EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 14(1) 2021 52-62
DOI 10.14456/ea.2021.6
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Phosphorus Mass Flows: A Planning Tool for Food Waste Management in Pathumthani Province, Thailand

Manaporn Wongsoonthornchai and Bussarakam Thitanuwat*

Faculty of Public Health, Thammasat University, Pathumthani, Thailand

*Corresponding author: b.thitanuwat@fph.tu.ac.th
Received: August 22, 2020; Revised: October 1, 2020; Accepted: October 16, 2020

Abstract

Phosphorus (P) shortage has direct impact on Thailand's food security. Strategy focusing on increased resource efficiency and reduced P losses is becoming a challenge. P mass flows through food consumption system was performed in Pathumthani city. The purposes of this study are (1) to develop a P balance model using mass balance approach as a tool and (2) to identify and quantify the potential source for P recovery and recycle. Results of P balance showed that P of approximately 1,856 tons were entered to Pathumthani via food consumption system with 85% collection efficiency. Due to the insufficient wastes sorting, only 10% of P contained in food waste (FW) was utilized at composting center. The remaining P, amounted to 1,217 tons, was entirely ended up in landfill. This led to a clear conclusion that current FW practice is reducing the ability to recover P from waste since most of P was deposited in landfill. Therefore, recycling FW as well as P into a value-added product i.e. soil conditioner via composting process, the simplest alternative method for FW management, was recommended for this study. In addition, environmental and financial benefits gained from FW composting scenario were estimated. Recovery of about 1,217 tons per year into soil conditioning material, landfill emission reduction of 105 thousand tons carbon dioxide equivalent per year along with disposal cost saving of 6 million baht per year can be potentially achieved if FW was preliminary sorted at home.

Keywords: Phosphorus; Food waste; Mass balance; Waste management; Waste recycling

1. Introduction

Phosphorus (P) is an essential element for food production system. It is one of the main three nutrients most commonly found in fertilizers. P deficient in crops limit leaf expansion and reduce the number of leaves as well as slow the processes of carbohydrate utilization (Bryan, 2015). All agricultural production depends heavily on it and there are no substitutes for agriculture cultivation. However, phosphate rock (PR) mineral reserves which is used to manufacture phosphate fertilizers and industrial products, are controlled by only a few countries and will run out in the near future (Cordell *et al.*, 2009). In addition, a study on P modelling to predict phosphorus fertilizer demand has concluded that the mined P up to 23 Mt per annum (compared to 18 Mt in 2018) will increase by the end of this century (Helin and Weikard, 2019). While it has been estimated that only 20% of P in human consumption is recycled back to agriculture (Smil, 2000). This imbalanced reserve may lead to severe impact on phosphorus shortage including higher selling price and food security, especially in the countries with limited RP deposits which include Thailand.

Thailand has long been known as a Kitchen of the World due to the combination of having a year-round growing season and one of the largest net food exporting countries in the world. Currently, approximately 500 kilotons of P fertilizer accounting for 187 million USD was annually imported. P is not only used to produce food for human consumption but also animal feed. Study of Helin and Weikard (2019) have concluded that growing demand for livestock food products is one of the key factors driving the global phosphorus demand. Hence, the scarcity of global PR reserve could directly impact on Thailand's food security.

Food waste can occur at many stages in its production processes ranging from plantation, post-harvest handling, processing, distribution till consumption. Globally, one-third of FW arising from human consumption is lost or wasted without utilization, this significant proportion amounts to about 1.3 billion tons per year (FAO, 2011). Improper waste management i.e. uncontrolled open dump and non-sanitary landfill have adverse effects on the environment and human health. These include soil and water contamination, air pollution, unpleasant odor, a shortage of landfill space as well as P-losses during organic waste decomposition into soil and water bodies. Despite seeming to be a vulnerable and vital resource, accumulation of P-nutrient play an important role for water eutrophication in lakes, reservoirs, estuaries and rivers (Camargo *et al.,* 2005; Davis *et al.,* 2006; Paerl, 2009). Thus, developing P management strategy that focusing on increased resource efficiency coupled with reduced P losses would help to address both the environmental and resource scarcity issues. Thus, many researcher and local authorities have examined a practical approaches to managing FW (Agapios *et al.,* 2020; Filimonau *et al.,* 2020; Mak *et al.,* 2020).

