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Life Cycle Assessment of Southeast Asian Diets

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Abstract

Population growth has increased demand for food globally. Food production has negative impacts on the environment. Previous research has shown that dietary choices significantly influenced environmental impacts. Studies on the environmental impacts of Southeast Asian diets are still limited and needed. The objectives of this study are to assess and compare the life cycle environmental impacts of diets in 9 Southeast Asian countries (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam), to identify the dietary choices causing the environmental impacts and to provide recommendations on environmental impact reduction. The functional unit of this assessment is food consumption in kilograms per capita per year. The assessment scope is from cradle to gate. Foreground data were obtained from Food and Agriculture Organization (FAO) food balance sheets with the representative year as of 2018 and International Coffee Organization (ICO). Background data were obtained from ecoinvent and Agri-footprint databases. Four environmental impact categories (human health damage, ecosystem damage, resource scarcity, and global warming potential) were assessed using the ReCiPe 2016 method (v1.04). Healthy diet scenarios with the diet and energy intake adjustments to achieve the recommended standard healthy diets were also analyzed. The dietary choices with higher amount and more high-impact food groups would cause higher environmental impacts. Vietnam, Myanmar, and Laos had higher impacts for all impact categories, while Timor-Leste had the lowest impacts among Southeast Asian countries. Meats/meat products and cereals were significant contributors to all impact categories, followed by fish and seafood. Based on the healthy diet scenario analysis, overall reduction and meats & cereals reduction were recommended for environmental impact reduction because meats, fish and seafood, cereals were the major contributors to all impacts categories in Southeast Asia. As meats/meat products lead as a critical food group causing environmental impacts, it is recommended that governments should take specific measures to reduce the consumption of animals and animal products and to support meat substitutes (e.g., tofu, tempeh, beans, etc.).

Keywords : LCA; Southeast Asian diets; Human health; Ecosystem; Natural resources; Global warming potential

Introduction

Due to the rapid growth in world population, global food production and consumption increase and affect human health, the environment, and ecosystems. Global agricultural and food production released more than 25% of all greenhouse gases (GHGs). Fresh and marine water quality was affected by agrochemicals from agricultural and food production [1]. The non-vegetarian diets required more energy and resources than vegetarian diets, specifically more than 2.9 times of water, 2.5 times of primary energy, 13 times of fertilizer, and 1.4 times of pesticides. A higher environmental cost occurred in a non-vegetarian diet than a vegetarian diet. This showed that dietary choices could make environmental changes [2].

On the other hand, there would be a significant effect on land use when meat consumption was reduced or switched entirely to plant-based protein food. Regrowing vegetation in abandoned land (up to 2,700 Mha of pasture and 100 Mha of cropland) could absorb a large amount of carbon. Furthermore, methane and nitrous oxide emissions could be substantially reduced, and it could achieve a 450 ppm CO_2-eq (targeted 50% reduction by 2050) from changing to a low meat diet, which was also recommended for health reasons. Hence, diet changes would benefit human health and global land use; and play a vital role in future climate change policies [3].

Increasing the awareness of the importance of environmental protection and the interest in the possible impacts of the products has led to developing methods to assess, understand, and address these impacts [4]. Life cycle assessment (LCA) is a well-known and widely used tool to evaluate the environmental burdens of a product, process, or service through its entire life cycle. LCA has been a suitable tool to analyze the environmental performance of a food product or industry [5]. Hence, LCA was chosen as part of the methodology to conduct this study. Lucas et al. [6] conducted a study on global environmental and nutritional assessment of national food supply patterns of countries around the globe by applying Data Envelopment Analysis. The study was conducted based on the existing studies, applied FAO food balance sheets of the year 2017 and assessed the environmental impacts including land use, GHG emissions, acidification potential, eutrophication potential, and freshwater withdrawals from each nation's average per capita food supply [6]. However, the results only highlighted the country groups regarding their income levels (high-income, upper-middle-income, middle-income, lower-middle-income, and low-income levels). It did not indicate environmental impacts of specific countries. Furthermore, a study related to the environmental sustainability of food consumption in Asia was done by Adhikari and Prapaspongsa [7]. Nevertheless, only one Southeast Asian country – Thailand - was considered in the study. Regarding the existing studies, the assessment of the diet's impacts in Southeast Asian countries is still limited. Therefore, this study aims to assess and compare the life cycle environmental impacts of diets in 9 Southeast Asian countries (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam); to determine the diet systems highly contributing to the environmental impacts, and to provide recommendations about ways to reduce the impacts on the environment.

Material and Methods

This study uses LCA to assess the environmental impacts of a process's inputs and outputs according to ISO 14040 [8]. The LCA framework - the research framework in this study - which includes four phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation, can be seen in Figure 1. This study analyzes and quantifies the impacts affecting the environment and determines the significant contributors in the diet systems with the "cradle-to-farm gate" perspective. The functional unit of this study is defined as "food consumption in kilogram per capita per year" in Southeast Asian countries. Table 1 shows the parameters of Southeast Asian countries. There are eleven countries in Southeast Asia; nevertheless, only nine countries can be assessed in the study due to the lack of data availability.

