Abstract
Countries in Southeast Asia have high and stagnant rates of undernutrition. While about 26% of children under 5 years of age are stunted (i.e. have an age inappropriate height), the region also shows continuous growth in overweight rates. It is not uncommon to find undernutrition coexisting with overweight, obesity or diet-related non-communicable diseases within the same country or even within the same household, particularly in urban settings.

Food systems are an important driver for both trends. On the one hand, there is a rapid increase in the consumption of animal-based food items and highly processed food, overconsumption of which can damage health. On the other hand, consumers are becoming more aware about health and food safety resulting in a rising demand for quality and nutritious food, particularly in urban areas. Responding to that demand and facilitated by the development of modern retail, some countries in Southeast Asia are witnessing a rapid uptake of vegetable food system innovations. Specific improvements are found in the areas of quality seed, protected cultivation, smart decision-support tools and precision application of inputs. Cold chain development, food processing technology and improved logistical and financial arrangements are being adopted to reduce post-harvest losses and add value in the supply chain. However, not all innovations are health-promoting, as the region also experiences an increase in pesticide misuse.

We adopt a food systems framework, looking at consumer demand behavior, food supply chains, and mediating factors in the food environment to illustrate and discuss innovations and interventions that can lead to greater vegetable production and consumption and healthier diets in Southeast Asia.

On the demand side, we review options to influence consumer behavior and enhance the acceptability, desirability and affordability of vegetables. This includes information campaigns, regulating advertisements for unhealthy foods and financial incentives. Next, we zoom into supply chains and review options to increase the availability and affordability of vegetables from seed to market and across growth conditions, i.e. from open field to low-cost protected cultivation to greenhouses and ‘plant factories’. We discuss food safety concerns and options to enhance the desirability and acceptability of vegetables through the introduction of traceability and certification systems. Options to change the settings in which people access and eat food (e.g. in wet markets, supermarkets, schools, restaurants) are then reviewed to further increase the accessibility and affordability of vegetables.

Addressing supply-side opportunities and demand-side motives separately may not result in lasting positive outcomes. Food systems change will require a thorough understanding of dietary gaps and consumer behavior, food environments, food supply chains and external drivers, such as climate change, urbanization, youth unemployment and migration. There is an urgent need to pilot food systems change in Southeast Asia, linking urban consumers with peri-urban and rural vegetable farmers, and aiming to achieve favorable and lasting dietary, economic and environmental outcomes at scale.

Introduction
Approximately 10% of Southeast Asia’s 662 million people are undernourished and about 26% of children under 5 years of age are stunted, compared to 22% world-wide. The highest level of stunting prevalence is 50% in Timor-Leste followed by Lao PDR, Indonesia, Philippines and Cambodia with more than 30% (Global Nutrition Report 2018). Meanwhile, changes in lifestyles and standards of living due to rapid urbanization are steering Southeast Asia’s population towards consuming more processed food,
containing more sugars, saturated fats and salts. This ‘nutrition transition’ is leading to excessive weight gains across populations and in particular in urban areas. As a result, malnutrition in all of its forms in the region: undernutrition, micro-nutrient deficiencies and over-nutrition and obesity, is now present in the region, within a same country, sometimes even among members of the same family.

Stunting in Southeast Asia is strongly correlated with household income, with 37% of children stunted in low-income families and only 12% in high-income families. Overweight problems of children under 5 follows the opposite trend: with 8% of children in high-income families, compared to 3% in low-income families (Global Nutrition Report, 2018). Children and adolescents between 5 and 19 years old in the region suffer from either underweight (36% of boys and 31% of girls) or overweight and obesity (24% of boys and 18% of girls).

Diabetes affects 7% of men and women, whilst overweight and obesity affects 38% of women and 30% of men. About 28% of Southeast Asia’s women of reproductive age suffers from anemia, reaching 46% in Cambodia and Myanmar. Anemia also affects between roughly a third and three-quarters of children under two years of age, reaching 75% in Cambodia (Global Nutrition Report, 2018).

People that have been under-nourished in their childhood run a greater risk of becoming overweight or obese and/or diabetic in their adult life (Martins et al., 2011). World-wide, low and middle-income countries (LMICs) are moving into a new area of such diet-related diseases and are often ill-prepared for this. As a result, problems dealing with diet-related non-communicable diseases such as cardiovascular diseases and diabetes are more pronounced in LMICs as compared to high-income countries (Afshin et al., 2019).

Along with disease, poor diets are key drivers of malnutrition. Low intake of micronutrient-rich foods, high intake of compounds that inhibit absorption of key nutrients such as iron and zinc, and monotonous diets based largely on staple grains such as rice are considered prime contributors to micronutrient deficiencies in Southeast Asia. Micronutrient deficiencies of particular concern include iron, zinc, vitamin A, iodine, and calcium deficiencies. Vitamin A deficiency is of greatest concern in Myanmar and Laos (where 30% of preschool-age children are estimated to be deficient).