Studies relevant to P management have been conducted in many countries. In Australia, Cordell *et al.* (2013) studied P flows through the food system and offered four key opportunities to deal with food crisis. One of the keys involved P use efficiency and P recovery. Findings from P flows performed in the UK food production and consumption system have concluded that in order to replace imported fertilizer, waste management should focus on P recycling from animal manure, food waste and sewage sludge (Cooper and Carliell-Marquet, 2013). As well as in Asian countries like China and Thailand, human food consumption contributed greatly to nutrient loading to the environments (Qiao *et al.,* 2011; Thitanuwat *et al.,* 2016)

Other studies related to P resource availability are investigated. These include P recovery and recycling from human urine, organic waste (Drangert and Olof, 2012), sewage sludge (Klinglmair *et al.,* 2017) and agricultural sector (Iho and Laukkanen, 2012). Especially for food, studies on the recovery of P from FW have been receiving more attention in many researchers (Nakakubo *et al.,* 2012; Li *et al.,* 2020)

Applications of Material Flow Analysis (MFA) and mass-balance approach in waste management are widely accepted as a tool for supporting environmental management. The model is based on the principle of mass conservation (Allesch and Brunner, 2015; Blikra *et al.,* 2018). This tool has been used for investigating flows and stocks of resources (Zhang *et al.,* 2017), analyzing pathway (Stanisavljevic and Brunner, 2014), understanding more about emissions and determining the net environmental benefits (Allesch and Brunner, 2017). Several studies, mostly related to waste management, have been applied this tool in order to deals with the complexity of interested substance or chemical. Villalba (2020) has revealed that MFA can be focused on goods (e.g. mixed waste or a waste category) and/or on substances (e.g. phosphorous) (Prathumchai *et al.,* 2018).

Since very little information on P flows in Thailand and it is important to sustain this P scarcity, understanding how it flows and where is the potentials source for recovery and recycling could help a lot for decision makers for a better P management to decide which step must be paid attention towards food security. The research objectives of this study are: (1) to develop a P balance model for the food waste management and (2) to identify and quantify the potential source for P recovery and recycle.

2. Methodology

2.1 Background information and case study

Pathumthani province is one of the cities located in the Central region of Thailand. Its area covers approximately 1,500 square kilometers which is divided into seven districts including Mueng Pathumthani, Khlong Luang, Thanyaburi, Nong Suea, Lat Lum Kaeo, Lam Luk Ka and Sam Khok. This province is comprised of several areas i.e. residential area, industrial area, agricultural area and also educational service area (Pathumthani, 2019). According to the provincial statistics during the year 2014 to 2018, the number of registered and non-registered population both living in urban and rural areas has a tendency on constantly increasing (NSO, 2019). In addition, the city has been accepted from many nature lovers since it was originally known as The Town of Lotus. Statistical data during the year 2014 to 2018 from the Ministry of Tourism and Sports (MOTS) shows that more than 18 million visitors (both Thais and Foreigners) have been travelled in the city annually. Those visitors can be divided into 2 groups; tourist and excursionist depends on the length of stay (MOTS, 2019). Due to the rapid urbanization and industrial expansion in the city resulting a tremendous amount of resources i.e. water, food and facilities have been consumed for their livings, at the same time, generating a high rate of solid waste including FW (Pokpong, 2018). As a results of population expansion together with continued high level of resource consumption leads to the limitation of land use for waste disposal site (Noinumsai and Wachirawongsakorn, 2017). Despite an inefficient solid waste management issue in Pathumthani has long been perceived, a proper and sustainable waste management is still a challenge (Kerdput, 1999). In this study, a P mass flow throughout the food consumption was conducted in Pathumthani provice. It should be noted that P consumers who contribute to the food consumption and FW generation were estimated from two groups of population. One is the Pathumthani's residents (both registered and non-registered habitants) and another is Pathumthani's visitors (including tourists and excursionist both Thai and foreigner)

2.2 Data acquisition

In order to perform a study of P balance, primary and secondary data in association with FW management in Pathumthani province i.e. number of residents, number of visitors, P intake rate, waste quantities, waste composition (i.e. plastic, food waste, metal etc.), existing waste management procedure as well as P content in FW were gathered from a numerous sources. Data sources used in this study are fiscal year book, statistic reports, operation records, publications, scientific paper, national and international statistics, waste disposal center and also laboratory. Data on waste quantities, operation cost, numbers of trucks and other resources were derive from waste recording questionnaire and reliable online database. Waste recording questionnaire developed for this study were hand-delivered and gathered from local officers who directly in-charge on waste reporting system. While data on management procedure ranging from source, transfer station to final disposal center was done by field survey, phone interview, master plan review, and employee inquiries.

