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The Evidence Base on Policies for Food System Transformation

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1. Introduction

It is widely recognized that the world's food system needs transformation (FOLU, 2019). Nearly one billion people are undernourished while another billion people are obese; these problems are exacerbated by healthy diets being unaffordable for 3 billion people worldwide. The food system is part of the livelihood strategy of 4.5 billion people worldwide, however poverty persists among smallholder farmers and others who depend upon the food system for their livelihoods are not paid a living wage. Farming has degraded much agricultural land and is responsible for a large share of GHG emissions, biodiversity loss and pollution. Furthermore, the food system is vulnerable to price shocks. The Food System Economics Commission[1] recognizes five operational goals as central to a successful transformation of the food system; these are:

- **Consumption of healthy diets by all**. This objective means ensuring food security and nutrition for all, addressing undernourishment of more than 1 in 10 people on the planet while also improving diets of the more than 1 billion people worldwide who are obese (FAO et al, 2021a and WHO, 2022a). The second is ensuring the affordability of healthy diets for the over 3 billion people for whom they are out of reach (FAO et al, 2021a). Pursuing this operational goal involves a global convergence in quantities of foods consumed , and relative convergence in the proportional distribution of that consumption across major food groups. Such convergence would require a nearly universal increase in the consumption of whole grains, fruits, vegetables and nuts; reductions in consumption of highly processed foods; and regionally distinct changes in animal- sourced food consumption, with the global North significantly reducing its consumption, while consumption in the South rises to ensure adequate consumption of essential nutrients.
- **Strong livelihoods throughout the whole food system.** As many as 4.5 billion people depend at least in part on food systems for their livelihood (UN, 2020). Those livelihoods encompass a variety of jobs, spanning from manual daily labourers on farms to managerial employees of large supermarket chains. The persistent concentration of extreme poverty among those working in agriculture can be taken as an indirect indication that low productivity and limited access to production factors (security of tenure, capital, improved inputs) are limiting the productive potential and the wellbeing of those engaged in agricultural production. It is crucial that a livelihood perspective is part of designing a food system transformation.
- **Protection of intact land and restoration of degraded land.** Setting boundaries for the expansion of agricultural production is an essential element of an agenda to ensure the sustainability of food systems, and their ability to benefit from the ecological services that nature provides. In addition efforts are needed to restore the 34% percent of total agricultural land that is degraded (FAO, 2021).

[1] The FSEC is an independent academic commission formed to provide policy makers with the tools and evidence need to transform food systems so that they are more inclusive, health supportive and nature-positive.

- **Nature-positive production throughout the food system.** Food systems contribute significantly to GHG emissions, biodiversity loss and environmental pollution (IPCC, 2023). A sustainable transformation to the food system will address emissions, halt biodiversity loss and reduce pollution.
- **Resilient food systems maintain food and nutrition security in the short and long run.** Closely interwoven with all other operational goals is the goal of resilience, intended as maintaining food and nutrition security over time. Shocks, such as food price spikes, can play a major role in derailing a food system transforma tion. Crisis management to ensure food security particularly for lower- income groups without undermining long term transition goals is important.

Transforming food systems to achieve the aforementioned operational goals requires considering a host of policies. Section 2 of this paper provides a list of 33 widely considered policies and maps each policy to the operational goal it is most likely to impact. Section three presents a deep dive into ten of the policies, providing a review of impact evaluations for each of the ten policies. Section 4 concludes by describing key findings and areas for future research.

2. Policies often recommended for consideration

To explore key elements of a food system transformation agenda, we have identified 33 policies/ types of policies that are often considered to be effective; this is based upon extensive literature review (with a focus on high profile global reports) and consultation with subject matter experts including commissioners of the FSEC. Some sources offer specific diet-related "best buys" (intended as cost-effective recommendations, eg. WHO (2022)) or lists of policies to consider and for which there is evidence of implementation and impact (JHU and GAIN, 2021). The policy mapping is shown in Table 1 with policies (and, in some cases, policy types) organized according to the operational goal that they likely impact the most; this does not mean to imply that each policy impacts only one operational goal. If we consider the meat tax, for example, we see it listed under consumption of healthy diets by all, however if it reduces demand for meat from ruminants it will also result in reductions in methane emissions thereby helping to achieve the operational goal on climate and nature positive production.

The policies in Table 1 deserve close consideration, warranting more careful discussion as well as evaluation going forward. Indeed, several of the policies in Table 1 are currently the object of intense discussion and academic scrutiny. It is, however, not possible based on the literature to identify "ideal policies" that might be recommended in the abstract. There are multiple reasons for this, including: context matters in recommending policies, the literature on effectiveness of policies is often inconclusive due to methodological controversies and/ or the need to account for local specificities and many policies exhibit trade-offs across different operational objectives.

Table 1: Policies/ types of policies for the food system transformation, by FSEC operational goal

Consumption of healthy diets by all	**Strong livelihoods along the whole food value chain**	**Protection of intact land and restoration of degraded land**	**Climate and nature positive production throughout the food system**
Tax on consumption of meat Repurpose agricultural support Behavioral (SMS reminders; menu labelling; limits on portion size; media campaign; education, etc) Taxes on sugar sweetened beverages Subsidy on consumption of fruits and vegetables Public food procurement policies for more nutritious and local foods or environmentally sustainable products Restrictions on marketing unhealthy foods Product labeling to indicate high fat, sugar, salt content Regulations to reformulate processed foods to reduce fats, sugar and salt Investment in food fortification Trade policies encourage nutritious and discourage ultra-processed foods	Agricultural R&D to increase smallholders' income and for more nutritious and environmentally sustainable foods School feeding with a focus on locally produced, more nutritious foods and school gardens Training and financing to increase smallholders' income and for more nutritious and environmentally sustainable foods Rural infrastructure devt (roads, electricity, internet) Support for farmers' cooperatives Support for standards and certification in farming and other segments of the food system	Spatial planning and zoning regulations Property rights and secure land tenure Regulations on deforestation Subsidy for afforestation	Emission taxes (CO2, N2O, CH4) Subsidies for carbon sequestration Payments for ecosystem services including biodiversity habitat, water quality, and reduced emissions. Regulations/ standards/ certification on methods of production Policies to reduce food loss (investing in storage, refrigerated transport, etc) Policies to reduce food waste (regulations not to throw food away)
Resilient food systems maintain food and nutrition security in the short and long run			
Safety nets, cash transfers and productive safety nets Incentives for crop diversification Trade policies for stable and diverse food supply (eg. no export or import bans) Strategic reserves			

Disaster proofed infrastructure Crop insurance

Sources: Fan et al., 2022; Gautum et al., 2022; GLOPAN, 2021; IFPRI, 2021; IPCC, 2022; FAO, 2019; FAO et al, 2021a; FOLU, forthcoming; JHU & GAIN, 2021; Laborde et al., 2020; OECD, 2022; United Nations, 2021; UNEP and FAO, 2021; United Nations, 2021; WBA 2012, WBAE/WBW 2016, WBAE 2020 and WHO, 2022b.

3. The Evidence on Select Food System Related Policies

We conducted detailed literature review for select policies shown in Table 1. Results of the literature review presented by individual policy or policy group are displayed in the following subsections. Each subsection includes, for one of the 10 policies (or in some cases types of policies), a definition of the policy, description of where it is being considered, recommended and/ or implemented, overview of the evidence on impact of the policy and discussion of how the policy leads to synergies or tradeoffs among the five operational goals.

3.1 Meat tax

A relatively new policy measure (relevant to high income countries) has not been implemented, but is being considered by numerous European countries. This is a tax on meat purchases by consumers. The idea is that the value added tax on meat products would be increased or a new tax would be assessed on consumer purchases of meat products.

Meat taxes have been recognized as promising interventions by Wellesley et al. (2015) and by scientific and institutional boards that advise the German government (Postpischil et al., 2022; WBA 2012, WBAE/WBW 2016 and WBAE 2020). Furthermore, the meat tax is discussed in politics and society in many European countries (e.g., Germany, Netherlands, Denmark, Sweden and France) and at the level of the European Union (Charlton, 2019; Pinto, 2021; WBAE, 2020; Postpischil et al., 2022; Caro et al., 2017 and Säll and Gren 2015).

