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Original Article

Sustainability assessment for Thai mango: The environmental impact and economic benefits from cradle-to-grave

Narissara Jantuma[1], Sukhum Ruangchai[2], Chavis Ketkaew[1], Phaninee Naruetharadhol[3,*]

[1] *International Technology and Innovation Management Division, International College, Khon Kaen University 123 Mitrphap Road, Khon Kaen 40002, Thailand*

[2] *Department of Physics, Faculty of Science, Khon Kaen University, Khon Kaen 40002, Thailand*

[3] *Center for Sustainable Innovation and Society, International College, Khon Kaen University 123 Mitrphap Road, Khon Kaen 40002, Thailand*

ABSTRACT

This study provides an evaluation of the environmental impact and economic benefits associated with the disposal of mango waste in Thailand, utilizing the methodologies of life cycle assessment (LCA) and cost-benefit analysis (CBA) in accordance with internationally recognized standards such as ISO 14046 and ISO 14067. The study aimed to assess the environmental impact of mango production in Thailand, with a specific focus on its contribution to global warming. This was achieved through the application of a life cycle assessment methodology, which enabled the determination of the cradle-to-grave environmental impact, including the estimation of the mango production's global warming potential (GWP). Based on the findings of the feasibility analysis, mango production is identified as a novel opportunity for mango farmers and environmentally conscious consumers. This is due to the fact that the production of mangoes of the highest quality is associated with a carbon footprint and other environmental considerations. Based on the life cycle assessment conducted on conventional mangoes, taking into account greenhouse gas (GHG) emissions, it has been determined that the disposal of 1 kg of mango waste per 1 rai through landfilling results in an annual emission of 8.669 tons of carbon. This conclusion is based on comprehensive data collected throughout the entire life cycle of the mangoes. Based on the available data, it can be observed that the quantity of gas released through the landfilling process of mango waste exhibits an annual increase in the absence of any intervening measures. The cost benefit analysis conducted on the life cycle assessment (LCA) of traditional mango waste has demonstrated that the potential benefits derived from its utilization are numerous. The utilization of the life cycle assessment (LCA) methodology and the adoption of a sustainable business model exemplify the potential for developing novel eco-sustainable products derived from mango

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*CORRESPONDING AUTHOR
Phaninee Naruetharadhol, Center for Sustainable Innovation and Society, International College, Khon Kaen University 123 Mitrphap Road, Khon Kaen 40002 Thailand
phaninee@kku.ac.th

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waste in forthcoming time.

KEYWORDS

life cycle assessment; cost-benefit analysis; mango wastes; landfill; sustainable development goals

1. Introduction

Economic and environmental consequences of food loss and waste (FLW) are numerous. FLW is defined by the United Nations Food and Agriculture Organization (FAO) as the discarding or other use of food that was voluntarily fit for human consumption but spoiled or expired due to negligence (FAO, 2015). Globally, FLW amounts to 1.3 billion tons per year. Each year, FLW produces 4.4 Gt of greenhouse gases (GHG) based on "carbon footprint" calculations. Anthropogenic GHG emissions amount to 8% of global emissions (FAO of the UN, 2015). Developing countries suffer 40% of their losses after harvest and during processing (WFP, 2020). Waste management is a challenge in Thailand. Open burning and open dumping accounted for approximately 20% of the total amount collected (PCD, 2016). The Thai government introduced the 3Rs (Reduce, Reuse, Recycle) in 2016 for all stakeholders: civilian, public, and industrial. Due to an underdeveloped food waste treatment system, inadequate financial incentives, and an absence of a viable market for food scraps, the success of the project has not been archived (Righi et al., 2013; Rotthong et al., 2023).

Mangos (Mangifera indica L.) are one of the most important tropical fruits in 2020, with global exports increasing by 2.9 percent, and 60,000 tons, from the previous year. The global shipments of mangoes continue to make up nearly 90% of all exports (FAO, 2021). Globally, mangoes grow on about 3.7 million hectares (Jahurul et al., 2015).

The geographical location of Thailand makes it one of the best places in the world for mango cultivation and production. As mangoes are capable of growing in a wide range of environments, Nam Dok Mai (NMD) is the most demanded variety for export (Lui, 2019). Approximately 903,311.82 tons of mangoes will be produced annually on over 913,887 rai (1 rai = 1600 square meters) by 2021, according to Trade Policy and Strategy Office. A total of 113,806 tons of fresh mangoes worth THB 2934.61 million will be exported. The largest mango acreage is in Phitsanulok (102,712 rai), followed by Chiang Mai and Loei (74,409 rai and 51,435 rai, respectively) (TPSO, 2022). Over 80% of the cultivated land is dependent on natural rainfall in the northeastern region of Thailand, compared to other areas. Taewichit et al. (2013) report that the average annual rainfall (1971–2009) is 1044 mm, which is conducive to mango cultivation. Mangos are therefore considered another important cash crop in Thailand.