Table 1 presents data related to a hidden hunger index (HHI) for countries in Southeast Asia for 2001 and 2011. Iron-deficiency anemia, vitamin A deficiency, and stunting (used as a proxy indicator for zinc deficiency) are equally weighted in the calculation of the HHI. Improvements in HHI were mostly due to reductions in zinc and vitamin A deficiency, while iron-deficiency anemia persisted and even increased.

**Table 1: Hidden hunger index (HHI) of selected Southeast Asian countries (2001-2011)**

<table>
<thead>
<tr>
<th>Country</th>
<th>2001</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambodia</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Indonesia</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>Malaysia</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Myanmar</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Philippines</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td>Thailand</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Timor-Leste</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>Vietnam</td>
<td>29</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Ruel-Bergeron et al., 2015

Increased consumption of healthy, nutrient-dense foods, such as fruits, vegetables, legumes, nuts and reduced intake of unhealthy and processed foods will improve nutrition and contribute to environmental
sustainability if they are produced in a safe manner, with minimum reliance on chemical pesticides. ‘Global’ vegetables (e.g., tomato, peppers, cucurbits, brassicas, alliums, legumes) and ‘traditional’ vegetables (e.g., bitter gourd, kangkong, okra, nightshade, amaranth) are efficient sources of important micronutrients such as β-carotene (precursor of Vitamin A), folate, iron, calcium, zinc, dietary fiber and functional phytochemicals, both per unit cost of production and per unit of land area.

The World Health Organization (WHO) recommends consuming 200g of vegetables and 200 g of fruits a day. Consuming more fruits and vegetables has been credited to reduce the risk of many diseases, including heart disease, high blood pressure, and type II diabetes through provision of essential vitamins, minerals, fibers and anti-oxidants. Accurate data on consumption of fruits and vegetables are hard to get by. Based on food balance sheets sourced from FAO (2017), Schreinemachers et al. (2018) showed that fruit and vegetable consumption is well below the recommended 400g per day in LMICs across continents. It should be noted however, that food availability based on food balance sheets (production + import - export) is not the same as consumption and is likely to lead to an overestimation of actual vegetable consumption.

Peltzer and Pengpid (2012) reported on fruits and vegetable consumption among in-school adolescents in five countries in Southeast Asia (aged 13-15 years). Overall 76% of these children had inadequate fruit and vegetable consumption (i.e. less than 5 servings per day). About half of the children reported consuming fruits less than once per day and 14% indicated consuming vegetables less than once per day. Whilst malnutrition is already affecting billions of people, the world’s population is predicted to grow further, reaching 10 billion by 2050. The urban population in Asia alone will rise by 1 billion. As a result, 64% of the Asian population will live in cities by 2050 (UN, 2014). Urbanization is changing diets in at least three ways (Tschorley, 2017): food is becoming more purchased rather than home grown, food is becoming more perishable with increasing consumption of meat, dairy and fresh produce (fruits and vegetables) and food is becoming more processed. This transition is happening rapidly in Asia. An ongoing project of the World Vegetable Center in Nepal studied the transition from home-grown to purchased foods in Nepal after the 2015 devastating earthquake. It shows that reconstruction efforts tripled local wages and increased the number of shops selling snacks. The study reports substantial changes in food behavior including increased consumption of rice, meat, and snack foods. The increased availability of cash was the key direct driver of food choice. Food choices were conditioned by taste preferences for meat and snack food and convenience, and limited nutrition knowledge.

Urbanization is leading on the one hand to growing problems of non-communicable diseases because of poor-quality diets, but there is also a rising demand for healthy and nutritious food, such as vegetables, in small and big cities alike. Meanwhile, the great majority of very poor and undernourished people are living in rural areas or in slum areas within or near city boundaries. There is a clear opportunity to connect cities and smallholder farmers, and tap into the rising urban demand for safe vegetables, whilst reducing poverty on-farm in the rural and peri-urban areas. This could potentially lead to a triple-win of favorable dietary, economic and environmental outcomes: greater diversity of safe and affordable nutritious food, employment and income for actors along the supply chain, from farm to market, and safe and environmentally friendly production practices.

The High Level Panel of Experts on Food Security and Nutrition of the United Nations recently published a food systems framework (HLPE, 2017) that will be adopted in this paper to highlight opportunities for food systems change with a focus on the vegetable sector. A food system as defined by HLPE (2017) ‘gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes’. HLPE (2017) describes food systems as fundamentally made up of three elements: food supply chains, food environments and consumer behavior. These core elements are influenced by five categories of drivers of food system change, i.e.: biophysical and environmental drivers; innovation, technology and
infrastructure drivers; political and economic drivers; socio-cultural drivers; and demographic drivers. The interaction between these drivers, the core elements and food systems interventions targeting one or more of the three core elements shape the diets people choose, with particular health, socio-economic and environmental outcomes (Figure 1).