A global modelling exercise considered the impacts of taxing meat and processed meat consumption in 149 regions of the world (Springmann et al., 2018). In this model, taxation would increase the price of processed meat by an average of 25% (1% in low-income countries and more than 100% in high-income countries). The consumption of processed meat would decrease by 16% on average (1% to 25%). Meanwhile taxes for red meat would increase the price by 4% (0.2% to over 20%), but substitution effects would mean that consumption of red meat would remain unchanged despite taxation. Deaths from both red and processed meats would decrease by 9% and 222,000 lives would be spared annually; meanwhile the cost of healthcare associated with meat consumption would decrease by 14%. The tax would likewise reduce greenhouse gas emissions from livestock production by 1.2% globally, with the majority of the reduction in high-income countries.

A review of studies examining policies intended to reduce meat consumption, increase consumption of plant-based foods and reduce overconsumption (published from January 2000 to December 2019) suggests that tax rates must be quite high in order to reduce meat consumption. It found that the increasingly common behavioral policies (such as those that alter the food environment in retail stores or cafeterias) may have a greater impact on meat consumption patterns (Temme et al., 2020).

Funke et al. (2022) provide a rough estimate that the price of meat would need to increase by 20 – 60% in order to cover associated environmental externalities. Increases to cover the health impacts would be even larger, with the price of unprocessed beef tripling.

Studies of European countries and the European Union as a whole show the potential to reduce meat consumption by implementing a tax. In Germany, Grethe et al. (2021) find the potential for a 3-12% reduction in consumption of animal products resulting from an increase in the value added tax on meat from 7% (the rate currently applied to food products) to 19% (the rate applied to all non-food products). A study by Säll and Gren (2015) finds that in Sweden a tax ranging from 9 to 33% on seven different meat and milk products would result in a reduction of total emissions by 1.5% and emissions from the livestock sector by 12%.

There are numerous considerations in the design of the meat tax, although what is most effective will be context specific and remain unknown until such taxes are actually implemented. For instance, any type of meat tax needs to be accompanied with information and awareness raising measures (Pinto, 2021 and Grethe et al., 2021). Second, the meat tax might be combined with production-side measures; indeed, it is often discussed together with carbon taxes, including Emission Trading Schemes (ETS). Third, if the meat tax is only implemented in one or a few countries, leakage is a problem with consumers shopping across borders in neighboring countries that do not charge such a tax. Fourth, increased prices on domestic products could result in substitution with less expensive traded products that may have higher environmental impacts (Caro et al., 2017 and Pinto, 2021). Finally, if not consumed domestically, livestock products from exporting countries could be exported and sold elsewhere without reducing total livestock production and therefore without environmental benefits (Grethe et al., 2021). Border adjustments may be needed or there may be a need to improve environmental standards used in international trade.

Meat taxes may be synergistic in that they may improve the health of some populations (mostly the more affluent populations in high income countries), while also tackling environmental problems.

As often recognized, a tradeoff of the meat tax is that it may be regressive and could hurt lower income groups who might substitute more unhealthy foods for meats that are being taxed. A solution to this may social safety nets or compensatory measures for the poor (Grethe et al., 2021, Säll, 2018 and Postpischil et al., 2022); revenues from the meat tax could even be ring-fenced for use as compensation to the poor (Wellesley et al.,2015).

Another trade-off can be negative effects on biodiversity. Extensive pasture lands in Europe contribute largely to increasing biodiversity, carbon sequestration and erosion protection. A reduction in livestock could lead to a conversion of pastureland to arable land with negative effects on the above-mentioned attributes, depending on the management and production system (Grethe et al., 2021 and Moberg et al., 2021). Tax revenues might be used to subsidize environmentally friendly production and management systems (Grethe et al., 2021; WBAE, 2020; WBAE/WBW, 2016; WBA, 2012; Postpischil, 2022; Säll, 2018 and Pinto, 2021).

3.2 Repurposing agricultural support

Numerous recent publications consider the potential impacts of repurposing agricultural subsidies. One such publication defines repurposing of agricultural subsidies as a

"…reduction in agricultural producer support measures that are inefficient, unsustainable and/ or inequitable in order to replace them with support measures that are the opposite."

(FAO, UNEP and UNDP, 2021)

The repurposing of agricultural support has been widely recommended as an important opportunity to transform food production and help achieve goals of environmental sustainability, inclusion, improved nutrition and resilience (FAO, UNEP and UNDP, 2021; Gautum et al.,2022). Recent work considers numerous scenarios regarding how support might be repurposed in countries throughout the world. Support is defined broadly to include both trade policies, known as border measures, and farm subsidies.

Glauber, Laborde and Piñeiro (2022) show that in less developed countries farmer support mostly consists of border measures, while in more developed countries support consists mostly of farm subsidies. At the global level removing farm subsidies is regressive, increasing poverty and undernourishment, however it does have a beneficial impact on the environment by reducing emissions. The results of removing border policies are desirable in the case of less developed countries where it reduces undernourishment, poverty and emissions; in other countries there is a reduction in undernourishment and emissions, but no change in poverty.

A recently released report on repurposing agricultural support (Gautum et al.,2022) shows that simply removing all agricultural support is not sufficient to achieve the goals of healthier diets, improved environmental sustainability and reduced poverty. Furthermore, while such removal would help reduce emissions, it would impact poverty, nutrition and farmers' incomes negatively. The authors therefore model more elaborate scenarios. These are:

- Redistribute domestic support across all products evenly
- Remove support and reallocate it to low carbon intensity products only
- Conditional: provide domestic support to those farms using less environmentally harmful production processes
- Repurposing for green innovation: remove support and use the funds to invest in research on agricultural technologies that reduce emissions and increase productivity

The third and fourth scenarios have the largest impacts, whereas impacts of scenarios 1 and 2 are minimal. The third scenario is counterproductive in relation to all goals except reduction of emissions. The fourth scenario, redirecting funds from support to investments in green technology is helpful in achieving all goals (increased GDP; increased volume of agricultural production; decreased poverty; reduced prices of healthy foods; reduced emissions and decreased usage of land for agriculture).

3.3. Behavioral policies

Behavioral interventions are used in an attempt to improve diets and reduce the risk of non-communicable diseases arising from overweight and obesity. This category encompasses a wide variety of interventions such as those that are information related, or based on nudges. Key features include: the type of intervention and whether it is implemented on its own or as part of a package of policies; the type and size of incentive (when applicable); and the duration of the intervention (Finkelstein, Bilger and Baird, 2019). A thorough review of impact evaluations of behavioral policies in LMICs showed clear limitations in terms of study design and geographical coverage (Nugent et al, under review). Impacts were relatively small suggesting there may be limited scope to improve diets through behavioral interventions. The rest of this section is dedicated to the high-income country context as most impact evaluations of behavioral interventions focus on the high-income countries.

Interventions to enhance consumer knowledge include labelling on restaurant menus with nutritional and caloric information, nutritional labels on food products and short message service reminders to eat healthfully. Evidence from menu labelling policies suggests that they have a small impact on calories purchased, however there is insufficient evidence to draw conclusions on outcomes in terms of obesity and non-communicable diseases. Rincón-Gallardo Patiño (2020) performed the first meta-analysis to consider the impact of restaurant menu labelling policies by transnational companies in

middle and high income countries. They found evidence of changes in meal orders in the United States where customers purchased lower calorie items; no such evidence was found for other countries. The authors conclude that menu labelling policies alone are not effective in improving the healthiness of meal orders, but they may be effective when implemented as a package of supportive policies and actions implemented by various stakeholders.

In a widely cited review of 120 articles studying the effectiveness of nutrition labels, Campos, Doxey and Hammond consider the extent to which such labels are used (read). The reading of such labels is most often associated with better diets, however label-readers do not always understand the content of the labels and improvements to diet do not automatically result from usage of such labels. With the exception of Thailand, the studies in the review are from high income country contexts (Australia, Canada, European countries, New Zealand, Trinidad and the United States). Most studies show at least 50% of the population reading labels, it is more common among the more affluent and better educated segments of the population; less common among already obese children and older adults. The usage of labels is strongly associated with healthier diets, however there are challenges in consumers' understanding of the informational content of labels. The authors conclude that nutrition labels are a promising intervention particularly due to the low cost associated with them as well as their ability to reach large segments of the population, however the format and information they contain needs to be better designed so that they are understood by consumers.