Mango is consumed both as fresh fruit and in a variety of processed and packaged forms such as juice, nectar, puree, ice cream, jam, preserves, chutneys, etc. (Alañón et al., 2019), but at the end of consumption, the peel, seeds, and kernel are discarded as waste. the kernel accounts for 20–60% of the fruit weight, and 30–60% of the waste is generated during the production process, with the peel accounting for 12–20% and the kernel for 10–25% (Lim et al., 2019; Mwaurah et al., 2020; del Pilar Sánchez-Camargo et al., 2021; Torres-León et al., 2017). Most often, it is stored in a landfill or burned (Zhao et al., 2012), which is more expensive because the husk contains a lot of moisture (Banerjee et al., 2016). This agro-industrial waste has a high biological oxygen demand and pollutes the environment. It is a significant source of unpleasant odor and soil pollution, which can contribute to microorganisms and insects polluting the environment (Goel et al., 2020). Apparently, only about 20 million tons of these wastes is disposed yearly, which causes water and air pollution, damage to plants, and the release of GHG (Castañeda-Valbuena et al., 2021; Mutua et al., 2017; Sáyago-Ayerdi et al., 2019).

As a fresh fruit as well as in processed and packaged forms such as juice, nectar, puree, ice cream, jam, preserves, chutneys, etc., mangoes are consumed, but the peel, seeds, and kernel are discarded (Alañón et al., 2019). As much as 20–60% of fruit weight is made up of kernels, and 30–60% of waste is generated during the production process (Lim et al., 2019; Mwaurah et al., 2020; del Pilar Sánchez-Camargo et al., 2021; Torres-León et al., 2017). The husk is usually burned or disposed of in a landfill (Zhao et al., 2012), which is more expensive because it contains a lot of moisture (Banerjee et al., 2016). Agro-industrial waste pollutes the environment with a high biological oxygen demand. This is one of the biggest sources of unpleasant odors and soil pollution in the environment (Goel et al., 2020). It is estimated that only about 20 million tons of these wastes is disposed of yearly, resulting in water and air pollution, plant damage, and greenhouse gas emissions (Castañeda-Valbuena et al., 2021; Mutua et al., 2017; Sáyago-Ayerdi et al., 2019).

The growing demands of a rapidly developing world have made it difficult to achieve environmental sustainability. In September 2015, the United Nations (UN) passed the Sustainable Development Goals (SDGs), which promote 17 goals for a sustainable environment. People, planet, prosperity, peace, and partnership goals (UN, 2015). For pursuing sustainable development, the circular economy (CE) has emerged as a crucial model. With the goal of creating a closed-loop system, this model emphasizes reducing waste and reusing and recycling resources (Bakker et al., 2014; Bocken et al., 2014; EMF, 2013; Rashid et al., 2013). The paper provides an overview of the aspects of (9) Industry, innovation and infrastructure (12) Responsible consumption and production, and (13) Climate action in addition to the 17 goals.

An LCA is an analytical tool that measures how products, processes, and technologies affect the environment over time. LCA analyzes all stages of a product's lifecycle, from the gathering of raw materials to its eventual disposal. In this methodology, all aspects of the life cycle are considered, including resource use, emissions, and potential impacts on human health and the environment. In product design, process optimization, and policy development, LCA is widely recognized as an important decision-making tool (Christensen, 2011; Guinée et al., 2011). Analyzing mango waste generated in Thailand according to international standards (ISO 14046 and ISO 14067) and conducting a cost-benefit analysis is presented in this study.

2. Literature review

2.1. Context of sustainable development goals (SDGs)

In September 2015, the United Nations adopted a blueprint for Sustainable Development Goals (SDGs), containing 17 goals and 169 targets. Global goals were developed to address pressing environmental, political, and economic issues facing our planet (Gigliotti et al., 2019). As previously abnormal inequalities within and between countries became more commonplace, sustainable development was created in an effort to change people's perception of the planet. Poverty increased, especially in developing countries, the ozone layer was damaged, natural resources were depleted, and many animal and plant species were endangered, air and water were polluted, and more (Hajian and Kashani, 2021). Sustainable practices must be incorporated into business operations in order to achieve these goals. Using tools like LCA can help companies improve sustainability in the long run.

2.2. Life cycle assessment (LCA)

According to Christensen (2011), consumers began to question the environmental impacts of the food they consumed in the early 1980s. The incorporation of a life cycle perspective into environmental assessment has led to a whole new field of study, LCA. Since then, this concept has become widely implemented in industry to reduce environmental impacts throughout the supply chain (SPC) from production to disposal. Environmental impacts of waste management have also been better understood through LCA in the last decade. In Europe and North America, the manufacturing and packaging industries were the first to benefit from the LCA methodology, which was later applied to the agricultural sector (Guinée et al., 2011). For decades, LCA has been the main method for assessing the environmental impact of human activities at every stage of the SPC (Basset-Mens et al., 2018).

LCA is an analysis tool described in two standards from ISO (the standards ISO 14040 and 14044, respectively) and consists of 4 steps: Definition of objective and scope, inventory, impact assessment, and interpretation. The agricultural sector LCA considers global warming, acidification, eutrophication, and depletion of fossil, phosphate, and potash resources (Brentrup et al., 2004). Because agricultural and food production systems are inherently variable, the application of LCA presents additional difficulties (Notarnicola et al., 2017). When considering the ecological interrelationships of agricultural and food systems in general, their complexity must be taken into account. In particular, for perennial fruit crops, it is necessary to take a specific view in terms of methodological choices and underlying assumptions when conducting LCAs (Sala et al., 2017). Weidema and Wesnæs (1996) conducted one of the earliest LCA initiatives in agriculture. The nursery and the entire orchard life cycle are of the highest priority. Apples are the most common fruit variety studied at LCA (Svanes and Johnsen, 2019). According to Basset-Mens et al. (2018), in a cradle-to-farm gate LCA study comparing four fruits consumed in France, the researchers presented the first thorough LCA study for export mangoes from the Rio São Francisco Valley in Brazil. The other two fruits were grown in France: an apple and a peach, while the clementine came from Morocco. In addition, LCA has been the subject of numerous studies in fruits such as citrus, grapes, olives and peaches.

