Via Campesina in governance spaces like the United Nations, its lack of conceptual clarity contributes to a variety of often diverging interpretations (Dekeyser et al., 2018). We use a food security framing in this paper, recognising that alternative framings would result in a different emphasis on transformative pathways. A food and nutrition security framing allows for an analysis of bottom-up as well as top-down governance interventions and has been referenced in the transformations literature (see Hebinck et al., 2018).

We next present the range of different farmer types and transformation pathways considered in our analysis.

### 2.1. Conventional large-scale, commercial farmers

Average farm sizes are generally larger in countries with higher average per capita GDP (Lowder et al., 2016). Such large-scale farmers are commonly commercially oriented, with their decision-making under certain circumstances, largely driven by the markets they can access to sustain and enhance their profitability. At the same time, some large-scale private companies and quasi-governmental agricultural enterprises have been shown to be involved in transnational land and water "grabbing" (Borras et al., 2011; Rulli et al., 2013; Gilbert, 2016) that also pursues this model. Land management practices are often criticized for being environmentally insensitive, requiring agrochemicals, large machinery, transportation infrastructure, and irrigation (e.g. see Pereira et al., 2018a, 2018b). Negative environmental consequences include the eutrophication of water bodies, aquifer depletion, soil degradation, increases in greenhouse gas emissions, declines in pollinator abundance and diversity, as well as negative impacts on off-farm ecosystem and human health (Schindler et al., 2016; Dalin et al., 2017; Smith, 2016; Ramankutty et al., 2018; Goulson et al., 2015). The power of large-scale commercial farming can reinforce inequalities, which in the Global South includes a loss of local livelihoods and food security, especially when larger commercial farms negatively disrupt established local income generation patterns (Shete and Rutten, 2015; Mellor and Malik, 2017). Large multinational and supermarket purchasing models, supported by consumer demands, also favour larger-scale producers (Stringer et al., 2008). Such actions reflect specific modes of development that favour economically-driven capitalist approaches (e.g. economies of scale efficiencies) with often negative effects on local livelihoods and land rights (Dell'Angelo et al., 2017; Lambin et al., 2001). Nonetheless, some large-scale commercial farming operations are well suited to adaptation interventions. In terms of transaction costs, persuading a few large farmers to make positive changes could be easier, more effective and have a wider impact than influencing large numbers of small-scale farmers.

Sustainability pathways for conventional large-scale commercial farmers need to support development of markets for more sustainably created produce in order to meet food security and climate change challenges. From a regulatory perspective, regional, national and international governance processes must establish a coherent framework to ensure that sustainable practices are prioritised, emphasising environmental and social-cultural aspects. Such measures could include pricing mechanisms on carbon and payments for ecosystem services (PES) that incentivize creation/maintenance of biodiversity and ecosystem services. The logic behind these kinds of schemes has been well articulated, and experts, industry and policymakers have been aware of these possibilities for decades (Redford and Adams, 2009). In parallel to supporting farmers to pay more attention to socio-cultural and environmental concerns, awareness-raising and education is needed on the consumer side of the food system. This will ensure that consumers demand food that has been produced to the highest environmental and ethical standards, and that they are willing to pay for it, especially in wealthier parts of the world where individuals have more disposable income.

Another possible pathway of particular relevance to large-scale farmers who have easy access to capital for investment requires levers that harness the power of technology. Digital technology has been proposed as a 'quick-fix' (Falk et al., 2018), offering hope as a route both to attract new farmers and keep some people in farming, especially in the global north. Robotics, artificial intelligence and big data analytics all offer potential to produce more food on less land and with fewer inputs (Lindblom et al., 2017; Parizat and Strubenhoff, 2018). However, these technologies are not a panacea, and concerns have been raised about e.g. the effect of automation and robotics on rural labour, particularly in locations where youth unemployment is already high (Fraser and Charlebois, 2016; Rotz et al., 2019). The development of technology further presumes some level of investment capacity, literacy and infrastructure, excluding some farmers from the outset (Trace, 2016). Consequently, the development and application of specific technologies in local contexts needs to be guided by local stakeholders,

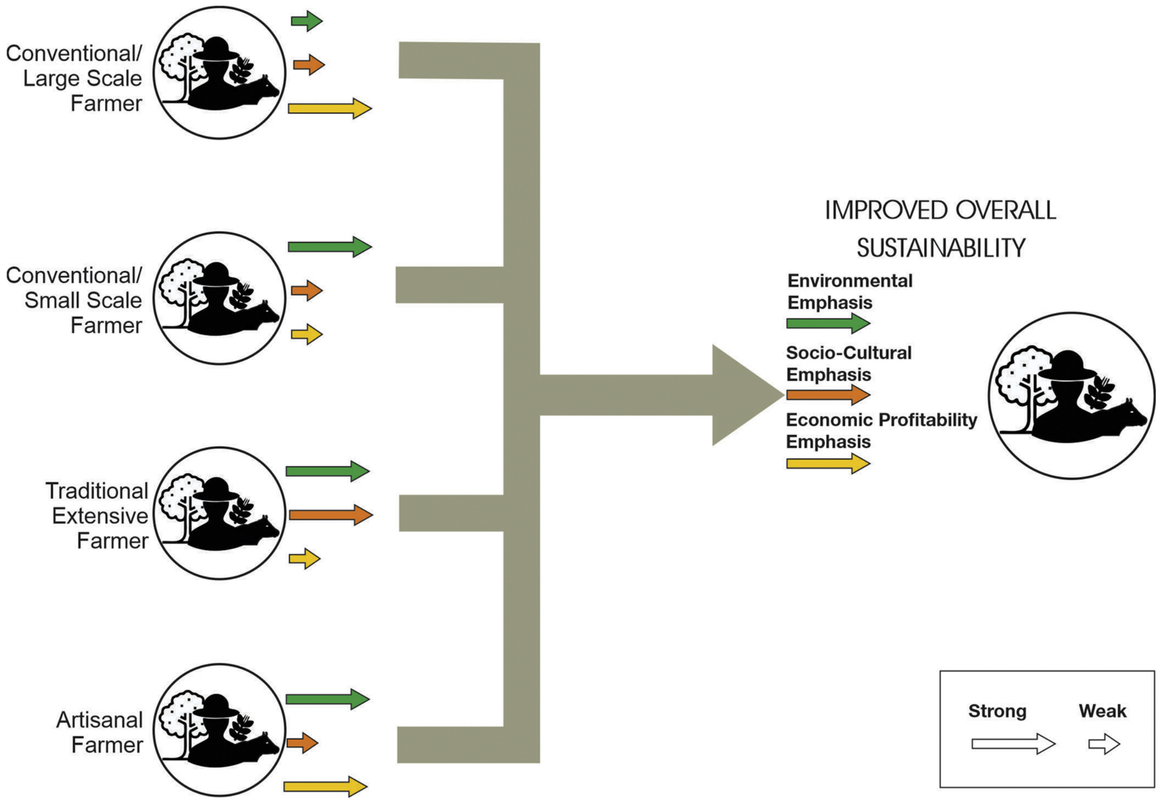


**Fig. 1.** Heuristic illustration of how different types of famers today (left) respond differently to economic, social and environmental imperatives (denoted by the length of the three coloured arrows) yet all must transition to a future situation (right) where all three types of driver are more balanced.

with farmers themselves playing a key role by engaging from the very beginning.

In summary, pathways for large-scale commercial farmers demand legal frameworks and regulations pertaining to the environment, supported by necessary policy, financial and economic mechanisms; consumer advocacy around sustainably produced products, grounded in long-term awareness raising and education programmes; and technological interventions. In reality, these pathways and many more will be required, in order to ensure that the environmental impact of conventional large-scale farming is reduced, production levels are sustained and enhanced, and social and cultural conditions are improved, especially where large-scale agricultural corporations lack connection to the land.