Figure 1: Food systems framework used in this paper (simplified version after HLPE, 2017).

The objective of this paper is to: (i) discuss innovations and interventions to connect urban consumers with vegetable farming in rural and peri-urban areas in Southeast Asia using the HLPE framework; and (ii) discuss the importance of addressing simultaneously the supply and demand for safe vegetables to achieve positive and lasting nutrition and health, economic and environmental outcomes.

We start with a review of innovations and interventions across the entire food systems spectrum, from consumer food choices behavior, to food environments, to supply systems. We then discuss the challenge of addressing supply and demand motives for healthier diets simultaneously. The paper concludes with recommendations for policy and decision-makers to further plan and invest in innovations, research and interventions to improve food safety and nutrition security using a food systems approach.

Food system innovations and interventions stimulating greater dietary quality

Consumers’ diets are shaped by personal preferences and behavior, their food environment (i.e. where they access food) and the food supply system feeding into the food environment (i.e. what is grown, processed and ultimately arrives in the food environment). Nudging consumers towards purchasing and eating more vegetables requires these to be available, accessible, affordable and acceptable - in particular in terms of food safety. Food systems innovations and interventions stimulating greater dietary quality are reviewed below, following the HLPE (2017) framework (see Figure 1).

Consumer behavior

HLPE (2017) defines consumer food behavior as ‘choices made by consumers, at household or individual levels on what food to acquire, store, prepare and eat, and on the allocation of food within the household’. Decisions are based on what consumers can access and afford in the food environment (see below), on personal taste and preferences, as well as on income levels and cultural norms. Innovations need to nudge consumers towards greater acceptance of healthier food. To influence urban consumer behavior, it will be critical to have a clear view on current food choice trends among urban consumers with different
purchasing powers and understand barriers to increased consumption of healthier food, such as vegetables. Based on a thorough analysis of urban consumer behavior, different interventions can be proposed to make healthier food more acceptable, accessible and affordable:

Information campaigns
Targeted information campaigns and nutrition counseling may help nudge urban consumers towards healthier food choices. Social media may become an important pathway to influence the choice for healthier food options, e.g. through the use of smart phones to guide purchasing healthy food (Gilliland et al., 2015). Food festivals or cooking shows on TV are also effective manners to nudge large numbers of people towards healthier food options. Consumers often simply do not know enough about vegetable diversity and their nutritional benefits. With 75% of the food being consumed coming from 12 crops only, there is a huge opportunity to increase knowledge, exposure, and interest for many more nutritious crops, through targeted information and education media campaigns.

One way to nudge children towards healthier diets is to use more attractive packaging and labeling or associating eating vegetables with super powers (such as done by ‘Popeye the Sailor Man’). Moving consumers towards accepting vegetables and fruits that do not have a ‘perfect appearance’ may help in cutting back on food waste, see e.g. www.endfoodwaste.org.

Financial incentives
Vegetables may be out of reach for certain urban consumers because of their high price. Financial incentives towards healthier food choices may include subsidies on healthy food and/or taxes on unhealthy food items. Hidrobo et al. (2014) showed that vouchers were the most effective means to stimulate vegetable consumption in Ecuador, comparing food, cash or voucher options among low-income populations. Bartlett et al. (2014) reported similar positive results in the United States of America (USA). Some countries are even considering health insurance rebates. Results obtained by Lee et al. (2019) indicate that that may indeed be justified. They estimated the health and economic impact of two policy scenarios in the USA: (i) a 30% subsidy on fruit and vegetables and (ii) a 30% subsidy on a healthy food basket, including fruit and vegetables. Both scenarios were highly effective in preventing cardiovascular disease events and related deaths and would reduce health care costs by US$ 40 to 100 billion.

Rising incomes does not automatically result in greater consumption of healthy food. Vegetable consumption may even decline with rising average income (Global Panel, 2016). This may be due to lack of awareness or simply because of the abundance of advertisement in Asia for unhealthy food choices. Vegetables may also not be a regular component of diets because of taste, changing lifestyles, convenience, food habits, and food safety concerns (Schreinemachers et al., 2018).

Collective consumer action
‘Food deserts’ are places in cities where healthy foods are simply unavailable or unaffordable. Urban consumers can be nudged towards working together to tackle such ‘food deserts’ in their cities and stimulate an increased offer of healthy food choices in their neighborhood – this may work for both low-income consumers and high-income consumers.

Regulatory interventions
Banning advertisement for unhealthy food is an example of a hard policy measure that may have substantial benefits. For example, the Chilean government, facing increasing rates of obesity, has decided to implement marketing restrictions, mandatory packaging redesigns and labeling rules to transform consumer behavior. Banning unhealthy food options inside or near schools can also be considered. Another example is the city of London, where advertising for unhealthy food inside the metro is now
prohibited. Recognizing the impact on health, these restrictions have started with the advertisements for smoking, and are now slowly being applied to unhealthy food items.