An LCA follows four steps described in two ISO standards (the ISO 14040 and 14044, respectively): Definition of objective and scope, inventory, impact assessment, and interpretation. Agricultural sector LCAs consider global warming, acidification, eutrophication, and depletion of fossil, phosphate, and potash resources (Brentrup et al., 2004). LCA presents additional challenges because agricultural and food production systems are inherently variable (Notarnicola et al., 2017). It is necessary to take into account the complexity of agricultural and food systems when considering their ecological interrelationships. When conducting LCAs on perennial fruit crops, it is necessary to take a specific view regarding methodological choices and underlying assumptions (Sala et al., 2017). Weidema and Wesnæs (1996) conducted one of the earliest LCA studies in the agricultural sector. A nursery and all aspects of orchard life are of utmost importance. Among the fruit varieties studied at LCA, apples are the most common (Svanes and Johnsen, 2019). Taking into account cradle-to-farm gate LCA, Basset-Mens et al. (2018), conducted the first comprehensive LCA study for export mangoes from the Rio São Francisco Valley in Brazil. A peach and an apple were grown in France, while the clementine was grown in Morocco. Additionally, LCA has been studied in citrus, grapes, olives, and peaches.

2.3. Cost-benefit analysis (CBA)

A cost-benefit analysis is an analytical method for assessing whether a particular project or program, often social in nature, is worth undertaking (Mishan and Quah, 2020). Florio (2014) defines CBA as a partial or general equilibrium exercise. To determine which projects to pursue or which measures to implement, a cost-benefit analysis is typically conducted. In addition to creating environmentally and economically sustainable facilities, investing in state-of-the-art waste management can also generate biogas, bioenergy, and compost. In making policy decisions, the result of the analysis is often a net economic cost or gain. When calculating energy consumption and environmental impacts (typically noise and air emissions), CBA takes into account only the operational lifetime of the transportation infrastructure, which causes a significant underestimation of total life-cycle emissions (Jones et al., 2018).

The majority of waste management investments aim to improve people's lives and the environment. A monetary value should be placed on the amount of waste that does not end up in landfills as a result of waste management projects. By reducing landfill waste, the economy benefits from longer use of the waste (Policy, 2008). This study uses NPV and IRR.A discount rate of 10% was used to calculate the NPV.

The return and cost of mango trees were analyzed using a 10% opportunity cost of capital. A total of THB 68,405 was invested in cultivation materials and labor. Ten-year depreciation of agricultural expenses and labor costs constitute operating costs, i.e., fixed costs.

2.4. Variety of mango in Thailand

South and Southeast Asia are the native regions of mangoes (Mitra, 2016). Per capita consumption rates in Thailand are among the highest in Asia. In addition to being a producer, Thailand is also a consumer. There is, however, a limited selection of cultivars available for export. In general, mangoes can be eaten unripe, ripe, or processed.

In Thailand, green, unripe mangoes are known as mamuang man, and Thais consume more of them than foreigners. Unripe or green mangoes are favored for their crunchy texture and slightly sweet, nutty flavor. When ripe, they are flavorless. The kaew mango has a small, round shape and a hard skin. The fruit is also widely consumed raw (Bangkok Post, 2018).

NMD mangoes are the most popular variety of ripe mangoes. This variety is ideal for distribution due to its delicately sweet and silky flesh, along with a pleasant aroma. In the market, Ok Rong is more widely available due to its aromatic sweetness, intense flavor, and smooth texture, although its flesh may be a bit fibrous. The mango is sour when it is still green. Nam prik and yum (salad) are the most common ways to eat them (Bangkok Post, 2018).

In the fruit processing industry, Kaew and Chok Anan are usually used for pickling. Maha Chanok mangoes are also commonly used in canned and freshly squeezed fruit products.

Among the other varieties, but less commonly used commercially, are Phimsen Man, Nong Saeng, Man Khun Sri, Salaya, Phet Ban Lat and Sai Fon.

Mangoes from Nam Dok Mai (NMD) have a sweet nectar-like taste. It is delicious on its own, but it can also be added to savory dishes, desserts, and even smoothies. Mangos weigh between 250 and 500 grams. Each mango weighs between 250 and 500 grams. The fruits should be transported at a temperature of 12 to 18 degrees Celsius, and they should reach the market within three to seven days of harvest (Fakkhong, 2022). Due to their excellent quality, NMD are increasingly in demand throughout the world, especially in South Korea, Japan, Vietnam, China and Malaysia. South Korea, Japan, and some European countries require mangoes to be steamed before they can be exported (Jang, 2022). The focus of this study is primarily on NMD mangoes.