### *2.2. Conventional smallholder farmers*

Farmers of this type span a very large spectrum, with those farming for subsistence at one end and those generating a small surplus for market at the other. Income generated by conventional smallholder farms is seldom adequate to ensure a meaningful livelihood (Homann-Kee Tui et al., 2015; Harris and Orr, 2014). There are an estimated 570 million farms in the world (Lowder et al., 2016) and around 85 % of these (480 million) comprise 2 ha or fewer. While large numbers of people operate these small farms, they occupy only around 12 % of global agricultural land area. Even using best-practice farming methods, such small farms are often not financially viable (Harris, 2019), with land users also relying on other sources of income, particularly where fragmentation reduces the effective land area available for cultivation. Farmers with < 2 ha of land are unlikely to become prosperous, no matter how productive they are (Harris, 2019), and meaningful poverty reduction will generally not be achieved from increasing crop and livestock productivity alone (Wichern et al., 2017). Rare exceptions are capital-intensive enterprises such as glasshouses producing high-value crops and intensive livestock production.

Although most smallholder households sell a proportion of their produce at some time, this is not really ‘commercial’ market agriculture. They are not selling a surplus for profit but are doing so to generate cash to pay for goods and services that cannot be provided by a subsistence lifestyle. Significant opportunities exist for sustainable intensification on these very small farms, but it may be difficult to achieve large enough yield gains. This means it is unlikely that most conventional smallholders will make a major contribution to increased global food security (Thornton et al., 2018). In particular, there seems to be some consensus in the literature that very small farms cannot be commercial in any real sense unless they gain access to more land, which would allow them to focus more on producing surpluses for sale (Diao et al., 2003; Poulton et al., 2010). Sustainable development pathways for such farmers should then respond to the same incentives as large conventional farms (Dorward et al., 2004). Thus, the pathways from subsistence to commercial farming are predominantly (though not wholly) a function of farm size, with these types of smallholder farmers viewed on a continuum. It should be noted, however, that shifting from a food security framing to that of food sovereignty that is associated more with a right to food and food justice discourse would alter this emphasis on land consolidation for profits.

The traditional model of agricultural transition, whereby people leave land that is then consolidated into larger and more capital-intensive farms, is generally not happening quickly in regions such as sub-Saharan Africa, where rural households are strongly attached to their land (Tafira, 2015), even for non-agricultural use (Masterson et al., 2017). At the same time, there is mounting evidence of environmental degradation, while yield gaps tend to reinforce existing poverty

(Tittonell and Giller, 2013), in combination with population growth and high levels of rural youth unemployment. Several smallholder households diversify their livelihoods by engaging in non-farm income generating activities, although many of these are currently seasonal and/or precarious (Harris and Orr, 2014). Whether or not countries can generate enough economic opportunities for people to leave farming completely remains questionable. The current situation, where households operate small land units as low-cost, low-risk, 'safety net' enterprises alongside other income generating activities, making valuable contributions to local livelihoods and food security, is a perfectly reasonable social system and can be relatively durable given enough support (despite that environmental aspects are often somewhat neglected). However, it is not readily amenable to agricultural intensification.

Widespread efforts to de-carbonise agriculture could potentially hit smallholders disproportionately hard, especially given that their greenhouse gas emissions are smaller than those of intensive large-scale commercial farms. Boosting or sustaining productivity through e.g. climate-smart agricultural practices offers one feasible option. For instance, integration of *Faidherbia* with grain crops on nutrient-poor African soils can both sequester more carbon in soils and trees while increasing yields. However, polycultures are not popular in climate mitigation schemes as they require rigorous monitoring and reporting. Despite local climate and food production 'wins', potential gains on very small farms will almost always be small and represent poor incentives for investment (Harris and Orr, 2014; Harris, 2019). Given that smallholder households already rely on multiple income sources, an important pathway for conventional farmers with the smallest, least viable farms, may be to develop more secondary or tertiary economic opportunities in the rural environment. This may include improving the post-harvest value chain and other ancillary economic activities. These efforts require innovation, institutional support, infrastructure, education and training, as well as resourcing and investment. They also necessitate consideration and mitigation of greenhouse gas emissions from new sources as novel opportunities emerge.

Another sustainable development pathway, involving reform of tenure rights and enabling land ownership, could help those households with agricultural ambitions to access extra land, creating larger viable, profitable farms, oriented more firmly towards markets (Collier and Dercon, 2014). Such changes need to come with technical support and advice that is appropriate and consistent. This pathway is equally relevant to small commercial farmers who wish to expand their enterprises. Reformed land ownership, coupled with appropriate technical advice, could support a vibrant and effective land rental market (e.g. Deininger and Jin, 2005). Urbanisation trends offer an opportunity for this pathway as millions of people are likely to exit from smallholder agriculture altogether (see Section 2.5). At the same time, agricultural re-engagement efforts are needed to help the 65 million refugees and displaced people in the world (UNHCR, 2018), many of whom live in camps, to derive their own food security at a small scale. This is vital if the post-2015 development aspiration to 'leave no one behind' is to be achieved. Positive examples of refugees striving to become food self-sufficient while keeping emissions low are found in countries such as Kenya (FAO, 2018).

### 2.3. Traditional extensive farmers

Traditional extensive farmers start from a point of strong environmental and socio-cultural emphasis but are not always profitable, so pathways need to attend to this. One example of a traditional extensive farmer operates in a silvopasture system. Silvopasture systems are characterized by agroforestry and the co-location of animals or crops and trees, often, but not always, in extensive systems (Mosquera-Losada et al., 2009, 2012; Cubbage et al., 2012). Silvopastoral activities can be found in landscapes around the world (Maia et al., 2007), and their scale and potential to deliver multi-functional benefits varies hugely from region to region. For example, in South America, small-scale systems can be classified as 20–50 ha; medium scale from 90 to 800 ha and large-scale > 1100 ha (Frey and Nicole, 2007), while in other regions more extensive systems are found (Cubbage et al., 2012).

The traditional extensive farmer type faces challenges and constraints, particularly relating to integrating formal and informal forms of knowledge, initial capital and labour costs, operational issues, resource tenure, niche markets and incentives (Thevathasan et al., 2012; Hernández-Morcillo et al., 2018; Šūmane et al., 2018). However, in general, traditional extensive land management practices deliver a wide range of ecosystem services, and hold high socio-cultural values for human populations that live in and manage these areas (Atangana et al., 2014; Simelton and Viet Dam, 2014). Possibilities for profit are challenged, however, by the often remote, extensive nature of these systems, which can stifle market access; while smaller plots offer limited opportunities for the movement of livestock (Mirzabaev et al., 2016).

Traditional, extensive farmers tend to suffer from a lack of economic profitability. Yet, diverse, multifunctional, traditional extensive systems such as silvopasture offer at least two opportunities for income generation for both small and large farmers as pathways seek to better harness economic, environmental and socio-cultural benefits: i) money from the sale of trees/shrubs and their products, and ii) income from the sale of livestock. Some types of trees (e.g. *Gliricidia sepium* in Nigeria) provide secondary resources such as fodder and browse, while products such as berries, nuts and mushrooms can be gathered for subsistence and/or sale (Vandermeulen et al., 2018; Rousseau et al., 2015). Overall, decision making about the types and numbers of animals in these systems plus the types and numbers of trees creates opportunities and limits relating to both food production capabilities and opportunities to mitigate and adapt to climate change. Trees on farms can further aid faster economic recovery after natural disasters (Simelton et al., 2015) and improve adaptation to climate change (Mbow et al., 2014). At the same time, benefits from farming can include less materially tangible components linked to wellbeing, such as preservation of traditions, status, lifestyle, satisfaction, and so on.