**Food environments**

People access, purchase and consume food in various food environments. For purchased food this may include informal wet markets, supermarkets, food stalls, food carts, restaurants, hospitals, and canteens. Food environments can facilitate and constrain access to food (Lartey et al., 2016). They determine what type of food consumers can access at a given time, at what price and with what degree of convenience. Many urban food environments in Asian LMICs provide very little options for consumers to purchase healthy food such as fruit and vegetables. Highly processed, fast food and snacks are often much more available. Such food environments are often referred to as ‘food deserts’ as explained above. Interventions in food environments will need to be based on a thorough understanding of the food environment for low- and high-income urban consumers alike and focus on making healthier food more acceptable, accessible and affordable.

**Markets**

Most urban consumers in Southeast Asia access their vegetables from informal markets. Informal markets are often not well equipped to deal with perishable foods, such as vegetables. Cold storage facilities are often lacking which translates into substantial losses at the end of the supply chain. This is in particular true for leafy vegetables that are not sold at the end of the day as they cannot easily be kept overnight without proper storage conditions.

**Food safety**

Most consumers pay attention to the appearance of fresh produce offered in markets and this means that farmers resort to excessive use of pesticides to limit economic risks. As a result, food safety is a particular concern for vegetable consumers in Southeast Asia. Hai et al. (2013) showed that Asian consumers are willing to pay more for safely produced vegetables. A survey with 185 consumers purchasing vegetables from four large supermarkets in Vietnam showed a price premium of 70% for organically grown vegetables. At a workshop on the ‘Use of Science throughout the food chain for safe foods’ held for Codex member countries in Asia and the Pacific from 18-20 November 2010 in Bali, Indonesia, countries identified pesticide residues as the highest risk factor in food safety, followed by heavy metals, mycotoxins, and pathogenic microorganisms. Kuo et al. (2019) conducted a literature survey on food safety concerns related to vegetables in LMICs in South and Southeast Asia. A total of 160 publications published between 2004 and 2019 were analyzed in detail. A total of 42 out of the 160 articles were related to pesticide residues in marketed vegetables. About 80% reported pesticides residues that were beyond maximum residue limits. Some classify as highly to extremely hazardous following WHO standards. A total of 24 articles in the literature review by Kuo et al. (2019) was dedicated to contamination by pathogenic microorganisms. Contamination may occur during production and after harvest. The most common food borne pathogens on vegetables in Southeast and South Asia found in supermarkets and informal markets include *Salmonella* spp., thermo-tolerant *Campylobacter, Escherichia coli*, *Shigella* spp. and *Listeria* monocytogenes. A further 47 articles were related to heavy metal contamination in vegetables, in particular settings, e.g. production areas near heavy industry or busy roads. These food safety studies are hard to compare because of differences in methodology and sample bias but the results, reported below, raise concern about food safety in the vegetable sector in Asia’s LMICs.

**School meal programs**
Mid-day school meals are an important intervention to improve the nutritional status of school children. Unfortunately, such meals are often made of non-perishable foods, and do not contain fresh fruit and vegetables. Home-grown school feeding programs connect school meal provision to local agricultural production and these offer opportunities to get vegetables included in school meals.

**Home gardens**
Growing vegetables near the homestead is an effective way to increase affordability and availability of vegetables. Programs to promote such home or kitchen gardens among women in LMICs in rural settings in Africa and Asia have shown to be very effective, in particular if training in growing vegetables is combined with education on nutrition knowledge and best sanitation and hygiene practices (World Vegetable Center, 2016). Targeting women is particular effective as they often decide on food choices at the household level. Baliki et al. (2019) investigated the impact of a home garden program in rural Bangladesh on vegetable production and consumption three years after the end of the intervention. The average impact on vegetable production per household was 43 kg/year (+49% over baseline levels; p<0.01), contributing to a significant supply of iron, zinc, folate and vitamin A to the diets of family household members and women empowerment. Proven household garden technologies in rural areas may be adapted to urban slum settings, e.g., using sack gardens, low-cost vertical gardens, container gardens, raised bed gardens and community gardens.

**Food supply chains**
Food supply chain innovations and interventions attempt to add nutrients and/or reduce nutrient losses along the supply chain, starting from the choice of the crop grown to how products are stored, processed, transported and ultimately accessed by consumers in markets or other food environments. Interventions in food supply systems need to be based on a thorough understanding of nutrient additions and losses in the entire food system, from seed to retail, and focus on making healthier food more available, acceptable, accessible and affordable.

**Seed**
Supply chains start with the choice of crops grown. Increasing the diversity in farmers’ fields and including crops like vegetables will add nutritional and health value to the food system. The availability of quality vegetable seed resistant to pests and diseases and tolerant to abiotic stresses, such as heat, and flooding is fundamental. Such constraints are predicted to become even more severe with climate change. Varieties also need to be robust to tolerate suboptimal storage and transport conditions and must be attractive to consumers in terms of taste, texture, shape, color etc.