Mobile phone interventions that remind individuals to maintain healthy behaviors after a clinical intervention are a potentially effective tool to increase adherence to clinical advice. Evidence from a meta-analysis by Yasmin et al (2016) indicates that short message service and voice calls are promising technologies to encourage adherence to treatment programs for chronic disease care. The effectiveness was observed in high income as well as low and middle income countries. These interventions were aimed at encouraging taking medications as prescribed, regular doctors' visits and engagement in physical activity as well as changing diets, so the relevance to improving diets may be somewhat limited.

Another meta-analysis by Liu et al (2015) of 14 studies evaluating mobile phone interventions in high income countries found them to be effective in participants' losing weight. The study authors conclude that such measures are promising for addressing the epidemic of overweight and obesity; they also recommend mobile phone messaging be paired with other interventions in order to be more effective.

"Nudges" are another type of intervention that provides consumers with information or a different environment within which they are free to make their own choice. Mertens et al, (2021) reviewed more than 200 impact evaluations of 440 behavioral nudge intervention; most interventions had been made in high income countries. They considered numerous types of nudge policies which they classify as: policies for decision information (eg. increase information and visibility of information to the consumer), decision structure (eg. change the physical placement of various choices) and decision assistance (eg. reminders or encouragement to exercise self-control) policies. They likewise consider policies implemented to alter decisions related to health, food, environment, finance, pro-social and other domains. Their results show that the policies aimed at decision structure and the food domain are by far the most effective resulting in healthier dietary choices.

Blaga et al (2018) review studies on interventions to reduce a variety of risks for non-communicable diseases in high income countries. Nutrition outcomes are described in 45 studies which cover changes to choice architecture (changes to serving lines, vending machines and usage of traffic light labels) and framing of choices (to influence portion sizes and encourage the selection of one or more servings of fruit or vegetables). Methods included RCTs, field experiments and quasi-experimental studies. Many of the interventions were implemented in cafeterias, canteens or schools with populations ranging from children to adults. Their results show that traffic light labels indicating

nutritional value of foods as well as changes to serving lines are effective in improving consumers' diets.

In conclusion, evidence on the effectiveness of behavioral policies is promising for some, but certainly not all, interventions in high income country contexts. Evidence on the effectiveness of such policies is promising for some, but certainly not all, interventions in high income country contexts. Among the more successful are: labelling on food packages; mobile phone interventions; traffic light labels indicating nutritional value of foods and behavioral nudges such as changes to the physical placement of food products or changes to serving lines. These policies typically show results in terms of intermediate outcomes (such as healthier dietary intake) rather than improved health outcomes (such as reduced BMI).

3.4. Tax on SSB

Consumption of sugar sweetened beverages (SSB) is recognized as a cause of rising rates of obesity, diabetes and cardiovascular disease. Taxes paid by consumers on sugar sweetened beverages are often recommended as a way to reduce their consumption.

The WHO (2016) advocates for taxing consumer purchases of sugar sweetened beverages as do meta-analyses published in numerous peer reviewed journals (see for instance: Popkin and Hawkes, 2016; Allcott, Lockwood, and Taubinsky, 2019; Powell et al., 2021; Teng et al.,2019 and Nakhimovsky, 2016). More than 45 countries and several localities throughout the world have implemented taxes on SSB (Andreyeva et al., 2022).

There is concern that while taxes on sugar sweetened beverages may help in achieving healthier diets, they are regressive since SSBs are on average consumed in greater quantities by lower income populations. In terms of effectiveness, numerous studies of taxes on sugar sweetened beverages have shown the policy instrument's effectiveness in reducing consumption of such drinks, however reductions in overweight and obesity have not yet been observed; this may simply be due to a lag in the effectiveness of such interventions in impacting rates of obesity.

Teng et al. (2019) systematically review 17 evaluations of real world cases of the impact of taxes on SSB on beverage sales, purchases and consumption. They find that a 10% tax on SSB reduces sales, purchases and consumption of sugar sweetened beverages by 10% on average, with a wide variation among the different studies. The study does not distinguish between sales, purchases and dietary intake.

Recent work by Andreyeva et al. (2022) does consider the impact on sales and impact on consumption separately. They find that such taxes are effective in reducing sales by 15%, but changes in consumption of SSB were insignificant. Where taxes were implemented locally cross border shopping was observed. Despite widespread concern over cross border shopping (leakage), evidence from local taxation in the United States suggests that such leakage only accounts for 25% of the reduction in sales (Powell et al., 2021).

Finally, a systematic review of nine studies on the effectiveness of taxes on SSB in middle income countries concluded that a 10% increase in the price of SSB would decrease calorie consumption by amounts ranging from 20 to 160 calories per person per day (Nakhimovsky, 2016). It found that such taxes reduce consumption enough to stop the growth in rates of obesity (a significant achievement), however they have not been linked with permanent reduction in population weight.

3.5. Fruit and vegetable subsidies

A fruit and vegetable (F & V) subsidy is a consumption subsidy that is realized as a standalone intervention or in combination with other consumption policies, e.g., taxes on unhealthy food. It has been implemented as a general policy for the entire population and as one that is targeted for specific groups, e.g., low-income households and children. The subsidy aims to change the consumption choices of individuals by reducing the price of healthy foods and therefore increasing their affordability.

Some European countries have implemented targeted F & V subsidies (e.g., Norway for primary schools, France and the UK for pregnant women and/or families with children under four, and Scotland for hospital settings (European Commission 2022)).

F & V subsidies are a widely discussed policy tool in the literature aiming to change consumers' dietary choices. Different systematic reviews, meta-analyses, modeling, and case studies examine the size of an effective subsidy, its corresponding implications on consumption and individual health, and its cost-effectiveness.

Subsidies of at least 10% are effective in increasing consumption (Thow et al. 2014, Blakely et al. 2020, An 2013, Niebylski et al. 2015). Consumption gains of 5% with a subsidy of 10% are found in a systematic review by Thow et al. (2014). In a modeling study for New Zealand, Blakely et al. (2020) indicate increases of more than 16% for fruits and 32% for vegetables, implementing a F & V subsidy of 20%.

Increases in the consumption of F & V have positive health impacts. Powell et al. (2013) analyze in a systematic review of interventions in the US that a F & V subsidy is associated with lower body weight among low-income households, particularly for female adults and children. In New Zealand, this instrument has the potential to gain 212 health-adjusted life years per 1000 people (Blakely et al. 2020).

The highest impact of a F & V subsidy can be seen in combination with other interventions on healthy or unhealthy food, in particular with taxes on sugar, sugar-sweetened beverages, or fat (Powell et al. 2013, Nieblyski et al. 2015, Blakely et al. 2020, Cobiac et al. 2017). In their modeling study for Australia, Cobiac et al. (2017) indicate that a F & V subsidy on its own does not positively impact health because of substitution effects with unhealthy food. In a package with taxes on unhealthy foods (salt, sugar, sugar-sweetened beverages, saturated fats) and the F & V subsidy, significant advancements for the nations' health and cost-savings in the sector can be achieved.

Few studies consider cost-effectiveness a critical variable to evaluate the effect of a F & V subsidy. Cobiac et al. (2017) and Niebylski et al. (2015) imply that a subsidy-tax combination is the most cost-effective intervention, as it includes potential substitution effects. Another component in increasing cost-effectiveness is implementing a targeted F & V subsidy. Powell et al. (2013) and Pinho-Gomes et al. (2021) suggest support for low-income households to reduce inequalities and to expand the consumption of healthy foods among the poorest.

In addition to their failure to consider cost-effectiveness, studies on F & V subsidies suffer several other limitations (An, 2013). The magnitude of effects often relies on the correct measurement of the price elasticity (Cobiac et al. 2017, Powell et al. 2013). An (2013) recognizes that most studies in his systematic review of F & V subsidies in seven countries comprise small sample sizes and only short-term interventions. Blakely et al. (2020) confirm that missing long-term and substitution effects analyses can distort the impacts of a F & V subsidy.