Food consumption is derived from the food availability in Southeast Asian countries, including importing and exporting food in the country. Data from the FAO food balance sheets with the representative year of 2018 and data from international coffee organizations [9] are utilized as foreground data. The background data of each food item are acquired from the ecoinvent and Agri-footprint databases. The food items are categorized into thirteen groups based on the FAO classification and Adhikari and Prapaspongsa [7]. The categorized food groups can be seen in Table 2, which shows the food supply of Southeast Asian countries in kg per capita per year. The food items considered under each food group can be observed in Adhikari and Prapaspongsa [7], categorized twelve food groups. Spices are considered as an additional food group in this study.

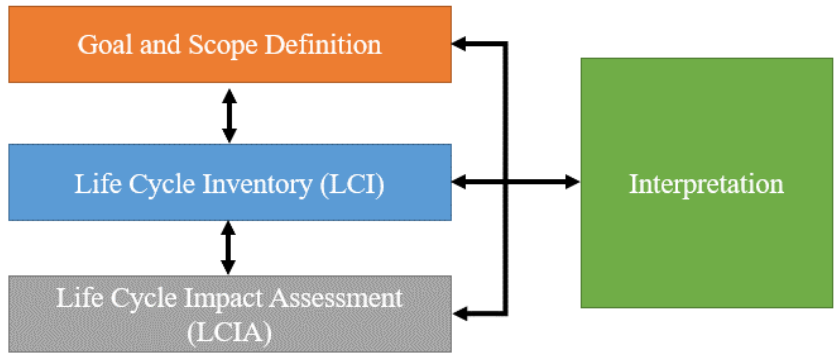

Figure 1 Life Cycle Assessment Framework (ISO 14040; [8])

Table 1 Characteristics and energy intakes per person in Southeast Asian countries

No	Countries [10]	Population (2020) [11]	Population Density (people per sq.km) [11]	Urbanized Population (% of total) [11]	Energy Intake (kcal/capita/day) [12]
1	Cambodia	16,718,971	95	24%	2884
2	Indonesia	273,523,621	151	56%	2492
3	Laos	7,275,556	32	36%	2758
4	Malaysia	32,365,998	99	78%	2845
5	Myanmar	54,409,794	83	31%	2673
6	Timor-Leste	1,318,442	89	33%	2287
7	Philippines	109,581,085	368	47%	2662
8	Thailand	69,799,978	137	51%	2804
9	Vietnam	97,338,583	314	38%	3025

Table 2 Thirteen food groups consumed per person in Southeast Asian countries in 2018

No.	Food Categories (2018) (kg/capita/year) [12]	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Timor-Leste	Philippines	Thailand	Vietnam
1	Cereals	254	260	264	175	213	210	230	195	234
2	Root Vegetables	19	69	57	19	14	44	17	10	17
3	Sugar and Confectionary	33	20	51	45	28	26	25	103	22
4	Legumes, nuts, and oilseeds	14	23	8	12	31	11	9	15	43
5	Oils	3	12	3	17	21	7	6	9	3
6	Vegetables	38	45	220	69	84	27	63	42	173
7	Fruits	19	66	148	42	43	15	98	88	80
8	Coffee [9] and Tea	0	1	2	1	2	0	2	2	3
9	Meats and meat products	14	13	28	54	51	34	43	31	74
10	Fish and Seafood	42	44	25	57	46	8	26	29	37
11	Animal Products	5	11	6	24	32	9	9	29	15
12	Spices	1	2	2	5	2	0	0	6	3
13	Alcohol and Beverages	29	1	12	9	2	4	16	44	20
	Total	**471**	**567**	**826**	**529**	**569**	**395**	**544**	**603**	**724**

Various life cycle impact assessment (LCIA) methods are available; however, ReCiPe 2016 is selected as the LCIA method in this study, with a large set of midpoint indicators (18) and three endpoint indicators. Harmonized characterization factors at the mid-point and the endpoint levels are provided in the ReCiPe 2016 method. The characterization factors in ReCiPe 2016 represent the global scale instead of the European scale. The midpoint and endpoint methods have factors according to the three cultural perspectives: individualist, hierarchist, and egalitarian. These perspectives can be chosen according to time duration or expectations to avoid future damages. Hierarchist perspective is selected in this study, which is based on scientific consensus with regard to the time frame and acceptability of impact mechanisms. Four environmental impact categories (human health damage, ecosystem damage, resource scarcity, and global warming potential) were assessed by conducting the ReCiPe 2016 (V1.04) in Simapro 9.1.1.7. Damage impact categories show the area of protection affected by the 18 midpoint categories, namely climate change potential (GWP), ozone depletion, ionizing radiation, fine particulate matter formation, photochemical oxidant formation: ecosystems quality, photochemical oxidant formation: human health, terrestrial acidification, freshwater eutrophication, human toxicity: cancer, human toxicity: non-cancer, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, marine eutrophication, land use, water use, mineral resource scarcity, fossil resource scarcity [13]. Targeting specific impacts could improve in the selected impact categories; however, some crucial points could be overlooked. Therefore, this work is determined to analyze the environmental impacts at the endpoint level. It should be mentioned that although all LCIA methods have aimed to model possible environmental impacts, it is not possible to include all possible impact pathways. Different methods have different modelling choices and limitations. The detailed methodology and limitations of the ReCiPe method can be seen in Huijibregts et al. [13]. Figure 2 shows the overview of the impact categories covered in the ReCiPe 2016 method and its relation to the area of protection at the endpoint level. In the figure, the impact categories considered in this study are highlighted in red boxes.