The World Vegetable Center (WorldVeg) is actively working on enhancing such key traits in vegetable crops, paying due attention to maintenance or enhancement of nutritional content and shelf life using its vast collection of vegetable genetic resources. The WorldVeg genebank collection comprises more than 60,000 accessions originating from 151 countries representing 439 species. For example, for tomato, the center is working on varieties resistant to major insect pests, such as white fly (*Bemisia tabaci* Genn.), tomato leaf miner (*Tuta absoluta*) and spider mite (*Tetranychus urticae* Koch) whilst maintaining and enhancing disease resistance. This resistance is sourced from wild relatives of tomato contained in the Center’s genebank (Rakha et al., 2017).

The formal seed sector has grown rapidly in many parts of Southeast Asia. WorldVeg is, therefore, actively seeking partnerships with private seed companies. In December 2016, WorldVeg and the Asia and Pacific Seed Association (APSA) established a vegetable breeding consortium for the region to promote access to WorldVeg breeding lines by seed companies. As of June 2019, 40 seed companies have joined.
Meanwhile, informal seed systems remain very important for the vast majority of traditional vegetables and legume crops, relying on farmer-to-farmer seed exchange, community-based seed conservation efforts and varietal testing efforts and seed distribution driven by the public sector.

**Pest and disease management**

Most vegetables are highly susceptible to insect pests and plant diseases which reduce marketable yield. This includes pod, fruit and shoot borers; bacterial, fungal and viral pathogens responsible for major epidemic diseases in vegetables such as late blight, bacterial and Fusarium wilt, and whitefly-transmitted begomo-viruses; and abiotic stresses such as high temperature, drought, rain, floods and wind. Traditional vegetables are reported to be ‘more robust’ than global vegetables, requiring less external inputs such as pesticides than global vegetables, but concrete evidence about such benefits is still scarce.

Growers have been reported to spray pesticides more than 50 times during a cropping season in tomato (Nagaraju et al., 2002). Farmers often spray as a preventive measure (de Bon et al., 2014) because pesticides are relatively inexpensive while the risk of losing a crop due to pests and diseases is high. Farmers often lack the knowledge on what products to use given symptoms observed in the field, when to spray, and general pesticide application techniques. The excessive use of pesticides in vegetable production raises major health concerns for producers and food safety concerns for consumers. Schreinemachers et al. (2019) quantified pesticide overuse in vegetable production systems in Southeast Asia, working with about one thousand farmers growing yard-long bean and leaf mustard in Cambodia, Laos and Vietnam. All farmers in Vietnam, 70% of farmers in Cambodia and 59% of farmers in Laos overused pesticides. This is a health danger for both producers and consumers, and a highly inefficient use of resources.

Pest and diseases can be managed through biocontrol measures including the application of pheromone traps, bio-pesticides, integrated pest management practices, and the introduction of biocontrol agents such as insect pathogens, parasitoids, and predators.

Grafting technology can be used in some vegetable crops to overcome soil-borne diseases. In the 1990s, WorldVeg developed a combination of tomato scions with excellent fruit quality and eggplant and tomato rootstocks resistant to soil-borne diseases, nematodes and flooding. The technology was introduced in Vietnam in 1998 and by 2014 the technology was adopted by nearly all producers in Lam Dong province. Grafted tomato had a 37% yield advantage over non-grafted tomato. WorldVeg has restarted research to widen the availability of disease resistant and flood tolerant rootstocks from multiple sources and for multiple crops.

Governments need to introduce policies that facilitate removal of ineffective or highly dangerous pesticides from the market and encouragement of the bio-control industry, training of farmers or farm operators on safe use of pesticides and integrated pest management. It is encouraging to see that many Asian countries are embracing biocontrol measures and speeding up legislation.

One option to reduce pest incidence in vegetables is to grow them under protective structures. This keeps insect pests out (in principle) and enables farmers to produce the crop during the off-season when vegetables fetch higher prices in the market. However, damage from pests may also occur inside net houses. For example, Bangladeshi vegetable farmers trained in off-season vegetable production methods, including the introduction of disease resistant, heat tolerant tomato varieties and net houses with plastic roofs increased income by about 48%, but pesticide use also increased by 56% (Schreinemachers et al. (2016).
Crop management and protected cultivation

The combination of seed, management practices and the environment (open-field, protected cultivation) will determine the influence of growth limiting factors (light, water, temperature, nutrients) and growth reducing factors (pests and disease pressure) and eventually yield levels and quality of the produce at harvest. Yield levels can be raised through improved soil and water management options (e.g. crop rotations, drip irrigation) and introduction of forms of protected cultivation. Protected cultivation systems change the growth environment and may enable year-round production, making vegetables more affordable and available. A major challenge for research and agricultural service providers is to develop ‘baskets’ of technological innovations that farmers can afford and that are effective given soil, climate and market conditions, and that permit year-round production. Moving from open-field to protected cultivation radically changes the growth environment and baskets need to be revisited.