Furthermore, FW samples of approximately thirty five samples were separately and randomly grabbed on-site in triplication over a five months period (during May 2019 - September 2019). The size reduction of collected FW samples generated from households, schools, supermarkets etc. located in Pathumthani from food preparation and leftovers after meals at home i.e. vegetables and fruit peels, fish bone, and etc. were achieved by coning and quartering technique. The process was repeated until the desired sample (20-30 kilograms per sample) is obtained. Then, FW samples were thoroughly shredded, air dried and packed prior being sent to an authorized laboratory. In this study, the spectrophotometric molybdovanadophosphate method was used for P analysis. Physical and chemical characteristics of FW samples, which comprised of organic matter, organic carbon, C/N ratio, nitrogen, phosphorus, potassium, pH, EC, moisture, calcium and magnesium, were determined. Other relevant data such as a mass balance key concept, conversion unit and P intake rate were taken from the literature related to P quantification.

2.3 P quantification framework

P mass balance analysis was completed following four steps. These include (1) defining the system border, (2) gathering the data, (3) applying the principle of mass balance and (4) interpreting the results. The system border of this study was defined in section 2.1. The second step is to gather all relevant data (see section 2.2) to be used for the quantification. Following by the application of mass balance, a schematic P diagram of incoming flow from food consumption through outgoing flows from FW management in Pathumthani were developed using mass balance as a tool. Lists of incoming, accumulating and outgoing flows considered in this study are summarized in Table 1. Last step, interpreted results from this study were reported using simple descriptive statistics i.e. mean, standard deviation, range, ratio, and percentage. Potential recovery and/or recycling of P was interpreted for a case study of Pathumthani city as well.

Table 1. Summary of incoming, accumulating and outgoing flows considered in this study.

P Flow*	Description
Incoming P flows	
F1	P consumption via food intake by local population who listed in the registration system
F2	P consumption via food intake by local population who not listed in the registration system
F3	P consumed by visitors (both Thais and Foreigners) who stay more than 24 hour
F4	P consumed by visitors (both Thais and Foreigners) who stay less than 24 hour
F5	P resulted from food consumption. It is including wastes from food preparation, leftovers, and other food waste discarded
Accumulating P flows	
F6	P in a fermented organic material utilized for plant growth
F7	P which can be collected by the local organization
F8	P which cannot be collected by the local organization
Outgoing P flows	
F9	P which is sent to sanitary landfill site
F10	P which is sent to disposed of in non-sanitary landfill site

Remark * P flows were drawn following the existing waste management in Pathumthanni province.

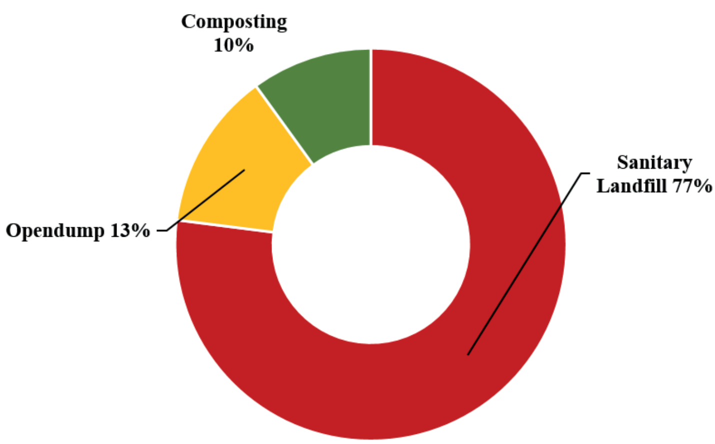

Figure 1. Proportion of FW management in Pathumthani province.

