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Sustainable solutions for solid waste management in Southeast Asian countries

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ABSTRACT

Human activities generate waste and the amounts tend to increase as the demand for quality of life increases. Today's rate in the Southeast Asian Nations (ASEANs) is alarming, posing a challenge to governments regarding environmental pollution in the recent years. The expectation is that eventually waste treatment and waste prevention approaches will develop towards sustainable waste management solutions. This expectation is for instance reflected in the term 'zero emission systems'. The concept of zero emissions can be applied successfully with today's technical possibilities in the agro-based processing industry. First, the state-of-the-art of waste management in Southeast Asian countries will be outlined in this paper, followed by waste generation rates, sources, and composition, as well as future trends of waste. Further on, solutions for solid waste management will be reviewed in the discussions of sustainable waste management. The paper emphasizes the concept of waste prevention through utilization of all wastes as process inputs, leading to the possibility of creating an ecosystem in a loop of materials. Also, a case study, focusing on the citrus processing industry, is displayed to illustrate the application of the aggregated material input–output model in a widespread processing industry in ASEAN. The model can be shown as a closed cluster, which permits an identification of opportunities for reducing environmental impacts at the process level in the food processing industry. Throughout the discussion in this paper, the utilization of renewable energy and economic aspects are considered to adapt to environmental and economic issues and the aim of eco-efficiency. Additionally, the opportunities and constraints of waste management will be discussed.

1. Introduction

Waste is the most visible environmental problem among many in urban areas in Southeast Asian Nations (ASEANs). This region has also been experiencing rapid urban growth since the late 1980s. Increasing population, changing consumption patterns, economic development, changing income, urbanization and industrialization result in increased generation of solid waste and also a diversification of the types of the solid waste generated. Increased waste generation creates more environmental problems in this area, as many cities are not able to manage wastes due to institutional, financial, technical, regulatory, knowledge, and public participation shortcomings. The consequence is environmental degradation, caused by inadequate disposal of waste. The impact of disposed waste is composed of: (i) the contamination of surface and groundwater through leachate; (ii) soil contamination through direct waste contact or leachate; (iii) air pollution through burning of wastes; (iv) spreading of diseases by different vectors like birds, insects, and rodents; (v) odor in landfills, and (vi) uncontrolled release of methane by anaerobic decomposition of waste. Although some governments have formulated policies for environmental protection, these policies have been implemented only in the national capital cities. In rural areas, open dumping is still the most commonly used method of solid waste disposal.

Waste cannot responsibly be dumped without due concern and preparation, because not only is it unsightly, unhygienic, and potentially disastrous to our environment, it also requires the allocation of space and incurs costs related to the consequences of the waste disposal. Moreover, suitable landfill sites are becoming more difficult to find as urban areas expand. Also, individuals are not willing to accept the implementation of a new landfill site near them because of concerns about smell, litter, pollution, pests and the reduction in the value of their homes. There are large costs involved in providing conveniently located and environmentally responsible landfill facilities.

In recent years, the notion of integrated waste management, applied to reduce waste at its source before it even enters the waste stream, has spread. It means that waste materials generated must be recovered for reuse and recycling, and the rest should be disposed at landfill sites. Unfortunately, disposal is not a sustainable solid waste management solution. Also, the zero emissions concept has arisen since the late 1990s. The concept is reflected by the phrase 'no time for waste' because the concept envisages all industrial outputs from processing being used as input process materials or converted into value added inputs for other processes, maximizing resource consumption and increasing eco-efficiency. In this way, the production process is reorganized into a closed loop system

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which emulates as an industrial metabolism of the sustainable cycles found in nature 'grown–use–waste–reuse'. Also, waste can be fully matched with the input requirements of any other processes. A perfectly integrated process management produces 'no waste' and it can be an innovative system of sustainable industry development, where reduction, minimization, and utilization of waste are simultaneously realized.

2. The state-of-the-art of waste management in the Southeast Asian Nations

2.1. What is waste?

Waste includes all items that people or companies no longer have any use for, which they either intend to get rid of or have already discarded. However, waste can also be a resource if it is put in the right place. Many items can be considered as waste, for instance household rubbish, sewage sludge, wastes from manufacturing activities, packaging items, discarded cars, discarded electronic devices, garden waste, old paint containers, etc. Thus all our daily activities can give rise to a large variety of different wastes arising from different sources.

Solid waste also includes wastes generated from residential, commercial, industrial, or institutional construction, as well as from demolition processes and municipal services. However, this definition varies greatly among waste studies, and some sources are commonly excluded, such as industrial, construction and demolition, and also commercial and municipal services.

2.2. Waste generation rates

Waste generation rates are affected by socio-economic development, degree of industrialization, and climate. Generally, the greater the economic prosperity and the higher the percentage of urban population, the greater the amount of solid waste produced. Table 1 and Fig. 1 show generation waste rates per capita as a weighted average of waste in ASEAN.

Malaysia generated an estimated 5475,000 tons of solid waste in 2001, which is about 0.81 kg/cap/day (Hanssan et al., 2001). This is much lower than the waste generation rate of 2.2 kg/cap/day in the USA and 1.5 kg/cap/day in European countries. The quantity of waste generated in Malaysia is comparable to that in Singapore in the same year, i.e., 5035,415 tons. However, Singapore's per capita waste generation rate is much higher (1.1 kg/cap/day) because it has a population of only 4484,000. In Singapore, solid waste is generated by domestic as well as non-domestic commercial and industrial activities. Approximately 1400 tons/day of this type of waste was generated, from which a maximum of only 9% can be processed. By 2012, the country wishes to have increased this proportion to 30% (National Environment Agency, 2001).

Vietnam generates about 49,134,000 tons per year (about 0.61 kg/cap/day). In the Philippines, an average of 36,172.50 tons of waste is generated per year, and the waste generation rate is 0.52 kg/cap/day (in urban areas) and 0.30 kg/cap/day (in rural areas). In Lao PDR, the average urban waste production is 0.55 kg/cap/day (Urban Development Sector Unit, 1999). The quantity of waste produced by Thailand in 2001 was 38,640 tons/day (approx. 0.64 kg/cap/day), an increase of about 470 tons/day compared to the prior year (Ministerial Regional Forum, 2007). Brunei, with a population of 383,000 persons, has a waste generation rate of 0.66 kg/cap/day, comprised of 22% paper, 44% food waste, 2% plastic, 5% metals, 4% of glass and 13% others (Ministry of Environmental Resource Development, 2006). In Myanmar, 10,526 tons of waste is generated per year, consisting mostly of organic waste; the waste generation rate is 0.45 kg/cap/day. With a population of 1 million, Cambodia had a waste volume of 450,963 m^3 in 2000 at a rate of 0.52 kg/cap/day) (Lwin, 2003). Fig. 1 displays the rates of waste generation for these ASEAN countries. Due to growing population and increasing consumption, solid waste generated in Indonesia went up from 16,200 tons/day in 2001 to 19,100 tons in 2005, at an average of 0.76 kg/cap/day. In Kuala Lumpur, waste generation is about 3000 tons/day. Determining the waste generation rate for various countries in ASEAN is problematic because very little information about rural waste generation rates is available. However, it can be assumed that rural populations will generate less waste because these areas have lower per capita incomes, and the composition of waste generated in rural areas is mainly agricultural. In contrast, urbanization and rising incomes, which lead to more use of resources and therefore more waste, are the most important trends that factor into rising waste generation rates.

2.3. Waste sources and composition

Waste composition is also influenced by external factors, such as geographical location, the population's standard of living, energy source, and weather. The most fundamental step in waste source management is quantifying and qualifying the different types of waste being generated. It is important to have a system for the collection, segregation, and analysis of basic information about wastes, for example, the sources of wastes, the quantities of waste generated, their composition and characteristics, the seasonal variations and future trends of generation. This is the best way to identify the method to treat waste, since municipal, industrial, agricultural, hazardous and toxic wastes, as well as wastewater, require different treatment methods.

Table 1
Selected basic and key ASEAN macroeconomic indicators.

Country	Total population (thousand)	Annual population growth (%)	Total land area (km^2)	Growth rate of gross domestic product (%)	Ratio of imports to GDP (%)	Waste generation rates (kg/cap/day)
Brunei	383	3.5	5765	5.1	12.9	0.66
Cambodia	14,167	2.1	181,035	10.8	40.3	0.52
Indonesia	222,192	1.5	1890,754	5.6	16.8	0.76
Laos	5747	2.2	236,800	8.3	16.7	0.55
Malaysia	26,640	2.0	330,252	5.9	81.8	0.81
Myanmar	57,289	2.3	676,577	7.0	17.7	0.45
The Philippines	87,099	2.1	300,000	5.3	44.1	0.52
Singapore	4484	3.3	704	7.9	180.1	1.1
Thailand	62,829	0.7	513,120	5.0	61.5	0.64
Vietnam	84,156	1.2	329,315	8.2	66.0	0.61
ASEAN	564,986	1.6	4464,322	6.0	61.0	

Source: ASEAN Financial and Marco-economic Surveillance Unit Database and ASEAN statistical Yearbook, 2006.
World Bank, 2001.

