08

Consumption: the missing link towards phosphorus security

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Left: Plant protein burgers cooked with vegan cheese. A reduction in the production of animal products may reduce global agricultural demand and contribute to healthier environments. Image courtesy of likemeat on www.unsplash.com; for further info see www.likemeat.com

Supporting low levels of animal product (meat, dairy, and eggs) consumption and food waste can significantly reduce the impacts of unsustainable phosphorus use. In addition, consuming products grown with good on-farm nutrient management practices, including phosphorus recycling can further reduce impacts. These changes can contribute to achieving multiple United Nations' Sustainable Development Goals related to improving human and environmental health.

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Challenge 8.1: Animal products have high phosphorus footprints

The production of meat, dairy and eggs requires disproportionately high amounts of mineral phosphorus fertilisers. Under 2011 global farming practices, it took 16 times more mineral phosphorus fertiliser to produce 1 g of beef protein than 1 g of legume/pulse protein.

Challenge 8.2: Consumption of animal products is increasing

A 38% rise in the phosphorus footprint of the average diet in the last 50 years is mostly associated with the increased consumption of animal products. A remarkable increase has occurred in China and Brazil; however, their footprints are still below the USA and other industrialised countries (e.g. average per capita protein intake in the EU is about 70% higher than recommended). Economic development correlates with increased consumption of animal products. Some populations still require a more diverse and calorie-rich diet.

Challenge 8.3: Food loss and waste is high across the globe

Globally, 23% of nutrients in fertilisers are used to produce products that are then lost in agricultural and food wastes. The loss at each stage, from farm to fork, differs among regions. Generally, waste is higher on a per-capita basis in industrialised countries, whilst in lower-income countries, losses are driven by insufficient infrastructure.

Challenge 8.4: Changing consumer food habits is difficult

Whilst a shift towards more phosphorus-sustainable diets and waste management practices is required, a complex network of conditions must be met for an individual to change behaviour, which varies by region, country, town, and even family. Raising awareness of negative environmental and/or health impacts (including phosphorus sustainability issues) of certain food choices alone is not enough to change behaviours. People's resources and capacity to change need to be considered as well.

Challenge 8.5: Unsustainable pricing models may slow a transition to sustainable practices

There is a disconnect between what a consumer pays for food and the true 'costs' of food production. The costs involved in mitigating environmental degradation and biodiversity loss from phosphorus losses, and in developing more phosphorus sustainable agriculture systems, are not covered in the price of food products.

Solution 8.1: Reduce consumption of animal products to recommended levels

Wider adoption of healthy diets with low to moderate amounts of meat and dairy (especially low in red meat) could radically reduce demand for mineral phosphorus fertilisers and thus phosphate rock mining. While some demographics could benefit from increased access to animal products, large gains can be made from reducing meat consumption in countries that already consume more than is recommended. The global adoption of a vegetarian diet would cut both fertiliser needs and eutrophication effects by 50%. Although this may be unrealistic, it indicates the major influence of diet change on the global phosphorus cycle.

Solution 8.2: Promote the wide adoption of healthy and regionally appropriate diets

The wide adoption of healthy diets rich in plant-based foods and sustainable aquaculture produce is compatible with sustainable phosphorus management. Sustained communication, along with global and regional structural changes to food systems can help consumers adopt diets that are good for them and the environment.

Solution 8.3: Reduce food loss throughout food production, retail, and consumption sectors

Most food loss in low-income countries occurs before products reach consumers; meanwhile wealthier nations waste more food in retail and at home. Efficient strategies to reduce waste will target the most wasteful, with support underpinned by evidence that quantifies the benefits of change.

Solution 8.4: Make being 'sustainable' easy and rewarding for consumers

It should be easy and affordable for everyone to make healthy diet choices, decrease food waste, and support the safe use of recycled phosphorus from organic wastes (e.g. food waste and excreta) in food production. Incentive structures (including 'health nudges' and 'choice editing') embedded in food systems should be transformed to make phosphorus-sustainable food choices the 'default' option.

Solution 8.5: Develop policies that encourage and support consumers to lead sustainable phosphorus lifestyles

Developing economic and regulatory policies that encourage and support high recycling rates, low animal product consumption and low waste production will be necessary for sustainable change. This may involve setting high goals for organic waste recycling, direct taxes on animal products, or decreasing subsidies that affect the price of meat.

8.1 Introduction

The role that consumers play in the phosphorus (P) cycle is often overlooked. Although most consumers do not physically control how much P is used to fertilise food crops or where their waste goes, they still have great influence over the P cycle through their individual and collective purchasing power, waste management, and through the policies they support. Yet, many consumers feel disconnected from how their food is produced and processed; a trend that is increasing with global urbanisation (Jones et al., 2013).

8.1.1 Individual impacts on phosphorus sustainability

Individual citizens and families affect P sustainability in many ways, however, the largest impact stems from what they eat. Around 85% of all mined P is used in food production (de Boer et al., 2019). Over the last 60 years, 38% of the increased use of mineral P fertilisers can be attributed to global diet changes (Metson et al., 2012). This increase is predominantly related to increased consumption of animal products (meats like beef, poultry and pork, as well as milk and eggs) (Metson et al., 2012, 2016a; Poore and Nemecek, 2018; Li et al., 2019; Oita et al., 2020), especially in wealthier countries where per capita consumption is often higher than is recommended (WHO, 2003). If this trajectory continues, most of the United Nations Sustainable Development Goals will not be met (SDGs) (IPES-Food, 2017; Gordon et al., 2017).

Whilst food consumption is the biggest driver of household P flows, other decisions also have an impact. For example, the maintenance of household sanitation systems (e.g. leaky septic tanks; Withers et al., 2014), the use of lawn and garden fertilisers (Lehman et al., 2011), laundry and dishwashing detergents (van Puijenbroek et al., 2018) and the number of household pets (Chowdhury et al., 2014; van Dijk et al., 2016), can all affect P flows. Also, increasingly affluent and high-tech lifestyles are driving demand for high-grade P in industrial sectors such as steel, iron and battery production (Matsubae et al., 2015) and clothing and construction materials (Hamilton et al., 2018). Indeed, in 2011, 35% of marine and coastal eutrophication and 38% of freshwater eutrophication was associated with the production of non-food products (i.e. clothing, goods for shelter, services and other manufactured products) and these proportions have increased over time (Hamilton et al., 2018).