P contained in food can be separated into 2 parts; edible and non-edible. P in edible part was entered into human body via food eating while P in non-edible part, referred to FW, was discarded along with other solid waste in household. Quantification of P from food intake and food waste, therefore, were determined as an "Incoming P flows" for this study. Following by "Accumulating P flows", all flows of P relevant to FW management i.e. collection, transportation and source utilization were included in the consideration while P flows through FW disposal either sanitary or non-sanitary methods were grouped as "Outgoing P flows". A proportion of FW treatment and disposal is illustrated in Figure 1.

In order to estimate the P mass flows which comprised of incoming, accumulating and outgoing flows, the computation were calculated based on the following three equations. Equation (1) was used to quantify the quantity of P for the incoming flows from food intake (F1-F4) as follow:

$$P_{FCi} = N_i \times IR_i \times T_i \times 10^{-9} \ldots\ldots\ldots\ldots\ (1)$$

Where P_{FCi} is the total amount of P consumed in the food consumption system in any population group (e.g. residents and visitors) (tP/y); Ni is the number of population who contribute to the food consumption (residents and visitors) (capita/y); IRi is the rate of P intake for human (mgP/capita-d); and Ti is the duration of food consumption in any population group (e.g. residents and visitors) (day).

Calculation of other P flows following the FW management (F5-F10) can be estimated by the multiplication of the quantity of FW with their P content as shown in Equation (2)

$$P_i = Q_i \times C_i \ldots\ldots\ldots\ldots\ (2)$$

Where Pi is the quantity of phosphorus in any system i.e. consumption system, waste generation system, waste utilization system such as composting and/or waste disposal system (tP/y); Qi is the amount of FW in any system (ton/y); and Ci is the content of P in FW in any system (%P).

While the potential P recovery and/or recycling in Pathumthani can be computed using Equation (3) as below:

$$P_{potential} = P_{collected} - P_{utilized} \ldots\ldots\ldots\ldots\ (3)$$

Where $P_{potential}$ is the quantity of potential phosphorus to be recovered and/or recycled (t P/y); $P_{collected}$ is the quantity of phosphorus during the collection and transportation step in Pathumthani (t P/y); and $P_{utilized}$ is the quantity of phosphorus which already been utilized by composting and/or others (t P/y).

Additional details of data values i.e. number of residents, visitors, FW quantity, P intake rate, P content and etc. used to perform a P mass balance are summarized in Supplementary Information.

3. Results and Discussion

3.1 Food waste situation in Pathumthani city

Municipal solid waste (MSW) of over 1,500 tons/d (555 ± 41 thousand tons per year) was generated in Pathumthani province. The majority sources of MSW were households, hotels, restaurant, supermarkets, shopping malls, schools, universities, temples and etc. Based on the research survey conducted in the city, more than a half of this amount, accounting for 57 percent, was food waste. Indicating that Pathumthani people and visitors consume a variety of food, with a per capita wastage in the range of 0.23 - 0.29 kg per day (0.26 ± 0.03 kg per capita per day). The rate of FW in this study was lower than those measureable case in Chiang Rai, Thailand (0.38 kg per capita per day) since it is not consider only FW but also garden waste (Suma *et al.,* 2019).

Currently, approximately 85% of MSW generated in Pathumthani province which received from surrounding communities was capable to be collected and transported to the transfer stations. Thus, it is possible to estimate that a daily amount of 741 ± 55 tons of FW was collected from sources. Around 10% of FW amounted to 32 thousand tons per year was separated to compost. While the remaining 5% of FW was unable to collect due to the limited staff resources and working time compared to the solid waste volume of over thousand tons a day.

At transfer station, it should be noted that collected FW were occasionally mixed with other solid wastes during the collection and transportation owing to the fact as mentioned above. Therefore, several waste treatment and disposal such as composting, uncontrolled open dump, and landfilling (as illustrated in Figure 1) were applied to handle this great quantity of waste. However, for FW which might not be suitable for RDF production or incineration because of having high moisture content, hence, landfilling have been proposed as a final disposal method for this study.