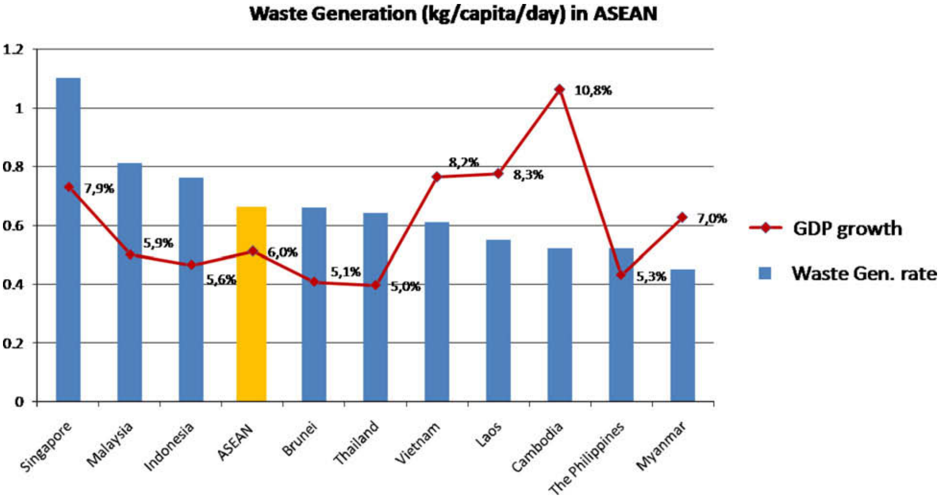

Fig. 1. Waste generation rates in the Southeast Asian Nations.

2.3.1. Municipal Solid Waste

Municipal solid waste (MSW) is generated by households, commercial activities and other sources whose activities are similar to those of households and commercial enterprises, for example, wastes from offices, hotels, supermarkets, shops, schools, institutions, and from municipal services such as street cleaning and maintenance of recreational areas.

It does not include other wastes, such as those arising from mining, industrial production or construction and demolition processes. The major types of MSW are food wastes, paper, plastic, rags, metal and glass, with some hazardous household wastes such as electric light bulbs, batteries, discarded medicines and automotive parts. In addition, waste composition, waste generators, and types of solid waste are found in Table 2. Also the composition of MSW typical of cities in Southeast Asian countries is presented. As can be seen, the largest fraction is paper and cardboard at 28% of the waste stream. The highly urbanized cities apparently generate a high percentage of organic and mixed inorganic waste (55–70%), with about 10–16% made up of plastic, approximately 4–10% of glass and about 4–12% of metal.

2.3.2. Industrial waste

Industrial waste is a type of waste produced by production activities such as that of factories, mills and mines. It has existed since the outset of the industrial revolution. Much industrial waste is neither hazardous nor toxic, such as waste fiber produced by agriculture and logging. Toxic waste and chemical waste are two designations of industrial waste. The manufacturing industry generates many different waste streams from a wide range of industrial processes. Some of the largest waste generating industrial sectors in Southeast Asian areas, especially in Singapore and Malaysia, include the production of basic metals, tobacco products, wood and wood products, and paper and paper products. An estimated 19 million tons of industrial waste were generated in 2000 in the Southeast Asian Nations (Hotta, 2007). Waste from the manufacturing sector continues to rise, despite national and international declarations to reduce waste from industry.

2.3.3. Hazardous waste

Hazardous waste arises from a wide range of different sources including households, commercial activities and industry. Hazardous waste represents approximately 1–3% of all waste generated in ASEAN. The estimate in 2000 for hazardous waste was three million tons. Wastes are classified as being hazardous waste depending on whether they exhibit particular characteristics.

2.3.4. Agricultural waste

Agricultural waste is composed of organic wastes (animal excreta in the form of farmyard manures, sludge, soiled water and silage effluent), plant residues (leaves, wood, branches and plant) and waste such as plastic, scrap machinery, fencing, pesticides, waste oils, and veterinary medicines. No overall estimates are available on the quantity of agricultural waste produced by agricultural activities in the recent years, but it is estimated that in

Table 2
Composition of municipal solid waste in Southeast Asian Nations.

Country	Waste composition (%)					
	Organic waste	Paper cardboard	Plastic	Glass	Metal	Others
Brunei	44	22	12	4	5	13
Cambodia	55	3	10	8	7	17
Indonesia	62	6	10	9	8	4
Laos	46	6	10	8	12	21
Malaysia	62	7	12	3	6	10
Myanmar	54	8	16	7	8	7
The Philippines	41	19	14	3	5	18
Singapore	44	28	12	4	5	7
Thailand	48	15	14	5	4	14
Vietnam	60	2	16	7	6	9

Sources: Solid waste management in Asia, 2000.
Waste management in Thailand (2007).
Solid waste management with a special attention to Malaysia (2001).

Table 3
The trends of municipal solid waste generation rate per capita by 2025 in urban ASEAN.

Country	GNP per capita (USD)		Population		Waste generation rates (kg/cap/day)		Predicted urban waste generation	
	1995	2025	Total (millions)	Urban (% of total)	Generation rates (kg/cap/day)	Total waste (tons/ day)	Municipal solid waste (kg/cap/day)	Total (tons/day)
High income								
Singapore	26,730	36,000	4.4	100	1.1	4840	1.1	4840
Middle income								
Malaysia	3890	9440	26.6	72.7	0.81	15,663	1.4	26,812
Thailand	2740	6700	62.8	39.1	0.64	15,715	1.5	36,738
Indonesia	980	2400	212.0	60.7	0.76	96,672	1.0	127,200
The Philippines	1050	2500	87.0	74.3	0.52	33,477	0.8	51,504
Low income								
Myanmar	240	580	57.3	47.3	0.45	12,118	0.85	22,891
Cambodia	220	700	14.2	48.6	0.52	3544	1.1	7497
Laos	350	850	5.7	44.5	0. 55	1379	0.9	2257
Brunei	260	750	383	59.0	0.66	149,140	0.95	216,931
Vietnam	240	950	84.0	39.0	0.61	19,983	1.0	32,760

Source: The state-of-the-art of waste management in Vietnam, 2003.
ASEAN statistical Yearbook 2003.
World Bank, 2001.

1999 agricultural waste was about 15% of all waste generated in ASEAN (Hsing et al., 2001).

2.4. Waste trends

Waste quantities are inextricably linked to economic activity, resource consumption, and economic growth. Economic growth in Southeast Asian countries is also driving urban growth rates, which are approximately 6–8% per year, a trend that is expected to continue for several decades. Because of increasing economic development growth, the trend in waste generation is predicted to increase. Waste generation trends are found in Table 3. They are estimated from economic trends, population predictions, and MSW per capita generation rates. Table 3 shows that waste generation rate will increase at approximately 0.3 kg/cap in the middle income countries such as Malaysia, Thailand, Indonesia, and the Philippines. The increase is largely a result of paper, plastics, bulky wastes, and another multi-material packing prevalent in the waste streams in the middle income countries. In Singapore, a high income country, the waste generation rate is predicted to stay relatively constant and then fall significantly to below its current level. In the other countries – Vietnam, Cambodia, Laos, Brunei, and Myanmar – the waste generation rate will increase by about four to six times the current amount. The basic difference between waste generation in the middle income and low income countries are the density of organic matter and the ash residues in waste streams, which, in the low-income countries, are higher. Moreover, the increasing percentage of plastic and paper materials in the waste stream will also contribute to the growing waste amount. Generally, the total amount of waste in ASEAN until 2025 is estimated to increase by about 1 million tons/day compared to the current waste quantities because of the growing path of economic development predicted (Inanc et al., 2004).

2.5. Where the waste goes?

Open landfill sites are the most popular solid waste treatment method in Southeast Asian countries. The open landfill has been applied to manage waste for many years, since it is a method which can solve the huge quantities of waste generated per day. This method is applied because it is generally the least costly cheapest and most common method to treat solid waste because of the percentage of organic material in waste. However, landfills in many places in ASEAN are mostly unsanitary open disposal sites, without a leachate management system, geo-membrane liner system at the bottom of the landfill, a clay-lined layer, a gaseous migration system, perimeter control, etc. Although the governments have started working to develop sanitary landfill sites in few urban areas, open dumpsites still remains the least costly and most effective solution to get rid of the mounting amounts of garbage. From a practical viewpoint, sanitary landfills are often located at distances too far from generators, compared to the open dumpsites within municipal limits. The sites far from the source of waste generation increase transfer costs and require additional investments for infrastructure as well. Moreover, waste is also often thrown directly into the waterways and rivers, or dumped at the roadside. Especially in the countryside, the amount of waste dumped openly is not known, without any environmental perspective plans. The reasons for these problems are lack of finance, land acquisition problems, and insufficient waste-collection and transfer system.

Besides this, incineration is also applied practically to treat waste. This method has been applied successfully in Singapore and other countries. For example, Malaysia has one municipal incinerator in a local township and has plans to establish another in Kuala Lumpur. Indonesia and Thailand also each have one municipal waste incinerator in their capital cities. However, controversy remains over the soundness of incineration, as it poses the problem of gas emissions from the incinerators. In particular, persistent organic pollutants (POPs-dioxins, furan, PCBs, hexane, etc.) are the compounds of concern. That is the reason why, for instance, in the Philippines waste incineration has been completely banned under recent laws on waste management.