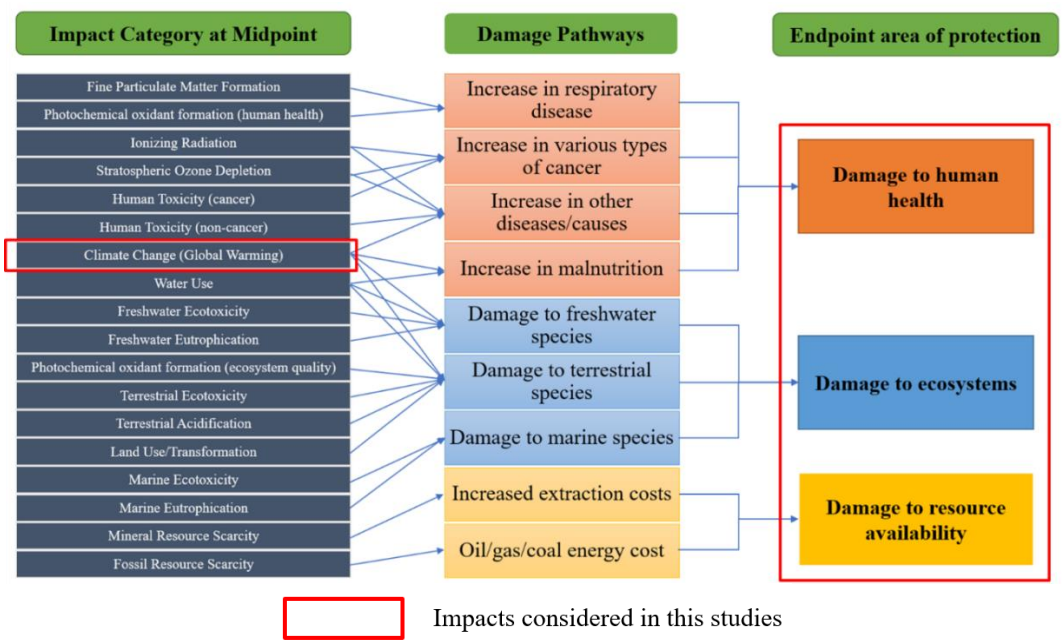

Figure 2 Overview of the impact categories that are covered in the ReCiPe 2016 method and their relation to the areas of protection (endpoint) [13]

Human health damage shows years of life lost and disabled related to respiratory disease, various types of cancer, malnutrition, and other diseases caused by climate change, stratospheric ozone depletion, ionizing radiation, particulate matter formation, photochemical ozone formation, toxicity, and water consumption. Its unit is described as disability-adjusted life years (DALYs). Ecosystems damage describes species losses affected by climate change, photochemical ozone formation, acidification, eutrophication, toxicity, water consumption, and land use in freshwater, marine, and terrestrial species. It is shown in the unit of species-year. The resource scarcity shown in the unit of dollar (USD) refers to the additional extraction costs for mineral and fossil fuel (oil/gas/coal) resources in the future. Additionally, the climate change at the midpoint is used as global warming potential (GWP), in which the integrated infrared radiative forcing increase of greenhouse gas (GHGs) is quantified and expressed in kg CO_2 equivalent [13]. The global warming potential (kg CO_2 equivalent) is considered to be assessed in the study because agriculture and food production contributed more than 25% of greenhouse gas (GHGs) emissions [1]. Hence, assessing the global warming potential of Southeast Asian countries could not be neglected.

Healthy Diet Scenario Development

Healthy Diet Scenarios (HDS) were developed by reducing or increasing the calorie intake of diets in order to reach the healthy level. Calorie intakes differ according to age and gender. Typically, men consume more calories than women; likewise, elders require fewer calories than adults. However, this study does not consider specific age, weight, and gender variants groups. According to FAO, the benchmark intake is 2300 kcal per day [14]. Hence, 2300 kcal per capita per day is determined as the healthy diet intake for adults.

Regarding 2300 kcal per day as a targeted diet intake to clarify the food groups' impacts on the environment and health in Southeast Asian countries, the scenarios are considered three fragments, reduction in overall consumption (HDS_1), cereals only (HDS_2), and HDS_3 meats and, cereals consumption. The reduction in daily energy intake can lead to healthy lifestyles and increase in daily intake in lower kcal consumption would also have a healthy diet style. This LCA identifies the HDS scenarios based on the impact assessment results. Regarding meats (meats, fish and seafood, and animal products) which had significant impacts on the environment, the reduction of the impact in the consumption of indicated food groups alone is not feasible to be considered as a standalone scenario as the intake of animal and animal products was not high in Southeast Asian countries. Hence, reduction in cereals consumption is taken into account along with meats under scenario 3 (HDS_3) to achieve healthy diets. Table 3 describes HDS scenarios reducing/increasing calorie intakes in Southeast Asian countries.