Finding from data collection, 85% of collected FW were disposed of in sanitary landfill while the remaining (15%), accounting for 38 thousand tons were annually treated by non-sanitary such uncontrolled open dumping. Based on the existing situation, it can be concluded that the city has less contribution to FW utilization (composting) than FW disposal (landfilling).

Results from laboratory analysis found a 0.45% of P constituted in FW collected from Pathumthani province. Additional physical and chemical characteristics are summarized in Table 2. As with the P concentration, the value for FW found in this study was slightly higher compared to other studies (0.12 - 0.40%P) (Garcia *et al.,* 2005; Bernstad and la Cour Jansen, 2012; Thitanuwat *et al.,* 2016).

3.2 Phosphorus mass balance through the food consumption

The incoming P flows through food consumption in this study are consisted of two components; direct human consumption (food intakes) and food waste as a results of food preparation and leftover part. According to the survey records conducted in Thailand, the daily average per capita P intake throughout the food consumption stands at approximately 800 mg P (HISO, 2009). The quantification of P incoming flows from a varieties of P consumers; registered resident, non-registered resident, tourist and excursionist, as denoted in F1, F2, F3 and F4, respectively were found to be about 324 ± 8, 97 ± 2, 1.02 ± 0.07 and 1.00 ± 0.12 tP annually. While P incoming flow from FW generated in the city, denoted as F5, which can be estimated from the multiplication between the quantity of FW with their P content were found to be in the range of 1,310 - 1,577 tP/y (1,432 ± 105 tP/y). Therefore, a total of 1,855 tons of P, determined as P incoming flows were annually inputted to the food consumption system in Pathumthani.

Accumulating P flows refer to P flows related to FW management in Pathumthani city. P flows through the composting, collection and transportation and those uncollected part denoted as F6, F7 and F8, respectively were included in this group. As mentioned in section 3.1, only 10% of FW was utilized as compost whereas the largest portion

Table 2. Characteristics of food waste in Pathumthani province, Thailand.

Characteristics	Value (Mean ± SD)	Unit
Organic matter	73.85 ± 2.57	%
Organic carbon	42.84 ± 1.49	%
C/N ratio	11.2 ± 2.15	-
Nitrogen	3.86 ± 0.54	%
Phosphorus	0.45 ± 0.08	%P
Potassium	3.01 ± 0.95	$\%K_2O$
pH	5.16 ± 0.46	-
EC	13.65 ± 1.79	dS/m
Moisture	84.86 ± 6.19	%
CaO	2.92 ± 0.52	%
MgO	0.63 ± 0.15	%

(85%) of FW generated in Pathumthani has been collected. Hence, during this process, an estimated amount accounting for 1,217 ± 90 t P/y were sent to the MSW transfer stations without utilization. Since FW cannot be completely collected, P amounted to72 ± 5 tons which unable to collect was discarded at sources.

At the sorting station, non-recycling material including FW were sorted and wrapped prior being landfilled. As mentioned in section 2.3 and 3.1, Sanitary landfill and uncontrolled open dump were proposed as the final disposal method for FW. Therefore, "Outgoing P flows" mentioned in this study were encompassed with the flows of P which was either sent to sanitary landfill or dumped in an uncontrolled-opened spaces. Based on the results derived from waste recordings, more than 270 thousand tons of FW were disposed without recycling. Of which 86%, containing about 1,045 ± 77 tons P, were ended up in sanitary landfill (denoted as F9) while the remaining 14%, having 172 ± 13 tons P, were gotten rid of by uncontrolled open dump (denoted as F10). Likewise, findings from P quantification carried out in Bangkok and other countries have concluded that most of P in a variety forms of wastes were deposited in landfill (Baker, 2011; Li *et al.,* 2015; Thitanuwat *et al.,* 2016). Overall P mass flows through food consumption system in Pathumthani is illustrated in Figure 2.

Based on the results found in this study, it is possible to conclude that P of approximately 1,856 tons were entered to Pathumthani via food consumption system with 85% collection efficiency. Whereas only 10% of P generated was utilized. Thus, the potential P for recovery and/or recycling was estimated to be about 1,074 tons/y or equivalents to 883 mg $P.cap^{-1}.d^{-1}$. In comparison with the P consumption rate (1,525 mg $P{\cdot}cap^{-1}{\cdot}d^{-1}$), more than a half of consumed P through food consumption system in Pathumthani has potential for recovery and recycling.