2.6. How we are doing with waste in the ASEAN region?

We buy more and consume more; hence we create more waste. Waste management practices employed in the ASEAN region so far have been:

(i) *Landfill and open-dumping sites:* open dumping is the common practice for disposal of waste, for example, waste is dumped on swamplands and in low-lying areas. Approximately 50–80% of solid waste is collected each day, and then disposed in landfills or dumpsites. Unfortunately the capacity of the landfills is mostly surpassed due to a lack of waste management planning, so the environmental pollution (leachate, gas, odors, flies, vermin, and pathogens) poses serious problems.

(ii) *Incineration:* is one of the options for waste treatment in the ASEAN region. This method appears to be an extremely attractive option. However, operating efficiency depends on the waste characteristics as well as the waste composition. This method is agreed to be an inappropriate approach for most low-income countries due to the high financial start-up and operating capital requirements. Nevertheless, many incinerators still exist to treat medical and hazardous wastes. It seems that about 80–95% of medical waste is burned in the incinerators.

(iii) *Composting:* A somewhat more low-technology approach to waste reduction is composting. However, composting is not well practiced in ASEAN because, still, composting has not been overwhelmingly successful due to high operating and maintenance costs, the high cost of compost compared to commercial fertilizers, and the available market. Yet governments do support the treatment of organic waste by composting.

(iv) *Recycling or recovery:* In high income countries such as Singapore, about 44.4% of solid waste is recycled. In the middle income countries, the percentage of waste recycled is about 12%, and it is approximately 8–11% for the rest of ASEAN. However, recycled waste is mainly composed of plastic, paper, glass, rubber and ferrous. Recycling has been done by the separation of valuable materials by waste-pickers. They remove the most valuable materials, either before garbage enters the waste stream or en-route at households, especially in the lower and middle income areas of many municipalities. Then, waste-pickers sell recovered materials to the mills where waste will be recycled into new products. Waste recycling activity is popular in ASEAN because it is an economically viable undertaking. This undertaking is currently accomplished by medium-scale or household enterprises, and is predicted to grow where it offers a beneficial economic impact.

2.7. Food processing industry and food waste

The food processing industry is an important industry for the economic development in ASEAN due to the tropical climate as well as the divisible agricultural products. The food processing industry is a part of a complex and interlinked group of sectors because most food products must be transported, warehoused, and sold in the huge consumption network. Also, it is important because it can gain a significant economic influence on society. Table 4 shows agricultural products for ASEAN countries. The food industry is divided into two sectors (manufacturing and services) and four activities (processing, packaging, flavours, and storage). With tropical climate conditions, food industries in ASEAN focus on canned fruits, frozen vegetables, juices, and drinks, fruit, and vegetable sauces, cereal and flour milling, etc.

The food processing industry requires agricultural raw materials; derived primarily from crops, plants, and fresh fruits; as process input materials. At present, available data indicates that there are more than 500 agro-based food processing industrial sites in ASEAN. This industry is mostly dominated by state-owned enterprises. The main products are canned products (mango, pineapple, longan, corn, banana, papaya, lychee, and vegetable), beverages, milling products, and frozen vegetables. Unfortunately, besides the products, there are huge amounts of waste (solid, organic waste and wastewater). This volume is a source of serious environmental pollution regarding sanitary and environmental issues. The available data shows that if waste treatment and management methods have not been applied thoroughly, the negative impacts on the environment and on people will be very serious, especially the effects resulting from unsanitary conditions (fly larvae, soil contaminants, ground water pollution, pathogens, and odors) at open-landfill sites.

3. Sustainable solutions for solid waste management

Integrated waste management includes seeking management methods to reduce waste at its source before it even enters the waste stream. More especially, sustainable solid waste management aims to offer a chance to prevent waste through designs based on the full life cycle of the product, similar to natural cycles, which function without producing waste. Generally natural cycles are driven by the sun, which provides the energy for the system; the energy drives the photosynthesis process that orders atoms and molecules to higher value such as forest and food products. Dead matter is processed by microbes in the soil to become food for the next cycle (McDonough and Braungart, 2002). By this way, waste should, like any residue, be thought of as potential inputs for starting new processes. Waste materials that are generated must be recovered for reuse and recycling to reach the goal of 'using everything, nothing left'.

3.1. Sustainable production design – a case study on the citrus processing industry as a practice

3.1.1. Citrus processing production description

The operation of the citrus processing industry is divided into four stages: material, preliminary, primary, and product stages.

Table 4
Agricultural products (tons/year) in Southeast Asian Nations.

Country	Brunei	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Thailand	Vietnam
Cassava	2	142	17,055	71	380	97	1652	18,396	2806
Total Cereals	–	*4285*	*59,808*	*2446*	*2161*	*22,713*	*17,480*	*31,634*	*34,093*
Rice Paddy	–	4099	50,461	2335	2094	21,900	12,955	26,954	31,970
Maize	–	186	9347	112	67	524	4525	4466	2123
Coconut	–	70	15,164	–	700	275	13,208	1396	892
Coffee	–	0	527	26	20	2	132	85	841
Primary fruit	–		*8205*	*179*	*1014*	*1365*	*11,122*	*7671*	*4248*
Banana	–	146	3696	23	530	–	5061	1750	1126
Mangoes	–	35	844	3	20	–	884	1700	179
Pineapple	–	16	450	35	86	–	1620	1979	285
Rubber	–	39	1547	–	547	36	73	2424	313
Soybean	–	25	827	–	–	110	1	292	176
Sugarcane	–	169	–	3	1600	5894	24,962	60,013	14,657
Tobacco	–	5	134	–	9	48	48	64	31

Source: FAO Database website, 2003.

Material: Citrus fruits such as orange, mandarin, lemon, and grapefruit, which will be used for production activities, are harvested from the citrus yield. They must principally be fresh. Then they are transported to the plants, where the citrus fruits are loaded for weighing and recording before they are ready for production.

Preliminary stage: The citrus fruits are graded; debris is roughly removed at the first step in this operation. Here the citrus fruits are culled again for qualifying and sampling. Then, they are segregated to storage. The selection is carried out on a conveyor belt. After this operation, the citrus fruits are moved to the washing area. Water is supported and replaced continuously to clean the fruits.

Primary stage: This stage consists of four operations. Continuously, final grading is used to cull the fruits. Then, the fruit is sent to the juice extractors. Extraction is an important step in juice making. It can be done by way of blending, milling, pressing, and centrifugation. Here juice is heated to activate the pectic enzymes after the extraction step. The juice is transferred then into the syrup tanks for the processing step. It is mixed with acid citric, sugar, enzymes, pectic, and vitamin C in the syrup tanks for 2–8 h to obtain the best quality of citrus juice in this operation. Then the juice is transferred to the filters to produce pure juice (see Fig. 2).

Product stage: After the filter step, the juice will be filled into the bottles, boxes, and canes. Retort, seamier, and labeling are also done in this operation step. Then the fluid is boiled, to sterilize it from microorganisms that can be destroyed by heat. The cans holding the juice are kept in hot-water boilers for 10–15 min. Cooling will be done after sterilization. The products are quickly cooled to prevent overcooking to preserve sensory impacts and color, and to avoid steel erosion after sterilization. All processes are displayed in Fig. 3.

3.1.2. A zero emissions agro-based industrial ecosystem (AIZES) – methodology of AIZES model

The methodology for a model of a zero emissions industrial ecosystem is established having three basic steps. It starts with analyzing the material and energy flows that run through the industrial systems and partly end up in wastes (solid waste and wastewater), followed by analyzing various possibilities to prevent the generation of wastes in the second step. The third step concentrates on identifying, analyzing and designing potential offsite recovery and reuse options. It also entails the identification of remaining wastes in this step for treatment to follow a reasonable method towards the term of sustainable development.

3.1.3. AIZES model description

The AIZES model is introduced on a case study of medium-scale citrus processing in Ho Chi Minh city, Vietnam. The plant processes 30 tons of citrus fruit per day. The type of citrus fruit being processing depends on the season of the year. A chain route of citrus processing originates continuously from preliminary, primary, and secondary stages to final product processors for the consumer market. Production activities require input materials for the process, including citrus fruits such as orange, lemon, mandarin, and grapefruit. Besides, it also includes water, sugar, chemicals, and energy. The AIZES model starts from the analysis of the amount of citrus waste (peels) generated during the production. The material flow model is simulated in Fig. 4. In the model, water is supplied from a local well.

Wastewater, which is discharged from the production processes, has high concentrations of nitrogen, phosphorus, and potassium (N–P–K), and is treated in the wastewater treatment plant. Water, after treatment, meets the standard for discharge of industrial wastewater used for irrigation. Electricity powers all stages of processing, including conveyer transport, washing, grading, filling, seamier, retort, sterilization, and cooling. In citrus beverage production, the plant produces 7000 tons of citrus waste annually. This organic waste, which is frequently disposed in landfills or fed to cattle, is collected and used as input material for a digester in anaerobic fermentation. This fermentation with input material from citrus waste can produce biogas at a lower production cost, and is economically attractive. Biogas, which is a product of anaerobic digestion, can be used directly as gasification for lighting, cooking, and boiler demand in the factory. Another product is a type of N–P–K enrichment fertilizer, which can be used as plant fertilizer and sold in the market for ornamental horticulture and for use by homeowners.