2.5. The use of mango in Thailand

Thai mangoes can be eaten in a variety of ways. In addition to being eaten fresh with spices, ripe green mangoes are also added to yam salad as a vegetable (Iguchi, 2016). It has been reported that some mangoes have been consumed as canned goods similar to toffee or jam (Yumi et al., 2016). The Thai people consume mango not only as a fruit but also as a medicine. Cooking the fruit or preparing various drinks is used to treat illnesses such as fevers, stomachaches, and even wounds. Traditionally, Thais believed that even the young leaves, which are usually eaten along with Nam Prik or chili paste, had medicinal properties, such as pain relief and the prevention of asthma attacks (Nualkhair, 2019). There are many delicacies to choose from in the Thai cuisine, including Khao Niew Ma Muang (mango sticky rice), a popular Thai dessert that has been around for a long time. A delicious flavor and aroma are created by combining NMD with glutinous rice and coconut milk (Lui, 2019). Ma-Muang Bao Chae-Im, an unripe native mango in southern Thailand, is used to make a deliciously sweet cucumber (Indrati et al., 2022).

2.6. Exports

Approximately 3.7 million hectares of mango trees are commercially cultivated in 87 countries around the world (Parvez, 2016). According to Saúco (2013), the four leading export destinations for fresh mangoes are the European Union, the United States, the Arabian Peninsula, and Asian markets, accounting for 34%, 20%, 14%, and 27% of the global market demand, respectively (Market Intelligence Team, 2020). NMD, one of Thailand's export crops, has been adversely affected by the COVID-19 epidemic. NDM mango producers have suffered significant losses as a result of the decline in commercial flights, the increase in transportation costs, and the decline in domestic prices (Sornsena et al., 2021). Exports to Japan and South Korea have been severely affected. However, China is the largest market for Thai fruits. A roller coaster ride awaits Thai fruit exporters in 2021: the first half of the year is good, while the second half of the year sees a substantial drop in prices and export volumes (China ASEAN Studies and PIM, 2022). Accordingly, the director-general of the Department of Trade Negotiation (DTN), Auroman Supthaweethum, mangoes are one of the top export products to many countries that are members of Free Trade Agreements (FTAs), including South Korea, Japan, Malaysia, Hong Kong, and China. Chok Anan, Maha Chanok, and Khiew Sawoey are other types that are commonly found. According to the head of DTN, Thailand's demand for processed fruits is also rising (Rujopakarn, 2022).

2.7. Processed mango products

Mangoes that are overripe are transferred to food processing factories for processing. The top producers of frozen pulp are India, the Philippines, Thailand, and Mexico. There are over half of Thailand's exports of canned mangoes (59%), and 6 percent of Thailand's exports of dried mangoes (Sangudom et al., 2019). In comparison with other tropical fruits, mango products are gaining market share and fetching higher prices. A significant postharvest process is the drying of mangoes, which is done to meet the growing demand for dried fruits on both the domestic and international markets (Janjai, 2012). It is common to find a variety of varieties being used for different purposes. A popular variety is Sampee, which is used to make candies, and Keaw, which is used to make dried mango products. "Maha Chanok" varieties are preferred by juice producers, while "Chok Anan" varieties are ideal for dried mango products (Sommano et al., 2018). In addition, Thailand exports fruit chips and fruit snacks made from mangos (DTIP, 2020).

3. Methodology

3.1. Field research

A "participant observation" or the researcher takes the point of view of a participant in an event that is happening in a natural setting (Schein, 1987; Whyte, 1984).

3.2. Field site

Nam Dok Mai (NMD) mango plantations in the northeastern part of Thailand. The northeast is, geologically, a plateau (UNFCCC, 2021). The area is covered by mountains for a length of about 25,000 km, accounting for 15% of the area. In addition, agriculture is the main economic activity in the mountains (14–19°N, 101–106°E) (Choenkwan et al., 2014).

3.3. Qualitative interview

In this research, qualitative interview was used to collect data, and the sample was divided into 3 main groups: 30 mango farmers, 2 entrepreneurs, and a researcher from ESAN Circular X Creative Economy—A Business Model for Circular and Creative Economy to Manage Food Loss and Waste from the Mango Processing Industry in the North-east Region.

The price trends of Nam Dok Mai mangoes were reported by the Ministry of Commerce's Public Data between 1 January and 1 September 2023 (MOC, 2023). Below is a graph illustrating the average monthly price of the highest and lowest price.

Based on the average price of Nam Dok Mai illustrated in **Figure 1**, grade 0 in 2023, the highest price is 130 THB, and the lowest price is 45.50 THB. The best time to sell mangos is during the months of August, September, and January of the year. Since it is the harvesting season, May and June are highly fruitful months for mangoes, the trend of mango prices is dropping down to almost the same level as the capital investment in May and June. Every season, mango prices vary depending on demand. Based on an interview from farmers in northeastern orchards, however, they gain an average selling price of 70 THB per kilogram.