3.3 Opportunities for P recycling in Pathumthani

Since sanitary landfill received almost the entire load of P, recycling FW as well as phosphorus into a value-added product is becoming a new challenge for Pathumthani province. Several experimental studies have conducted in order to recover P from waste materials (Idowu *et al.,* 2017; Leng *et al.,* 2019; Pinatha *et al.,* 2020). Also, waste composting is currently done in Pathumthani, therefore, co-composting of FW with other organic waste i.e. garden waste, the most local and simple method for waste recycling (Keng *et al.,* 2020) is recommended for this study.

As mentioned in section 3.2, an annual amount of 270 thousand tons of FW were ended up in landfill with the disposal cost in the ranges of 150 - 300 baht per ton.

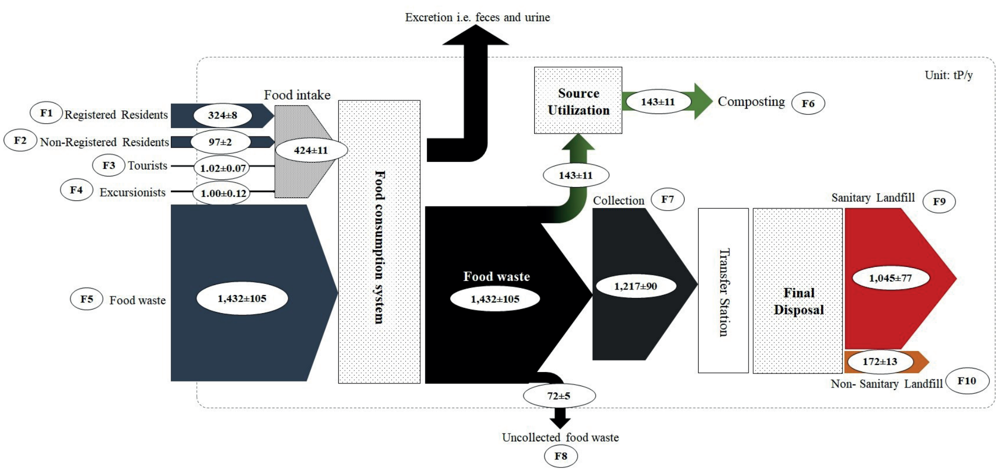

Figure 2. Overall P mass flows through food consumption system in Pathumthani, Thailand.

Table 3. Annual Benefits from FW Composting in Pathumthani

Benefits	Estimated values
Quantity of FW for composting	270,484 ± 19,923 tons[1]
Environmental benefits	
• Compost	81,145 tons of compost[2] with 1.5% P[3]
• Avoided landfill emission	105,489 tCO_2e[4]
Financial benefit	
• Landfill disposal cost saving (unit)	64 million bahts[5]

Remarks [1] Calculation is consider under the condition of collected FW was totally recycled into composting process [2] The compost yield was adapted from the study performed by Keng *et al.* (2020) is about 30%; [3] Value is estimated by applying the principle of mass balance; [4] Avoided landfill emission factor was taken from guideline provided by CEPA (2017) and [5] Waste disposal costs for Pathumthani city are approximately 250 and 150 baht per ton of waste for sanitary landfill and non-sanitary landfill, respectively.

The results below (see Table 3) show the potential benefits in case of FW was recycled as soil conditioner for agricultural uses. Assumptions and conditions from numerous sources were applied. However, it is better if food waste and other organic waste were preliminary sorted either at home or transfer station.

4. Conclusion

Since P scarcity has widely impact on food security in Thailand, especially for Pathumthani where more than half of the total area belongs to agricultural area and food production is relied on imported P-fertilizer. Quantification of P mass balance throughout food consumption system have been conducted to identify the priority management in Pathumthani city. Presently, a total P of approximately 1,856 tons, was consumed via food consumption system. Due to the insufficient wastes sorting, only 10% of P contained in FW was utilized at composting center. The remaining 85% without utilization accounting for 1,217 tons P was entirely disposed in landfill. This research led to a clear conclusion that current FW practice is reducing the ability to recover P from waste. The alternative management, composting, considered in this study offers the opportunities not only improving P recycling and reuse in Pathumthani area but also avoiding landfill gases emission and saving waste disposal cost. However, it is better if food waste and other organic waste were preliminary sorted either at home or transfer station. Based on the results found in this study, researcher should put emphasis more on in-depth analysis for food waste recycling coupled with a technology for P recovery.