3.1.3.1. Inputs of a zero emissions agro-based industrial systems. Nonwaste: Citrus waste generated from the production is collected, gathered, and then put into a digester for anaerobic digestion. The digester is fed with citrus waste, residues, livestock manure,

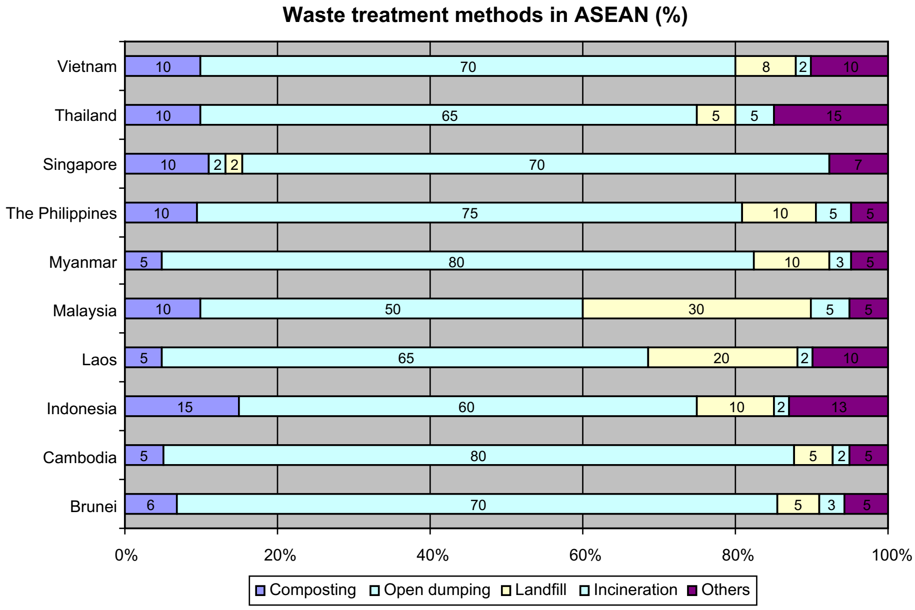

Fig. 2. Waste treatment methods in Southeast Asian countries.

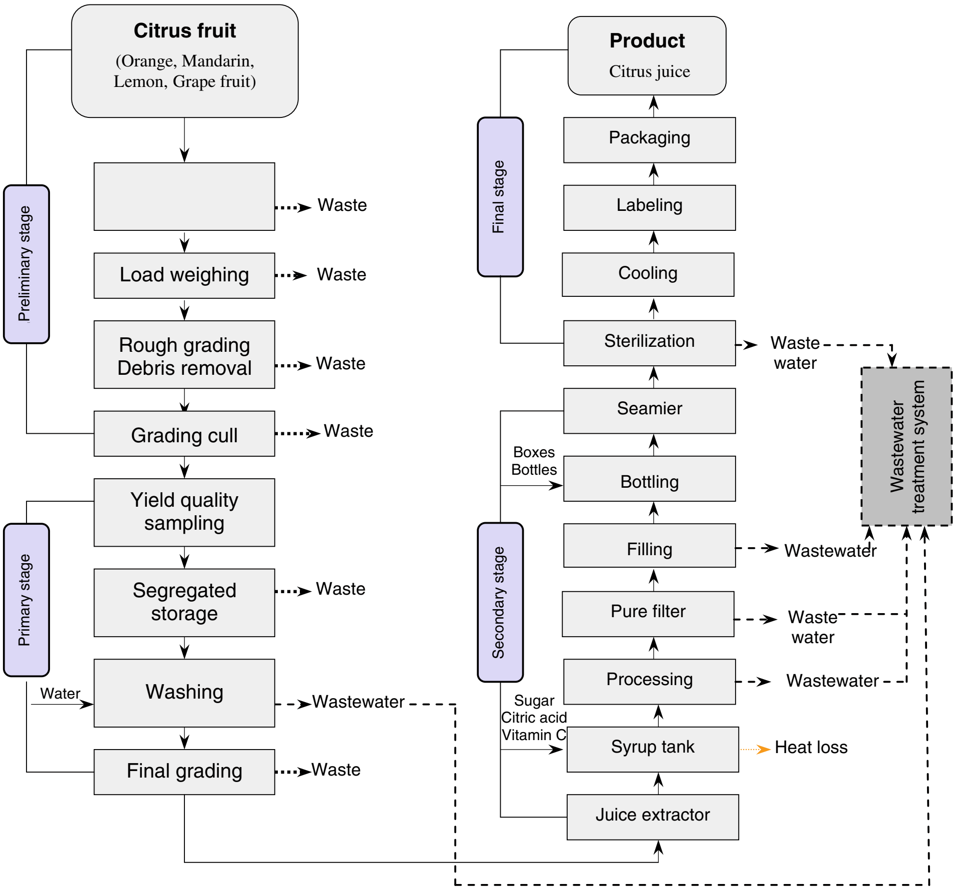

Fig. 3. Citrus processing industry in the Southeast Asian countries.

and sludge from a wastewater treatment plant. Approximately, 300 kg of waste is generated when 1 ton of citrus is processed.

Water and non-wastewater: Water consumption to process 1 ton of citrus fruit is approximately 15 m^3. It is used mainly for washing and processing. Water is mainly supplied from the local well, pumped at a rate of 450 m^3/day for the citrus beverage production. Wastewater is discharged, at approximately 450 m^3/day; it is collected and then piped directly to the wastewater treatment system. Part of the wastewater after treatment is used to mix the substrates in the digester for biogas production. Wastewater flows through the system using a combination of physical, biological and chemical treatment methods, to remove suspended solids, organic matter, and bacteria. Treated water meets the industrial standard B discharge and is reused for irrigation in agriculture.

Energy demand: Citrus processing uses energy for beverage preservation, safe packaging, and storage. Proper storage is also energy dependent. Cooling and sterilization are the most crucial steps of beverage storage, and require strict temperature control. The freezing operations require a large amount of electricity. Energy demand for the production consists of electricity at 97 kWh/ton of citrus fruit.

Outputs: Biogas and fertilizer: Corresponding to input materials of production capacity, outputs from sectors of the citrus beverage production were waste, odors, and air-polluted exhausts. However, the result measured for the odors from the production was within the exhaust industrial standard. The amount of solid waste produced was approximately 9 tons/day. In the AIZES model, the system outperforms its design goals by a significant margin; all citrus waste is used as either input substrates or, in the case of treated wastewater, as supply water for mixing substrates (waste and manure) in anaerobic digestion. Biogas conversion was efficient throughout the experiments (methane content was 70–80.05%). If possible, the gas is combusted in the factory in oil boilers, which transfers the thermal energy to oil-carrying media inside the combustion chamber. This is also one advantage from the AIZES model that if we can use the gas for combustion in boilers for energy, the costs for FO (fuel oil) payment will be less, bringing economic benefits from these savings. The sludge in the 4th layer in the digester can be used as a plant fertilizer, see Fig. 8.

3.1.4. Material balances of AIZES model

Material balances are fundamental to control production processes based on input–output balances from the model. The calculation of material and energy balances is based on material, waste, and energy. Material balances in this case study are formulated as the law of conservation of mass.

The basic formula is:

Total mass in – total mass out = mass accumulated

Then:

$$\sum m_R = \sum m_p + \sum m_w + \sum m_s + \sum m_L$$

In which:

$$\sum m_P = m_{P1} + m_{P2} + m_{P3} + \cdots + m_{Pn} : \quad \text{total products}$$
$$\sum m_w = m_{w1} + m_{w2} + m_{w3} + \cdots + m_{wn} : \quad \text{total wastes}$$
$$\sum m_s = m_{s1} + m_{s2} + \cdots + m_{sn} : \quad \text{total stored products}$$
$$\sum m_P = m_{L1} + m_{L2} + \cdots + m_{Ln} : \quad \text{total losses}$$