Results and Discussion

Environmental impacts of Southeast Asian diets

Figure 3 presents the life cycle environmental impacts of Southeast Asian diets. Results indicated that Vietnam, Myanmar, and Laos had significant impacts on all impact categories from their dietary choices, while Timor-Leste had minor impacts. Fish and seafood (27%), cereals (26%), meats, and meat products (23%) highly contributed to human health damage. For resource scarcity, cereals contributed the most (25%), followed by meats and meat products (23%) and fish and seafood (20%). On the other hand, ecosystem damages were caused by meats and meat products (26%), cereals (18%), coffee and tea (15%), and spices (14%). Finally, only cereals (39%) and meats and meat products (28%) were the main contributors to global warming potential.

Table 3 Description of HDS Scenarios reducing/increasing calorie intakes in Southeast Asian countries

Countries	HDS1_Overall	HDS2_Cereals	HDS3_Meats* & Cereals	Description
Cambodia	8%	12%	10%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2492 kcal/capita/day
Indonesia	20%	33%	30%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2882 kcal/capita/day
Laos	17%	28%	24%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2756 kcal/capita/day
Malaysia	19%	46%	32%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2843 kcal/capita/day
Myanmar	14%	27%	20%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2671 kcal/capita/day
Philippines	13%	23%	18%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2657 kcal/capita/day
Thailand	18%	38%	29%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2801 kcal/capita/day
Timor-Leste	-1%	-1%	-1%	increase in food items to achieve calorie intake 2300 kcal/capita/day from 2286 kcal/capita/day
Vietnam	24%	47%	32%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 3023 kcal/capita/day

*meats, fish, and seafood (which will be called as a group of meats)

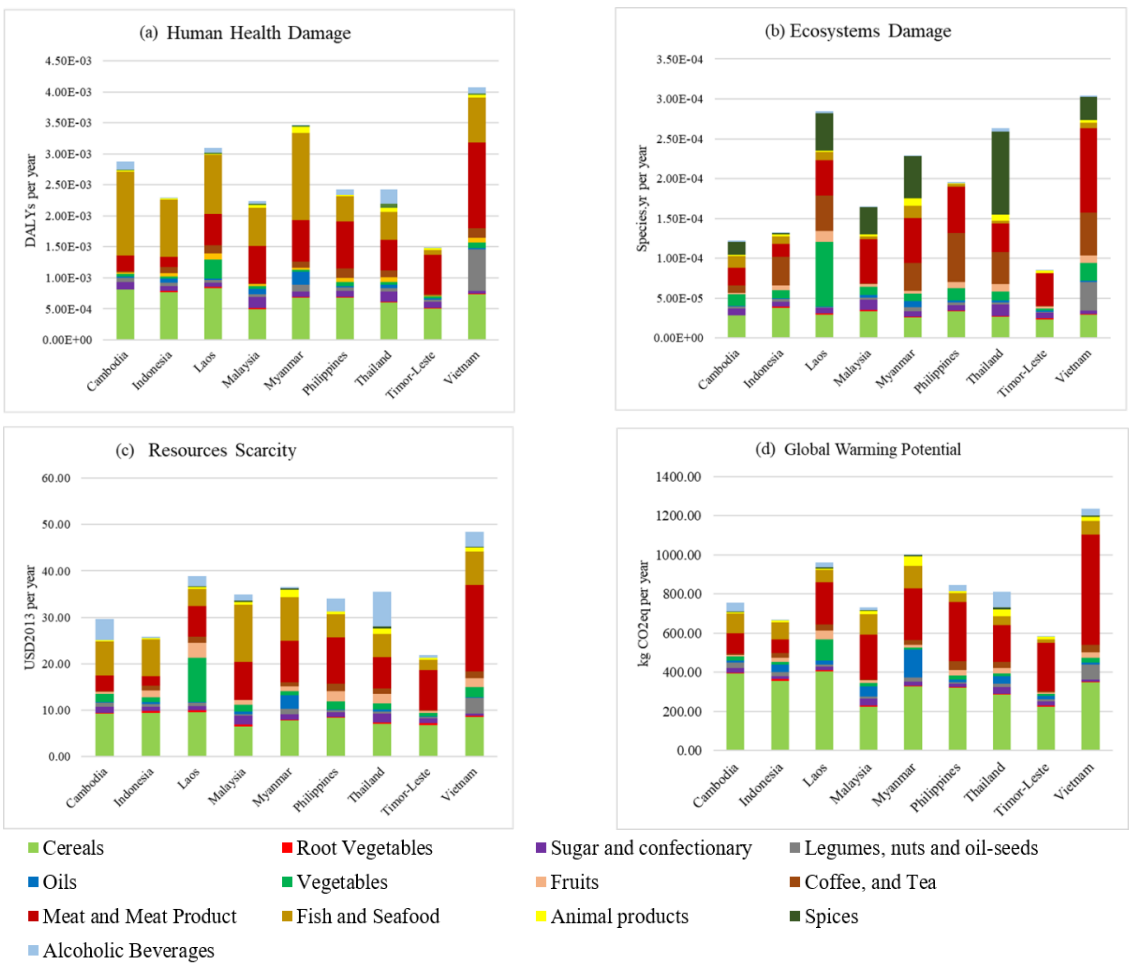

Figure 3 Comparison of life cycle environmental impacts of Southeast Asian diets under the impact categories of (a) human health damage, (b) ecosystems damage, (c) resources scarcity, and (d) global warming potential