Acknowledgements

This work is part of a 2018 research project, "Potential phosphorus recycling and recovery from wastes: A case study of Pathumthani province, Thailand" supported by Thammasat University Research Fund, Contract No. 9/2018. Data provision and assistance from anonymous officers at the Pathumthani's Department of Environment are also greatly appreciated. The authors would like to thank the anonymous reviewers for their incredibly thorough critique of the paper and extensive feedback.

References

Agapios A, Andreas V, Marinos S, Katerina M, Antonis ZA. Waste aroma profile in the framework of food waste management through household composting. Journal of Cleaner Production 2020; 257: 120340.

Allesch A, Brunner P. Material Flow Analysis as a decision support tool for waste management: A literature review. Journal of Industrial Ecology 2015; 19.

Allesch A, Brunner PH. Material Flow Analysis as a tool to improve waste management systems: The case of Austria. Environmental Science and Technology 2017; 51(1): 540-51.

Baker LA. Can urban P conservation help to prevent the brown devolution? Chemosphere 2011; 84(6): 779-784.

Bernstad A, la Cour Jansen J. Review of comparative LCAs of food waste management systems-current status and potential improvements. Waste Management 2012; 32(12): 2439-2455.

Blikra VE, Sanchez V, Thomsen M. A Review of waste management decision support tools and their ability to assess circular biowaste management systems. Sustainability 2018; 10: 3720.

Bryan GH. Phosphorus. Handbook of Plant Nutrition: CRC Press 2015.

Camargo J, Alonso A, Puente M. Eutrophication downstream from small reservoirs in mountain rivers of central Spain. Water research 2005; 39: 3376-3384.

CEPA. Method for estimating greenhouse gas emission reductions from diversion of organic waste from landfills to compost facilities. California: California Environmental Protection Agency; 2017.

Cooper J, Carliell-Marquet C. A substance flow analysis of phosphorus in the UK food production and consumption system. Resources, Conservation and Recycling 2013; 74: 82-100.

Cordell D, Drangert J-O, White S. The story of phosphorus: Global food security and food for thought. Global Environmental Change 2009; 19(2): 292-305.

Cordell D, Jackson M, White S. Phosphorus flows through the Australian food system: Identifying intervention points as a roadmap to phosphorus security. Environmental Science and Policy 2013; 29: 87-102.

Davis J, Koop K. Eutrophication in Australian rivers, reservoirs and estuaries – A southern hemisphere perspective on the science and its implications. Hydrobiologia 2006; 559: 23-76.

Drangert JO. Phosphorus–a limited resource that could be made limitless. Procedia Engineering 2012; 46: 228-233.

FAO. Global food losses and food waste-Extent, causes and prevention. Rome 2011.

Filimonau V, Todorova E, Mzembe A, Sauer L, Yankholmes A. A comparative study of food waste management in full service restaurants of the United Kingdom and the Netherlands. Journal of Cleaner Production 2020; 258: 120775.

Garcia A.J, Esteban M.B., Marquez M.C., Ramos P. Biodegradable municipal solid waste: Characterization and potential use as animal feedstuffs. Waste Management 2005; 25(8): 780-787.

Helin J, Weikard H-P. A model for estimating phosphorus requirements of world food production. Agricultural Systems 2019; 176: 102666.

HISO. Survey of Food consumption in Thailand. Thailand: Health Information System Development Office; 2009.

Idowu I, Li L, Flora JRV, Pellechia PJ, Darko SA, Ro KS, Berge ND. Hydrothermal carbonization of food waste for nutrient recovery and reuse. Waste Management 2017; 69: 480-491.

Iho A, Laukkanen M. Precision phosphorus management and agricultural phosphorus loading. Ecological Economics 2012; 77: 91-102.