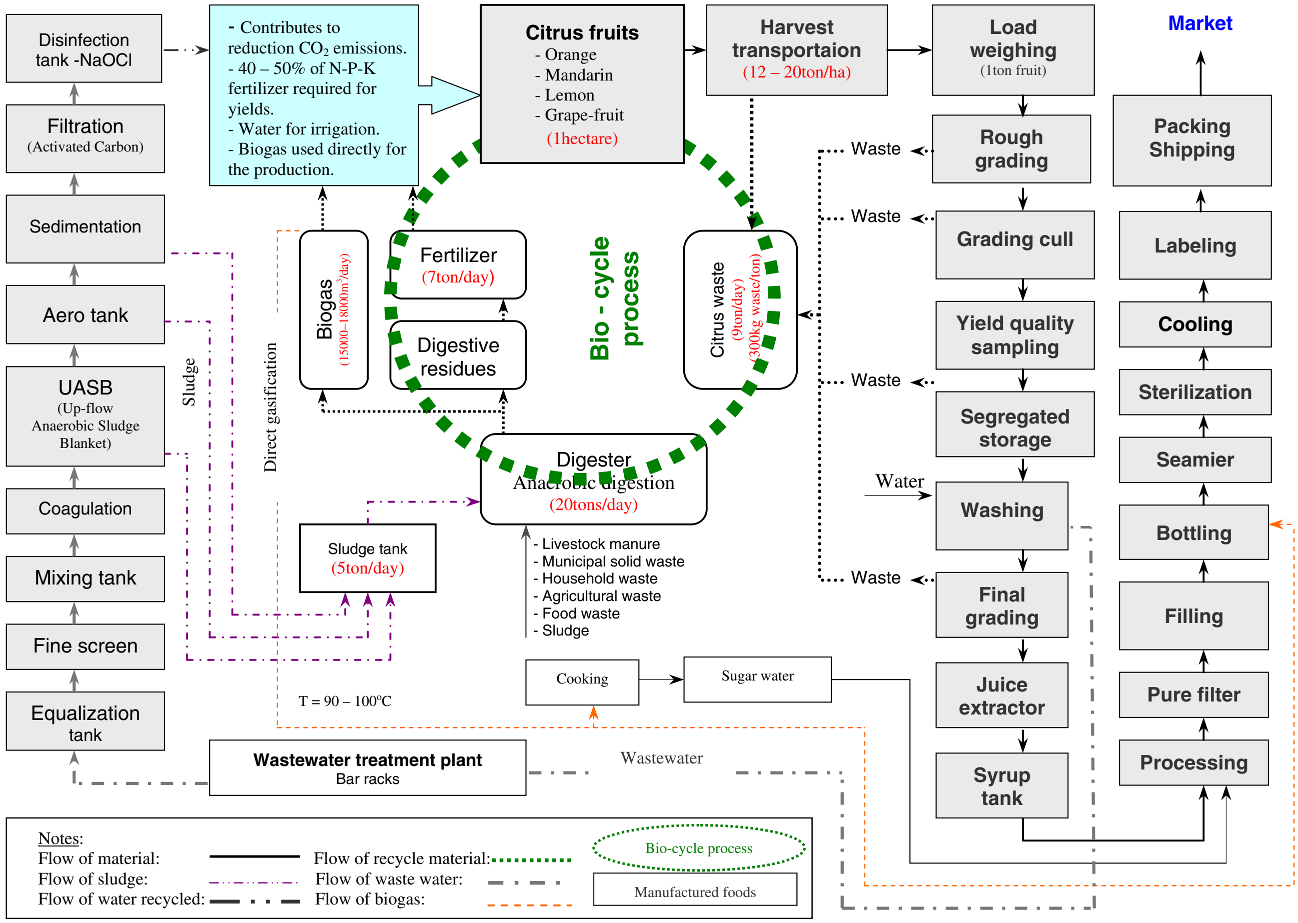

Fig. 4. AIZES model on the citrus beverage production.

Mass in

$$\text{Total water supplied} = \sum m_{\text{water}} = m_{\text{washing}} + m_{\text{w.can}} + m_{\text{filling}} + m_{\text{sterilization}} + m_{\text{cooling}} + m_{\text{process}} + m_{\text{others}} = 450 \ \ \text{m}^3/\text{day}$$

$$\text{Total citrus(orange)supplied} = 30 \text{ tons/day}$$

$$\text{Total waste} = \sum m_{\text{citrus}} + \sum m_{\text{others}} = 9 + 11 = 20 \text{ tons/day}$$

$$\text{Chlorine}: \quad \sum m_{\text{Cl}} = m_{\text{Cl,W.W.T.P}} = 300 \text{ kg/year}$$

$$\text{Total lemon} = \sum m_{\text{R}} = 2 \text{ tons/day}$$

$$\text{Acid citric} = \sum m_{\text{A}} = 2 \text{ tons/year}$$

Mass out

$$\text{Total citrus waste} = \sum m_{\text{citrus}} + \sum m_{\text{others}} = 9 + 11 = 20 \text{ tons/day}$$

$$\text{Total water for digester} = \sum m_{\text{mixing}} = 100 \text{ m}^3/\text{day}$$

$$\text{Total substrate loading}: \quad \sum m_{\text{Rloading}} = 30 \text{ tons/day}$$

$$\text{Biogas} = 15{,}000\text{–}8000 \text{ m}^3/\text{day}$$

$$\text{Fertilizer} = 30\% \times m_{\text{digestate residue}}$$

$$\text{Fertilizer mass} = 7 \text{ tons/day}$$

3.1.5. Energy balance

Energy balances are normally not simple because they can be inter-converted, for instance mechanical energy to heat energy, but overall the quantities must be balanced. As mass conserved, energy coming into a unit operation can be balanced by energy coming out and energy stored. In the AIZES model, the following are calculated for mass-in and mass-out in the citrus processing production, simulated in Fig. 5:

$$\text{Energy}_{\text{in}} = \text{Energy}_{\text{stored}} + \text{Energy}_{\text{out}}$$

$$\text{Energy}_{\text{stored}} = \sum E_{\text{E}} + \sum E_{\text{S}}$$

$$\text{Energy out} = \sum E_{\text{L}} + \sum E_{\text{P}}$$

In which:

E_{e} : total energy entering the process

$\sum E_{\text{S}}$: total energy stored

E_{P} : total energy leaving with the products

$\sum E_{\text{L}}$: total energy lost to surroundings

Then:

$$E_{\text{In}} = \sum E_{\text{E}} + \sum E_{\text{L}} + \sum E_{\text{P}}$$

In which:

$$\text{Total energy entering process} = \sum E_{\text{e}} = E_{\text{ecans}} + E_{\text{washing}} + E_{\text{extraction}} + E_{\text{coring}} + E_{\text{heating}} + E_{\text{eggrading}} + E_{\text{strilization}} + E_{\text{cooling}}$$

$$\text{Heat in cans} = E_{\text{h}}$$

$$E_{\text{h}} = 1500 \times 0.08 \times (100 - 40) \times 0.5 \text{ kJ/kg } ^{\circ}\text{C} = 3.6.10^3 \text{ kJ}$$

The weight of each box is 353 g, and the quantity of boxes used for 1 ton of fruit is 2833 boxes.

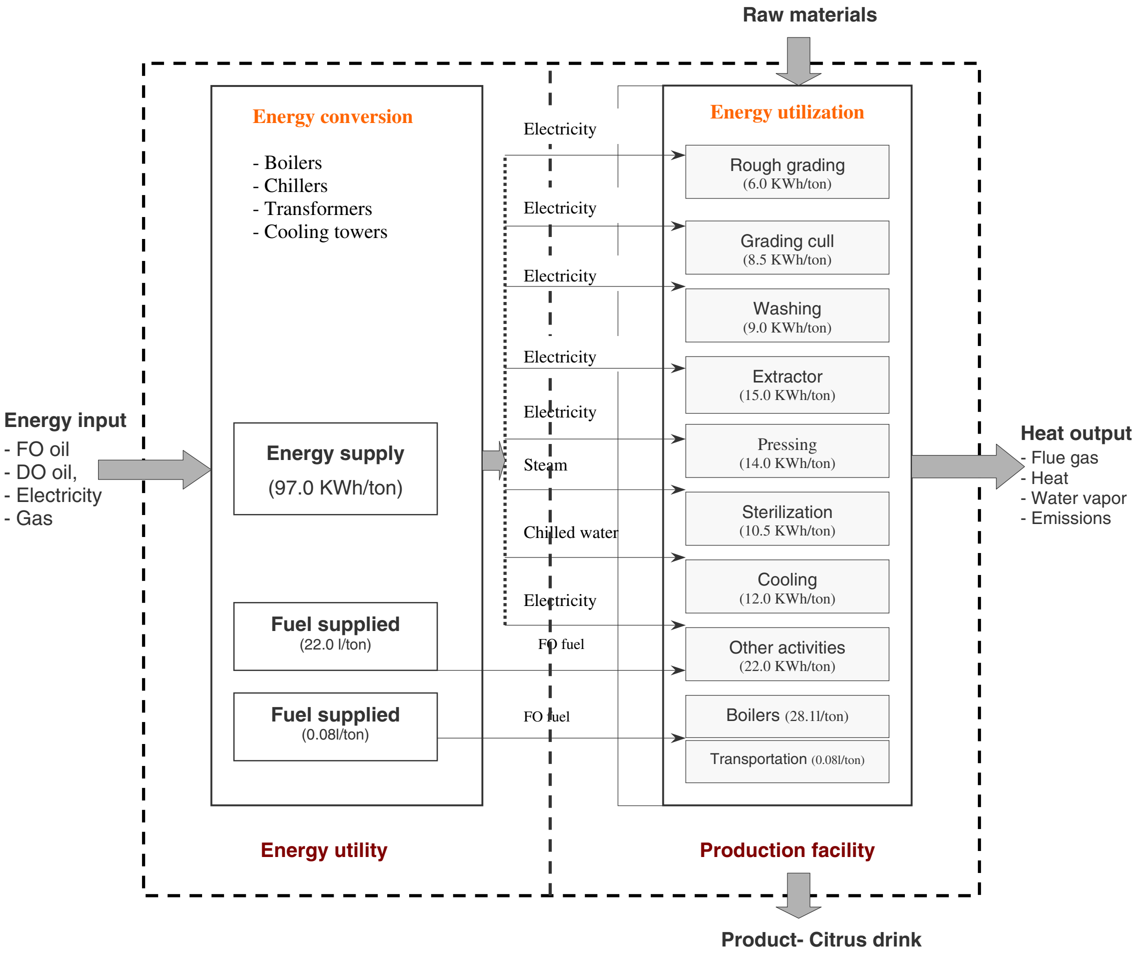

Fig. 5. Diagram considered for energy balance on canned pineapple production.