In general, larger extensive farms offer greater opportunity for economic gain while maintaining environmental and socio-cultural values and non-material benefits purely because of their larger land base. One trade-off is that with a bigger area to manage, it can be more difficult for a single farmer to justify the labour given the sometimes lower economic returns per ha compared with other farming-systems (Antonini and Argilés-Bosch, 2017; Duffy, 2009; Woodhouse, 2010). Larger farms are nevertheless more likely to be able to gain market access, especially in locations where extension and other agricultural learning institutions are more easily accessible (Jin and Huffman, 2016). These opportunities and resources can combine to help to generate higher returns than is the case for smaller farms.

While small-scale silvopastoralists may be hampered by their land size, collective action can be stimulated to pool both input resources (land, knowledge, infrastructure, etc.) and outputs, supporting marketing of diverse products from smaller scale systems. For example, in Romania following the collapse of Communism, owners of degraded, fragmented plots united to harness World Bank funding for tree planting via the Government. This enabled access to funding which was only available for land areas of a certain (larger) size (Stringer et al., 2007). Other collective options include cooperative grazing (Lesorogol, 2008) or engagement in land rental, although these may result in economic changes or create environmental degradation if not carefully managed (Sklenicka et al., 2014). Further pathways include microfinance to provide upfront capital to invest in the system (e.g. use of microfinance to support set up of a cooperative), while learning platforms can provide an opportunity to share knowledge between different small farmers- an important gap in many regions (Djanibekov and Khamzina, 2016)- facilitating collective action. These pathways can be supported by rebalancing subsidies and improving market access, marketing and the opening up of new markets (Frey and Nicole, 2007). Viable levers may also include innovations such as PES, certification of niche products, or diversification of income streams into cultural/eco-tourism (Tew and Barbieri, 2012; Heikkinen et al., 2012). Again, such mechanisms need to be supported by appropriate and timely support, advice and infrastructure, and are insufficient on their own.

### 2.4. Artisanal farmers

Artisanal farmers start from a point of profit-orientation, but often market their produce using some sort of environmental emphasis (e.g. goose farmers who specialise in ethical foie gras, relying on geese feeding naturally on a diverse landscape (Barber, 2015)). This type of farmer is often responding to the increasing disconnection between food consumers and producers (Goodman, 2011; Schneider and McMichael, 2010). Artisanal farmers short-cut industrial supply chains by marketing more directly, emphasizing the locality/region or provenance of the food they grow (Marsden et al., 2018; Goodman et al., 2012). While some commentators contend this creates better environmental and social outcomes, the ability of “alternative” networks to deliver these win-wins may be overstated (Hodgins and Fraser, 2018). Often, for instance, this sort of niche food production is more expensive than conventional agriculture because it incorporates environmental externalities of the production process, so it can be unaffordable for many. In order to improve food security while keeping emissions low, enhanced access to products developed by this kind of farmer is necessary.

Bread is a staple food for many people and can be made with various different grains. In South Africa perceptions about the link between increased diabetes and the consumption of highly processed white bread made from wheat flour, has become a concern to some (Markey, 2017). Artisanal bread, made from biologically-grown wheat, stone-ground into coarse flour, has become a conventional product for the middle classes in Cape Town. Being able to harness a premium price for higher quality produce offers an incentive to artisanal farmers to use more sustainable farming practices and to grow a greater variety of crops (e.g. indigenous grains or landraces). The impact of improved soil health and biological farming methods affects the taste and nutritional value of the food produced on the farm. By widening the societal base that can access these higher quality products, farmers are offered markets to which they can tailor bespoke produce. However, this healthier bread alternative, that supports artisanal small-scale wheat farmers, is not affordable for the majority of South Africans, especially those living in informal settlements. Innovative business models by bakers that include cross-subsidisation of produce by those who can afford it for those who cannot is one intervention that can enlarge the customer base for these niche products. This model allows processors to support farmers to grow more organic and specialty grains, whilst ensuring it results in improved accessibility of these products for a larger proportion of the population (Markey, 2017).

The evolution of ethical food culture through, for example, vegetarian choices, brand choices and avoidances, provides a trend through which alternative food networks are entering the mainstream (Cronin et al., 2014). Such networks and practices present opportunities for climate-smart production and consumption, offering potentially appealing alternatives to unsustainable options in the current dominant food system. They also present a market that is willing to pay an increased price for a higher quality product that is more climate-smart and agro-ecological. One example of a food movement centred on the artisanal farmers is the Slow Food Movement: a gastronomy that endorses the principles of taste and pleasure whilst at the same time defining food as a thoroughly cultural product linked to issues of quality, sustainability, biodiversity, and social justice (Schneider, 2015; Fraser and Rimas, 2011). Emphasising the quality of produce, connecting to specific farmers and their practices has important environmental outcomes, as people are sometimes willing to pay more for what they see as premium food and drink (Guerrero Lara et al., 2019). However, ‘small batch’ mentality means that this produce is often accessible only to a small consumer base and excludes the majority. Enabling transformative pathways for artisanal farmers requires them to make their products more accessible to wider society.

The success that gastronomic movements have in shifting perceptions of food, and what can be considered as good food, offers a starting point for moving taste preferences towards more sustainable produce, such as alternative proteins to ruminant-based meat. A classic example is how high-end restaurants like Noma in Copenhagen opened the door for entomophagy- the eating of insects- that offers a viable alternative protein source to meat (Ceurstemont, 2013; Cressey, 2014; Vantomme, 2015; Halloran et al., 2018). Insects provide a viable alternative to meet protein demands of a growing world population (Van Huis, 2017; Hanboonsong et al., 2013), yet attitudes remain a barrier in certain cultures and countries. Private companies in USA and Europe continue to develop products using insects at a small scale, but research is exploring how to increase appeal to a wider market. Studies have shown that strategies such as processing insects into familiar products and promotion via ‘celebrity chefs’ and well-known restaurants, can help to shift attitudes (Van Huis, 2017). Education and awareness-raising are key here. The implication is that there is a growing demand for insects that requires a shift towards their cultivation and away from foraging, in order to prevent over-harvesting as demand increases (Vantomme, 2015). There is also technological potential for insect farming to become less labour intensive via use of robotics (Aspire, 2016).

Foraging enables individuals, restaurants or small companies to promote local ingredients, however, it can lead to sustainability issues if demand is too high (Lindow, 2017; Gordon et al., n.d.). The seaweed industry provides examples of how foraging can move towards cultivation, enabling wider market access and increasing supply without threatening wild populations. There is a growing market for seaweed (Rebours et al., 2014), but issues with seasonality and over-harvesting present barriers to scaling up (Hasselström et al., 2018; Hafting et al., 2012). There is, nevertheless, potential for on-land cultivation which still allows for the quality, traceability and availability that is preferred by the current premium market (Hafting et al., 2012). There are already examples of this happening successfully in the USA and Europe via improvements in technology and knowledge sharing between companies and countries such as Japan and China, where seaweed farming has been established for longer (Rebours et al., 2014).

### 2.5. Pathways out of agriculture

An exit pathway away from agriculture is possible for all the farmer types considered above. For large-scale conventional commercial farmers, an exit pathway looks more likely when e.g. technology changes production, or low profit margins or natural disasters put enterprises out of business, such that huge financial costs are felt. In many ways, this is a process that has been underway for generations and is linked to what is known as the “cost price squeeze”. In particular, stagnant commodity prices have suppressed farm incomes while rising input prices (including land values and property tax) have increased the cost of farming. The vast majority of farmers have simply exited farming while those that remain have, in general, adopted a high-volume low-margin approach that is extremely capital-intensive (Troughton, 1989). Insurance also plays a key role for those who remain (Partridge and Wagner, 2016; Duong et al., 2019).