Phosphorus foot-printing methods have allowed analysis of the P requirements of individuals (Dhar et al., 2021; Metson et al., 2016b; Poore and Nemecek, 2018; Oita et al., 2020), and populations, as well as the P footprint of individual products (Metson et al., 2012). The use of P footprints to assess the sustainability of a given action, behaviour or product should be accompanied by careful analysis of footprint definitions (Čuček et al., 2012). Considerations when interpreting assessments based on P footprints are provided in Focus Box 8.1

Focus Box 8.1 - A closer look at phosphorus footprints

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As consumers, the choices that we make each day leave impressions on our environment. These impressions can be called "footprints" which can be tracked using assessments like life-cycle analysis or material flow analysis. Footprints can be used to compare products for the amounts and sources of P used in their manufacture.

A P footprint is quantified using the inverse of the equation used for P use efficiency (see Chapter 4); it is given in terms of P input or flow per unit of output. Many different footprints can be defined depending on spatial scale, temporal scale, and system boundary.

Foods differ in P footprint, with animal products generally having higher impacts than plant products (Metson et al., 2012). Such footprints can, however, be difficult to calculate. The mined P used in crop production generates fibre and fuel as well as food, and co-products of fuel can transfer P from one production stream to another. For example, dried distillers' grains from ethanol manufacture, rich in P and other nutrients, are consumed by cattle, swine, and poultry. The P in the manure from these animals can support the growth of other crops, including wheat grown for food. The calculation comparing the P footprint of wheat to meat involves allocation assumptions that may need to change when the relative sizes of the different production streams change or as the industries and markets evolve.

The kind of P is as important as the amount. The P input in the footprint could be from mined or recycled sources. Recycled sources could be derived from animal manures, food waste, sewage, or other sources. Another useful but different definition of the footprint might involve the amount of P lost to drainage water per unit of agricultural production.

As a sustainability metric, P footprints should be considered in balance with others. For example, the "field-print" defined by the Field to Market Alliance for Sustainable Agriculture includes biodiversity, energy use, greenhouse gas emissions, irrigation water use, land use, soil carbon, soil conservation and water quality. Phosphorus footprints need to be considered in the context of these other metrics, selected for their priority to the stakeholders of the food value chain (Field to Market, 2018). They should also be considered in the context of the footprint of other nutrients including nitrogen and potassium.

8.1.2 The capacity of consumers to support phosphorus sustainability varies

Globally, the human population is increasing. However, stabilising this increase may not significantly improve P sustainability as high per capita consumption and pollution needs to be addressed (Vörösmarty, 2000; Bapna, 2011). The exponential growth of 'middle class' populations around the world complicates matters because increased wealth has historically meant greater resource demand, and this cannot continue indefinitely (Bapna, 2011).

To better understand sustainable phosphorus behaviours, we must better understand what motivates food consumption and waste management behaviour. For instance, social norms play a large role in why increased income and urbanisation in China has translated to a large increase in the consumption of animal products (Zhai et al., 2014); the aspiration towards a Western diet (and arguably Western waste management systems) is a powerful driver even if those Western systems are not sustainable. Individual food consumption behaviours are also sometimes determined by religion (Pechilis and Raj, 2012). For example, most followers of the Hindu faith are lacto-vegetarians (e.g. exclude meat, fish, poultry and eggs) and followers of the Buddhist faith are strict vegetarians, while the Christian faith does not have any rules regarding food choice (Kittler et al., 2016). If wealthy, and/or socially powerful, consumers and organisations set dietary norms to be less animal product intensive, then it may be possible to decouple increasing wealth with resource- and waste-intensive lifestyles. Re-imagining what it is to live a good life within planetary boundaries requires rethinking our social boundaries, including equity and justice (Brand et al., 2021).

Importantly, not all consumers have the same financial, infrastructural, and social resources to support sustainable P management. In some contexts, reducing animal product consumption is neither desirable nor possible due to serious health concerns (e.g. childhood stunting) (Kaimila et al 2019) and/or a lack of affordable, accessible, healthy alternatives (Widener 2018). Similar concerns arise when considering access to sanitation and waste management options (e.g. Öberg et al., 2020), which can affect P recycling. Consumers (primarily, but not exclusively, in the Global North) who do have the capacity for sustainable P lifestyles can directly reduce P demand and pollution with their choices, and indirectly support P security by affecting global food supply chains and social norms.

In this chapter, we argue that although different strategies will be required for different regions, the goal is the same: to support both environmental quality and human health in the long term through better consumption practices. This chapter highlights that the public, as food consumers, waste producers, and decision-makers, play a critical role in the sustainability of the P cycle. However, sustainable products should be readily available and affordable for consumers to choose from, which in most cases will require greater collaborative efforts among policymakers, institutions (e.g. schools, hospitals), and food processing, distribution, and retail services (e.g. restaurants). In the following sections, we summarise the key challenges to increasing phosphorus sustainable consumption behaviours and suggest potential solutions to overcome them.

8.2 The Challenges

Challenge 8.1: Animal products have high phosphorus footprints

The production of meat, dairy and eggs requires disproportionately high amounts of mineral phosphorus fertilisers. Under 2011 global farming practices, it took 16 times more mineral phosphorus fertiliser to produce 1 g of beef protein than 1 g of legume/pulse protein.