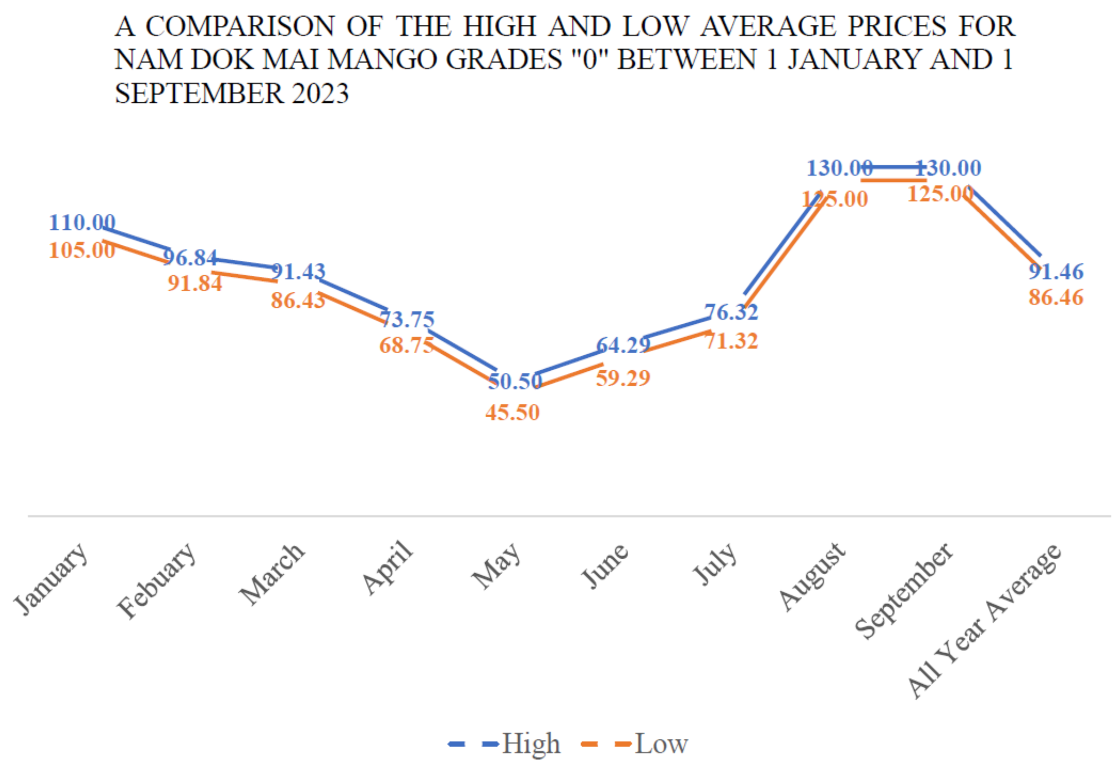

Figure 1. A comparison of the high and low average prices for Nam Dok Mai mango grades "0" between 1 January and 1 September 2023.
Figure credit: Ministry of Commerce, 2023.

3.4. Cost-benefit analysis (CBA)

CBA is a standardized method for weighing the relative costs and benefits of potential interventions (Drèze and Stern, 1987). CBA measured the gain and loss in planning to minimize mango waste in Thailand's northeast, which contributes to GHG emissions and global warming, which directly impacts people's health.

3.5. Profitability analysis

Profit maximization is the ultimate goal of any business. This study aims to measure the profitability of traditional mango waste disposal and the disposal of products made from mango waste. Specifically, this paper seeks to implement best practices and outcomes that benefit all stakeholders in mango production.

3.6. Costs

The major capital costs included all tools and equipment using in mango plantation. Operating cost covered labor costs, mango trees, packaging materials, utilities, and transportation.

Table 1 shows a cultivation material and labor charges in planting mango estimated 1 rai of land. All costs are gathered from an interview and MOC's report on mango prices was used as a benchmark (MOC, 2023). Other costs utilize in farm are listed below:

1) The cost of 1 mango sapling: THB 20.96/piece (1 rai/land accommodates 100 saplings).

2) Cost of 1 unit of power: THB 2.0889/unit< 101 units; beyond this is THB 3.2405/unit (PEA, 2015).

Noted, there could be some extra charges for labor tents and additional labor employment, which are not included in this project.

Table 1. Mango plantation direct cost.

Cultivation material and labor charges	Investment (in THB)
Manure and fertilizer cost	5660
Insecticide and pesticide cost	150
Labor cost for 30 days for 3 persons (350 THB/person/Rai)	31,500
Power requirement (300 THB/per day/Rai)	9000
Tube well pump cost (per Rai)	1800
Pump house	600
Agriculture equipment (per Rai)	1200
Soil preparation	1000
Mango Tree	11,475
Wrapping paper	20
Transportation (KKC-BKK/2000kg)	6000
Total cost	**68,405**

Table credit: Data adapted from MOC report 2023 with an interview from the farmers.

3.7. Planting space

A suitable cultivation area should have a distance of 6 × 6 meters between each row of mango trees. In an area of 1 rai, 45 mango trees can be planted. The rainy season is best for mango cultivation. However, with a drip irrigation system, you can grow mangoes all year round.

NMD in size 40–60cm worth 255 THB/ton. Mango yield per rai in 1 year is 1 ton. The cost of 1 kg of mango: equivalent to 67,556 THB (average cost but may vary by variety). Profit per kg is 70 THB/kg (market price varies seasonally).