The environmental impact intensity shown in relative percentages is illustrated to determine each impact category's contributors (13 food groups) as can be seen in Figure 4. One kg of each food group was assessed, summed up and presented as relative percentages. Per kg, coffee and tea had the most significant impacts in all impact categories. In human health damage, coffee and tea contributed to 45% of total impacts, followed by meats (14%) and fish and seafood (11%). In ecosystem damage, coffee and tea contributed to 49% of total impacts, and followed by spices 31% of total impacts. Moreover, resource scarcity was highly affected by coffee and tea (27%), fish and seafood (14%), meats (13%), and alcoholic beverages (13% of total impacts). Almost 50% of total global warming potential was caused by 1 kg of coffee and tea consumption followed by 1 kg of the meat consumption (17%).

In human health damage, the intensity of damage ranged from 1.50E-03 to 4.07E-03 DALYs in Southeast Asian countries. Vietnam had significant impacts on human health damage with 4.07E-03 DALYs per capita per year. In which, meats consumption was the primary contributor that caused more severe damage to human health (34% of total impacts) and followed by fish and seafood, cereals consumption with (18% of total impacts, respectively). The human health damage impacts in Myanmar (3.47E-04 DALYs per capita per year) and Laos (3.10E-03 DALYs per capita per year) were not much different. Fish and seafood was the major contributor in Myanmar (40%), and meats and meat products (34%) consumption contributed a lot to human health damage in Timor-Leste. In contrast, Timor-Leste had the minimum amount of impact (1.50E-03 DALYs per capita per year) on human health damage among Southeast Asian countries.

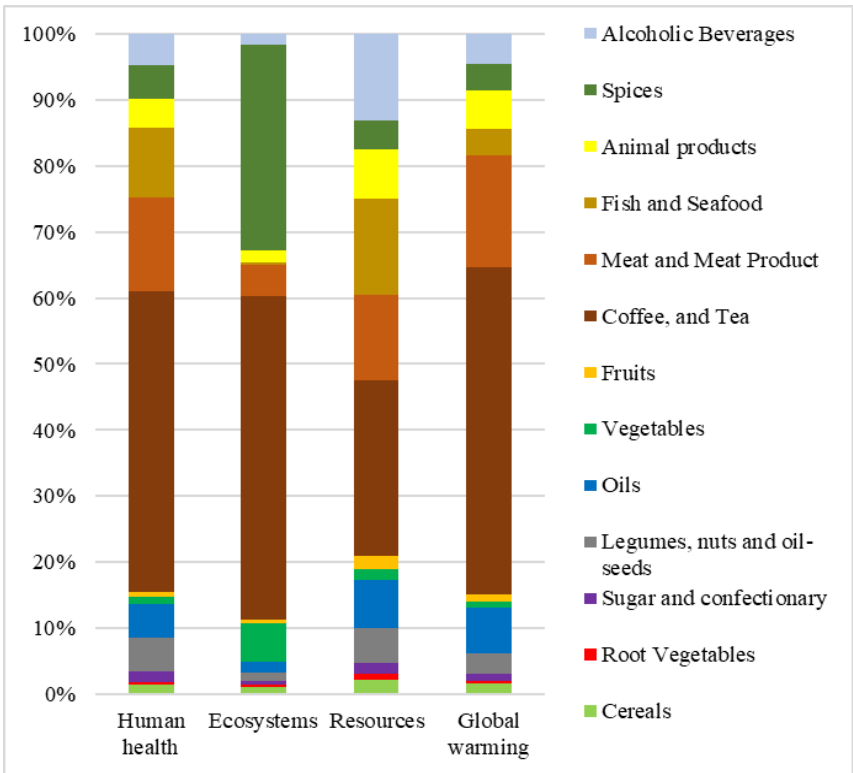

Figure 4 Environmental impact intensity per kg of each food group illustrated in relative percentages

Regarding ecosystems damage, it ranged from 8.50E-05 to 3.04E-04 species-year per capita per year. Meats and meat products (35%) were the primary reason causing intense damage to ecosystems in Vietnam (3.04E-04 species-year) among the Southeast Asian countries. Laos (28.40E-04 species-year) ranked as the second country with a high impact on ecosystems damage from vegetables (42%). The ecosystem damage in Thailand, Myanmar, and the Philippines ranged from 1.96E-04 to 2.64E-04 species-year. Spices (40% of total impact) were also a part of Thailand's major contributors to ecosystems damage. In comparison, coffee and tea (31%), meats and meat products (30%) were principal contributors in the Philippines; furthermore, meat/meat products (25%) and spices (23%) performed as higher contributors in Myanmar. Timor-Leste had the least impact on its ecosystems damage (8.50E-05 species year), where meats/meat products (48%) contributed to its impact.