Exiting agriculture offers a very real possibility for smallholder farmers facing situations where livelihoods are increasingly marginal, where there are few other on-farm livelihood options and where vulnerability to civil unrest and extremism is high (Fraser and Rimas, 2011; Sneyd et al., 2013). An exit pathway can present knock-on impacts for migration and movement as people seek jobs outside of the agricultural sector. This kind of pathway is particularly critical given high levels of youth unemployment in many rural regions (White, 2012). Deagrarianization also feeds urbanisation trends and can exacerbate already widening inequalities, both within and between countries. In some regions, an exit from agriculture is fueled by civil unrest and extremism, which could further increase numbers of refugees and internally displaced people (Suckall et al., 2015, 2017), as seen, for example, in Nigeria, where people have been driven away from their land by Boko Haram (Enobe and Johnson-Rokosu, 2016). Smallholders in the global north are not immune from the exit pathways either. The blight *Xylella fastidiosa* has affected olive groves across southern Europe since 2013, and has put small specialist farms out of business, despite that for hundreds of years they successfully lived off olive oil production (Strona et al., 2017). Similar push factors could easily emerge over short- medium- and long-terms.

Traditional and extensive farmers could exit agriculture when viable and desirable alternative livelihoods and robust transition supports (e.g. training programmes and income support) are available. Without such supports, farming households that exit agriculture face substantial obstacles in terms of relocation and establishing new livelihoods (Anderson and McLachlan, 2012). For more traditional hunter-gatherer societies who turned to farming (e.g the Kalahari San people), exiting agriculture becomes a much more likely pathway when their rights to access land alter (see Thebe, 2012). In many parts of Africa, designation of land for e.g. conservation purposes has caused populations to move to urban centres and seek livelihoods outside of farming (Lunstrum et al., 2016; Agrawal and Redford, 2009).

Artisanal farmers are likely to take an exit pathway when there is no viable demand for their higher priced goods. This could occur, for instance, during an economic downturn, when people have less disposable income and start cutting down on luxuries. If these producers are focusing on specific markets, for example tourists or for export, then they would be hit hard by changes in tourist numbers (e.g. safety alerts or damage to transport infrastructure) as well as changes in trade regulations (e.g. new import tariffs to a market they rely on). These types of shocks may result in these farmers having to exit from farming altogether.

For all farmer types, exiting farming may bring mental health and well-being challenges independent of transition support mechanisms. Farming, like other rural livelihoods, provides a deep sense of personal identity and meaning to rural lives and communities that links with strong attachment to place and landscapes (Parkins and Reed, 2013; Tafira, 2015). Being pushed out of farming may cause gendered psychological harm with higher suicide risks for men (Hogan et al., 2012; Alston, 2012; Carleton, 2017). Such disruptions of rural livelihoods in highly gendered rural economies may also result in higher rates of domestic abuse and family dissolution (Alston, 2012; Whittenbury, 2013). Depending on local cultural orientations to collective action, rural communities also may resist exit (Lyon, 2014; Lyon and Parkins, 2013). Thus, well-resourced engagement and transition measures for exiting farm households should form part of any climate and agricultural transition policy (Bourque and Cunsolo Willox, 2014). Cultivating a link between place attachment (i.e. the emotional links between people and places), social capital, and environmental values (the things that people appreciate and hold in high regard in a place) may help to mitigate the need to exit farming or its risks to well-being (Lincoln and Ardoin, 2016). For example, local livelihood diversification interventions can support this, which include expanding local or household assets, improving literacy, and training through extension services, all of which can soften exit hardships (Martin and Lorenzen, 2016; Asfaw et al., 2017). In turn, these measures could help to slow urbanisation rates and reduce some of the tensions associated with migration as people seek alternative employment and wellbeing.

### 2.6. Towards transformation

Given the diversity of starting points and the different challenges faced by each type of farmer, it is clear there is no silver bullet for transformation. In reality there are many more possible pathways than we have space to address, but focusing on a selection for different farmer types allows us to identify the kind of levers and interventions, along with some of the risks that would need mitigating. Table 1 summarises indicative possible situations that each farmer type might be in if they take the pathways we have considered and if they remain within agriculture up to 2030 and beyond.

The range of pathways in Table 1 are illustrative and necessarily partial given the diversity of farmer types globally. Some pathways tackle single trends; others attempt to target multiple trends. All pathways require a mixture of interventions to help address the innovation, social and economic challenges associated with each. To deliver transformation requires fundamental shifts in how food and agriculture are understood and governed, meaning that each pathway comes with a suite of caveats, uncertainties, challenges, trade-offs and limitations. All pathways require policy and behavioural changes involving one or more types of actor, making education, awareness raising, and learning central to the process. It is also clear that top-down governance interventions need to be met by bottom-up solutions that fully appreciate the variety of contexts in which they are deployed. Understanding context requires engagement with farmers to appreciate their decision-making, uncertainties and motivations, and to co-develop appropriate pathways and the necessary levers to advance along them. The components of the enabling environment do not operate in isolation either. All interventions and levers depend on appropriate governance, knowledge and education, resourcing and finance, and the support of legal and regulatory frameworks and their enforcement (UNEP, 2019a, 2019b).

Considering the feasibility of different pathways in terms of sustaining food production while minimising climate change impacts suggests that overall we may see a convergence towards smallholder and traditional farmers becoming more like artisanal farmers with a greater market share beyond 2030. An idealized transformation would see this shift coupled with substantially improved connectivity between producers and consumers, shorter supply chains and larger areas under production as a result of rental markets and consolidation, potentially through cooperatives and supported by collective action. At the same time, technology would need to evolve to support the different farmer types.

No new technology is without risk. Innovations are often implemented under high uncertainty where the degree of unwanted side-effects are unknown. These ‘unknown unknowns’ demand some degree of caution. For instance, from an equity perspective, technological change impacts diverse social classes and gender differently (Taylor, 2018). Most importantly, the transition towards food system digitalization will introduce a host of “behind-the-scenes” actors including national and supra-national level regulators, technical standard bodies, private corporations, and potential hackers into everyday agriculture/