3.8. Analytic procedures

For the economic viability of this mango orchard project, the net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR) were used as discounting measures to analyze the break-even point of the mango orchards in northeastern Thailand applied by using data in **Table 2**. The undiscounted method or payback period was used to determine how quickly the product processed from mango waste would generate sufficient funds to repay the initial capital investment. The following lists describe the analytical tools:

Table 2. Estimation of fruits produced and revenue of Nam Dok Mai mango in 1 rai.

Mango trees/rai	Mangoes	Price/kg	Ave/month
1 Tree	120		
45 Tree	5400		
1 Kg	4	120	
1 Rai	1350	162000	
Total profit	93,595		7799.58

Table credit: Author, 2023.

3.9. Net present value (NPV)

The net present value (NPV) of an invested capital is the sum of all cash flows expected over the life of the investment, both positive and negative. When assessing the value of a business, a security, a capital project, a new project, a cost reduction program, or any other project involving cash flow, NPV analysis is often used.

The NPV is modeled in this paper; NPV can be stated in Thai baht (THB/t). The waste management sector uses a functional unit of THB /t to maintain the discussion and accounting of waste management costs.

$$NPV = \frac{R_t}{(1 + i)^t}$$

where NPV is a net present value; refers to net cash flow at time *t*; means discount rate; and shows the cash flow time. In the present study, the net cash inflows showing the opportunity cost of capital were discounted at a rate of 10%. This result indicated that the NPV value was positive, which meant that it was financially possible to run this business.

The NPV was calculated in Microsoft Excel using the formula; therefore, the result is 136,513.47 THB, demonstrating that mango waste is worth investing in.

3.10. Internal rate of return (IRR)

Internal rate of return (IRR) measures how profitable an investment would be if undertaken, assuming all other factors remain constant.

$$IRR = \left(\frac{\text{Future Value}}{\text{Present Value}}\right)^{\frac{1}{\text{Number of Periods}}} - 1$$

The IRR was calculated on Microsoft Excel; therefore, the result is 8%, proving that mango waste is valuable to invest in.

3.11. Benefit-cost ratio (BCR)

BCR evaluates investment cash flows considering their discounted costs and benefits. The results of BCR and NPV are similar, but BCR determines how profitable an investment is compared to others, while NPV considers the total net benefits. BCR is therefore preferable to NPV when investors are interested in determining the profit earned per dollar invested in the business (Gittinger, 1982).

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+r)^t}}$$

The BCR was calculated on Microsoft Excel with the discount rate of 12%; hence, the result is 2.83.

3.12. Payback period

$$\text{Payback Period} = \frac{\text{Cost of Project or Investment}}{\text{Annual cash flow}}$$

The payback period was calculated on Microsoft Excel; therefore, the period of returning the capital is within 10 years 4 months.

With a required return of 12%, BCR of 2.83 and an IRR of 8% stated the empirical result that total NPV of THB 136,513.47. The findings suggest that this project is worthy profitable. To our best of knowledge,

4. Life Cycle assessment (LCA)

4.1. Goal & scope

Assess the environmental impact of greenhouse gas emissions from traditional mango waste, cradle to grave. The field took place in mango orchards in the northeastern region of Thailand. The functional unit was 1 kg of NMD mango waste.

4.2. System boundaries

From cradle-to-grave, the flow chart in **Figure 2** above illustrates the boundaries of traditional mango production. Even though mangoes have not yet been processed, emissions continue to be generated. Mangoes are not all ready for sale when they are fully grown. Several of the mangoes are rotten or of poor quality, and others have fallen off the tree; therefore, these unused mangoes will be thrown away. Furthermore, after consumption, the peel and stone will also be discarded.

As we study the orchard waste more closely, we can see that it will be transported to the manufacturing process where utilities will be used. Raw material extraction (mango peels, stones, and pulp), input operation, output, consumption, and disposal. There is waste throughout the entire manufacturing process since some parts of the raw materials are not usable or are of poor quality. Additionally, waste is moved using primitive methods such as open trucks, hand carts, and donkey carts. Due to these inadequate modes of transportation, littering has taken place, resulting in an unsightly accumulation of waste in the environment, especially plastics (Runyora, 2016). In the paper, these issues are discussed through landfilling, which results in the release of methane gas.