Protected cultivation systems range from low-tech, low-cost poly-tunnels made of recyclable materials, which rely mostly on natural solar energy input, to high-tech, expensive greenhouses, which differ in size, shape and materials used, ranging from single-span structures covered with plastic to multi-span greenhouses with glass cover (Table 2). Plant factories with sophisticated and expensive instrumentation relying almost exclusively on artificial energy input are becoming more and more common in high-income countries.

Many vegetables and different stages of plants (e.g., seedlings for direct transplanting, grafting to overcome soil-borne diseases and add extra vigor to the plant, and vegetables grown for leafy greens, stems, bulbs, tubers, roots, inflorescences, and fruits) can be produced profitably under various types of protected cultivation. The diversity of these protected cultivation systems is very much influenced by local climatic and topographical conditions, availability of capital, skilled labor, energy, equipment and service level, market infrastructure and size, cost of operation, and legislation in terms of food safety and environmental sustainability (Van Henten et al., 2006).

Protected cultivation allows extension of the growing season; reduces the incidence of pests and diseases and mitigates the effect of abiotic stresses and extreme weather. As a result, farmers can increase the quantity, quality and safety of vegetables during the regular and the off-season and obtain favorable market prices. World-wide, about 0.5M hectares of vegetables is grown in greenhouses (Cuesta Roble Greenhouse Vegetable Consulting, 2018). Protected cultivation of fruit, vegetables and ornamentals has increased significantly in East Asia over the last three decades, to ensure vegetables are available year-round, to reduce labor requirements and address concerns about food safety; i.e. to about 50,000 ha in 2012 for Japan (Kozai, 2013), 55,000 ha in 2015 for South Korea (Yu et al., 2017), and 34,000 ha in 2015 for Taiwan (Wang et al., 2017). In these high income countries that are faced with acute labor shortage there is an increasing tendency for automation and use of connected sensors along the supply chain to reduce losses, monitor product quality and allow for traceability.

In tropical Southeast Asia, climate volatility is impacting vegetable production through a number of ways, including high temperature, drought, typhoon damage, flooding due to excessive rainfall, emerging pests and diseases, etc. These also cause changes in the nutritional quality of many vegetable crops. Meanwhile, there is a growing number of urban, middle class consumers craving for healthy, safe and convenient vegetables and willing to pay for quality of vegetables. The latter spurs the fast development of cold chain management and large retailers, which call for reliable and sustainable supply of quality vegetables. To cope with these challenges, protected cultivation of vegetables has emerged as one of the options in urban and peri-urban settings. However, level of technology currently employed varies significantly amongst countries in the region. Moreover, there is a mixture of small-scale, family-based and large-scale entrepreneurial operations.

Subsidies on technologies that enable greater control over the growth environment, such as drip irrigation and protected cultivation structures are important to stimulate development of the horticultural sector.
Adoption of protected cultivation technology for vegetables for varying Southeast Asian agro-climatic and socio-economic conditions requires:

- Identification of potential markets for particular vegetables, e.g. niche markets that could generate sufficient revenue to recoup the upfront costs of protected cultivation, based on climate, crop requirements, technology level required, and premium market price potential
- Government policy and support towards small- and medium-sized enterprises using protected cultivation technology, e.g. subsidies of startup and operation costs as well as conducive environment for foreign investments
- Design and optimization of affordable constructions that respond to local growth conditions, e.g.:
  - typhoon-proof structures (e.g., withstand sustained wind speed of >100 km/h), especially for the Philippines, followed by Vietnam, and to some extent Thailand, Laos and Cambodia
  - UV-stabilized covering materials
  - efficient ventilation
  - large house volume over ground floor area structures ratio
- Capacity building efforts to increase growers’ knowledge and technical skills for stepwise adoption of protected cultivation techniques in crop management baskets
- Easy access to construction materials, equipment and technical services
- Scaling up of technologies to improve environmental control, integrated crop management, integrated pest management, harvesting, etc. within a protected cultivation system for premium and safe products

### Table 2 Types of protected cultivation of vegetables

<table>
<thead>
<tr>
<th>Input level</th>
<th>Type</th>
<th>Management</th>
<th>Tech up-scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Shade house Poly tunnel</td>
<td>No cooling or heating Soil-based Integrated pest management</td>
<td>Structures withstand weather elements</td>
</tr>
<tr>
<td>Medium</td>
<td>Net/screen house High tunnel</td>
<td>Integrated pest management Integrated fertiliser management</td>
<td>Covering materials with various colors &amp; meshes, and heating or cooling systems to control pests &amp; temperature Fertigation</td>
</tr>
<tr>
<td>Medium to High</td>
<td>Plastic house Greenhouse</td>
<td>Stand alone or multi-span Integrated environment management Integrated greenhouse management</td>
<td>Precision control of light, temperature, humidity, etc. Trellising Hydroponics Use of biological control agents</td>
</tr>
<tr>
<td>Extremely High</td>
<td>Vertical growing Plant factory</td>
<td>Closed system Integrated environment management Integrated greenhouse management</td>
<td>LED lighting, AI, M2M robotics, etc. for environment control &amp; harvesting</td>
</tr>
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</table>