$$E_{\mathrm{ecans}} = E_{\mathrm{heat}} \times 2833/1500 = 6799.2\ \mathrm{kJ} = 1.8\ \mathrm{kWh}$$

$$\text{Total energy entering} = \sum E_{\mathrm{R}} = 1.8 + 8.3 + 12.1 + 10.0 + 14.0 + 10.5 + 12.0 + 16.0 = 84.7\ \mathrm{kWh/ton}.$$

$$\text{Total energy stored} = \sum E_{\mathrm{s}} = E_{\mathrm{s\ primary\ frozen}} = 3.49\ \mathrm{kWh/ton}$$

$$\text{Total energy leavings with products} = \sum E_{\mathrm{P}} = E_{\mathrm{P1}} + E_{\mathrm{P2}} + E_{\mathrm{P3}} \cdots + E_{\mathrm{Pn}} = E_{\mathrm{Plighting}} + E_{\mathrm{Pother\ act}}$$

$$E_{\mathrm{lighting}} = 108{,}000/360 \times 6080 = 0.05\ \mathrm{kWh/ton}$$

$$E_{\mathrm{Pother}} = (202{,}000 + 475{,}000)/360 \times 6480 = 0.29\ \mathrm{kWh/ton}$$

$$\sum E_{\mathrm{P}} = 0.05 + 0.29 = 0.34\ \mathrm{kWh/ton}$$

Total energy lost to surroundings:

$$\sum E_{\mathrm{L}} = E_{\mathrm{L1}} + E_{\mathrm{L2}} + E_{\mathrm{L3}} + E_{\mathrm{Ln}} = E_{\mathrm{Lboilers}} + E_{\mathrm{Lprocess}}$$

$$\underbrace{CH_4}_{\text{Methane}} + 2O_2 \rightarrow \underbrace{CO_2}_{\text{Carbon dioxide}} + 2H_2O + \underbrace{\text{Energy released}}_{\text{Heat}}$$

Radiation heat transfer losses at boiler:

$$q_{1-2} = \varepsilon_1 \times A_1 \times (T_1^4 - T_2^4)$$

where ε_1 is the emissivity, $\varepsilon_1 = 0.8$, A_1 is the surface area, q_{1-2} is the heat transfer losses at boiler, T_1 is the temperature measured at the surface and T_2 is the ambient temperature.

Basically, heat transfer is calculated as formulation (Guyer, 2001), but since it depends widely on surface area (vertical, horizontal surface temperature – upward facing or downward facing) and boilers, the way to calculate it will vary. For a boiler in the factory analyzed, heat input lost through the chimney was 9% and heat input lost through the boiler envelope was 1%.

$$E_{\mathrm{Lboiler}} = 0.293 \times 11.900/1000 = 3.49\ \mathrm{kWh/ton}$$

$$E_{\mathrm{Lprocess}} = 10\% \times 84.7 = 8.47\ \mathrm{kWh/ton}$$

Total energy to process each ton product:

$$\sum E_{\mathrm{In}} = 84.7 + 3.49 + 0.34 + 8.47 = 97\ \mathrm{kWh/ton}$$

3.1.6. Wastewater treatment system

The citrus processing operations discharge 450 m^3/day and generate a substantial amount of wastewater that is characterized by a high organic content, high strength chemical oxygen demand (9500 mg/l), biochemical oxygen demand (BOD) of 7500 mg/l, total suspended (TS) of 15000 mg/l and temperature of 30–40 °C.

The block-diagram in Fig. 6 simulates the citrus wastewater treatment system. The physical treatment method is applied first to remove coarse material by letting the wastewater flow through bar rack. Then the wastewater continuously flows into an equalization tank to control hydraulic velocity or flow rate. A fine screen is included inside the equalization tank to remove again the debris as well as solids. Flow equalization also controls the flow through each stage of the wastewater treatment system, allowing adequate time for the physical, biological, and chemical processes to take place.

After flowing into the equalization tank, wastewater is pumped into the mixing tank and coagulation tank to increase the removal of solids. This is a combined physical–chemical

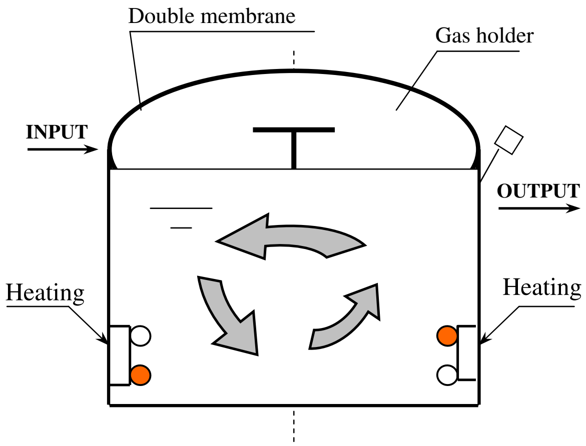

Fig. 6. A digester for anaerobic digestion.

wastewater treatment method. With the addition of specific chemicals, the solids become heavier than water gravity and will settle down. The process is known as chemical coagulation sedimentation. Poly aluminum chloride (PAC) is a chemical added to the citrus wastewater system. With PAC, the smaller particles clump together into large masses. Then, the large masses of particles will settle faster. The time for mixing is about 5–0 min, and the hydraulic detention time in the mixing tank and in the coagulation tank is approximately 15–20 minutes.

The UASB (up-flow anaerobic sludge blanket) and aeration tank can be considered as a biological phase in the system to remove up to 90–95% of the organic matter in the effluent. Then, the effluent flows to sedimentation tank. The sedimentation tank is also called a settling tank, a vessel in which solids settle out of water by gravity by pulling particles to the bottom of the tank. It is installed after the aeration tank. Effluent from the sedimentation tank is pumped into the AC (activated carbon) tower to purify the contaminant concentration through a bed of activated carbon, called a 'mass transfer zone'. This mass transfer zone is defined as the carbon bed depth reducing the contaminant concentration from the initial to the final level, at a given flow rate. Carbon is used as an adsorbent to remove a large variety of compounds from contaminated waters or toxic pollutants. The adsorption is a natural process by which molecules of a dissolved compound collect on and adhere to the surface of an adsorbent solid. Although the effluent is treated, it contains many types of human enteric organisms that are associated with various waterborne diseases. Disinfection can selectively destruct the disease-causing organisms in the effluent. The disinfection contact tank and the associated chemical dosing facilities will be designed to meet the *E. coli* criteria of $\leqslant$1000/100 mL (geometric mean). The chemical used to eliminate bacteria in the disinfection tank is NaOCL. NaOCl is pumped from the NaOCl drum to the efficient tank, where bacteria and *E. coli* are eliminated. The effluent is channeled into a clean water reservoir at a rate of 450 m^3/day, from where 350 m^3/day is going to be reused as irrigation water for agriculture or landscaping at the company, and 100 m^3/day is used in the digester. The calculation on the tank and architecture of the citrus wastewater treatment system is presented in Table 5.

3.1.7. Anaerobic fermentation – digester system

Anaerobic fermentation is a method introduced to the AIZES model. In the digestion progress, organic matter is digested in the absence of air to produce biogas. Biogas is a gas which is produced by micro-organisms in anaerobic digestion. The biogas consists of 50–70% methane, 20–25% carbon dioxide, and the rest is other trace compounds.

Anaerobic digestion progresses in four stages. The first stage is known as *Hydrolysis* where complex organic materials in solid forms are broken down by external enzymes into soluble forms. The second stage is *Acidogenesis* where the bacteria produce volatile fatty acids such as acetic acid, propionic acid, butyric acids, ethanol and others. Carbon dioxide and hydrogen will also be liberated in this stage. The third stage is *Acetogenesis.* H_2, CO_2 and NH_3 are by-products in this stage. *Methanogenesis* is the last stage, where the methanogenic bacteria utilize products of the second stage and convert them into methane.

A digester is used for the fermentation process (see Fig. 6). It consists of a mixing tank, sludge tank, an engine generator set and liquid storage. The digester is an in-ground concrete tank and coated by epoxy. When gas production has ceased, the digester is emptied and refilled with a new batch. The retention time in the digester is 28–35 days. In the first week, biogas was generated more slowly, but the yield was still released slowly until the end of the fermentation phase. Efficient digestion occurs at a pH near neutrality; the pH value was 6.0–8.0.

Biogas volume was measured at the batch reactor headspace by using a system pressure gauge. The biogas in the reactor headspace was released under water to prevent any gas exchange between the reactor and the air. Pressure was then measured a second time to provide an initial condition for the next day's test. The calculation on biogas yield in our experiment was 15,000–18,000 m^3/day. Biogas produced from the fermentation can be combusted for production requirements and lighting during the production processes. Gas of this quality can be used to generate electricity. It may be used as fuel for a boiler, space heater or refrigeration equipment, or it may be directly combusted as a cooking, lighting,

Table 5
Tank and architecture of the citrus wastewater treatment system.