Different trade-offs and synergies can occur with a F & V subsidy. As mentioned above, implementing a standalone F& V subsidy can produce substitution effects for unhealthy foods. However, combined with other interventions, such as taxes on unhealthy foods, positive consumption

and health impacts can be achieved cost-effectively. A targeted F & V subsidy to low-income households can reduce inequalities and can increase the affordability of healthy diets. Rising demand for fruits and vegetables can generate jobs in the agricultural sector. However, fruit and vegetable production is often associated with high amounts of pesticides, water withdrawal, or monoculture. Therefore, sustainable and nature-positive production systems are needed to reduce resource use and prevent negative environmental impacts.

3.6. Public procurement

Sustainable public food procurement has likewise been recognized as a promising type of regulation (JHU & GAIN, 2021; WHO, 2022b and OECD, 2022); it encompasses a wide range of policies from school or institutional feeding to public food distribution. SPFP may be used to achieve one or multiple operational goals; these include improving diets, livelihoods and/ or environmental outcomes. SPFP is widespread, found in all regions of the world and in countries at all income levels (FAO et al, 2021b).

In an effort to understand their ability to make diets healthier, Niebylski et al (2014) performed a systematic review of evaluations in high income countries (mostly the US, UK and Canada) of procurement policies in schools, worksites, hospitals, prisons and other settings. Most healthy food procurement programs were successful in increasing the availability of healthy food and decreasing foods high in sugar, salt or fat. In some instances, evaluations that considered health parameters showed improved health outcomes among the affected population.

The Indian PDS is the largest food procurement system in the world and was first implemented on a universal basis in 1939 (FAO et al, 2021b). In 1997 it was reformed to be the targeted public distribution system and it now provides subsidized prices for rice, wheat and other essentials (eg. sugar and oil) to vulnerable (rather than all) households and it ensures minimum standard prices for farmers. In 2013 the TPDS was expanded so that eligible commodities included small millets and other coarse cereals. The inclusion of small millets is noteworthy because they are well adapted to climate change, have rich nutritional profiles and are typically farmed by vulnerable groups and traditional farmers. With the inclusion of small millets the TPDS has great potential to improve nutritional outcomes and livelihoods among the vulnerable as well as adapt to climate change, however challenges of implementation have limited the success of this reform. Given the sheer size of the TPDS it has great potential to be used as a vehicle for achieving goals of healthier diets, more environmentally sustainable production and reduced poverty for a large segment of the earth's population.

Brazil is another country known for its procurement from family farmers. According to the law in Brazil, at least 30% of spending on the national school feeding program (PNAE) must be purchased from family farmers, defined as those farms smaller than a certain size (four fiscal modules that are defined based upon the locality), that rely mostly on family labor, their income comes mostly from the family farm and they are managed by the family that owns the farm (FAO et al, 2021b). The reasoning is that purchases from family farmers will help connect the family farms to markets driving their economic growth. It finds that the 30% requirement has not been met by most municipalities, with variation among regions; nationally the share of purchases from family farms is 25% and 50% of municipalities not purchasing from family farms. Despite failure to reach the requirement, rates of procurement from family farms have increased dramatically from 2011 to 2017 and there is room for further improvement. Borsatto et al (2021) evaluate the broader Brazilian Food Acquisition Program (PAA) and find that PAA has been successful in supporting family farms, however more is needed to establish local food systems.

Regional and local purchases by the World Food Programme have increased reaching 70% and 50% respectively in 2018; about 4% of total food procurement by the WFP was from smallholders (FAO et al, 2021b). The WFP's home-grown school feeding programs (those based on local procurement) in Cambodia were evaluated through interviews of parents, teachers and administrators. Interviewees agreed that the program had numerous positive impacts on children; their health improved, school attendance increased, school performance improved, fewer children repeated grades, more children completed sixth grade and graduations from primary to secondary school increased. Parents were able to save on the expense of feeding their children snacks on the way to school. Local farmers benefited since procurement was mostly done locally. Vegetables were procured locally from smallholders (those cultivating less than one hectare) and their production increased possibly as a result of the program.

An example of green public procurement is that of Sweden where in 2006 the government introduced a goal that 25% of public sector purchases of food be organic (Lindstrom, Lundberg and Marklund, 2020). The share of farmland that was organic increased dramatically (from 10,800 ha in 2006 to 26,300 ha in 2016) and that increase was due partly to the green public procurement goal.

Larrea-Gallegos et al (2022) evaluate public procurement policies, with particular attention to the mandating of local purchases, in 10 primary school catering programs in the UK, Croatia, Greece, Italy and Serbia; for each country they compare a local procurement policy with a non local procurement policy. Some programs have positive impacts on the environment (reducing carbon emissions), economy (generating multiplier effects on the local economy) and/ or nutrition (making meals healthier). There are, however, synergies and trade-offs among the different goals. They conclude that the most impactful procurement policies to reduce carbon emissions include low carbon food waste disposal (mandating composting, for instance) and adjusting menus to include more fruits and vegetables, more complex carbohydrates and reduce ruminant meat. Localization of the food supply has only a small impact in terms of reducing emissions, because transport represents a small share of total carbon footprint, with the menu composition and waste disposal methods contributing a larger share of the carbon footprint. Local sourcing has little impact on nutritional outcomes, however it can lead to positive local economic outcomes with strong multiplier effects. Equally large and in some cases larger improvements to the local economy are seen by improving the pay of canteen workers. The conclusions must be taken with caution given the small sample sizes and case study nature of the work.

Through a case study of a school catering service in an Italian city, Cerutti et al (2018) demonstrate that different procurement policies have different potential in terms of reducing greenhouse gas emissions attributable to school meals. In the example chosen, they find that the greatest reduction in carbon footprint resulted from a change in diet (resulting in a 32% reduction in CO2eq emissions) as compared to an 11% reduction in emissions resulting from improved agricultural production practices. The authors conclude that life cycle analysis is important to understand which policies are truly effective.

3.7 Reformulation

It is widely recognized that governments may encourage healthier diets by establishing mandatory or voluntary regulations for companies to reformulate processed foods to reduce their salt, sugar or trans fatty acid content (GLOPAN, 2021; JHU & GAIN, 2021; WHO, 2022b and Gressier, 2020). The Global Burden of Disease Study 2017 showed that consumption of trans fatty acids is a problem in many LMICs, especially in the Middle East and North Africa as well as South Asia (Downs et al, 2017). Although regulations to limit or end the use of trans fatty acids have been adopted in countries

throughout the world (WHO, 2021), measures to reduce the usage of sweeteners and salt have been largely voluntary.

Federici et al (2019) performed a systematic review of simulation studies modelling the impact of reformulation policies on nutrient intake, health outcomes and quality of life. Most (20) studies considered sodium, 5 of them looked at sugar and 3 looked at fats, while 5 more studies considered multiple nutrients. Most studies predicted the desired outcomes, including reduced consumption of sodium, sugar or fat; improved health outcomes such as reduced blood pressure or decreased incidence of stroke; and improved quality of life, measured as quality adjusted life years. In another review of impact evaluations focusing on policies to reduce trans fatty acids in high income countries, TFA bans were found to be more effective than voluntary and labelling policies (Downs et al, 2017). TFA bans reduced the risk of heart disease, saved costs and benefited socio-economically disadvantaged populations most.

Hashem et al (2019) find evidence of the effectiveness of product reformulation policies that reduce the sugar content of foods; such policies are found to reduce sugar and lead to weight loss in the affected populations. Another review by Bonab et al (2020) considers studies of children's body mass index (BMI) and reformulation policies aimed at reducing the caloric content of foods. It finds less promising outcomes of reformulation policies and provides evidence of the effectiveness of such policies in reducing caloric intake, but not in reducing BMI.

3.8. Reorienting agricultural research and development (R&D)

Current thinking advocates for reorienting agricultural R&D so that it increases the income of smallholders and leads to production of more nutritious foods as well as more environmentally sustainable methods of production. This contrasts to agricultural research and development that in the past focused on increasing the productivity of energy dense crops.

Agricultural research and development is the systematic study of crops, livestock, fisheries and forestry as well as the processing thereof in order to develop new methods of farming or food production or new varieties of crops or other agricultural products. This covers a wide range of activities from public institutions' efforts to develop drought resistant, high yielding crop varieties or smart fertilizers to technological advances more associated with the private sector (eg. improved farm machinery including precision agriculture, development of new food products such as meat alternatives and improved processing methods). Here we focus on public spending on agricultural R&D.