Post-harvest and processing
Operations after harvest encompass storage, processing and transportation. Post-harvest losses are typically large for vegetables and can be in the range of 30-50% (FAO, 2011). Sensors can be used to trace causes of such losses and keep track of freshness of produce. For example, vibration sensors have been used by researchers from the National Agricultural and Food Research Organization (NARO) in Japan to
determine periods of greatest vibration and shock during transport of strawberries. This helped optimize packaging and transportation means.

Harmonization of production and marketing is key to avoid post‐harvest losses. This will require places (‘packhouses’) for farmers to aggregate, clean, sort and temporarily store produce. Good results with this type of approaches were obtained by WorldVeg and partners in Asia, in particular if packhouses were equipped with relatively low‐cost cold storage facilities, e.g. using Coolbot technology (https://horticulture.ucdavis.edu/coolbot). Affordable drying and cooling technologies, such as Coolbot will help further reduce post‐harvest losses.

Food processing makes vegetables available outside growing seasons, reduces post‐harvest losses and transforms vegetables into higher value products (e.g. nutritious snacks). The effect of different storage and processing techniques on nutritional content still needs to be further measured.

Retailing

Shorter supply chains and greater connectivity between farm and plate may convince consumers about food safety issues related to vegetables. Once consumers understand how and where vegetables are produced they may become more confident in purchasing and consuming vegetables. Urban consumers will often be willing to pay more if they are convinced about food safety standards. Innovations may include ordering vegetables on‐line and delivery through Uber type of systems or door‐to‐door delivery of safely produced vegetables. Examples exist from around the world, where urban clients are purchasing baskets of organically grown vegetables from local producers but these initiatives remain largely experimental or at a relatively small scale.

Traceability

Traceability and certification systems are important to raise acceptability of vegetables and build trust among consumers concerned with food safety. Such systems can be very sophisticated using bar‐coding tracing the origin of the produce and spot checks on pesticide residues, such as seen in Taiwan. They can also be rather ‘low‐tech’, based on building trust among consumers about the safety of vegetables and involving simple visits to a farm practicing good agricultural practices and with minimum reliance on or zero use of chemical pesticides. Support can be provided to farmers to gradually achieve local certification standards to even global Good Agricultural Practices (GAP) standards for export.

ASEAN has published the ‘Good Agricultural Practices for the Production of Fresh Fruits and Vegetables for the ASEAN Region’ in 2006 to assist with the standardization of fruit and vegetable GAP across the region. The most important component of this ASEAN GAP relates to food safety, wherein the alignment of the national safety standards is mandatory for the facilitation of free flow of goods and the competitiveness of fruit and vegetable products in the global market. Many countries in Southeast Asian region now have GAP systems in place; however, some countries are lagging behind and not all countries have a standardized system in place yet. Also various GAP activities have been carried out in the region but at different levels and degrees related to the governments’ commitment, availability of financial resources and level of technical expertise. There is a need to develop a coherent road map for the management of the ASEAN GAP as well as national GAP standards across all countries in Southeast Asia including a common auditing and recognition process that satisfy export markets.

To address the issue of ensuring food safety, almost all countries in Southeast Asia have set up various acts, regulations, guidelines and measures. Moreover, ASEAN Member States (AMS) have adopted the ‘ASEAN Food Safety Policy’ in 2015 (ASEAN, 2016) with the objective of providing a basis for AMS to enhance food safety and protect consumers’ health, and to facilitate the free flow of food in the region. Digital technologies, block chain, big data, internet of things, artificial intelligence, smart everything—these emerging, innovative technologies are bringing new opportunities to more efficiently and effectively manage food for increased safety, especially for high income countries in East Asia. Yet, technology alone
will not enable regional traceability. All stakeholders must use open, regional standards that will enable the use of emerging technologies within food production, processing and delivery processes for end-to-end traceability. Traceability can only be effective if common requirements are met across all Southeast Asian countries. In addition to the general requirements, sector-specific standards need to apply to certain categories of food products (e.g., fruit and vegetables) so that consumers can identify their origin and authenticity.