Each crop and animal has particular nutrient needs. Thus, the foods that compose our diets affect how much P is used in food production (Figure 8.1) (Metson et al., 2012). In general, animal proteins (especially beef) require larger inputs of P to produce than legume/pulse protein (Dhar et al., 2021, Metson et al., 2012, 2016a; Poore and Nemecek, 2018; Li et al., 2019; Oita et al., 2020). This is because animals require not only a certain amount of P, but large amounts of feed crops to meet carbohydrate and protein needs, and these feed crops also require P to grow. Because there are more steps in animal production than plant production, animals are associated with larger P losses to waterways (see Chapter 5). Under 2011 global farming practices, it took 16 times more mineral P fertiliser to produce a gram of beef protein than a gram of legume/pulse protein (Metson et al., 2012). This is a conservative estimate because it assumes that grasslands and pastures are not fertilised (other than with recycled manure) which is not currently the case in many areas (e.g. North-Western Europe, Australia) and is unlikely in the future (Sattari et al., 2012). However, this assumption cannot be applied in some countries like Malawi, where 80% of livestock feed comes in the form of unfertilised pasture and 50% of the excreta remains on the land (Mnthambala, 2021). Pork, chicken, milk and egg production all require less P per unit of protein than beef. However, producing one unit of animal protein still takes up to ten times the resources (not just P) of producing one unit of vegetarian protein (White and Cordell, 2015). The dependence of animal production on mineral P fertilisers can be reduced by optimising the recycling of manure and other organic waste in the production of animal feed. Still, some losses are unavoidable, and there are multiple challenges to safe, economical and agronomically appropriate recycling that should be addressed (discussed in Chapters 6 and 7). Farmed blue food (fish and other aquatic foods from freshwater and marine environments) can also cause leakage of P, but most systems emit slightly less than poultry (in terms of kg of edible yield) (Gephart et al. 2021). For fed aquaculture, 94% of emissions stem from on-farm production (Gephart et al. 2021). In some circumstances, non-fed aquaculture, such as mussels and seaweeds, are extractive systems that remove P from the water body and can therefore be considered part of the solution to eutrophication. Blue food from capture fisheries causes no emissions of phosphorus.

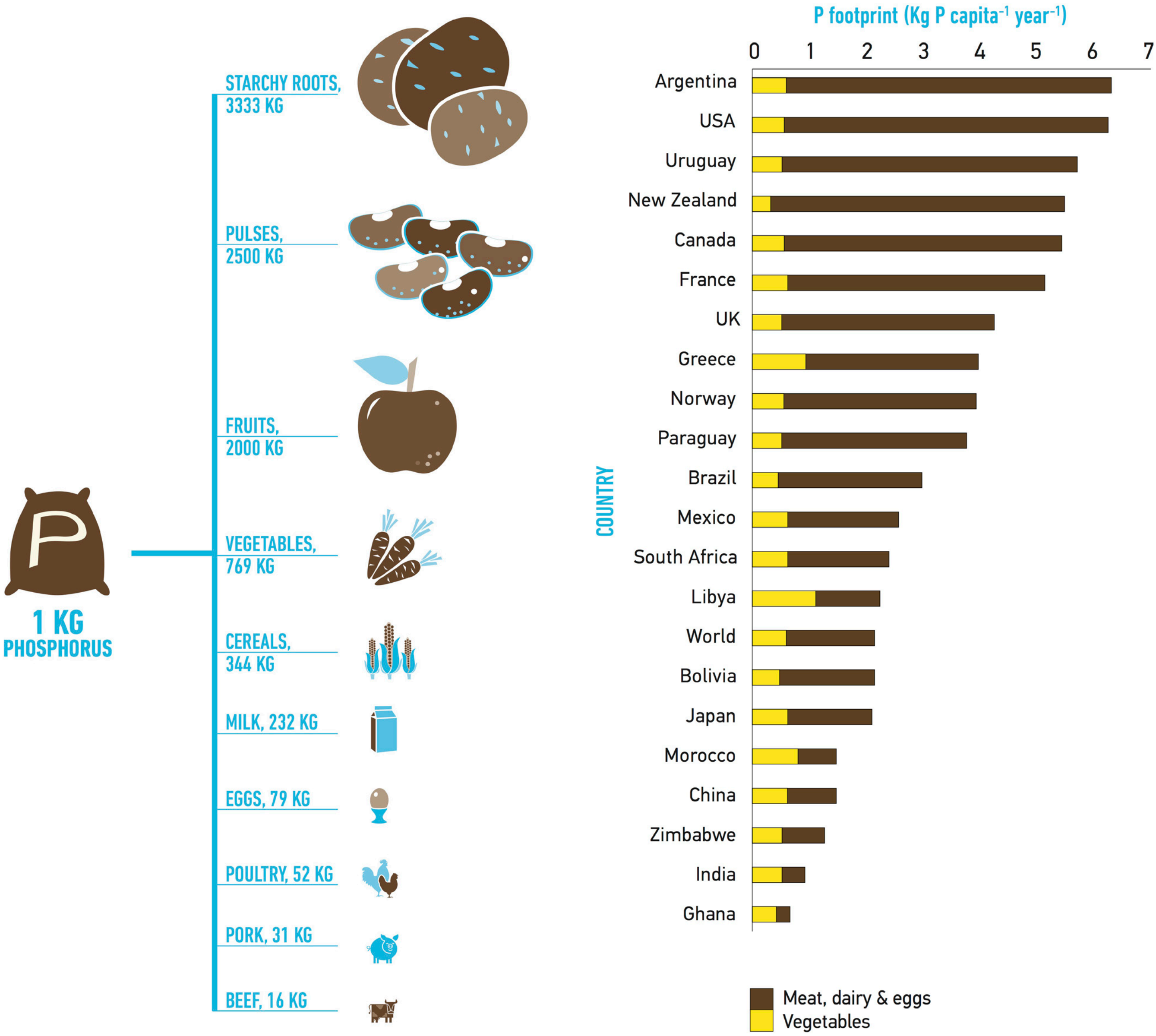

Figure 8.1 Dietary phosphorus (P) footprint associated with different food groups showing that animal products require more mineral fertiliser than plant crops (left side of figure), and the wide range of P footprint values across countries which are driven by meat consumption (right side of figure). The P footprint values for a country are expressed as the average amount of mineral P fertiliser required to produce food for one person for one year in that country given 'current' global agricultural practices. Reproduced with permission from HEADWAY (2013) with data based on Metson et al. (2012).

Challenge 8.2: Consumption of animal products is increasing

The average diet has seen a 38% rise in phosphorus footprint over the last 50 years; this can mostly be attributed to the increased consumption of animal products. A remarkable increase has occurred in China and Brazil; however, their footprints are still below the USA and other industrialised countries (e.g. average per capita protein intake in the EU is about 70% higher than recommended). Economic development correlates with increased consumption of animal products. Some populations still require a more diverse and calorie-rich diet.