Tank and architecture	Quantity	Dimension	Material
TK-101 EQ. tank	1 Basin	7.5M (L) × 4.0M (W) × 3.0M (D)/2.5M (SWD)	RC + epoxy coating
TK-103 mixing tank	1 Basin	2.5M (L) × 2.0M (W) × 1.5M (H)/1.5M(SWD)	RC + epoxy coating
TK-104 coagulation tank	1 Basin	2.0M (L) × 1.5M (W) × 2.0M (H)/1.7M (SWD)	RC + epoxy coating
TK-105 settle tank	1 Basin	3.5M (ψ) × 4.0M (D)/4.0M (SWD)	RC + epoxy coating
TK-106 buffer tank	1 Basin	2.0M (L) × 1.5M (W) × 2.0M (D)/1.5M (SWD)	Reforce concrete
TK-107 UASB tank	1 Basin	4.0M (L) × 3.5M (W) × 5.0M (D)/5.0M (SWD)	Reforce concrete
TK-108 extended aeration	1 Basin	6.0M (L) × 3.5M (W) × 4.5M (D)/4.0M (SWD)	Reforce concrete
TK-109 sedimentation tank	1 Basin	3.0M (ψ) × 3.5M (D)/3.0M (SWD)	Reforce concrete
TK-110 pumping Pit	1 Basin	1.5M (L) × 1.0M (W) × 4.0M (D)/4.0M (SWD)	Reforce concrete
TK-112 disinfection tank	1 Basin	2.0M (L) × 1.0M (W) × 2.0M (D)/1.5M (SWD)	Reforce concrete
TK-202 measure pit	1 Basin	1.0M (L) × 1.0M (W) × 0.8M (D)/0.6M (SWD)	
TK-204 collecting pit	1 Basin	1.5M (L) × 2.0M (W) × 1.5M (D)/1.5M (SWD)	Reforce concrete

Notes: L: the length, W: the width and D: dimension.
Source: Authors' calculation.

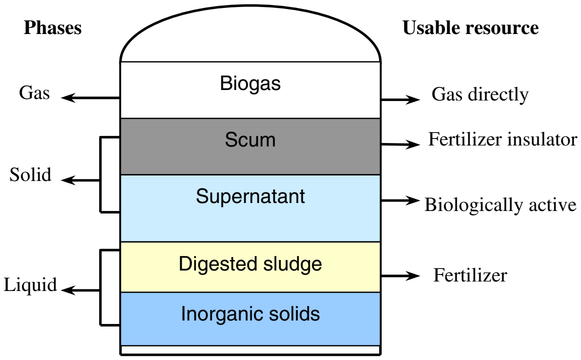

Fig. 7. The layers of a digester for fertilizer demand.

and fuel demand. The gas volume of each reactor was measured to determine the following equation:

$$V_{\mathrm{biogas}} = P \times V_{\mathrm{head}} \times C/R \times T$$

where V_{biogas} is the daily biogas volume (L), P is the absolute pressure difference (mbar), V_{head} is the volume of the head space (L), C is the molar volume (22.41 L mol^{-1}), R is the universal gas constant (83.14 L mbar K^{-1} mol^{-1}), and T is the absolute temperature (K).

The digester is sealed from the inside to prevent biogas leakage and insulated to maintain temperature. The separated liquids will flow to the storage by gravity, where the liquid is centrifuged and then used as fertilizer. The liquid fertilizer will flow to the concrete storage by gravity, where liquids are centrifuged and sold afterwards. The layers of the digester are simulated in Fig. 7. Most solids not converted into methane settle out in the digester as a liquid sludge used as a fertilizer for plants. With production capacity from the plant, the amount of fertilizer is estimated at approximately 7 tons/day. Although varying with the raw materials used (residues, food waste, swine manure, cow manure, chicken manure, MSW, or organic waste) and the conditions of digestion, this sludge contains many elements essential to plant life, e.g., nitrogen, phosphorus, and potassium, as well as small amounts of metallic salts (trace elements), calcium, copper, iron, magnesium, sulfur, zinc, boron, etc.

3.1.8. Economic considerations

Economic feasibility is one consideration in the decision to choose o between one option or another. In this case study, the economics of the system is also considered. It is calculated based on the costs for establishment, investment, and operation. In detail, it is shown by the calculation of the costs for the production, wastewater treatment system, start-up and operation a digester, as well as fertilizer production. Particularly, the costs for the citrus processing consist of the citrus purchasing costs, operation costs (cultural, labor, electricity, water, fuel, chemicals, etc.), cash overhead costs (office expenses, sanitation services, equipment, management, telephone, fax, etc.), and non-cash overhead costs (capital investment). The costs are described briefly in Table 6, where the profit per kilogram of citrus fruit processed is also calculated. The interest on capital is assumed at 3.5% and the increased cost of operation is 2%/year.

3.1.9. Discussion about the AIZES model

Solid waste management is an important part of urban management because it is linked directly to infrastructure, human health, and the urban and rural environment. The AIZES is a model in which industry and agriculture cooperate. The model looks at production progress towards sustainable development. The analysis and calculation of the AIZES model in our case study indicates that AIZES will be especially suitable for application to food processing industries that generate high amounts of wastes. The economic and ecologic advantages exceed the cost of implementation and operation shown in case study, which means that waste can be a resource. Its advantages can be listed by:

Table 6
Cost benefit analysis of AIZES model.

Items	Unit	Unit cost	Total cost (€/yr)
W.W.T.P	€/yr	99,640	14,880
Digester Start-up and operation	€/yr		32,500
Total costs			47,380
Fertilizer	kg/day	0.03 €/kg	75,600
Biogas	kWh/day	0.01 €/kWh	90,945
Profit	€/yr		119,165
Profit per day	€/day		331
Profit per ton	€/ton		11.03

(i) *Solves the huge amount of waste generated*: If waste is collected and treated using anaerobic digestion or composting, it not only saves the cost of waste disposal, it reduces pollution in the urban and rural environment. It also reduces the burden of disposal, in particular the land being used for landfill, environmental pollution by waste transport, odors, unsanitary conditions, contamination of the soil environment, leachate, etc. The odors from solid waste leachate in ASEAN landfills are very serious because of the high levels of ammonia.

(ii) *Supports sustainable development:* The concepts as well as the strategy of 'zero emissions' supports all three of the generally accepted goals of sustainability including environmental protection, economic sustainability and public well being. The AIZES model will enable organizations to identify the inefficiencies in production processes and to find cost saving solutions to them. A further enhancement is the replacement of fossil energy sources by renewable ones. Moreover, the zero emissions approach is proposing to improve material flows throughout the production processes, as well as enable low-CO_2 production.

(iii) *Supports economic benefits and saving money:* Since waste is a sign of inefficiency, the reduction of waste usually reduces costs. The criteria also include reductions in energy consumption, increased recycling, and reducing waste at the source, leading to economic benefits.

(iv) *Faster progress:* We realize that the concept of a zero emissions industrial ecosystem improves upon cleaner production and pollution prevention concepts by providing a visionary endpoint that leads us to take larger, more innovative steps. Because of the final goal, zero emissions ecosystem strategies lead to breakthrough improvements. This not only results in significant cost savings, greater competitiveness and reduced negative environmental impacts, it also will move more quickly towards sustainable development.

3.2. The solutions for solid waste management

3.2.1. Sustainable solutions for waste management are necessary in ASEAN

Our industrial system is primarily linear with a 'take-make-waste' process. It implies that materials are being transported to manufacturing sites, and then used to produce products; after that the products are transported to users, and finally discarded as waste at the end of product-life. This process implies that waste is generated. However, waste should not be disposed just anywhere. Sustainable solutions are what we are looking for because suitable landfill sites are becoming more difficult to find as urban areas expand, especially in the developing countries as ASEAN.

In ASEAN, waste management in the high-income countries such as Singapore is no longer a difficult problem because of its lower population and the application of high technology for landfills as well as composting, recycling, incineration, or anaerobic fermentation. However, in the rest of ASEAN, as middle or low income countries, waste management is a serious problem. Environmental pollution from the landfills is openly complained about by people living in ASEAN. For instance collection of MSW is inadequate in varying degrees – especially in the rural areas – waste is thrown directly into the river and waterways or is indiscriminantly dumped by the roadsides. Reasons for this are:

- lack of finance;
- lack of awareness of the environmental;
- inadequate solid waste management;
- lack of enforcement.