It has been widely recommended in recent work that, going forward, rather than prioritizing high energy output crops as it has in the past, investments in research and development prioritize more nutritious crops and poverty reduction as well as methods to farm more sustainably and adapt to as well as mitigate climate change (see for example, Fan et al.,2022; GLOPAN, 2021; JHU & GAIN, 2021 and Parsons and Hawke, 2019).

In terms of the impacts of agricultural R&D on productivity generally, pioneering work by Evenson and Gollin (2003) was among the first to demonstrate the beneficial impacts of such research. FAO (2012) compiled evaluations of the effectiveness of various interventions on poverty reduction in China, India, Thailand and Uganda; they found agricultural R&D to be one of the most effective in reducing poverty.

Recent modelling work addresses the trade-offs inherent to deciding which type of agriculture to invest in and where. Manners and Van Etten (2018) consider the global nutritional implications of investments in R&D on various crops as well as the future potential for such crops in particular locations given climate change. They find that, given their relatively low nutritional value, maize,

barley, rice, cowpea and lupin have received too much research funding. Research on sweet potatos, lentil, broad bean and chickpeas has been especially underfunded in regions where its cultivation is expected to become more suitable under climate change. They conclude that there is a need to reallocate research funds in light of these and other considerations.

Fuglie et al. (2022) conduct a different modelling exercise looking at the implications of investments in productivity growth (in low and middle-income countries only) on a wide range of outcomes including incomes, hunger, total nutrient availability (iron, zinc and protein), land and water use as well as GHG emissions. Contrary to the often cited need for investments in the productivity of fruits and vegetables to improve nutrition, they find that in low and middle income countries nutrient availability is best improved by increasing the productivity of cereals. Increased productivity of cereals is also effective in reducing hunger. And among the wide range of agricultural products considered (crops, roots, tubers, vegetables, fruit, livestock and fish) investments in the productivity of crops and livestock are the most effective way to reduce greenhouse gas emissions from agriculture. Finally, increased productivity of cereals is more effective in achieving several important goals (increasing income, improving nutrition and conserving natural resources) than is increased productivity of smallholder cash crops.

The seemingly contradictory conclusions from the modelling exercise of Manners and Van Etten (2018) and that of Fuglie et al. (2022) regarding the implications of investments in research on maize, barley and rice, certainly arise from the modelling exercise as well as assumptions used and geography considered. A key difference is that Manners and Van Etten (2018) consider the nutrient density of crops produced rather than total production of nutrients; the latter is what Fuglie et al. (2022) consider. There is a need for continued research on the implications of various funding allocations for improved nutrient availability, poverty reduction and environmental sustainability.

There are numerous conditions for agricultural research and development to improve nutrition and environmental sustainability; these include the following. First, funding levels must be sufficient and reliable (Stads et al., 2022). Second, governments can strengthen intellectual property rights to encourage investments from the private sector and focus their own research on areas of less interest to the private sector; these include how to use agriculture to improve nutrition, reduce poverty and increase environmental sustainability (Pardey, Alston and Piggott, 2016). Third, governments may allocate scarce research funds to under researched crops, including those that are nutrient dense and toward methods of production that are more environmentally sustainable (Chiurugwi, 2019; Fan et al.,2022; GLOPAN, 2021; JHU & GAIN, 2021 and Parsons and Hawke, 2019). Fourth, staffing issues including lack of promotion potential and insufficient training opportunities are areas for improvement by national agricultural research centers (Pardey, Alston and Piggott, 2016; also Beintema et al., 2020). Finally, decisions on which research programs to adopt can be improved by additional usage of guidance from ex ante evaluations and enhanced processes for competitive selection of programs (Pardey, Alston and Piggott, 2016).

Investments in agricultural R&D can affect agricultural productivity, hunger, poverty, the nutrient content of foods and diets as well as the environment. In choosing what type of investments to make in agricultural R&D, policymakers may be helping to improve environmental sustainability (land sparing through the increased productivity of rice crops, for instance), but doing little to increase the nutrient density of production. Had they invested in a crop such as sweet potatoes rather than rice, land might not be spared as a result, but the nutrient density of the food supply would improve.

3.9 Carbon tax

A carbon tax internalizes an externality by putting a price on a ton of carbon (CO2) emissions. In the agricultural sector CO2 emissions result mainly from energy use. However, using carbon equivalents,

other greenhouse gas emissions relevant in the agricultural context, such as methane (CH4), can be incorporated into a carbon tax. The emissions can be either determined by monitoring the amount of CO2 emitted on the farm or by including the agricultural sector into emission trading schemes (ETS) This may be done by monitoring the amount of CO2 emitted by farmers or include the agricultural sector into emission trading schemes (ETS) (Henderson, 2019).

Agriculture has considerable emission mitigation potential, however no country in the world has implemented a carbon tax. New Zealand considers introducing a carbon tax to the agricultural sector. International organizations have recommended emissions pricing (of various types of emissions) rather than specifically focusing on carbon emissions specifically (OECD, 2020; IPCC, 2022).

Analyses of the European Union Emission Trading Scheme (ETS), spanning the European energy and industry sector, demonstrate that significant emission reductions are possible and that they may even improve the competitiveness or the overall economic performance of participating firms (Henderson and Verma 2021). However, so far, emission-intensive sectors are exempted from the ETS. Henderson and Verma (2021) therefore use MAGNET to model a carbon tax on agriculture. Under the condition that tax revenues are invested in abatement technology for producers' usage, implementing such a tax in only a handful of countries would result in a global reduction of GHG emissions from the agricultural sector.

Such results of course vary by geography and context. Glauber, Laborde and Piñeiro (2022) caution that a tax on carbon in the agricultural sector of LDCs would be costly given low productivity in LDCs means high emissions intensity.

There are three main designs for a tax on CO2 emissions: polluter-pays policies, beneficiary-pays policies, and a hybrid policy model (Henderson, 2019; Arvanitopoulos et al. 2021; Henderson and Verma, 2021). The carbon tax in a polluter-pays scenario is applied directly to emissions instead of being applied to a proxy (e.g., fertilizer or fuels); the tax reduces emissions by internalizing negative environmental externalities. Although it is the most cost effective (lowest cost per ton CO2 emitted) and it reduces emissions in the long term, it may cause short-term issues, such as distributional impacts or leakage effects. Beneficiary-pays policies describe a mechanism whereby the government pays producers to abate emissions either by subsidies or through the creation of an offset market. These policies are politically more feasible and cause less leakage (increase of emissions in one country or locale as a result of decreases in another location) than do polluter pays policies. However, they are less cost effective; a rough estimate is that they are half as cost effective as a carbon tax on average. Furthermore, the large amount of financing required is a cost that accrues to governments and taxpayers. A hybrid tax-subsidy policy design uses carbon tax revenues to subsidize adopting low emission technologies. This can ease the distributional and leakage effects. Other policy options like improving agricultural productivity have a huge potential to substantially mitigate emissions without affecting food security but need to be designed carefully; otherwise, they might have unintended compromising effects. When abatement technologies are taken advantage of, leakage effects are not large enough to offset emission reductions (Henderson and Verma, 2021). Another way to prevent leakages would be to implement an emission mitigation policy in the agricultural sector on a global scale.

A carbon tax is implemented on the production side in order to encourage less emission intensive farming methods as well as reduction of food losses. A synergy is that it can also incentivize consumers by encouraging them to reduce food waste and to shift to less carbon-intensive diets due to higher food prices (Henderson, 2019; Arvanitopoulos et al. 2021). Trade-offs include higher food prices being harmful to the diets of low-income populations. As recognized earlier, a carbon tax would be regressive, costing more to farmers in LDCs who have low productivity and therefore higher emissions intensity (this includes many farmers in LDCs and farmers elsewhere who are not using

efficient technologies, many of whom are likely to be among the less well off) (Glauber, Laborde and Piñeiro, 2022).

3.10 Nitrogen tax

Another policy instrument to reduce agricultural emissions and pollution policy is the nitrogen tax, especially important given experts expect that synthetic nitrogen fertilizer related emissions will increase beyond their already significant levels (Martinez-Dalmau et al., 2021).