**Table 1**
Transformation matrix for different types of farmers (present - 2030+) and the necessary levers and risks.

| Farmer type $T_1$ (2019) | Farmer type $T_2$ (2030+) | Interventions for each pathway | Risks to be mitigated along each pathway |
|---|---|---|---|
| **Conventional large-scale commercial** e.g. 300 ha industrial monoculture maize farm | Big commercial with greater focus on environmental externalities e.g. 300 ha maize farm with hedgerows, wild flower and pollinator areas and certified organic status | Novel technology | Unequal access, energy intensive, environmentally damaging, increased social inequality, marginalisation of women, reduction/change in rural employment opportunities, loss of farmer control, technology lock-in, hackability and use of novel technologies to disrupt other technologies |
| | | Payments for Ecosystem Services | Unclear or ill-defined cost & benefit sharing mechanisms |
| | | Coherent regulatory framework, platforms, and enforcement | Unenforced or unevenly enforced laws and regulations that exacerbate inequality |
| | | Removal of perverse subsidies | Unintended consequences such as economic disruption and continued or worsening environmental degradation |
| | | Consumer awareness & education | Social upheaval and conflict with e.g. industry groups with a vested interest in maintaining the status quo, attempting to slow reform |
| **Conventional smallholder subsistence** e.g. 0.5 ha, low input, experiences food shortages at certain times of year | Smallholder market producer with land consolidation and increased market access due to urbanisation | Increased access to credit, technology, and infrastructure | Increased environmental externalities and potential trap of becoming the next generation of industrialised farmers in a different location, increased exposure to market fluctuations |
| | | Tenure reform, land rental markets | Conflict between traditional & formal authorities, land-grabbing |
| **Conventional smallholder market oriented** e.g. 5 ha growing a little excess for market | Smallholder market producer with increased access to markets thus giving them better supply chain security. | Increased access to credit | Increased debt and economic vulnerability |
| | | Access to appropriate technology and training | Unequal access, energy intensive, environmentally damaging, increased social inequality, marginalisation of women, reduction/change in rural employment opportunities, loss of farmer control, technology lock-in, hackability |
| | | Expansion of 'Fairtrade' style certification schemes | Unequal access, inequality, marginalisation of women, reduction/change in rural employment opportunities, high compliance costs |
| **Traditional extensive farmer** e.g. silvopastoral farmer or coastal mussel forager | Increased diversification of income streams | Certification | Lack of buy-in, greenwashing, increased inequality due to higher costs of artisanal foods |
| | | Payments for ecosystem services | Unclear or ill-defined cost & benefit sharing mechanisms |
| | | Infrastructure investment | Unequal access, energy intensive, environmentally damaging, increased social inequality, marginalisation of women, reduction/change in rural employment opportunities, loss of farmer control, technology lock-in, hackability |
| | | New market opportunities e.g. ecotourism | Reduction in food production due to non-agricultural incomes due to land-use change to conservation, increased carbon emissions from tourism (flights etc) |
| | | Improve credit access | Increased debt and economic vulnerability |
| | | Collective action | Failure of collective action due to fragmentation, conflict, or lack of interest |
| **Artisanal** e.g. urban roof, greenhouse or niche livestock producers (organic, free range) | Increased market share | Urban horticulture | Increased debt and economic vulnerability, competition in a niche market, regulatory resistance or hesitance |
| | | Certification | Lack of buy-in, greenwashing, increased inequality due to higher costs of artisanal foods |
| | | New business models enabling equitable consumer access | Social upheaval, lack of implementation, class conflict |
| | | Increase social movements | Failure of social movements, increased conflict within and between movements, lack of critical mass |
| | | Chef-farmer alliances | Cartels, inequality, competition-price issues, lack of buy-in, greenwashing, increased inequality due to higher costs of artisanal foods |

fisheries practices (Greenfield, 2018; Bronson and Knezevic, 2016). On the extreme side, this may create the potential for the weaponization of agri-food data, system hacking, and the fear of our food data falling into the wrong hands. As Taylor (2018) cautioned, the failure to address the underlying inequalities in the food system will impact who is rendered vulnerable and insecure by new technologies. Some technological solutions are currently only feasible at small scale and if large scale adoption takes place, adaptation could shift towards being maladaptation. Similarly, some innovations are more suitable in some contexts, much less so in others. Indeed, the application of less radical innovations such as climate insurance in agriculture illustrates how sometimes strategies originally designed to help farmers in the Global North end up causing unintended consequences, especially when they are transferred to the Global South. Müller et al. (2017) found that under traditional practice, farmers spread their risks, growing several crops in the hope that at least one can withstand climate extremes such as drought. Conversely, climate insurance in agriculture is often set up to target specific crops and therefore acts as a push factor for farmers to specialize. If crop insurance is targeted only at key staple crops, this strategy can undermine risk spreading, as well as contributing to biodiversity loss, land degradation and other challenges. Insurance can have social impacts too, reducing farmer-to-farmer or state-to-farmer assistance when insured farmers or governments no longer come to the aid of those who are not insured.

Careful planning and coordination will be vital, especially if co-benefits are to be harnessed while reducing risks. Institutionalised mechanisms for rapidly remedying trade-offs in months, as opposed to the years and decades that high-level political decision making requires, is necessary and involves a wide range of actors beyond those in the food and climate system. Nevertheless, even with the best laid plans, disruptions could take things in new (unexpected) directions. Disruptions could speed up or slow down progress along the various pathways or call their entire feasibility into question by e.g. altering transport routes, disrupting existing markets and creating new opportunities. For example, the New Silk Road Economic Belt (One Belt, One Road) project which is connecting Asia and Europe via new infrastructure could disrupt agriculture and markets in novel ways. A selection of five disruption scenarios is presented in Section 3.

## 3. Disruption scenarios

In this final section of the paper we explore five potential scenarios that may provide to be extremely disruptive in terms of the pathways different farmers take. We first present the various disruption scenarios before exploring their impacts on different types of farmer and the pathways. Scenario 1 considers the possible impacts that a global carbon pricing mechanism might have on the agricultural production model that is most responsible for environmental degradation: large-scale, industrialised monocultures (Gordon et al., 2017; Pereira et al., 2018a, 2018b). Although to date there is limited evidence that current carbon pricing schemes have resulted in any substantial reductions of greenhouse gases, there is a consensus in the literature that while market mechanisms on their own may not be sufficient, they are still needed (e.g. Campiglio, 2016), despite their social unacceptability, even in richer countries. To avoid exacerbating inequalities, clear mechanisms are needed to make sure polluting practices are not outsourced to poorer countries; that taxes are high enough to adequately compensate for damages; and that development activities in the developing world are not put in jeopardy. Addressing these challenges means uncomfortable conversations and actions are needed around equity and fairness, as opposed to equality, such that different abilities to pay are reflected in the tax system, and top-down and bottom up governance are brought together.

***Scenario 1 Disruption via a global carbon pricing mechanism***

*One reason for environmental degradation is the failure of the market to adequately cost externalities such as pollution or soil erosion. Regulations are needed to internalize the negative environmental costs associated with farming. Any such strategy would best be instituted at international level or included in multilateral trading agreements. Leaving aside the political feasibility and social acceptability of achieving this, there is widespread consensus that policies to internalize environmental costs are needed to promote sustainable pathways for agriculture and food* (Jaffe et al., 2005)*. Carbon pricing mechanisms stand as an illustrative example and include "cap and trade" programmes where economic actors are given a maximum amount of greenhouse gas emissions they are allowed to produce [the cap] and then allowed to trade with other economic agents, selling surplus carbon credits or purchasing more as needed.*

*Another carbon pricing mechanism would include a carbon tax on the amount of greenhouse gas emissions created by an economic agent. Applying such policy instruments to food and farming systems would have transformative impacts in at least four areas. First, farmers would receive a huge incentive to adopt farming practices such as conserving nitrogen fertilizer (fertilizer is a major source of greenhouse gas emissions as the creation of nitrogen fertilizer is extremely energy intensive). It should be noted, however, that area-based payments to smallholder farmers for environmental services entail very high transaction costs. Second, carbon pricing would likely have a significant impact on the technology used to transport food. In particular, it is likely that trucking and shipping companies would shift to an electric fleet. Similarly, it is likely that the compressors used to keep shipping containers refrigerated would also shift from diesel to electricity-based systems. Third, protein, and in particular conventional livestock, are amongst the most energy intensive aspects of our diet. However, alternative proteins based on ingredients such as algae, fungus, legumes, or insects can be produced at a fraction of the greenhouse gas emissions when compared with most conventional forms of livestock protein. A carbon pricing mechanism would have the likely effect of making alternative proteins more competitive in the marketplace and would create an incentive for industry to make greater use of these ingredients. A fourth potential impact of a carbon pricing mechanism would be to slow the rate of land-use conversion from forest to agriculture. In particular, if high carbon land uses, such as forests, were given carbon credits under a cap and trade program, then there would be a financial incentive to reforest marginal agricultural land as well as an incentive to protect forested land from being converted into farms. Taken together, therefore, the anticipated impact of a universal carbon pricing mechanism could have transformative impacts on food and agricultural systems. It would create incentives for farmers to use management practices that result in fewer inputs, create an incentive for firms to invest in a low greenhouse gas emission transportation infrastructure, be instrumental in creating a market opportunity for alternative proteins, and provide a catalyst for reforestation while preventing forest areas from being cleared for farming.*

Scenario 2 considers the impact of the fourth agricultural revolution which might use genetics to accelerate photosynthesis, in line with the development of new technologies. As noted earlier, such technologies are not without risk.