One of the asserted ten principles to ensure food safety in the aforementioned ‘ASEAN Food Safety Policy’ is the “Reliable Traceability System”. It states that a reliable traceability system covering relevant stages of production, processing and distribution of food products should be put in place by AMS to enable targeted and swift withdrawals of unsafe food products whenever needed. The traceability system is to be able to identify at any relevant stage of the food chain (from production to distribution) from where the food came (one step back) and to where the food went (one step forward), and priority given to the traceability of high-risk food products, such as meat, dairy and fruits and vegetables. It also urges AMS to cooperate and share information on unsafe food products, and establish national food recall procedures to prevent unsafe food products from reaching the consumer.

The increased requirements for documentation and reporting systems along with the cost of emerging technologies may be daunting for lower and middle income countries that are striving to enhance food safety and hoping to expand their trade in food or break into new markets. Smallholder farmers, such as vegetable growers, in particular could be further marginalized from the in-country or regional food trading system by the burden of the reporting requirements in the traceability system. Therefore, there should be policies and efforts within the Southeast Asia region to facilitate:

- Learning lessons on traceability systems from the countries which have well-established food traceability systems such as Australia, EU, Japan, New Zealand and USA.
- Establishing coherent safety standards for traceability systems related to different categories of food products.
- Establishing a centralized database to minimize the logistics of accounting requirements in traceability systems.
- R&D to reduce the cost of technology applications that the lower and middle countries in the region could afford in developing and applying traceability to enhance food safety.
- Raising awareness about traceability for stakeholders such as consumers, food producers, entrepreneurs, government officials, and NGOs acting in protecting consumer rights.

**Getting it together: Integrated food systems approaches**

We reviewed innovations and interventions to enhance dietary quality across the entire food systems spectrum, from consumer food choices behavior, to food environments, to supply systems. Achieving food systems change in a particular context will require in-depth knowledge of dietary gaps and consumer behavior, analysis of the food environments where consumers with different purchasing powers access their food and the food supply systems, from production to marketing. In addition, it will be important to understand the importance of external drivers on the food system. These may be of political, economic or environmental nature. Climate change may greatly affect opportunities to grow certain vegetables under open-field conditions. Demographic drivers, e.g. migration of young people to cities need to be well understood.

There is a great opportunity to realize both the nutritional and economic potential of vegetables in connecting rural and peri-urban farmers with urban consumers. In doing so, it will be important to address supply and demand motives for healthier diets simultaneously. For example, focusing only on demand-
side opportunities and raising the awareness about consuming vegetables may not result in improved dietary outcomes because availability or affordability of such vegetables for urban consumers may be a constraint. Similarly, focusing only on supply-side opportunities by improving the availability of nutrient-dense vegetables may not be sufficient because urban consumers may have food safety concerns because of perceived contamination with pesticide residues.

There are clear opportunities for spill-over of protected cultivation technology and product quality evaluation methods and sensors from HICs in East Asia to LMICs in Southeast Asia, reducing losses in the supply chain and ensuring vegetables are safe to eat. Including such modern technology will make horticulture a more appealing job opportunity for young people. However, concerns about food safety and introduction of high-tech traceability systems will also place increasing demands on smallholder farmers and processing firms and it may become difficult for them to connect to modern food supply channels delivering to supermarkets. Similarly, small-scale food services provided by street vendors and through food stalls will face increasing scrutiny in terms of food safety. Meanwhile, the vast majority of urban consumers buy their vegetables in informal markets, at food stalls or from street vendors. Effective and affordable ways need to be found to ensure food safety of vegetables and other perishable foods in these more informal settings as well.

In general, there is a need for increased understanding of appropriate models of collective action by smallholder farmers to access increasingly modern food supply chains in Southeast Asia. This is particularly critical because linking farmers to urban demand for quality and healthy food is seen as a key opportunity for job and value creation in rural and peri-urban areas in LMICs in Southeast Asia. This requires conducting pilot studies and surveys to look into the effectiveness and efficiency of different farmer aggregation models and job creation along the entire supply chain, from farm to market.

Given the complexity of food systems change, a linear, activity-based approach is unlikely to lead to lasting positive outcomes. We advocate for a ‘coaching or accompanying’ approach used by Pasiecznik (2018). This involves ‘bridging institutions’ facilitating change, strengthening innovation capacities of all stakeholders, and using real-time monitoring and evaluation to learn and adjust approaches over time. This means that there is a need to place emphasis on both technical and functional capacities of stakeholders to stimulate collaboration, reflection and learning and engagement in strategy and policy processes (Pasiecznik, 2018).

**Conclusions**

The HLPE framework (2017) was used to provide an overview of innovations and interventions that may lead to greater dietary quality in Southeast Asia by stimulating vegetable production and consumption and that have the potential to enhance food safety and nutrition security in Asian low and middle income countries. However, addressing supply-side opportunities and demand-side motives separately may not result in lasting positive outcomes. There is a need to create an evidence base for integrated food systems approaches that link rural and peri-urban farmers to the rapidly growing urban demand for quality vegetables in Southeast Asia, leading to favorable and lasting dietary, socio-economic and environmental outcomes.

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