Many landfills are unsanitary landfills due to land acquisition problems, insufficient collection, disposal fees, and insufficient number of landfills. For example in Malaysia, 70% of waste is collected and disposed, while 20–30% is dumped illegally into rivers or is burnt. Many areas in the city of Phnom Penh, with a population of 1.2 million people, are still facing inadequate waste collection services. The waste is dumped into rivers and ponds, burned or left uncollected. In the case of Vietnam, it is estimated that only 70–80% of waste is collected in urban areas, while in Thailand about 75% waste is collected. Many landfills are unsanitary landfills. Examples in Vietnam are Go Cat in Ho Chi Minh city; Can Tho, Bac Lieu, Soc Trang, Tien Giang, Chau Doc, Kien Giang, Ben Tre, and Kien Giang in the Mekong delta areas; and Ninh Thuan, Binh Thuan, and Da Nang in different provincial areas. In many cities in Southeast Asia, MSW collection, treatment and disposal services have been privatized with government supervision. Wastes are deposited in government-owned landfills, which are managed by a private consortium. However, waste collection has just stopped at urban collection levels of approximately 70–90% and there are still many open disposal sites, which have negative effects on human health and the environment.

3.2.2. Key sustainable solutions for solid waste management in ASEAN

There have been many discussions on the progress of waste management methods to protect the environment towards the aim of 'sustainability'. Starting from disposal and end-of pipe treatment, the issue moved into waste prevention, waste minimization, cleaner production, and then approached zero emissions systems. Sustainable solutions for waste management are also based on this pathway. The starting point of these solutions can be identified by: (i) environmentally sound management of waste, and then (ii) applying zero emissions industrial ecosystems, including agro-based industrial systems. Of course reusing, recycling, composting, bio-digestion, bio-refineries, and bio-extraction are encouraged.

3.2.2.1. Environmentally sound management of waste. Environmentally sound waste management is considered as the first method approaching sustainable waste management solutions. This management is recognized by most countries as an issue of major concern, but especially in Southeast Asia since the waste is mostly organic. However, environmentally sound waste management must go beyond the mere safe disposal or recovery of wastes that are generated and must seek to address the root cause of the problem by attempting to change unsustainable patterns of production and consumption. Additionally, it should be realized by using the technical, organizational and financial resources available in a particular locality, followed by waste policy (waste hierarchy), waste planning, regulatory framework, and enforcement of the law. Particularly, waste management should be regulated by waste policies, in which waste prevention, waste minimization, reuse, recycling; environmentally safe waste treatment and sanitary landfilling are included. Another important component is waste planning and the co-ordination of other policies on national, regional and local levels; for instance, waste planning makes it possible to take into consideration the large number of different factors that have an impact on the waste management system.

Unfortunately, in the Southeast Asian Nations, waste treatment facilities are not strictly regulated regarding licensing, authorization and compliance with the law. This can be one of the main constraints related to waste management. Enforcement of the law to ensure the regulatory framework must be applied strictly. The method of paying for pollution generation should be respected strongly. Although it is not easy to change the entrenched practices related to waste management, enforcement of environmental laws for industry on liquid waste discharged, waste generated, and gases exhausted can be a promising approach.

3.2.2.2. Developing zero emissions industrial ecosystems. A brief expression of this concept is that 'waste = food'. It means that the zero emissions ecosystem approach is employed when returning 'residual products' as inputs to further processes in industrial closed loop systems. This may involve redesigning both products and processes in order to eliminate hazardous properties that make the residues unusable and unmanageable in quantities that overburden both industry and the environment. A foundation of zero emissions systems is provided by the concept of industrial metabolism, which stands for the whole integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes in a steady state condition. The concept offers a chance that waste can be prevented through designs based on the full life cycle of the product, therefore offering opportunities for reduced costs and reduced negative environmental impacts. Also, the concept of focusing on renewable resources (energy, materials, and resources) seeks to achieve a sustainable future.

The rationale to apply a zero emissions industrial ecosystem, particularly a zero emissions agro-based industrial system model, is based on the concept of solving the problem of large quantities of waste generated, saving money, reducing the negative impact on the environment, enhancing sustainability of the development (renewable energy, renewable resources) and faster progress, regardless of how large or small the industrial system, what kind of production activities are used, how homogeneous or heterogeneous, and even its location. Furthermore, if it is an agro-based industrial system, applying the AIZES model is generally possible because analyzing the material flow and seeking sustainable solutions for waste prevention and minimization support the direction towards 'there is no chance for waste'; in particular, capital costs for the model are not high. This is a special point of concern because ASEAN is comprised largely of the developing countries.

There is a belief that the economic development in ASEAN relies largely on agriculture and agro-based industries. Agriculture contributes about 25–30% of total export earnings, and the countries are now becoming self-sufficient in food crops. This means that food waste from the food processing industry can be a potential feedstock to produce renewable energy. This not only reduces the amount of organic waste disposed, but also increases the reuse of waste (organic, agricultural, manure, sludge and residues) for biogas conversion. Also, it can approach a fundamental avoidance of environmental degradation. The principle of using organic waste to generate energy (gas and electricity) seems practical due to the rising amount of waste generation as well as the over-reliance on fossil fuels. This direction will be a way of adapting to the term of ‘waste to renewable energy’ since the goal is to increase the bio-energy use, and greenhouse emissions reduction in the Kyoto protocol have been established in ASEAN.

3.2.2.3. Recycling of waste. As we know, waste recycling is not a new method because it has been applied successfully in many mills in ASEAN, particularly at those with small-scale or medium-scale production capacity. There is a wide range of products made from recycled plastic in ASEAN, including: polyethylene bin liners and carrier bags; PVC sewer pipes, flooring and window frames; building insulation board; video and compact disc cassette cases; fencing and garden furniture; water butts, garden sheds and composters; seed trays; fiberfill for sleeping bags and duvets; and a variety of office accessories. However, the demand for recycled wastes is high only for plastic, glass, cardboard materials, and some special metals. Approximately, 40% of plastic waste is disposed in landfills because of poor waste segregation, so recycling of plastic waste is one of many ways to reduce waste. Most plastics are non-degradable; they take a long time to break down, possibly up to hundreds of years although no one knows for certain as plastics have not been in existence that long. If increased quantities of plastics waste are generated, recycling of plastic waste can be a growing concern. It can be an open and attractive market for investment and development. Certainly, the regulations as well as guidelines for waste recycling must be respected and adhered to strictly. Regarding organic waste, recycling is not a beneficial economic and environmental trait. Organic waste should be used as feedstock for aerobic or anaerobic digestion because these methods are more cost-effective and environmentally friendly. The products of those processes, fertilizers and biogas, are useful products in countries that have an economy relying widely on agriculture.

3.2.2.4. Reusing waste. The preferable method for handling products with plastic composition is reuse, because this way uses less energy and fewer resources. Especially, the production of long-life, multi-trip plastic packaging in ASEAN should be focused on more because those types of plastic packaging can replace less durable and single-trip alternatives, such that waste is reduced. For instance, system supermarkets can increase their use of returnable plastic crates for transport. Plastic cans may last up to 10–20 year and can then be recycled at the end of their useful life. If reusing waste is applied successfully, the amount of plastic waste (cans, boxes, bottles, tools, packaging, containers, equipment, etc.) requiring disposal will be less, thereby lessening the burden on waste disposal. Additionally, it can reduce energy consumption and can save money.

3.2.2.5. Developing the production of bio-products. In recent years, sustainable waste management solutions have been sought to adapt to the natural cycle of materials and energy. Probably because of this, the production of bio-products is being considered; switching to plant-based plastics might be such an approach. Bio-plastic bags are made from plant or crop starch. After use, the packaging can be disposed together with organic waste. It can be broken down when exposed to sunlight. Degradable plastics have been used successfully in Austria, Sweden, Germany, and other developed countries for 3 year. In ASEAN sustainable waste management should consider bio-products because of their environmentally friendly traits as well as the different advantages. Huge amounts of waste, crop residues, and agricultural by-products and a variety of crops (fruit and vegetables for example) are being considerable for production of bio-products, as describes in Fig. 9.

4. Conclusions

Although the topic related to waste management, as well as the environmental pollution caused by waste, is not a new topic, the need for reasonable and sustainable waste management is one of the most common complaints, especially since there is a growing concern among the Southeast Asian countries about the increasing rate of waste generation due to varying income levels and extent of urbanization. Even though, there are a number of laws related to waste management; they do not address waste management in its entire spectrum in most countries. What is especially missing is legislation for storm waste management. The institutional framework for waste management in most ASEAN countries is unclear. Specific government agencies are mandated to manage different waste sectors but their roles and responsibilities are not clearly defined. In addition, lack of resources, notably financing, technologies, capacity and skills for waste management, are bringing the impact of waste to the forefront. We will have to deal properly with the difficulties in waste management as well as the limits of natural resources if we do not think about the solutions to control and replacing the utilization of resources from the environment by integrated waste management. A vision of zero emissions ecosystems can offer a solution which will be a key of sustainable development to our grandchildren’s future – zero solid waste and zero wastewater. More especially, the use of an endpoint goal of ‘zero’ can promote not only ideas of material reuse and recycling, but also prevention and redesign along the entire product life cycle. The opportunities of waste management towards a zero emissions approach can be applied successfully because of its advantages as demonstrated in the AIZES model. For example, implementation will reduce high amounts of both liquid and sold waste. It can use waste from industry or by-products as input for anaerobic digestion. Biogas produced can be reintroduced to meet the requirements for production and lighting. This promises CO_2-free production and minimization of greenhouse effect gases. Moreover, fertilizers can also be used for agriculture. In addition these designs in AIZES will also strive for reduced materials use, use of recycled materials, renewable energy and more benign materials.

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