***Scenario 2 The fourth agricultural revolution***

*Averting the food crisis through technology has the potential to radically change food and farming systems. In particular, gene editing, robots, artificial intelligence and the Internet of Things lead many experts to believe that food and farming systems are on the cusp of the "4th agricultural revolution" that will be as significant for the 21st century as the Green Revolution was in the 20th century* (Pretty and Bharucha, 2018, World Economic Forum, 2018)*. These new technologies offer precision agriculture's "smart tractors" that help farmers boost profitability while reducing inputs by giving them the tools to plant the right seed in the right place within a field* (Capmourteres et al., 2018)*. Similarly, there are now robotic milking parlours that maintain the health and welfare of the animals while reducing potentially harmful* *inputs such as antibiotics* (Weersink et al., 2018). *Other major areas of potential innovation include the use of data analytics to help monitor and prevent zoonotic diseases* (Astill et al., 2019).

*One area of technological innovation that may prove to be particularly disruptive relates to the genetics of photosynthesis. In general, yields of our major food crops rose by over 100% since 1950, and approximately 50% of these increases can be attributed to genetic improvements while the other 50% relate to farm management and inputs* (Long et al., 2006). *One fixed limit on plant productivity has been the extent to which plants are capable of turning solar energy into biomass. While estimates vary, depending on the crop and the weather conditions, generally plants utilize < 5% of the solar energy they receive and reengineering crops so that they convert more solar energy into biomass represents a kind of "holy grail" amongst plant geneticists* (Santini, 2012). *As a result, the Gates Foundation has poured $70M into the "Realizing Increased Photosynthesis Efficiency" project. This involves using cutting edge genomic technologies to change the 170-step process that plants undergo when they convert sunlight and carbon dioxide into biomass* (RIPE, 2018). *One way to do this would be to engineer rice and wheat so that it uses the same photosynthetic pathways as do maize and sugar cane. Briefly, maize and sugar cane have an extra carbon molecule in the chloroplasts, and this enables these crops to be more efficient and able to remain productive under hot and dry conditions. Researchers estimate that if they were ever able create rice and wheat cultivars that use this "extra-carbon" (or "C4") form of photosynthesis, then they would be able to boost yields by 50%* (Bullis, 2018).

*If genetic engineers are able to develop germplasms that are able to boost production by over 50%, the context of global food and farming systems will fundamentally change. So long as these technologies are made accessible to small scale producers across the Global South, then hundreds of millions could be lifted out of poverty and the spectre of a global food crisis provoked by population growth will recede. Of course, creating plants with more productive photosynthetic pathways may also provoke additional problems, and super productive plants will also need huge amounts of water and nitrogen to fully develop. However, it is undeniable that developing more efficient crops may fundamentally alter the nature of food security debates over the next century.*

Scenario 3 picks up on the idea of engaging more people in small-scale agriculture through a vertical farming disruption scenario. This approach has been taken in refugee camps in Syria with a view to moving the displaced from a situation of 'surviving' to 'thriving' (Verner, 2016). Though currently unviable for many without access to electricity, other infrastructure and training, it can be a more environmentally friendly option as it takes up less land area than conventional surface cropping, and in many of these systems, water use is minimised and clean energy is used. Furthermore, it is feasible in the urban contexts that many smallholder farmers are migrating to in search for better economic opportunities.

***Scenario 3 Disruption via increased engagement in agriculture through vertical farming***

*An interesting technological innovation with potential to enable a pathway towards small-scale, but profitable production systems, with lower environmental impacts, is that of vertical farming* (Despommier, 2013). *This includes a broad suite of approaches that move production indoors into highly controlled environments. The potential of this is huge and proponents argue that vertical farms will, in future, be found in and around all major cities and provide a significant proportion of urban residents' diets. Small-scale vertical farms, which may be built in shipping containers, offer remote communities promises of year-round produce, supporting nutritional security in areas that are not well serviced by major trading routes. Ultimately, proponents argue that large multiscale facilities will integrate horticulture and aquaculture production in a way that is safe, nutritious and economically efficient* (Thomaier et al., 2015; Specht et al., 2014).

*Current technologies however, are too immature to realize this vision. To date, vertical farming has made huge inroads into creating both hydroponic growth solutions as well as utilizing LED lighting systems, removing both soil and sun from the farm equation. The current generation of vertical farms waste very little water while sophisticated robotics mean that low levels of human labor are needed to plant, tend or harvest crops. However, most vertical farms only produce green leafy vegetables such as basil, spinach and lettuce and are still highly energy intensive. Consequently, outputs of vertical farms typically result in very high-quality salads, sold at relatively high-end supermarkets and do not, yet, represent a viable food security strategy for the world's poor. However, their contribution to micro-nutrient deficiencies (rather than calorific content) could be significant. Looking into the future there are a number of horticultural challenges to overcome specifically to develop systems so that major vegetable crops like tomatoes, peppers and cucumbers can be produced in vertical farms. Equally, it may be possible to situate vertical farms adjacent to manufacturing facilities and engineer infrastructure to use waste heat from the manufacturing to heat and power the farm. A host of social and cultural issues would need to be overcome too in order to ensure that small vertical farms could produce culturally appropriate food for more remote communities.*

Scenario 4 considers a major socio-economic disruption that would alter the pathways of millions of farmers, in the form of Universal Basic Income. Universal Basic Income (UBI) is a simple idea that entails unconditionally providing every resident (child and adult) of a particular geographic location with a regular subsistence wage. Although a simple concept, it has potentially game-changing implications for how the world would operate in the future.

***Scenario 4 Disruption via Universal Basic Income***

*Giving every member of society a regular sum of money as a right has been posited as a tool for transformation towards a more egalitarian and ecologically sustainable economic order* (Perkio, 2015). *This idea has garnered support over the centuries from scholars and intellectuals, including Thomas More, Abraham Lincoln, Henry George, Bertrand Russell, and Franklin Roosevelt* (Klein, 2016). *UBI is currently being discussed in the United Kingdom, Greece and Spain, and trials are under way in India, Finland, Brazil, Kenya and the Netherlands* (Klein, 2016; Lowrey, 2018). *In terms of the impact of such a policy on indigenous and smallholder farmers, this sort of programme would mitigate the economic stresses and vulnerabilities that prevent farmers from adopting or experimenting with approaches such as climate-smart innovations.*

*UBI has already been proposed as an innovative food policy tool to further the transition towards fairer and more sustainable food systems (see, for example* https://www.ubie.org/project/agrarian-basic-income/*). The arguments underlying this financial intervention include that it would reduce the vulnerability of farmers to food price volatility and climate hazards, and that a basic income given individually, unconditionally and automatically to all food producers could considerably enhance the bargaining power of farmers vis-à-vis commodity buyers, food processors and retailers. UBI may complement or replace the numerous and often contentious agriculture subsidy schemes around the world, which may be of uncertain social-ecological benefit depending on context and application* (Annan and Schlenker, 2015; Minviel and Latruffe, 2017). *This would allow farmers to experiment with climate-friendly practices with reduced risk in terms of loss of income or viability.*