Keng ZX, Chong S, Ng CG, Ridzuan NI, Hanson S, Pan G-T, Lau PL, Supramaniam CV, Singh A, Chin CF, Lam HL. Community-scale composting for food waste: A life-cycle assessment-supported case study. Journal of Cleaner Production 2020; 261: 121220.

Kerdput K. Selection of potential solid waste disposal areas in Pathum Thani province. Bangkok: Chulalongkorn University (Master's Thesis) 1999.

Klinglmair M, Vadenbo C, Astrup TF, Scheutz C. An MFA-based optimization model for increased resource efficiency: Phosphorus flows in Denmark. Resources, Conservation and Recycling 2017; 122: 1-10.

Leng L, Bogush AA, Roy A, Stegemann JA. Characterisation of ashes from waste biomass power plants and phosphorus recovery. Science of the Total Environment 2019; 690: 573-583.

Li B, Boiarkina I, Young B, Yu W. Substance flow analysis of phosphorus within New Zealand and comparison with other countries. Science of the Total Environment 2015; 527-528: 483-492.

Li B, Yin T, Udugama IA, Dong SL, Yu W, Huang YF, Young B. Food waste and the embedded phosphorus footprint in China. Journal of Cleaner Production 2020; 252: 119909.

Mak TMW, Xiong X, Tsang DCW, Yu IKM, Poon CS. Sustainable food waste management towards circular bioeconomy: Policy review, limitations and opportunities. Bioresource Technology 2020; 297: 122497.

MOTS. Domestic Tourism Statistics. Thailand: Ministry of Tourism and Sports (MOTS); 2019.

Nakakubo T, Tokai A, Ohno K. Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery. Journal of Cleaner Production 2012; 32: 157-172.

Noinumsai S, Wachirawongsakorn P. The Assessment of suitable sanitary landfills area in Uttaradit province by using Geograpic Information System. Naresuan University Journal: Science and Technology 2017; 25(3): 12.

NSO. Provincial Statistic Report. Thailand: National Statistical Office (NSO); 2019.

Paerl HW. Controlling eutrophication along the freshwater–marine continuum: Dual Nutrient (N and P) reductions are essential. Estuaries and Coasts 2009; 32(4): 593-601.

Pathumthani Provincial Office. History, topography and geography of Patum Thani province; 2019.

Pinatha Y, Polprasert C, Englande AJ. Product and cost perspectives of phosphorus recovery from human urine using solid waste ash and sea salt addition – A case of Thailand. Science of the Total Environment 2020; 713: 136514.

Pokpong S. Management of accumulated waste in disposal sites in Pathum Thani province Thailand: National Institute of Development Administration; 2018.

Prathumchai N, Polprasert C, Englande AJ. Phosphorus distribution and loss in the livestock sector – The case of Thailand. Resources, Conservation and Recycling 2018; 136: 257-66.

Qiao M, Zheng Y-M, Zhu Y-G. Material flow analysis of phosphorus through food consumption in two megacities in northern China. Chemosphere 2011; 84(6): 773-778.

Smil V. Phosphorus in the environment: Natural flows and human interferences. Annual Review of Energy and the Environment 2000; 25(1): 53-88.

Stanisavljevic N, Brunner P. Combination of material flow analysis and substance flow analysis: A powerful approach for decision support in waste management. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 2014; 32.

Suma Y, Pasukphun N, Hongthong A, Keawdounglek V, Laor P, Apidechkul T. Waste composition evaluation for solid waste management guideline in highland rural tourist area in Thailand. Applied Environmental Research 2019; 41(2): 13-26.

Thitanuwat B, Polprasert C, Englande AJ. Quantification of phosphorus flows throughout the consumption system of Bangkok Metropolis, Thailand. Science of the Total Environment 2016; 542: 1106-1116.

Vaccari DA, Strigul N. Extrapolating phosphorus production to estimate resource reserves. Chemosphere 2011; 84(6): 792-797.

Villalba L. Material Flow Analysis (MFA) and waste characterizations for formal and informal performance indicators in Tandil, Argentina: Decision-making implications. Journal of Environmental Management 2020; 264: 110453.

Zhang L, Chen T, Yang J, Cai Z, Sheng H, Yuan Z, Wu H. Characterizing copper flows in international trade of China, 1975–2015. Science of the Total Environment 2017; 601-602: 1238-1246.