Despite a significant increase in the consumption of animal products in countries such as Brazil and China over the last 20 years, levels of consumption are still well below those of North American and most other industrialised countries (Westhoek et al., 2015). The current average per capita protein intake in the European Union (EU) is about 70% higher than necessary according to the World Health Organization (WHO) recommendations (WHO, 2003).

It is important to note that there are still undernourished populations that require more calories and a more diverse diet (Alexandratos and Bruinsma, 2012). In many countries across the Global South, a lack of animal protein is responsible for stunting in children under five and their diets must be artificially supplemented (often with milk powder) (Kaimila et al 2019). Animal products can provide high-value protein and essential micronutrients (i.e. iron and zinc, and vitamin A). However, high consumption of animal products, in particular red meat, in some countries and social classes has led to significant health issues (Alexandratos and Bruinsma, 2012) and global environmental damage (Stenfield et al., 2006; Machovina et al., 2015).

Economic development correlates with increased consumption of animal products. As a generalisation, as incomes increase, people tend to eat more meat (Stamoulis et al., 2004; Keats and Wiggins, 2014). For example, as China and India, which together account for 37% of the global population, have gained wealth and become increasingly urbanised, there has been a shift from a cereal-based diet to more animal products (meat, eggs, dairy, fish) as well as fresh fruits and vegetables (Gandhi and Zhou, 2014). Per capita income increased by over 1,000% in China from the early 1980s to 2010, accompanied by rural (300%) and urban (166%) increases in meat consumption, though meat consumption was already higher in urban areas (Gandhi and Zhou, 2014). Today China is the largest consumer of meat in the world (Godfray et al., 2018).

Increases in mineral P fertiliser consumption were significantly correlated with increases in meat consumption in China between 1950 and 2010 (Bai et al., 2016). China's P footprint increased by 400% between 1970 and 2010 (Metson et al., 2012). If the highest population projections become a reality, and global diets continue to shift towards more meat and more calories, by 2050 demand for P fertilisers could increase by 141% from

2007 levels (Metson et al., 2012). Under current production systems, animal products are associated with higher eutrophication potential per serving (Poore and Nemecek, 2018; Willett et al., 2019). Without changes to production practices, increased consumption will lead to more P pollution.

High consumption of dietary P is linked to eating more processed foods that use P as an additive (León et al., 2013), which can cause serious health problems for people with kidney disease (González-Parra et al., 2012). Prevalence of chronic kidney disease (defined as a reduced glomerular filtration rate, increased urinary albumin excretion, or both) is estimated to be 8–16% worldwide (Jha et al., 2013). Kidney disease is an increasing public health issue; the prevalence of end-stage renal disease in the USA population has been predicted to increase by 48% during the next decade and will pose a significant health cost burden (Nickolas et al., 2004; Jha et al., 2013). The increasing use of P additives in food could be problematic for people who do not know they have kidney problems and is complicated by the fact that food is rarely labelled for total P content, making it hard to avoid (Uribarri and Calvo, 2017). Awareness of the disorder remains low in many communities and physicians (Jha et al., 2013).

Challenge 8.3: Food loss and waste is high across the globe

Globally, 23% of nutrients in fertilisers are used to produce products that are then lost in agricultural and food wastes. The loss at each stage, from farm to fork, differs among regions. Generally, waste is higher on a per-capita basis in industrialised countries, whilst in lower-income countries, losses are driven by insufficient infrastructure.

Globally, 23% of the nutrients in fertilisers (P, nitrogen, and potassium) are used in products that are lost in food loss and waste (Kummu et al., 2012). While large amounts of food waste in Asia can be attributed to the large population, food waste is much higher on a per-capita basis in industrialised countries than in low-income countries (Kummu et al., 2012). Consumers in Europe and North America waste 95-115 kg year^{-1} of food, in contrast to only 6-11 kg year^{-1} in Sub Saharan Africa and South/South-East Asia (Gustavsson et al., 2011).

The amount of food loss or waste at each stage, from farm to fork, also differs across regions. In general, lower-income countries have more food loss before products reach consumers because of food storage issues, while wealthier nations tend to waste more food in retail and home settings (Parfitt et al., 2010). Therefore, interventions to reduce food loss and waste across regions may differ significantly.

A study in the US suggested that diets that are rich in fresh fruits and vegetables are linked to higher amounts of waste because these foods can easily perish

(Conrad et al., 2018). However, because fruits and vegetables have a lower fertiliser footprint than many other foods, this diet can still contribute less to the onset of eutrophication (Poore and Nemecek, 2018). Cultural aspects of diet, in conjunction with religious rituals, are also known to contribute to the problem of food loss. During Ramadan in some Arabic countries, almost 30%-50% of the food prepared is wasted because of excessive meal preparation (Abiad and Meho, 2018). Similarly in India, nearly 8 Mt waste $year^{-1}$ is produced from temple, mosque, and church offerings (ASK-EHS, 2019) which usually include milk, fruits and sweets along with flowers and tree leaves. These sacred offerings are frequently thrown into rivers, ponds and lakes where they can cause significant harm to water ecosystems (ASK-EHS, 2019). To achieve the maximum environmental and resource benefits, the potential of food waste and diet change should be considered together in the context of complex cultural norms.

Challenge 8.4: Changing consumer food habits is difficult

Whilst a shift towards more phosphorus-sustainable diets and waste management practices is required, a complex network of conditions must be met for an individual to change behaviour, which varies by region, country, town, and even family. Raising awareness of negative environmental and/or health impacts (including phosphorus sustainability issues) of certain food choices alone is not enough to change behaviours. People's resources and capacity to change need to be considered as well.

People do not make decisions based on a single criterion, which complicates finding strategies that address the needs of all consumers (Vermeir and Verbeke, 2006). A complex network of conditions must be met for an individual to change behaviour; spanning from individual- and household-level factors to more slow-changing contextual factors, which all shape our decisions (Schill et al. 2019). However, pro-environmental behaviours are often significantly influenced by social norms (Nyborg et al. 2016; Farrow et al. 2017) as well as habits, rather than reasoning (Klöckner and Matthies, 2004; Klöckner, 2013).