*To put the potential costs of UBI in perspective, giving each member of the 470 million smallholder farms (assuming an average of four members per household) $1.90 per day would cost around $1.3 trillion per year. This is around twice the proposed 2018 defence budget of the USA ($640 billion,* https://comptroller.defense.gov*) or roughly 10 times the global official development aid budget of $146 billion* (OECD, 2017). *One potential trade-off here is that some farmers receiving UBI may not necessarily remain in farming. If so, what happens to their land is crucial.*

**Table 2**
Potental impacts of the various disruption scenarios on different types of farmers.

| | Global carbon pricing mechanism | Fourth agricultural revolution (genetic engineering of photosynthesis example) | Vertical farming | Universal Basic Income | Dietary shift towards alternative protein sources |
|---|---|---|---|---|---|
| **Large-scale conventional commercial farmer** | Initial negative impact as the price of conventional production increases, but as farmers adjust to lower carbon intensive production mechanisms, over the long-term, this will ensure more climate smart agriculture. If they are unable to remain financially viable with the pricing mechanism, these farmers may have to exit agriculture | It could substantially increase the productivity and hence profitability of commercial farmers | Unlikely to have an impact beyond offering new investment opportunities | Unlikely to have an impact as farms already have high labour and financial inputs | This could result in an exit from farming of many large-scale livestock producers and farmers of grain and soy for feed |
| **Small-scale subsistence farmer** | Farmers with lower carbon intensive agriculture could receive payments for carbon sequestering production that could help meet their financial needs over the long term, especially if they restore degraded land | Unlikely to have an impact as they are not likely to have access to the technology, which would be aimed more at cash crops. Could exacerbate inequalities with larger farmers | Unlikely to have an impact given high energy and technology demands, need for re-skilling and high upfront investment costs | This will allow subsistence farmers space to continue to grow food for subsistence without having to shift to excess production to generate cash income. It should lead to improved food security as basic needs can be met | Unlikely to have an impact as farmers are not linked to markets and therefore unlikely to be affected by shifts in demand |
| **Small-scale market farmer** | If they are already producing with minimal carbon emissions, over the short term, these farmers would have a competitive advantage over conventional farmers that are more carbon intensive | If these farmers were able to access the technology, it could increase their viability in the long-term as they would be more productive per hectare and therefore more profitable | This could enable a diversification of these small-scale farmers into peri-urban and urban areas where they would be able to produce higher value crops from small pieces of land | This would provide a financial buffer for farmers during periods of stress, such as those expected under climate change, as they would still be able to buy basic goods. It could also provide a market for their produce closer to home as there would be more disposable income in poorer areas. Over the long-term, this could lead to financially viable smaller farming operations | Unlikely to have an impact unless diversification into e.g. black soldier fly larvae production has low entry costs |
| **Traditional extensive farmer** | The carbon pricing mechanism will make this type of farming more competitive against conventional farming and over the long term help to meet the financial needs of these farmers | Unlikely to have an impact as farmers may have greater focus on traditional methods and are unlikely to have access to technology | Unlikely to have an impact given farmers may have greater emphasis on traditional/ cultural methods of farming | As with subsistence farmers, this would enable a financial safety net for these farmers so that they could continue to farm traditionally without focussing on having to produce for markets | Unlikely to have an impact, unless dietary shifts focus on more extensively farmed protein sources. Alternatively a shift away from meat consumption could have negative impacts on some farmers |
| **Artisanal farmer** | As these farmers are already internalising their carbon costs in their pricing mechanisms, this would have little effect other than to make their produce more affordable compared to the produce from conventional farmers with an added carbon price | Unlikely to have an impact as it would likely not fulfill niche criteria, which is a key part of artisanal farming | This would enable a diversification of artisanal producers as they would be able to produce more efficiently and closer to their markets, therefore cutting the costs of their operations | Unlikely to have an impact although as for smallscale and extensive farmers, it could act as a buffer if demand for artisanal produce temporarily decreases (e.g. during economic downturn) | As with the vertical farming, this disruptor would enable more artisanal farmers focussing on alternative protein sources like insects to find markets for their goods. If they are no longer having to compete with industrial meat production, these alternative products are likely to become mainstream over time, thus strengthening the viability of these types of farmers |

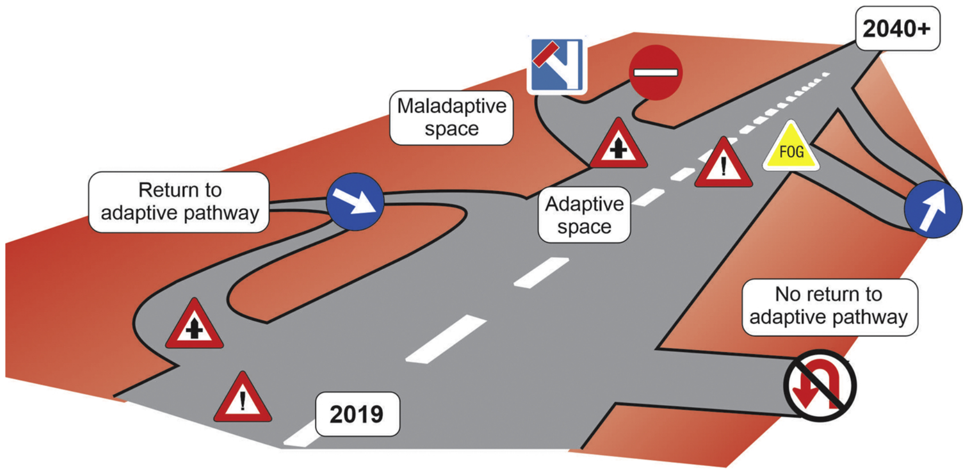


**Fig. 2.** Adaptive and maladaptive pathways, decision points, and disruptors (modified from Fazey et al., 2016; traffic signs are used with UK Crown Copyright, Open Government Licence).

Finally, Scenario 5 considers a global dietary shift towards non-meat protein sources as a possible disruptor that could further change consumer behaviours linked to the development of alternative protein sources.

***Scenario 5 Disruption via alternative protein sources***

*The literature often assumes that everyone in the world is transitioning to a diet similar to that of current North American consumers. There are at least two important factors that may change these projections. The first factor is sociocultural and relates to the rising interest in vegetarian-based diets specifically amongst young Westerners. This trend seems to be spreading* (Statista, 2018; Askew, 2017; Kenward, 2017; Cornish, 2018; Poore and Nemecek, 2018). *The second factor is technical, linked to the sharp rise in the number of non-traditional protein products available to consumers. Protein based on algae, fungus, legumes or insects can be produced at a fraction of the financial and environmental costs, of conventional livestock* (Alexander et al., 2017). *In addition, so-called "clean meat", which is a highly contested term that refers to meat substitutes produced using stem cell technology, seems poised to enter the market in the next five years* (Flink, 2018). *Regardless of whether the claims around synthetically manufactured meat prove accurate, this combination of new protein alternatives, along with the perception that there is a growing segment of the population who is experimenting with diets low in livestock products, has led to a flurry of interest by major players in the North American food industry. Companies such as Nestlé and Tyson have both made major acquisitions in non-meat protein products while Canada's Maple Leaf Foods, Canada's largest food processor, has in the last 12 months purchased two plant-based and one insect-based protein company. Maple Leaf now positions itself as on a trajectory to become the most sustainable protein company on Earth, a goal that they will accomplish in part by reducing the amount of conventional livestock in their portfolio* (Maple Leaf Foods, 2018). *This shows potential for producers to support both food security and sustainability. However, while the emerging interest in alternative proteins is fascinating, it is too early to ascertain with any confidence whether this is simply yet another consumer fad or a durable trend that will extend in the long term and become mainstream. Nevertheless, it is clear that if the shift towards alternative protein continues to grow this will have transformative and unpredictable effects on food system sustainability in the long term.*

Table 2 synthesises the possible impacts of the disruption scenarios on the different farmer types and the possible pathways, potentially changing what they will look like beyond 2030.