For resources scarcity, extraction fuel/energy costs from dietary choices ranged from 22 to 48 USD per capita per year in the Southeast Asian countries. A vast amount was found in Vietnam, with 48 USD per person in a year. Meats/meat products (39% of total impacts) contributed more severe resources scarcity in Vietnam, followed by Laos, with 39 USD contributed by cereals and vegetables (24%, respectively). Resources scarcity per capita per year in Myanmar, Malaysia, Thailand, and the Philippines were more or less similar. Fish and seafood food group was a significant contributor to resource scarcity damage in Myanmar (26%) and Malaysia (35%). Meats/meat products (20%) contributed to resources scarcity in the Philippines. At the same time, 21% alcoholic beverage, 20% cereal consumption, and 19% meats/meat products contributed to Thailand. Simultaneously, a person's cereals consumption for a year significantly contributed to resource scarcity damage in Cambodia (31%) and Indonesia (36%). Timor-Leste had the lowest impact cost (22 USD) in resources scarcity by meat and meat products (40% of total impacts).

Emissions caused to global warming in Southeast Asia fluctuated depending on dietary choices (ranging from 586 to 1234 kg CO_2 eq). Generally, cereals, meats, and meat products were the key contributors to GWP. Vietnam had significant emissions to the environment (1234 kg CO_2 eq), primarily by meats and meat products (46%), followed by Myanmar, which had 1001 kg CO_2 eq contributed by cereals (33%), meats/meat products (26%). Cereals (42%) contributed a lot to global warming in Laos, which had 959 kg CO_2 eq. Furthermore, emissions in the Philippines, Thailand, Cambodia, and Malaysia ranged 755 ~ 845 kg CO_2 eq per person and, majorly caused by cereals (>35%) in the Philippines, Thailand, Cambodia, while meat and meat products (32%) contributed to the global warming potential in Malaysia. Besides, cereals (54%) played as a leading contributor to climate change in Indonesia. In comparison, Timor-Leste (586 kg CO_2 eq) had the minimum impact on global warming per person in 2018.

Vietnam had the highest impact in Southeast Asia, contributing 17% of the damage to human health and ecosystems, 16% of the damage from resources scarcity, and the global warming potential. Majorly, cereals, fish and seafood, meats, and meat products were the significant contributors to all impact categories. However, legumes, nuts, and oils were an important food group that had the most significant impact on human health, ecosystems, resources scarcity, and global warming potential in Vietnam compared to the other Southeast Asian countries. Meats contributed 44% to GWP in Vietnam in 2011, and pork and bovine meat were the significant contributors to the meat impacts on the GWP (220 kg CO_2 eq per capita per year, respectively) (Heller et al., 2020). In 2018, meats contributed 46% to the global warming potential in Vietnam, in which pork (200 kg CO_2 eq per capita per year) was highly contributing to the meat's impact on the GWP than bovine meat (324 kg CO_2 eq per capita per year).

Healthy Diet Scenario Analysis

Figure 5 revealed the environmental impacts of HDS. Overall reduction (HDS_1) is favorable to reducing the environmental effects in all impact categories, followed by meats reduction (HDS 3). Vietnam had a high decrease in all impact categories for HDS_1 consideration, followed by Indonesia,