This is particularly the case for decisions about what to buy, cook and eat. Such weekly (or even daily) decisions are influenced by habit strength or simply the wish to have a convenient meal that everyone around the table likes (Ouellette and Wood 1998; Klöckner and Matthies, 2004; Nilsen et al., 2012; Nyborg et al. 2016). Therefore, to achieve more P sustainable behaviours, we must address how social norms and habits are created, reinforced and continued (Klöckner and Matthies, 2004; Nyborg et al. 2016).

Education about environmental problems may increase an individual's level of concern, but such concern is generally not sufficient to change behaviour (Kollmuss and Agyeman, 2002; Bamberg, 2003; Barr, 2004). Bamberg (2003) showed that environmental concern accounted for less than 10% of the variance in environmental behaviour in the combined meta-analyses of Hines et al. (1987) (128 studies) and Eckes (1994) (17 studies). However, conscious (rather than habitual) decisions to reduce consumption of animal products based on other motivations, such as health or animal welfare (Fox and Ward, 2008; de Boer et al., 2017), are in most cases also directly beneficial for P management. Attitudes and behaviours related to waste management, and acceptance of recycled organic residues as a fertiliser can also be difficult to change (Chapters 4 and 6).

Challenge 8.5: Unsustainable pricing models may slow a transition to sustainable practices

There is a disconnect between what a consumer pays for food and the true 'costs' of food production. The costs involved in mitigating environmental degradation and biodiversity loss from phosphorus losses, and in developing more phosphorus sustainable agriculture systems, are not covered in the price of food products.

In the UK, the 'hidden costs' of food production (which can include environmental degradation, biodiversity loss, diet-related disease, farm support payments, regulation and research) would almost double the price of food under current agricultural management and food purchasing habits (Fitzpatrick et al., 2019). Over a third of unaccounted costs (£45 billion out of the £120 billion estimated for 2015) are related to natural capital degradation and the loss of biodiversity and ecosystem services. This includes water pollution and wasted food, which is in part related to P management and sustainability. In many cases, P pollution is not sufficiently managed, and society pays the price with declining ecosystem services (e.g. recreational services, drinking water, ecosystem quality (Pretty et al., 2003; Dodds et al., 2009) (see Chapter 5).

Food prices rarely, if ever, cover costs of practices that would increase resilience to fluctuations in the availability of mineral P (phosphate rock and/or fertilisers).

For example, in 2008 the price of food sky-rocketed (e.g. rice prices doubled within five months, up to US\$757 t^{-1}) due to multiple stressors including energy prices, drought, and market speculation (Baffes and Haniotis, 2010) (see Chapters 2 and 3). This was accompanied by an 800% increase in the price of P fertilisers (Cordell and White, 2014) (see Chapters 2 and 3). This spike disproportionately affected poorer farmers (whose farm budget is often mostly spent on fertilisers) and poorer consumers for whom food is a higher part of overall household budgets. After 2008, however, there was no large shift towards investment in alternative or more diversified sources of P, and so communities remain vulnerable to such shocks (Cordell et al., 2015).

Investment in P recycling could help reduce food security risks associated with imported mineral P fertilisers (see Chapters 2, 6 and 7). Few countries, regions, and cities have set goals to minimise P waste and increase recycling; where goals exist, successful large-scale implementation remains limited (Metson and Bennett, 2015; Kabbe, 2019). A lack of waste collection and processing technologies and infrastructure are major barriers to recycling and recovery (see Chapters 6 and 7). These issues, however, are often underpinned by a lack of public support, laws and regulations, and unfavourable cost-benefit analyses (Drechsel et al., 2010; Withers et al., 2015; Seufert et al., 2017; Metson et al., 2018; Öberg and Mason-Renton, 2018).

8.3 Solutions

Solution 8.1: Reduce consumption of animal products to recommended levels

Wider adoption of healthy diets with low to moderate amounts of meat and dairy (especially low in red meat) could radically reduce demand for mineral phosphorus fertilisers and thus phosphate rock mining. While some demographics could benefit from increased access to animal products, large gains can be made from reducing meat consumption in countries that already consume more than is recommended. The global adoption of a vegetarian diet would cut both fertiliser needs and eutrophication effects by 50%. Although this may be unrealistic, it indicates the major influence of diet change on the global phosphorus cycle.

Lowering global consumption of meat, dairy and eggs could radically reduce the use of mineral P fertilisers. Producing a vegetarian's diet requires 1.0 kg P $year^{-1}$ less than for a meat-eater (Elser and Bennett, 2011). If all humans adopted a strictly vegetarian diet, it would decrease mineral P fertiliser needs by at least 50% (Metson et al., 2012), which could reduce eutrophication by 49% (37-56%, based on the current 'best' or 'worst' practices for vegetable protein production (Poore and Nemecek, 2018).

Figure 8.2 A meat market in China. Meat consumtion has increased significantly in China and Brazil in the last 20 years; however, their phosphorus footprints and average per capita meat conusmption are still below the USA, the EU and many industrialised countries.

Diets with moderate dairy and meat consumption can also improve health and average life spans while reducing global warming impacts (Tilman and Clark, 2014). That said, it is not realistic, or necessarily desirable that the entire human population would adopt a vegetarian or plant-based diet. Average global meat consumption is estimated at ~43 kg capita^{-1} year^{-1}, with consumption in high-income countries roughly double this at ~85 kg capita^{-1} year^{-1} (data for 2013; FAOSTAT, 2018). Defining how much meat or dairy should be considered 'low' or 'moderate' consumption depends on individual circumstances (e.g. the size of person, their diet and activity levels) and regional social and environmental context. In a study exploring how to sustainably feed Nordic populations, Karlsson et al. (2017) suggested a sustainable diet should contain between 80 and 150 g of meat capita^{-1} week^{-1} (~30 kg meat capita^{-1} year^{-1}). The EAT-Lancet Commission recommends 0-196 g of red meat capita^{-1} week^{-1} (Willett et al. 2019). Resare Sahlin et al. (2020) argue that the research community needs to provide a more informed explanation to consumers of what is 'less' and what is 'better' when providing guidance on meat consumption.

It is also important to note that although beef generally requires much more mineral P fertiliser than other animal products (Metson et al. 2012), this does not mean that it is the only product that needs to be consumed in moderate amounts. In fact, under a scenario where only pastures and food waste are used to feed animals in Nordic countries, overall meat consumption would need to decrease but the proportion of beef consumption could increase slightly (Karlsson et al., 2017). Nevertheless, low animal product diets are an essential part of P sustainability, whilst decreasing food waste and supporting safe recycling and sustainable farming can provide opportunities for a diversified food production system.