## 4. Discussion

Transformation pathways are unlikely to be smooth. The disruption scenarios above illustrate how changes in policies, technology and consumer behaviour may impact upon farmer adaptations, whether they are positive or negative, and how they may vary between farmer types. These are only a range of examples; there are many more potential disruptors and even more that may be difficult to predict. Policy makers will need to take into account the possibilities of these disruptors when designing interventions to encourage trajectories along certain pathways, ensuring that farmers are able to adapt to any changes that disruptions may cause and are not unintentionally pushed into maladaptive practices. Fig. 2 illustrates the complexity of potential routes towards 2030 and beyond. Adaptive and maladaptive pathways reflect the pathways for transformation in agriculture for all farmer types. Disruptors (! signs) and key decision points (intersection signs) reflect different combinations of options and levers (intersections) and varying levels of uncertainty (blind summit, fog signs). Farmers and agricultural systems at any level may be leveraged toward maladaptive directions, some of which may be difficult or impossible to recover from (no U-turn, cul-de-sac signs). The aim of farmers, governments, and other stakeholders as they navigate pathways into the future is to carefully facilitate interventions and mitigate risks to keep from straying into maladaptive space, evidenced by measures of farm household socio-economic well-being, climate impacts, and overall food security.

The consequences are likely to be severe if we do not meet the challenge of sustainably and nutritiously feeding the world's population both now and in the future. Worsening food insecurity, political and economic instability and the possibility of new waves of migrants and conflict as people move in search of food, water and livelihoods remain very real (Fraser et al., 2016), especially as nations become more inward-looking. We may even already be at the beginning of the crisis: for the last 10 years, food prices have been both high and volatile. Dozens of food riots occurred between 2008 and 2011 when food prices reached levels (in real terms) that had not been seen since the 1970s (FAO, 2017; Lagi et al., 2011). In addition, after decades of declines, the number of undernourished people (in both absolute and proportional terms) has risen for each of the last three years (FAO, 2018) while the world is thought to have become increasingly turbulent, uncertain, novel, and ambiguous (MOD, 2018).

Voluntary transformations and market solutions have thus far shown not to deliver fast enough action. With increasing nationalism, governance options of the past will not suffice for the future. Techno-optimists might point to organisations, industries and countries that have set standards and targets to help ensure agricultural technology is deployed to protect the environment, enhance environmental impacts and social development, but the challenge is great in the context of continued population growth and increasing consumption. While the population issue is stark in some areas meaning uncomfortable conversations need to be had, efforts that address other SDGs like empowering women, improving access to education and healthcare could shift trends away from burgeoning population growth. Addressing consumption patterns where aspirations are not all set to follow the consumerism of the West can similarly play a critical role towards more sustainable food systems (Ranganathan et al., 2016).

Interventions to date have largely centred on understanding and supporting the distribution of resources rather than the distribution of people in meeting increasing food demands. Migration patterns are starting to address this gap in a somewhat haphazard way as people seek their own redistributions. Migration from rural areas to the cities tends to remain within states and thus freedom of movement is upheld. However, migration from poorer countries to richer ones is limited by immigration policies and border controls, which may be revised as an as-yet under-utilised, but currently contentious, adaptive pathway. Importantly, even where population growth has stabilised or started to decline, consumption levels generally remain high, diets for many are poor and the food systems in place often fail to deliver the necessary balance of nutritious food. Business as usual is not an option if the world is to equitably, ethically and nutritiously feed its human population while meeting its sustainable development aspirations in a climate resilient way with minimal emissions (IPCC, 2019). A seismic shift in both production and consumption sides of the global food system is necessary (Davis et al., 2016; KC et al., 2018) and where appropriate, efforts to scale up and out better practices need to be rapidly deployed.

Global leaders have a suite of options that offer possibilities for action over different time frames that can help food producers and consumers across the spectrum should they want, through their governance choices, to act. Immediate actions include those that:

- Build on alliances that foster change through peer pressure and cooperation, to push others in the same direction. Examples of this are regional trade agreements and policies that can push towards implementing good practices and standards through national, international or national laws and their enforcement. This option will require a strategy for removing corruption in institutions that control export, import, sales and transport of prohibited goods
- Incentivise cooperation at local levels, to support small-scale farmer cooperatives to help them meet the costs and requirements of certification schemes, as well as providing appropriate technical advice, as levers towards sustainability
- Invest in education, technology and research to improve the quality, quantity and nutrition of raw products and plants; to facilitate more efficient use of environmental and human resources; to reduce overall consumption post-harvest losses, energy, transport and waste; and to empower women on their reproductive choices
- Remove subsidies for monocultures and other perverse incentives that undermine environmental quality, replacing them with subsidies that reward pro-sustainability behaviours in a substantial way. This needs to take place alongside more stringent implementation of polluter-pays principles and carbon taxes within the food system
- Develop national environmentally sustainable food security strategies for 2020–2050 that set out context-specific pathways and levers for different types of farmers and which promote land rental markets and consolidation

Longer-term actions include:

- Policies that support populations not just to develop secondary and tertiary industries in rural areas, but also so they have the necessary support to exit rural agriculture and engage with urbanization should they choose. Ensuring food production does not decline requires parallel investments in agricultural niches and re-skilling of the workforce, along with development of appropriate infrastructure, so they can engage in e.g. vertical agriculture, urban agroforestry, small-scale processing. This should happen in line with dietary shifts and the implementation of sustainable food security strategies
- Develop new technology to monitor environmental impacts and exert polluter pays principles. Such actions would make it easier and cheaper to punish those companies and countries who extract environmental values and functions without returning them.

Overall, strong good governance is needed at multiple levels to support transformations of different kinds as there is no one-size-fits-all pathway or single solution. Such governance needs to be both equitable and inclusive, in its processes and outcomes, over multiple time frames. The clock is ticking and there is urgent time pressure for multi-level governance to deliver the kinds of policies that support lower income countries and support the social movements that create and push demand for sustainable food value chains.

## 5. Conclusion

There is a global imperative to quickly embark on pathways that will protect biodiversity, decarbonize the economy and keep humanity within a safe operating space (Raworth, 2017). There is an equally strong imperative to ensure equity in these efforts, which will involve different types of farmers rethinking and rebalancing the emphasis they place on environmental, socio-cultural and economic aspects (Leach et al., 2018). This paper has identified some of the transformations that different types of farmers would need to radically shift agriculture away from business as usual trajectories, as well as the necessary levers to stimulate and support adaptation and change. Concurrent action is required urgently across the realms of technology, policy, finance, and consumer behaviour around dietary choices, tackling the key underlying trends both individually and in combination. Disruptions and trade-offs will be inevitable: spatially, temporally and across different groups in society. Some changes will also turn out to be maladaptive with hindsight. However, careful tailoring of adaptation and development pathways to the specific context in which they are enacted can offer some degree of risk mitigation and also offer opportunities to harness co-benefits. Understanding the context requires engagement with farmers themselves from the outset, so as to better understand their values, motivations and desired outcomes, along with the interaction of competing pressures that shape their decisions and practices. Good governance will be invaluable in achieving the necessary transformations.

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