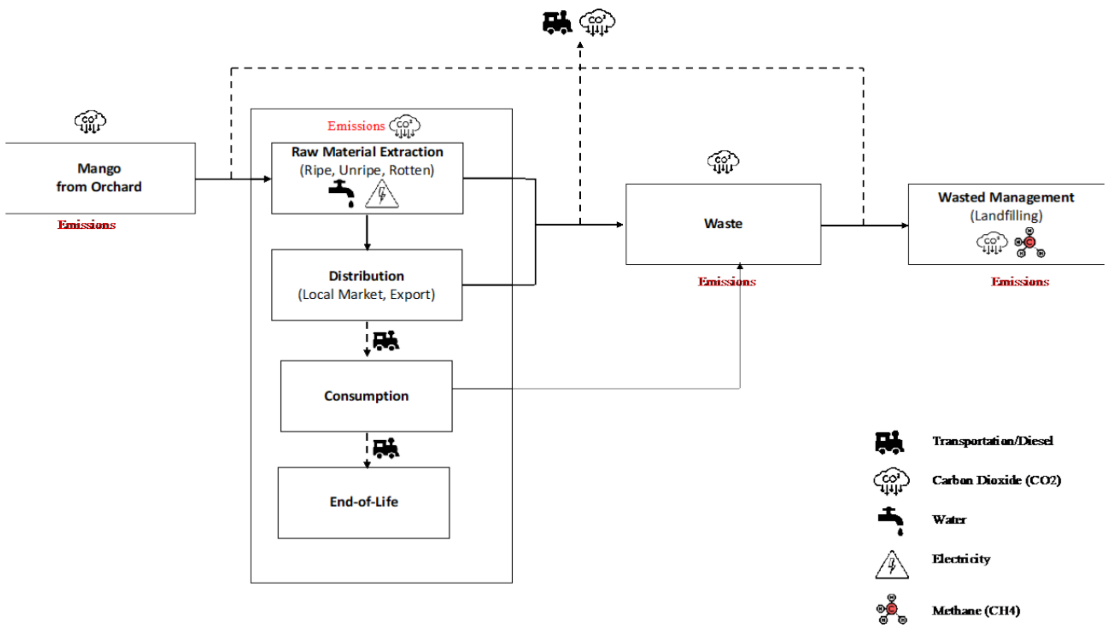

Figure 2. System boundaries of traditional mango production from cradle-to-grave.

4.3. Inventory

Tier 1, Volume 4: Agriculture, Forestry and Other Land Use (AFOLU) includes anthropogenic emissions and removals under the subcategory Cropland remaining Cropland (CC), for which mango is the perennial tree crop. In this study, emissions were evaluated at the national level using the IPCC 2006 default GHG Emission/Removal equation:

$$\text{Payback Period} = \frac{\text{Cost of Project or Investment}}{\text{Annual cash flow}}$$

where: Activity data = Human activity occurs; Emission factor = coefficients that represent the emissions or removals for each individual activity.

4.4. Impact assessment

Ecotoxicity, acidification, eutrophication of freshwaters, marine habitats, anthropogenic climate change, and toxicity for humans/non-cancer effects are considered using IPCC Guideline 2006. Global, regional, and local impacts are all caused by the elements. In addition to carbon dioxide (CO_2) and methane (CH_4), nitrous oxide (N_2O) is also considered a greenhouse gas. Three key gases converted into GWP equivalent to CO_2e (Eggleston et al., 2006).

Biological biomass mentioned in **Table 3**, including branches, seeds, bark, stems, roots, and leaves, living and growing above ground (IPCC, 2006). The majority of air is removed from the atmosphere by plants, both above- and below-ground meaning that both parts of plants which are the ones above the soil and under the soil. Through photosynthesis and respiration, large quantities of are exchanged between the atmosphere and terrestrial ecosystems.

Table 3. Default coefficients for above-ground woody biomass and harvest cycles in cropping systems containing perennial species.

Climate region	Above-ground biomass carbon stock at harvest (tonnes C ha-1)	Harvest /Maturity cycle (yr)	Biomass accumulation rate (G) (tonnes C ha-1 yr-1)	Biomass carbon loss (L) (tonnes C ha-1 yr-1)	Error range[1]
Temperate (all moisture regimes)	63	30	2.1	63	75%
Tropical, dry	9	5	1.8	9	75%
Tropical, moist	21	8	2.6	21	75%
Tropical, wet	50	5	10	50	75%

Note: Values are derived from the literature survey and synthesis published by Schroeder (1994). Error range[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.
Table credit: 2006 IPCC Guideline.

Annual change in carbon stocks in biomass in land remaining in a particular land-use category (Gain-Loss method):

$$\Delta C_B = \Delta C_G - \Delta C_L$$

where: ΔC_B= annual change in carbon stocks in biomass for each land sub-category, considering the total area, tons C yr-1; ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tons C yr-1; ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tons C yr-1.

According to the Emission Factor Database (EFDB) stated in **Table 4**, aboveground biomass and dead organic matter have carbon stocks of 12.4 tons carbon per hectare (Hergoualc'h and Verchot, 2011). The unit of this study is Rai instead of hectares (ha), with 1 ha equal to 6.25 Rai. Calculating the difference between the two years as shown in **Table 4**, the estimated value for 1 Rai in 2019 is 94.4694 and in 2020, it is 94.6026, resulting in 0.1332 tons of carbon dioxide per Rai. Consequently, the annual change in biomass carbon stocks) (multiplied by 65.1 tons C/Rai) is equal to 8.6690 tons C/Rai per year.

Table 4. Estimated value of land use in Asia.

Domain	Area	Item	Year code	Year	Unit	Value	Flag description
Land Use	Asia	Cropland	2019	2019	1000 ha	590434.03	Estimated value
Land Use	Asia	Cropland	2020	2020	1000 ha	591266.31	Estimated value

Table credit: FAOSTAT (2020).

4.5. Interpretation

The equation from IPCC 2006 guidelines was used to measure the carbon stocks in biomass in one kilogram of wasted mango per one rai as part of the interpretation process. Throughout the main phases of perennial cropping, field emissions were measured and modeled using modern techniques. Trucks transport the entire process from Khon Kaen and Bangkok to customers, according to the study. Further, this study only included orchards in the northeastern region of Thailand. The inventory was compiled primarily based on literature reviews and online resources available via a handbook, so there is a certain amount of statistical representation unknown. Due to the lack of water deprivation in our study, we were unable to assess the environmental risk to fruit and horticultural products (Payen et al., 2015).