Solution 8.2: Promote the wide adoption of healthy and regionally appropriate diets

The wide adoption of healthy diets rich in plant-based foods and sustainable aquaculture produce is compatible with sustainable phosphorus management. Sustained communication, along with global and regional structural changes to food systems can help consumers adopt diets that are both good for them and the environment.

Low to moderate consumption of meat, dairy, and egg consumption is in line with guidelines for healthy diets (Westhoek et al., 2015; Willett et al., 2019). High levels of processed meat consumption are associated with higher rates of colorectal cancer (Godfray et al., 2018), while low-animal, vegetarian and pescatarian (blue-food) diets have been associated with a lower incidence of type 2 diabetes, cancer, and death related to cardiovascular issues (Tilman and Clark, 2014).

Accompanied by increased yields from judicious P application and recycling, low animal product consumption and low food waste globally could reduce environmental degradation and feed more people adequately and sustainably. Converting lands that currently produce livestock feed and biofuels to crops for human consumption could produce food for an additional 4 billion people (Cassidy et al., 2013). In low-income countries, increasing recycling could help close yield gaps and contribute to food security (Dumas et al., 2011; Akram et al., 2018).

Using land and feed resources that do not compete with calories produced for direct human consumption could supply 15 to 46% of protein requirements per person per year, globally (van Zanten et al., 2018). To contribute to food system sustainability, however, countries that consume large amounts of animal products would have to decrease their current levels of consumption so that countries, where consumption is low (e.g. in parts of Asia and Africa), could moderately increase their consumption (van Zanten et al., 2018). Among populations that consume little protein such as in Malawi, crops like maize are culturally important but are not adapted to the local environment. Maize requires significant P inputs (e.g. 21 kg P ha^{-1}) and offers little nutrition. Encouraging the cultivation and consumption of more nutritious and well-adapted plants like cassava or sorghum (which require no additional P) could have an important impact on health and P use (Government of Malawi, 2012).

In summary, a globally sustainable and healthy diet would consist of vegetables, fruits, whole grains and vegetable proteins, with small amounts of animal products, blue food, and processed foods (Willett et al., 2019). To be environmentally sustainable, these foods should be produced in a way that minimises food waste and maximises nutrient recycling, including P (Willett et al., 2019). The specific composition of a healthy diet, the production practices that enable it, and who bears responsibility for change needs to be regionally specific. However, in all cases food production should embrace principles of equity and acknowledge differences in power and capacity to influence change (Hirvonen et al., 2020; Moberg et al., 2020; Mui et al., 2021).

Solution 8.3: Reduce food loss throughout food production, retail, and consumption sectors

Most food loss in low-income countries occurs before products reach consumers; meanwhile wealthier nations waste more food in retail and at home. Efficient strategies to reduce waste will target the most wasteful, with support underpinned by evidence that quantifies the benefits of change.

Food waste could be halved if every country had the lowest level of loss and waste currently achievable at each step of food production (Kummu et al., 2012). Eliminating consumer food waste alone for wheat, rice, vegetables and meat in the USA, India, and China could free up enough calories to feed over 413 million people year^{-1} (West et al., 2014), and could simultaneously reduce P application to fields and losses to waterways. Avoidable food waste in the USA in 2009 had a retail value of almost US$198 billion; 63% of that value was due to losses at the consumer level (Venkat, 2012). On the other hand, with limited energy for refrigeration, poor transportation networks, and prohibitive trade barriers, much of the seasonal crops in less economically developed tropical countries goes to waste: innovation is required to help producers reach markets before the next glut of mangos or avocados is left to rot, despite having eager buyers in the North (Affognon, 2015).

Eliminating consumer food waste would deliver economic benefits. For example, if EU households reduced food waste, it could yield annual household savings of €123 per capita (40% reduction by 2020), 7% of the average annual EU household budget spent on food (Rutten et al., 2013). Across the EU, this amounts to an annual saving of €75.5 billion. Reducing food waste by 40% in households and 60% in retail in the EU would free up 28,940 km^2 of agricultural land, equivalent to the land area of Belgium (Rutten et al., 2013). These savings could be used to purchase more expensive foods produced with good P management practices (including safe and effective recycling) from farms that may not be currently economical.

However, not all losses are easily avoidable, for example, the inedible parts of crops and animals, although recycling options exist for both (see Chapters 6 and 7). In addition to unavoidable losses before food is consumed, we should also consider post-consumption losses of P from animal and human excreta. All organic waste sources can theoretically be recycled. Food waste and human excreta will continue to accumulate in cities as populations urbanise and grow. Supporting behaviours and technologies that allow for P recycling will thus be essential for sustainable agriculture and limiting eutrophication (Willett et al., 2019; van Puijenbroek et al., 2019). Recycling P in the right amounts to achieve maximum yields is potentially one of the greatest opportunities to decrease mineral P fertiliser application rates (Springmann et al., 2018), but this requires large changes to current food production systems, as well as public support (see Chapters 6 and 7).

Solution 8.4: Make being 'sustainable' easy and rewarding for consumers

It should be easy and affordable for everyone to make healthy diet choices, decrease food waste, and support the safe use of recycled phosphorus from organic wastes (e.g. food waste and excreta) in food production. Incentive structures (including 'health nudges' and 'choice editing') embedded in food systems should be transformed to make phosphorus-sustainable food choices the 'default' option.

To reduce the P requirements of consumers', it is necessary to identify which behaviours contribute to their P footprint, as well as the factors that shape those decisions. Then, barriers to behaviours that promote sustainable P management can be removed and opportunities harnessed, while healthy dietary requirements can still be met, and safe waste handling achieved.