In the literature various types of nitrogen pricing policies are discussed: nitrogen tax, nitrogen surplus tax, nitrogen fertilizer tax (Wang et al., 2022; Andersen and Bonnies, 2021; Martinez-Dalmau et al., 2021; Henseler et al., 2020; Meyer-Aurich et al., 2020 and Xiang et al., 2007). A nitrogen tax imposed on fertilizer affects farmers of crops using synthetic fertilizer more than it affects producers of livestock even if livestock farmers are responsible for a larger share of nitrogen pollution given the amount of nitrogen fertilizer used to produce livestock feed (Hermann et al., 2020). A nitrogen surplus tax tackles the problem on the farm level by targeting the overuse of nitrogen fertilizer instead of punishing general fertilizer use (Hermann et al., 2020). This requires monitoring of the nitrogen balance on farms.

Nitrogen taxes have been recommended by recent international reports (IPCC, 2022; GLOPAN, 2021; Dasgupta, 2021). Sweden and Finland had a nitrogen tax implemented before joining the European Union in 1995 and 2010, respectively. China implemented a nitrogen policy in 2015.

Nitrogen tax evaluations from Finland and Sweden demonstrate the success of such a policy as both countries report reductions of 11% and 6%, respectively (Andersen and Bonnies, 2021). Case studies from China and Germany show that such a policy is effective and, when properly designed, only has a limited impact on production output (Wang et al., 2022, Henseler et al., 2020, Meyer-Aurich et al., 2020 and Xiang et al., 2007). In addition to their effectiveness in reducing pollution, nitrogen taxes are considered as very cost effective. With fairly low tax rates significant reductions may be achieved (Andersen and Bonnies 2021, Meyer-Aurich et al. 2020).

Kanter et al. (2020) highlight the role and responsibility of actors in the agri-food chain (other than farmers) for reducing nitrogen surpluses. Addressing actors such as fertilizer manufacturers, processors, retailers, consumers, wastewater treatment companies, farm advisors or financial organizations may be more effective in reducing emissions, leading to full-chain nitrogen use efficiency. Food waste beyond the farm gate is another lever to reduce nitrogen pollution.

Numerous studies confirm that a nitrogen tax needs to be accompanied by nitrogen use efficiency (NUE) measures to fully develop its potential; such measures include, for example, enhancing soil nitrogen uptake, improving nutrient management and manure application standards. Technological innovations, such as controlled application techniques, or innovations in breeding, irrigation, or management practices, are equally as important as increasing the price of fertilizers (Wang et al., 2022; Henseler et al., 2020; Hermann et al., 2020; Meyer-Aurich et al., 2020; and Xiang et al., 2007). In a meta-review analyzing more than 600 studies worldwide, Gu et al. (2021) report that nitrogen pollution can be reduced by 30 – 70%, while crop yields remain constant or even increase, by simply changing management practices or production methods.

Depending on its design, nitrogen taxes might have an impact on production output and therefore food security. A nitrogen tax aims to reduce the nitrogen use on farm, preventing water and soil pollution, as well as reducing nitrogen emissions. Nitrogen taxes may reduce yields, leading to increased prices and harming the diets of the poor. However, if it is implemented properly (e.g., only surpluses are taxed), then yields will not be changed and this trade-off will not be a problem.

4. Conclusions and areas for future research

A deep dive into the literature regarding selected policies brings to light three important points. Each of these points underscore the impossibility of identifying policies that are universally effective.

First, context matters, and it does so in many ways. At a very basic level, not all policies would apply in every context. For example, behavioral policies such as SMS reminders, menu labelling, limits on portion size, media campaigns or educational efforts (JHU & GAIN, 2021; WHO, 2022) are often recognized as important policies to consider in middle and high income countries for populations that are consuming too many calories. Such behavioral policies would not be relevant in many low-income country contexts where the concern for much of the population is how to consume adequate energy. Another example is policies on food loss and waste; it is widely thought that food waste is more common in high income countries and food losses (from production to processing) are more typical of developing countries (FAO, 2019; World Bank, 2021). The implication is that policies to address food loss are needed in developing countries while policies to address food waste are needed in developed countries (World Bank, 2021). In addition, context determines the distributional impacts of a given policy within a given country – measures to curb methane emissions for example, in some countries will affect mostly big agro-industrial groups involved with livestock, in others will affect small producers for whom livestock is a key asset as well as a source of much needed animal based foods.

Second, there is a lot of debate regarding effectiveness of the policies; much of this has to do with methods of evaluation as well as policy design, implementation and context. Assessing the impact and effectiveness of policies listed in Table 1 is not straightforward. This is due to variation in methods and indicators used to evaluate policies, a lack of evidence for some policies and context specificity, among other issues. For instance, there are numerous systematic reviews showing that reformulation policies related to salt, sugar and fat content of foods have been successful in reducing consumption of sodium, sugar or fat, improving health outcomes and improving quality of life (Federici, 2019; Downs et al, 2017 and Hasham, 2019). At the same time, a systematic review by Bonab et al (2020) finds less promising outcomes of reformulation policies; it provides evidence of the effectiveness of such policies in reducing childrens' caloric intake, but not in reducing their BMI.

Similarly, sustainable public food procurement (SPFP) has been recognized as a potentially robust tool for encouraging consumption of more nutritious and local foods as well as foods that are produced in a more environmentally sustainable way (JHU & GAIN, 2021; WHO, 2022b; OECD, 2022). It encompasses a wide range of policies from school and institutional feeding to public food distribution. SPFP is widespread, found in all regions of the world and in countries at all income levels (FAO et al, 2021b). In high income countries sustainable public food procurement policies have been shown to improve diets, health and environmental objectives (Niebylski et al, 2014 and Lindstrom, Lundberg and Marklund, 2020). Robust evaluation of SPFP is lacking for most such programs in LMICs (FAO et al, 2021b). However, given the sheer size of such programs they have high potential for impact. For instance, the largest food procurement system in the world is the Indian targeted public distribution system; it aims to improve livelihoods (by guaranteeing farmers a minimum price) and to improve food security (by subsidizing the price of staple foods). In 2013 eligible commodities under the TPDS were expanded to include small millets and other coarse

cereals. With the inclusion of small millets the TPDS has great potential to improve nutritional outcomes and livelihoods among the vulnerable as well as adapt to climate change.

Evidence shows limits to the effectiveness of taxes on sugar sweetened beverages in order to help ensure healthy diets for all. The WHO (2016) advocates for taxing consumer purchases of sugar sweetened beverages as do meta-analyses published in numerous peer reviewed journals (see for instance: Popkin and Hawkes, 2016; Allcott, Lockwood, and Taubinsky, 2019; Powell et al., 2021; Teng et al., 2019 and Nakhimovsky, 2016). More than 45 countries and several localities throughout the world have implemented taxes on SSB (Andreyeva et al., 2022). There is evidence that such taxes may reduce purchases of SSBs, but there is no evidence of improved health outcomes as a result (Teng et al., 2019; Andreyeva et al., 2022; Powell et al., 2021 and Nakhimovsky, 2016).

For some policies it is challenging to assess impact because the policy has not been widely implemented and therefore has been studied little. One such example is that of the nitrogen tax, which has been recommended by recent international reports (IPCC, 2022; GLOPAN, 2021; Dasgupta, 2021). In addition to their effectiveness in reducing pollution, nitrogen taxes are considered as very cost effective. With fairly low tax rates significant reductions may be achieved (Andersen and Bonnies 2021 and Meyer-Aurich et al. 2020). Such conclusions about the effectiveness of a nitrogen tax must however be taken cautiously given they are drawn on experiences of a relatively small number of countries including Finland, Sweden, China and Germany (see, for example: Andersen and Bonnies, 2021; Wang et al., 2022, Henseler et al., 2020, Meyer-Aurich et al., 2020 and Xiang et al., 2007).

Lastly, an important feature of the policies in table 1, and one that is particularly salient in the policy debate, are the inescapable trade-offs and synergies that most of these policy levers pose in the pursuit of different objectives. Take, for instance, the idea of repurposing agricultural support so that it leads to healthier diets, improved environmental sustainability and reduced poverty (FAO, UNEP and UNDP, 2021; Gautum et al.,2022 and Glauber, Laborde and Piñeiro, 2022). A recently released report on repurposing agricultural support (Gautam et al., 2022) shows that simply removing all agricultural support is not sufficient to achieve the goals of healthier diets, improved environmental sustainability and reduced poverty. Furthermore, while such removal would help reduce emissions, it would impact poverty, nutrition and farmers' incomes negatively. The authors therefore model more elaborate scenarios and find that redirecting funds to investments in green agricultural technology is helpful in achieving all goals (increased GDP; increased volume of agricultural production; decreased poverty; reduced prices of healthy foods; reduced emissions and decreased usage of land for agriculture).