5. Discussion

Analyzing the LCA and CBA method, the study also found that mangoes have a high return on investment, making them an ideal starting point. Mangoes are one of Thailand's most common crops because they can be grown anywhere. It is important to note, however, that not all outputs are of high quality. As a result, waste is generated. Additionally, landfilling is the only waste management practice used in this study, and improper treatment of mango waste remains a concern at present. It is the result of all gases emitted during the process, from the planting stage to the end of the life cycle. There is a possibility that it will not only harm human life but also other creatures, the environment, and the rest of life as well. This practice should be promoted among all stakeholders, particularly policymakers.

Based on a cost-benefit analysis of LCA for traditional mango waste, the data indicated that the overall capital requirement including projected operating costs is 67,556 THB for planting one full Rai of mango trees (45 trees). A kilogram of NMD mangoes currently sells for 120 THB per kilogram, an exporting grade, which is considered a high price. Investing in mangoes takes 3 to 4 years to fully grow. 93,695 THB will be the first benefit returned to the mango farmer after years of investment, which represents a positive return.

Furthermore, a financial viability analysis was conducted to determine the project's viability based on the discount rate of 10%, net present value, benefit-cost ratio, internal rate of return, and period of payback. We have calculated 136,513.47 THB, 2.83, 8%, and a term of 10 years and 4 months based on these calculations. Taking into account the positive NPV, it is evident that these investments will be profitable and viable for the foreseeable future. According to the reported data (BCR equal to 2.83), investors will receive 2.83 THB in derived benefits for every THB invested in mango orchards. In this case, the IRR is only 8%, which means that the payback period could be as long as 10 years and 4 months.

Based on the LCA performed on traditional mangoes taken from cradle to grave and considering the carbon emissions associated with landfilling, it was determined that 1 kilogram of mango waste per 1 rai emits 8.6690 tons of carbon per year. When evaluating a single rai of land, the majority of orchards in the northeastern region are planted with mangoes. As a result of the calculations that have been performed, this is only a rough estimate. As a result, the estimation is limited to the years 2019 and 2020. Since the unit of measurement is different, ha was converted to Rai and the multiplied number equaled 65.1 tons C/Rai instead of 12.4 tons C/Rai. As reported in the data, the amount of gas emitted from landfilling mango wastes is increasing every year without any action being taken.

Comparison of waste management in Thailand since waste management in Thailand has not been properly addressed. According to Chanchampee (2010), the only disposal options available in Thailand are landfills and incinerators. MSW is primarily disposed of in landfills. Mass burning of MSW accounts for less than 1% of the overall disposal of MSW. Moreover, it is more expensive to incinerate than to landfill (CCAN Action Fund, 2013). However, the purpose of this study was to reduce the capital costs associated with waste disposal by depositing the wastes in landfills rather than incineration. For a greater reduction of CO_2 however, mango waste can be converted into valuable products, and mango by-products are available in a variety of forms. For instance, an alternative waste management strategy for mango processing waste is biorefining, which can provide clean energy, diversify products, and improve economic performance (Manhongo et al., 2021). Moreover, by integrating mango stone into biofuel technologies, the sustainability of biopower is improved and biofuel can be produced from this waste resource (Perea-Moreno et al., 2018).

As a means of implementing the strategies, there has been serious damage done to the environment by firms in the course of their production and operation. The government should consider taxing carbon emissions on associated companies, which can be used as a tax reduction in the fiscal year if the company emits less carbon dioxide than it previously did. Furthermore, the government should subsidize the price of mango wastes and offer a discount to buyers, so that farmers are able to generate more revenue from the sale of mango wastes. A buyer could have valorized these mango wastes into a future product and could also have marketed them as a Product of Thailand. To market this product, A private company may be required to assist and invest in the marketing of this product. This could include investing in advertising, promotional activities, and sponsorships. It may also be necessary for the company to provide sales support and resources. As an additional service, the company may be expected to provide customer support. By providing incentives like these, the government can help to create a sustainable mango industry in Thailand. Circular economies can be promoted through these initiatives. Observational findings suggest that environmental leadership moderates the relationship between environmental management and green innovation (Andersen and Bams, 2022; Fan et al., 2022; Zhang and Ma, 2021). Overall, the use of these mango wastes could generate substantial revenue for the country in the long run.

The findings of this study could serve as a basis for future investigations of the environmental and social effects of waste management strategies. By doing so, it may be possible to develop a comprehensive understanding of the costs and benefits of various methods of disposing and utilizing waste. Consequently, the investment should benefit the government or a related company. A private company should, therefore, consider the value and pricing of mango wastes in its future research associated with food science. By conducting further research and development, this approach can be extended to other fruits and vegetables, thereby contributing to the sustainable management of waste.

Author contributions

Conceptualization, PN and CK; methodology, SK; software, NJ; validation, NJ, PN and SK; formal analysis, NJ; investigation, PN; resources, SK; data curation, CK; writing—original draft preparation, NJ; writing—review and editing, PN, NJ; visualization, SK; supervision, PN; project administration, PN; funding acquisition, CK. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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