Common to many models of environmental behaviour is the understanding that interventions must tackle the conscious and unconscious parts of decision making (Baranowski et al., 2003; Klöckner, 2013; Marteau, 2017; Godfray et al., 2018). Education campaigns and labelling (Leach et al., 2016) can be part of these interventions, but are not be sufficient on their own (Gordon et al., 2017; Poore and Nemecek, 2018, Röös et al., 2021). Education about the detrimental effects of high meat consumption on the environment (or other issues such as animal welfare) may increase the intention to reduce these behaviours but rarely results in actual behavioural change (Bianchi et al., 2018a). Interestingly, eco-labels are shown to work better in countries where there is more state control (Sønderskov and Daugbjerg, 2011). To make education more effective, tracking behaviour over time can help (Bianchi et al., 2018a), but sustainable products also need to be available (Bianchi et al., 2018b) and affordable (Widener 2018). Similarly, an increase in the supply of sustainable and healthy alternatives must be supported with education to underpin demand (Allcott et al., 2018). Regarding food waste, some hopeful results stemming from a longitudinal field experiment in Sweden, found a significant increase in recycled food waste following a household-targeting information campaign about food waste recycling (based on insights from nudging and community-based social marketing) and could inform similar pro-environmental behaviour interventions elsewhere (Linder et al. 2018).

More important, perhaps, is the perception that sustainable products are available, affordable, and part of the social norm (Vermeir and Verbeke, 2006; Nyborg et al. 2016). Explanations for differences in what people buy to eat across countries and regions are typically a combination of available incomes, food prices but also nutritional content and norms (Dubois et al. 2014; Nyborg et al. 2016). For some people, it is also important to feel their actions are desirable (a reward) while also making a difference (reflection) (de Boer et al., 2018; Vermeir and Verbeke, 2006). Similarly, for farmers to participate in sustainable P management schemes, they must feel that their actions are meaningful, and perhaps most importantly, that such actions match their values and those of their community (Chapman et al., 2019).

Donner (2017) suggests that sustained communication across a variety of platforms and audience-specific frames may be the best way for governments, businesses, and other organisations (e.g. schools, hospitals) to increase the relevance of environmental science to policy and the public. Successful examples of dietary change include awareness raising and education campaigns in South Korea, which focused on increasing the consumption of low-fat high-vegetable meals (Keats and Wiggins, 2014). This approach could be successful in other countries if policies supported pricing mechanisms that benefited plant-based agriculture, especially legumes, fruits and vegetables, rather than livestock and grains, as has been the case historically (Clonan et al., 2015). Interventions can also involve making more P-sustainable 'default options'. Decreasing the size of meat portions and increasing vegetable sizes in restaurants and cafeterias have successfully increased P sustainability without affecting customer satisfaction (Reinders et al., 2017; Wynes et al., 2018; Bianchi et al., 2018a). Systematic changes that make sustainable dietary choices easy, desirable, and affordable are more likely to produce lasting change.

Solution 8.5: Develop policies that encourage and support consumers to lead sustainable phosphorus lifestyles

Developing economic and regulatory policies that encourage and support high recycling rates, low animal product consumption and low waste production will be necessary for sustainable change. This may involve setting high goals for organic waste recycling, direct taxes on animal products, or decreasing subsidies that affect the price of meat.

To see the magnitude of change needed, the incentive structures embedded in food systems must be transformed (Oliver et al., 2018) (see Chapter 3). In industrialised food systems, power has become increasingly concentrated in a small number of large companies (Folke et al., 2019; Gordon et al., 2017; Godfray et al., 2018), meaning that directed interventions on a few key actors could have large and lasting effects throughout the system. Local cultural and resource contexts also need to be considered (Bere and Brug, 2009). Interventions that do not centre on individual choices to reduce meat consumption or waste, but rather the system that shapes those decisions, appear to be more successful (de Boer and Aiking, 2018). This should include policies that affect powerful actors, which can have cascading effects on large numbers of consumers and producers (Clapp 2018).

Governments could set high goals for organic waste recycling, directly tax animal products, implement a carbon tax that indirectly affects animal products or decrease subsidies that affect the price of intensively produced animal protein. All of these option could change incentive structures to decrease meat consumption and increase the recycling of P and other nutrients. Policies that target food system intermediaries, such as processors, distributors and retailers, will be essential since they have more direct contact with both farmers and consumers (Canning et al., 2016). Attention must also be given to the development and enforcement of policies that affect food producers in global food supply chains, most notably those that are using recycled P sources. For example, Kenyan growers who are allowed to use excreta in agriculture (within national frameworks) are prohibited from exporting their products to the EU (Moya et al, 2019).

Municipalities, certification organisations, and businesses can adopt policies and infrastructure that support systemic changes to food and waste sectors. For example, in Canada and the EU, cities that invested in centralised infrastructure for separated organic waste collection and economic disincentives for landfilling have diverted high amounts of organic waste from landfills, thereby recycling P to agricultural production (Treadwell et al. 2018). On the other hand, regulations can inhibit the recycling of P, for example banning human excreta from organic production (Seufert et al., 2017) or banning the reuse of animal bones at the EU level. Government agencies can also incentivise individual behaviours. In the USA, for example, providing participants in food assistance programmes with a voucher for fresh fruit and vegetables increased purchases, and reduced the gap between actual and recommended consumption of fruit and vegetables by 20%, compared with restricting purchases of unhealthy products or no intervention (Olsho et al., 2016). These interventions do not take away options but instead create a consumer environment where it is easy to make a sustainable choice, whilst benefiting business.

Fortunately, the changes in the food system required for P sustainability also align with many of the changes that are required to meet other societal goals. As such, interventions are likely to have multiple benefits, including both human (see Challenge 8.2 and Solution 8.2) and environmental health. For instance, producing animal protein requires more resources and causes more environmental harm than plant-based protein (Clune et al., 2017; Hilborn et al., 2017; Poore and Nemecek, 2018), not just associated with phosphorus. A 100% plant-based diet could reduce land use by 76%, would halve greenhouse gas emissions, acidification, and eutrophication, and would reduce freshwater withdrawals associated with the food system by 19% (Poore and Nemecek, 2018). Even a 50% cut in livestock production could make a huge impact. In the EU, for example, it would mean a 40% reduction in greenhouse gas emissions and reactive nitrogen use in the agricultural sector and a 75% reduction in soybean imports (Westhoek et al., 2014).

The challenges identified above must be tackled across different scales because patterns of food consumption and waste production stem from decisions and actions of policymakers, institutions (e.g. schools, hospitals), businesses (e.g. food processors, grocery stores and restaurants), households and individuals. They occur in the context of a diversity of local to global policies, infrastructure, and cultures. Different stakeholders need to participate collectively in making changes for better P management (Table 8.1).