Another example of synergies and trade-offs may be found with the implementation of a carbon tax on the production side. Such a tax can encourage less emission intensive farming methods as well as reduction of food losses. An additional synergy is that it can also incentivize consumers by encouraging them to reduce food waste and to shift to less carbon-intensive diets due to higher food prices (Henderson, 2019; Arvanitopoulos et al. 2021). Trade-offs include higher food prices being harmful to the diets of low-income populations. As recognized earlier, a carbon tax would be regressive, costing more to farmers who have low productivity and therefore higher emissions intensity (this includes many farmers in LDCs and farmers elsewhere who are not using efficient

technologies, many of whom are likely to be among the less well off) (Glauber, Laborde and Piñeiro, 2022).

Moving forward, research on the effectiveness of policies related to the food system may benefit from developing standard methods and indicators for measuring progress. Furthermore, impact evaluations that consider multiple policies and are able to show which policies have been most impactful would likewise fill an important gap. For some policies, such as public procurement in low and middle income countries, there have been few if any rigorous impact evaluations; these should prioritized. There is a need for more evaluation of efforts to encourage or mandate reformulation of food products to reduce sodium or sugar.

References

Ammerman, A. S., Lindquist, C. H., Lohr, K. N., & Hersey, J. (2002). The efficacy of behavioral interventions to modify dietary fat and fruit and vegetable intake: a review of the evidence. *Preventive medicine*, *35*(1), 25-41.

Arvanitopoulos, T., G. Garsous and P. Agnolucci (2021), Carbon leakage and agriculture: A literature review on emissions mitigation policies, OECD Food, Agriculture and Fisheries Papers, No. 169, OECD Publishing, Paris, https://doi.org/10.1787/9247f1e7-en.

Allcott, H., Lockwood, B. B., & Taubinsky, D. (2019). Should we tax sugar-sweetened beverages? An overview of theory and evidence. *Journal of Economic Perspectives*, *33*(3), 202-27.

Andreyeva, T., Marple, K., Marinello, S., Moore, T. E., & Powell, L. M. (2022). Outcomes Following Taxation of Sugar-Sweetened Beverages: A Systematic Review and Meta-analysis. JAMA Network Open, 5(6), e2215276-e2215276.

Barrett, Christopher B., Tim Benton, Jessica Fanzo, Mario Herrero, Rebecca J. Nelson, Elizabeth Bageant, Edward Buckler, Karen Cooper, Isabella Culotta, Shenggen Fan, Rikin Gandhi, Steven James, Mark Kahn, Laté Lawson-Lartego, Jiali Liu, Quinn Marshall, Daniel Mason-D'Croz, Alexander Mathys, Cynthia Mathys,Veronica Mazariegos-Anastassiou, Alesha (Black) Miller, Kamakhya Misra, Andrew G. Mude, Jianbo Shen, Lindiwe Majele Sibanda, Claire Song, Roy Steiner, Philip Thornton, and Stephen Wood. (2020). *Socio-Technical Innovation Bundles for Agri-food Systems Transformation* (Cornell Atkinson Center for Sustainability and Springer Nature). Cornell Atkinson Center for Sustainability and Springer Nature.

Blaga, O. M., Vasilescu, L., & Chereches, R. M. (2018). Use and effectiveness of behavioural economics in interventions for lifestyle risk factors of non-communicable diseases: a systematic review with policy implications. *Perspectives in public health*, *138*(2), 100-110.

Cadario, R., & Chandon, P. (2020). Which healthy eating nudges work best? A meta-analysis of field experiments. *Marketing Science*, *39*(3), 465-486.

Campos, S., Doxey, J., & Hammond, D. (2011). Nutrition labels on pre-packaged foods: a systematic review. *Public health nutrition*, *14*(8), 1496-1506

Capros, Pantelis, Leonidas Mantzos, Leonidas Parousos, Nikolaos Tasios, Ger Klaassen, and Tom Van Ierland. 2011. 'Analysis of the EU Policy Package on Climate Change and Renewables'. *Energy Policy* 39 (3): 1476–85. https://doi.org/10.1016/j.enpol.2010.12.020.

Clements, B., Coady, D., Fabrizio, S., Gupta, S., Alleyne, T., & Sdralevich, C. (2013). *Energy subsidy reform: Lessons and implications*. IMF.

Dasgupta, P. (2021) The Economics of Biodiversity: The Dasgupta Review. London: HM Treasury

Deconinck, K. and L. Toyama (2022), "Environmental impacts along food supply chains: Methods, findings, and evidence gaps", *OECD Food, Agriculture and Fisheries Papers*, No. 185, OECD Publishing, Paris, https://doi.org/10.1787/48232173-en.

Downs, S. M., Bloem, M. Z., Zheng, M., Catterall, E., Thomas, B., Veerman, L., & Wu, J. H. (2017). The impact of policies to reduce trans fat consumption: a systematic review of the evidence. *Current Developments in Nutrition*, *1*(12), cdn-117.

Fan, S., Chen, K., Zhu, J. and W. Si. 2022. *China and Global Food Policy Report 2022: Reforming agricultural support policy for transforming agrifood systems*. Beijing, AGFEP.

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

FAO, 2021. The State of the World's Land and Water Resources for Agriculture: Systems at breaking point (SOLAW 2021). Rome, FAO.

FAO, IFAD, UNICEF, WFP and WHO. 2021a. The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO. https://doi.org/10.4060/cb4474en
FAO, Alliance of Bioversity International and CIAT and Editora da UFRGS. 2021b. Public food procurement for sustainable food systems and healthy diets – Volume 1. Rome. https://doi.org/10.4060/cb7960en

FAO, UNDP and UNEP. 2021. A multi-billion-dollar opportunity – Repurposing agricultural support to transform food systems. Rome, FAO. https://doi.org/10.4060/cb6562en

Federici, C., Detzel, P., Petracca, F., Dainelli, L., & Fattore, G. (2019). The impact of food reformulation on nutrient intakes and health, a systematic review of modelling studies. *BMC nutrition*, *5*(1), 1-21.

Fesenfeld, L. P., Wicki, M., Sun, Y., & Bernauer, T. (2020). Policy packaging can make food system transformation feasible. *Nature Food*, *1*(3), 173–182. https://doi.org/10.1038/s43016-020-0047-4
IFPRI. 2022. Global Food Policy Report: Climate Change and Food Systems. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896294257

Finkelstein, E. A., Bilger, M., & Baid, D. (2019). Effectiveness and cost-effectiveness of incentives as a tool for prevention of non-communicable diseases: A systematic review. *Social Science & Medicine*, *232*, 340-350.

FOLU (Food and Land Use Coalition) (2019). Growing Better: Ten critical transitions to transform food and land use. https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU/GrowingBetter-GlobalReport.pdf

Gautam, M., Laborde, D., Mamun, A., Martin, W. Piñeiro, V. and, R. Vos. 2022. Repurposing Agricultural Policies and Support: Options to transform agriculture and food systems to better serve the health of people, economies, and the planet. World Bank, Washington, D.C.

Glauber, J., Laborde, D. and V. Piñeiro. 2022. Food Security in LDCs: A challenge for WTO. Brainstorming session: agenda. September 26, 2022. Available at: https://www.slideshare.net/ifpri/food-security-in-ldcs-a-challenge-for-wto

Global Panel on Agriculture and Food Systems for Nutrition (GLOPAN), 2021. GLOPAN Policy Tool. Available at: https://www.glopan.org/policy_tool/ Accessed May, 2021.

Gressier, M., Sassi, F., & Frost, G. (2020). Healthy foods and healthy diets. How government policies can steer food reformulation. *Nutrients*, *12*(7), 1992.

Hashem KM, He FJ, MacGregor GA. 2019. Effects of product reformulation on sugar intake and health-a systematic review and meta-analysis. Nutr Rev. Mar 1;77(3):181-196. doi: 10.1093/nutrit/nuy015. PMID: 30624760.