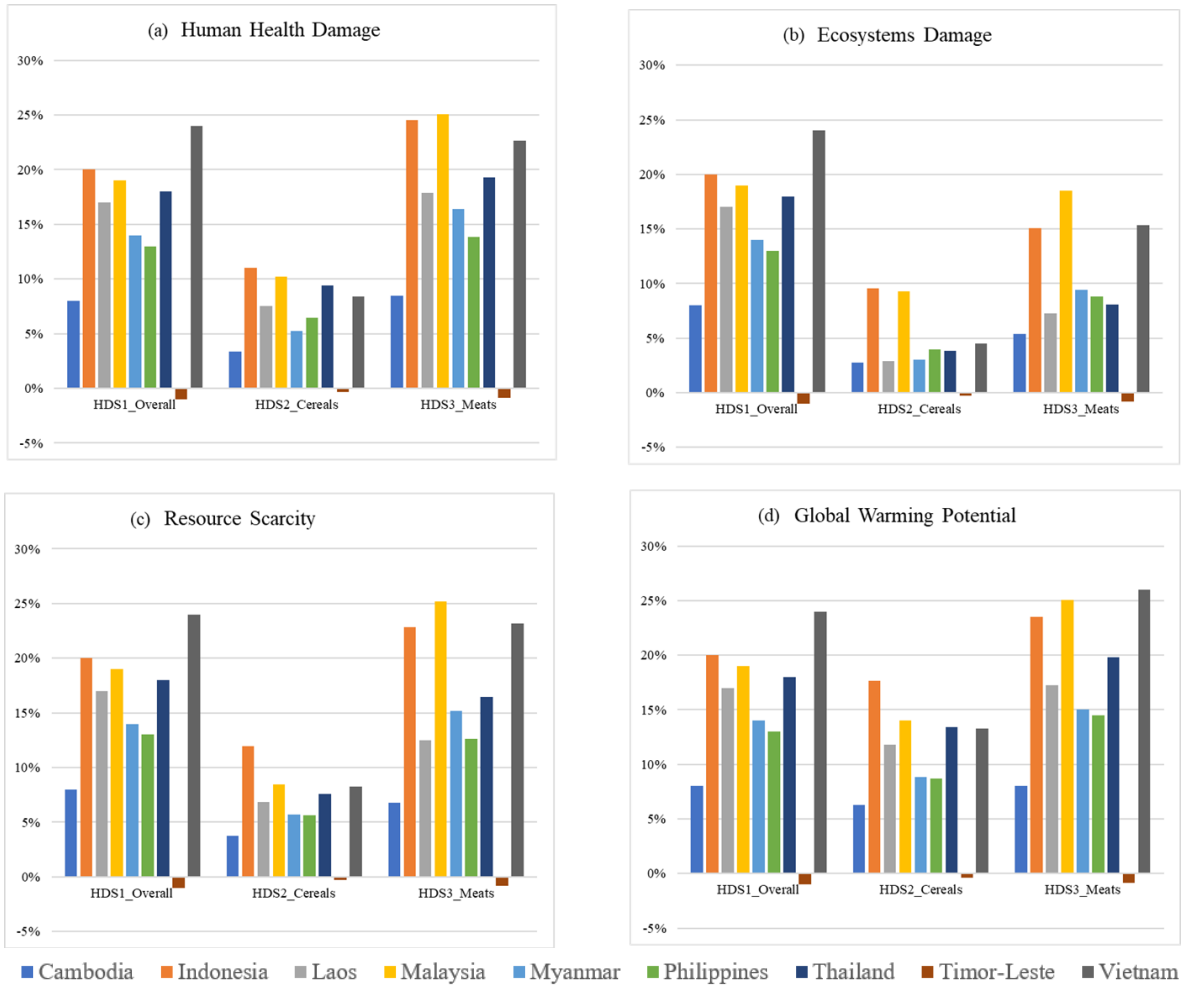

Figure 5 Percentage differences of damage impacts and the global warming potential resulted by applying Healthy Diet Scenarios (HDS)

Malaysia, Thailand, respectively. In order to achieve the benchmark intake of 2300 kcal per capita per day, the consumption was required to be reduced >8% for all countries in all impact categories except Timor-Leste. Timor-Leste, with the lowest diet intakes, 2286 kcal/capita/day, is demanded to be raised in its consumption. However, there was no significant impact increase (1%) after increasing its intake (1%) to hit the benchmarked intakes in all impact categories. Vietnam would require to be reduced 24% of its overall consumption (HDS_1), which had 24% decline in all impact categories. Indonesia (20%), Malaysia (19%), and Thailand (18%) made decreases in their impacts with directly proportional to its percent decreases of their consumption. Furthermore, 17% overall consumption reduction is required to reduce the impacts in Laos (17% of total impacts decrease). Meanwhile, 14%, 13%, and 8% of total impacts in human health damage, ecosystems damage, resources scarcity, and the global warming potential are dropped by the decrease of overall consumption in Myanmar (14%), Philippines (13%) and Cambodia (8%).

Under HDS_2 analysis, global warming potential is affected by the reduced cereal consumption in Indonesia (18%), 14% in Malaysia, 13% in Vietnam and Thailand, 12% in Laos, 9% in Myanmar, and the Philippines of total impacts, and 6% in Cambodia. Indonesia had 11% reduction, 10% of total impacts reduction in Malaysia and Thailand, 9% reduction in Vietnam, 6% decline in the

Philippines, 8% reduction in Laos and 5% in Myanmar, 3% reduction in Cambodia occurred in human health damage. There is a slight decrease in impact percentage (<10%) for all countries in ecosystems damage by cereal consumption reduction because meats, coffee and tea, spices were the significant contributors to the ecosystems. Similarly, in resources scarcity, besides cereal consumption, as meats, fish and seafood largely contributed to the resources scarcity, a minor impact reduction occurred (<12%). However, the intakes in all countries were considered to reduce above 12% of their consumption. As for Timor-Leste, there was no impact increase (0%) due to raising its intake to achieve the healthy diet by FAO.