Although not all specific local interventions will be win-wins without careful planning, the three major changes proposed here are in line with the changes required globally for a better food system (Figure 8.2).

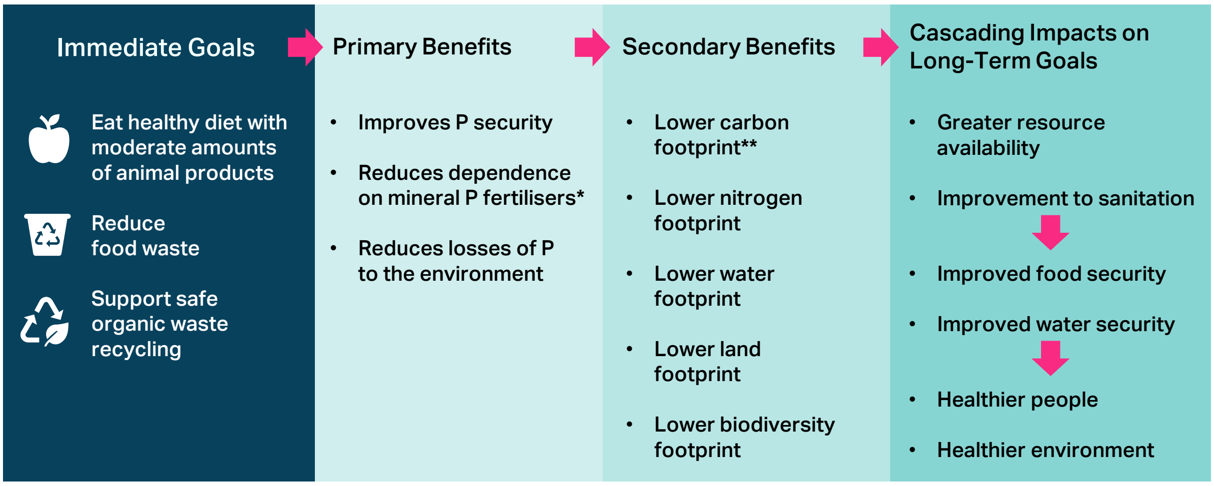

Figure 8.3 Benefits of the goals and interventions recommended by this Chapter (*we highlight fertiliser use is still encouraged where appropriate and **lowering the carbon footprint of dietary consumption can contribute to a reduction in climate change impacts).

Table 8.1 Examples of actions that different actors can take to enhance phosphorus (P) sustainability/security, in support of the three goals (left side of the table) related to food consumption.

		Actors			
		National, regional & municipal policymakers/regulators	**Certification bodies and stand-ards organisation**	**Food processors, distributors, and retailers (including restaurants, cafeterias, and catering)**	**Citizens/consumers**
Goals	**Eat healthy diets with moderate amounts of animal products**	Tax on animal products. Finance education and research on communicating healthy low impact diets. Eliminate subsidies for food produced in non-environmental ways. Create coupons for food items that have low environmental impacts.	Set food guides that reflect the latest research.	Increase the production and availability of vegetarian and pescatarian options. Offer default vegetarian meals. Decrease animal product portion size.	Buy fewer (and better) animal products. Eat more healthy plant-based whole foods. Create advocacy groups and vote for people and policies supporting access to healthy food for all.
	Reduce food waste	Set waste reduction goals. Finance education campaigns on waste reduction. Support local food systems that bring consumers and producers closer together.	Enforce penalties on large waste producers. Implement tools for tracking products and their environmental impacts.	Invest in proper (cold) storage facilities. Buy in the correct quantity. Allow the sale and use of 'imperfect' but safe agricultural produce.	Do not buy more than you can eat or freeze. Buy from shops and restaurants that have a low/zero waste policy.
	Support safe organic waste recycling	Set recycling targets and laws. Invest in source separation and waste collection infrastructure. Finance research in recycled products development. Finance education campaigns on the importance of recycling.	Create labels that indicate good nutrient management (including recycling). Require the use of recycled P in ecologically certified products. Develop and enforce certification standards for recycled P fertiliser.	Eliminate packaging that makes recycling difficult. Set purchasing policies that require good nutrient management (including recycling). Enforce separate organic waste collection in buildings.	Create advocacy groups and vote for people and policies supporting P recycling. Live in, or advocate for, buildings and cities that invest in source separation of waste (e.g. excreta, food, and garden waste). Buy products that are certified for good nutrient management.

This means that communities can, and should, harness the fact that goals other than P may be stronger motivations for change. For example, reducing meat consumption in Sweden by 50% and replacing it with Swedish-produced legumes would allow citizens to meet healthy diet recommendations (SDG 2), decrease greenhouse gas emissions (SDG 13), and free up 21,500 ha of land to meet other national goals including biofuel production (SDG 14) or nature conservation (SDG 15) (Röös et al., 2018). With judicious planning, better animal welfare (which currently does motivate plant-based and low-meat diets) could also support P sustainability. Less demand for meat, eggs, and dairy could allow a transition away from highly specialised, concentrated animal production systems towards integrated animal and crop production systems (Robbins et al., 2016). Shorter transport distances between areas where animals are born, raised, and slaughtered are beneficial for animal welfare (Schwartzkopf-Genswein et al., 2012), as animals can spend more time outside. This could improve P management, as manure transport is often a barrier to recycling (Westerman and Bicudo, 2005; Keplinger and Hauck, 2006; Nicholson et al., 2012).

Improving P sustainability by reducing animal product consumption, reducing food and agricultural waste, and increasing organic-waste recycling will help deliver multiple United Nations Sustainable Development Goals (SDGs). For instance, achieving universal sanitation (SDG 6) with nutrient recovery and energy recovery technology could meet approximately 9% of P fertiliser demands (SDG 2) and 1% of household energy needs (SDG 13), with larger gains in areas with current low access to sanitation infrastructure (Trimmer et al., 2017). Harnessing such potential not only requires large investments, but as put forth in this Chapter, coordinated efforts of governments, businesses, and other organisations allied with citizens who accept and support these efforts in their purchasing and voting decisions.

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