Henderson, B. and M. Verma (2021), Global assessment of the carbon leakage implications of carbon taxes on agricultural emissions, OECD Food, *Agriculture and Fisheries Papers, No. 170*, OECD Publishing, Paris, https://doi.org/10.1787/fc304fad-en.

International Food Policy Research Institute (IFPRI). 2021. 2021 Global food policy report: Transforming food systems after COVID-19. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896293991.

IFPRI. 2022. Global Food Policy Report: Climate Change and Food Systems. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896294257

IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Johns Hopkins University and Global Alliance for Improved Nutrition (JHU & GAIN), 2021. Food Systems Dashboard: Data sources and methodology. Available at https://foodsystemsdashboard.org/data-sources-and-methodology. Accessed May, 2021.

Kuiper, M., van Zeist, W. and van Meijl, H. 2022. "Addressing Synergies and Trade-Offs in the Food System Transformation: Global CGE simulations of policy bundles." Working paper commissioned by the Food System Economics Commission.

Laborde, D., Murphy, S., Parent, M., Porciello, J., & Smaller, C. (2020). Ceres2030: Sustainable Solutions to End Hunger—Summary Report. *Cornell University, IFPRI and IISD: New York, NY, USA*.

Lindstrom, H., Lundberg, S. & Marklund, P. 2020. How green public procurement can drive conversion of farmland: an empirical analysis of an organic food policy. Ecological Economics, 172: 1−19.

Liu, F., Kong, X., Cao, J., Chen, S., Li, C., Huang, J., Gu, D., and TN Kelly. 2015. Mobile phone intervention and weight loss among overweight and obese adults: a meta-analysis of randomized controlled trials. Am J Epidemiol. Mar 1;181(5):337-48. doi: 10.1093/aje/kwu260. Epub 2015 Feb 10. PMID: 25673817; PMCID: PMC4339384.

Maier, M, Bartos, F., Stanley, T.D., Shanks, D.R., Harris, A.J.L. and E. Wagenmakers. 2022. "No evidence for nudging after adjusting for publication bias." PNAS. Vol 119 (31). https://doi.org/10.1073/pnas.2200300119

Meyer-Aurich, A., Karatay, Y. N., Nausediene, A., and D. Kirschke. (2020). Effectivity and cost efficiency of a tax on nitrogen fertilizer to reduce GHG emissions from agriculture. *Atmosphere*, *11*(6), 607.

Mertens, S., Herberz, M., Hahnel, U.J.J. and T. Brosch. 2021. "The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains." PNAS. 119 (1). https://doi.org/10.1073/pnas.21073461

Nakhimovsky, S. S., Feigl, A. B., Avila, C., O'Sullivan, G., Macgregor-Skinner, E., & Spranca, M. (2016). Taxes on sugar-sweetened beverages to reduce overweight and obesity in middle-income countries: a systematic review. *PloS one*, *11*(9), e0163358.

Niebylski ML, Lu T, Campbell NRC, Arcand J, Schermel A, Hua D, Yeates KE, Tobe SW, Twohig PA, L'Abbé MR, Liu PP.2014. Healthy Food Procurement Policies and Their Impact. *International Journal of Environmental Research and Public Health*. 2014; 11(3):2608-2627. https://doi.org/10.3390/ijerph110302608

Nugent, R., Thirumurthy, H., Chakrabarti, A., Ellermeier, N. and A. Tripathi. Under review. "Diet-focused Behavioral Interventions to Reduce the Risk of Non-Communicable Diseases in Low- and Middle-income Countries: A Scoping Review of the Existing Evidence."

Parsons, K., & Barling, D. (2021). *Food Systems Transformation: What's in the Policy Toolbox* [A Report for the UKRI Transforming the UK Food System Programme]. Food Systems and Policy Research Group, University of Hertfordshire.

Parsons, K., Hawkes, C., and R. Wells. 2019. Brief 2. What is the food system? A Food policy perspective. In: Rethinking Food Policy: A Fresh Approach to Policy and Practice. London: Centre for Food Policy.

Popkin, B. M., & Hawkes, C. (2016). Sweetening of the global diet, particularly beverages: patterns, trends, and policy responses. *The Lancet Diabetes & Endocrinology*, 4(2), 174-186.

Powell, L. M., Chriqui, J. F., Khan, T., Wada, R., & Chaloupka, F. J. (2013). Assessing the potential effectiveness of food and beverage taxes and subsidies for improving public health: a systematic review of prices, demand and body weight outcomes. Obesity reviews, 14(2), 110-128.

Rincón-Gallardo Patiño, S., Zhou, M., Da Silva Gomes, F., Lemaire, R., Hedrick, V., Serrano, E., & Kraak, V. I. (2020). Effects of menu labeling policies on transnational restaurant chains to promote a healthy diet: A scoping review to inform policy and research. *Nutrients*, *12*(6), 1544.

Stern, N. (2006). *Stern Review: The economics of climate change.*

Teng, A. M., Jones, A. C., Mizdrak, A., Signal, L., Genç, M., & Wilson, N. (2019). Impact of sugar sweetened beverage taxes on purchases and dietary intake: Systematic review and meta-analysis. *Obesity Reviews*, *20*(9), 1187-1204.

Thow, A. M., Downs, S., & Jan, S. (2014). A systematic review of the effectiveness of food taxes and subsidies to improve diets: understanding the recent evidence. *Nutrition reviews*, *72*(9), 551-565.

United Nations, 2021. Solutions and Coalitions: Solution clusters: Game changing propositions. Available at: https://foodsystems.community/game-changing-propositions-solution-clusters/?_sft_category=5-3-climate-resilient-pathways-to-food-system-transformation. Accessed October, 2022.

WBA (Wissenschaftlicher Beirat Agrarpolitik beim BMEL) (2012), Ernährungssicherung und nachhaltige Produktivitätssteigerung. Stellungnahme, Berlin

WBAE (2020) Politik für eine nachhaltigere Ernährung: Eine integrierte Ernährungspolitik entwickeln und faire Ernährungsumgebungen gestalten. Berlin: Wissenschaftlicher Beirat für Agrarpolitik, Ernährung und gesundheitlichen Verbraucherschutz beim Bundesministerium für Ernährung und Landwirtschaft.

WBAE / WBW (2016) Klimaschutz in der Land- und Forstwirtschaft sowie den nachgelagerten Bereichen Ernährung und Holzverwendung. Gutachten. Berlin: Wissenschaftlicher Beirat Agrarpolitik, Ernährung und gesundheitlicher Verbraucherschutz und Wissenschaftlicher Beirat Waldpolitik beim BMEL.

WHO (World Health Organization) (2016) Fiscal policies for diet and prevention of noncommunicable diseases. Technical Meeting Report 5–6 May 2015, Geneva, Switzerland.

WHO, 2021. Countdown to 2023: WHO report on global trans-fat elimination 2021. Geneva, WHO.

WHO, 2022a. World Obesity Day 2022 – Accelerating action to stop obesity. 4 March 2022 News release. Geneva, WHO.

WHO, 2022b. Technical briefing for Appendix 3 of the Global Action Plan for Non-Communicable Diseases: Interventions to promote healthy diets Available at: https://cdn.who.int/media/docs/default-source/ncds/mnd/2022_discussion_paper_01_aug.pdf?sfvrsn=6aa03d21_3 Accessed August, 2022.

Xiang, P. A., Yan, Z. H. O. U., Huang, H., and H. Zheng. (2007). Discussion on the green tax stimulation measure of nitrogen fertilizer non-point source pollution control–taking the Dongting Lake area in China as a case. *Agricultural Sciences in China*, *6*(6), 732-741.

Yasmin, Farzana & Banu, Bilkis & Sikder, Zakir & Sauerborn, Rainer & Ali, Liaquat & Souares, Aurélia. (2016). Positive influence of short message service and voice call interventions on adherence and health outcomes in case of chronic disease care: A systematic review. BMC Medical Informatics and Decision Making. 16.

Zhou, S. & M. A. Brown (2017). Smart meter deployment in Europe: A comparative case study on the impacts of national policy schemes. Journal of Cleaner Production Vol. 144, 22-32, doi: 10.1016/j.jclepro.2016.12.0