Animals, animal products, and cereals consumption reduction is considered as one scenario, HDS_3. Malaysia has the higher impact decrease in all impact categories after applying HDS_3, followed by Vietnam, Indonesia, and Thailand. Since cereals, meats, fish and seafood were primary contributors to human health damage, resources scarcity, and global warming potential, the impacts are more prominent than ecosystems damage. 25% decrease in human health, resources scarcity, and global warming potential, 19% decrease in the ecosystems are discovered when Malaysia's energy intake is reduced by 32%. After Vietnam is considered to be reduced by 32% of its consumption under HDS_3, a 15% impact decrease occurred in ecosystems damage, 23% in human health damage, resources scarcity, and 26% in global warming potential. Meanwhile, although the percent reduction of consumption in Indonesia (30%) and Thailand (29%) are almost the same, the differences in impacts decrease in those countries are more or less significant. While there are 25%, 15%, 23%, and 24% of total impact decrease occurred in Indonesia for human health damage, ecosystems damage, resources scarcity, and global warming potential, 19%, 8%, 16%, and 20% in Thailand. The impacts declination in Myanmar and the Philippines are only 1~3% different, similar to the percent reduction of their consumption (20% of Myanmar, 18% of Philippines). In Cambodia, 8% reduction in human health damage, 7% reduction in resources scarcity, 8% reduction in global warming potential, and 5% reduction in the ecosystems damage occurred if the consumptions of animals, animal products, and grains in Cambodia are reduced by 10% in order to reach the benchmark of 2300 kcal/capita/day from 2492 kcal/capita/day. A non-significant decrease (7%) occurred in ecosystems damage in Laos. Furthermore, 12% impact declination is occurred in resource scarcity, 12% in global warming potential in Laos after its consumption was reduced by 18% to achieve healthy diets. Like HDS_1, Timor-Leste had no severe impact increase after raising its intake from 2286 to 2300 kcal per day. Vietnam had the highest energy intake (3023 kcal per day) among Southeast Asian countries. Therefore, there is a significant reduction in impact in all impact categories (HDS_1 and HDS_3) when the healthy diet scenario analysis is applied and 2300 kcal per day is taken as a benchmark for a healthy diet. As meat consumption in Malaysia is the highest in Southeast Asia, significant percentage decreases in all impact categories are found in all scenarios. Only Indonesia and Malaysia have significantly lower ecosystems impacts under HDS_2, as meat/meat products and spices are major contributors to ecosystems damage in the other countries. Timor-Leste, which had lower consumption than the reference value, is assumed to have increased its consumption. However, no significant increase in impacts was found.

Conclusions

This study has shown that differences in dietary habits across Southeast Asian countries have significant implications on human health, ecosystems, resources, and global warming. Vietnam, Myanmar, and Laos had the largest impacts, while Timor-Leste had the lowest impacts in all categories. In all countries, the consumption of fish and seafood, meat/meat products, and cereals caused high levels of harm to human health, while meat and meat products, coffee and tea, and spices damaged ecosystems. In terms of resource scarcity and global warming potential, grains, meat, and meat products topped the list of contributors to damage. On average, seafood consumption, grains, meat, and meat products contributed the most to impacts in all categories. Based on the healthy diet scenario analysis, total

consumption and reduction in meat consumption are the most favorable scenarios in terms of reducing the impact of meat, fish, and seafood, with cereal consumption contributing the most to all impact categories in Southeast Asian countries. After applying the three scenarios, Vietnam had a large reduction in impacts in all categories, followed by Indonesia and Malaysia. However, Timor-Leste found no significant impact decrease after applying the scenario analysis.

Although the consumption of meat, fish, and seafood contributes significantly to the impacts, the intake (2018) in the Southeast Asian countries was not high enough to reduce the consumption and develop the scenarios to achieve a healthy diet of 2300 kcal per capita per day from the consumption of these products alone. However, if the consumption of animals and animal products were reduced along with the consumption of cereals, this would lead to a significant reduction in impact in Southeast Asian countries. Therefore, future studies should consider only reducing the consumption of animals and animal products to determine the reduction in impact. [15] showed that meat contributed to 44% of GHG emissions in Vietnam in 2011, with pork and beef accounting for the largest share of meat GHG emissions impacts (both 220 kg CO_2 eq per capita per year). In this study, meat contributed to 46% of the global warming potential in Vietnam, with pork (200 kg CO_2 eq per capita per year) contributing more to the GWP impact of meat than beef (324 kg CO_2 eq per capita per year). It is recommended that governments take specific measures to reduce the consumption of animals and animal products and support meat substitutes (e.g., tofu, tempeh, beans, etc.). It is also recommended that, in collaboration with the public health and education sectors, a project be launched to educate and encourage citizens to adopt a balanced diet.

Besides cereals, meats, fish and seafood, coffee, and spices, alcoholic beverages also contributed to the environmental impacts, especially on resource scarcity and human health damage. Nevertheless, as the contribution of alcoholic beverages was not much significant among food groups, the influential food groups were only highlighted. However, from a health perspective, alcoholic beverages have risks in health. Excessive alcoholic consumption would lead to chronic diseases and other severe problems, including high blood pressure, heart disease, stroke, liver disease and various cancers (breast, mouth and throat, liver, colon and rectum, esophagus, voice box), learning and memory problems, mental health (depression and anxiety), and social problems [16]. Moreover, other food items such as sugar, oil, salt, etc., also have health risks. Consuming too much sugar has heart disease risk factors such as obesity, high blood pressure, and inflammation. Moreover, diabetes and the increase in the risk of dying from heart disease have been linked to high-sugar diets [17]. Conclusively, choosing vegetables over meats have benefits to the environment. Moreover, if it looks up from the health perspective, meats also play a non-negligible role that gives required protein to have healthy diets. Certain nutrients like iron can be dropped when meats are taken off from the diets. Iron plays as an importan nutrient which function to convey oxygen in the whole body for producing energy and chronic fatigue, hair loss, dizziness, weakness, headaches, pale skin and fast heartbeat symptoms can be found when the taken iron are not suffient [18]. Moreover, omega-3 fatty acids can primarily be achieved from fish such as mackerel, herring, sardines and salmon. Omega-3s are crucial for cardiovascular health, eye and brain function. Omega-3s from plant-based versions cannot efficiently give what humans required [19]. However, this study only highlighted related to environmental problems. Hence, future studies should consider the health perspective with the sustainable diet systems.

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