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Addressing Rice Waste in University Cafeterias Using Material Flow Analysis and System Dynamics Modeling

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Food waste has emerged as one of the focus areas in sustainability research. At the Ateneo de Manila University, previous studies have found that food waste is composed mainly of rice. This study, therefore, analyzed cafeteria rice systems in the university through a material flow analysis (MFA) to identify key factors for formulating effective rice waste reduction techniques and then applied the results toward developing system dynamics (SD) models as tools for decision-making. The MFA found that the total mass of produced known rice waste was 49.48 kg/d. The largest sources of rice wastes were the upstream processes of the cafeteria rice system involving the cooking and serving of rice. The SD model developed for one cafeteria found that the service stage was the largest source of rice waste. The main factor influencing service waste generation was the surplus of cooked rice. A scenario was simulated in which the amount of rice used in additional batches cooked was minimized, yielding a substantial decrease in the mass of service waste and lost revenue. Not only does this research provide baseline information that enables the university to enhance sustainable consumption and food waste minimization efforts, but it also contributes to the data pool for rice wastage in the Philippine and Southeast Asian contexts. Furthermore, results indicate a need to re-strategize rice waste campaigns that focus on consumption when much can be done in the preparation and service stages. Collaborating with cafeteria management to improve efficiency in the kitchen is key in addressing the overall rice waste problem. Downstream, consumer-focused interventions targeting changes in attitudes and behaviors must be complemented by upstream changes in operations and management approaches to support both a structural and cultural transformation for sustainability.

Keywords: food security, food waste, material flow analysis, rice, system dynamics modeling

INTRODUCTION

In the Philippines, there is a growing concern about food waste (Arcalas and Ordinario 2018; dela Peña 2021). Most of the attention has been on rice, being the main staple in Filipino diets and an agricultural commodity with great political and economic significance due to its contribution to the gross domestic product (Maclean *et al*. 2013). Rice has also become the central focus of the government's agricultural policies, which primarily revolve around the promotion of rice self-sufficiency and national food security. Many of these are directed towards the post-harvest and processing stages of rice production, which echoes findings in other South and Southeast Asian countries that rice losses are relatively higher at these stages. It has also been reported that food losses at the post-harvest and processing stages of the food value chain

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make up 40% of total food losses (FAO 2011).

While the Philippine government and rice research institutes focus on rice losses and wastage at the post-harvest and processing stages, there is a dearth of literature on rice in the procurement, consumption, and post-consumption stages. In addition, while there are a few studies on food waste at the macro-, meso-, and micro levels (Favis and Estanislao 2016; Mopera 2016; Sahakian *et al*. 2020), there are no other studies found specifically on rice waste at the institutional and household contexts in the Philippines. The lack of sufficient data, such as information on pre- and post-consumer food waste in smaller food industries, hinders the comprehensive understanding of food waste generation. Thus, conducting studies on food losses across the entire food chain is vital toward enhancing the environmental performance of waste management systems and improving our ability to make use of increasingly scarce resources (Amicarelli *et al*. 2021).

Food waste has become a focus of sustainability research with many studies investigating generation at the national and household levels (Moraes *et al*. 2021; Principato *et al.* 2021), including foodservice industries (Huang *et al.* 2021). However, food waste audits conducted in university cafeterias (Abdelaal *et al.* 2019; Zhang *et al.* 2021; Qian *et al.* 2022) focus on the consumption stage of the food value chain more than on the upstream processes. This presents missed opportunities for reducing food wastage even before the food reaches the consumers. Conducting food waste reduction at the source entails an assessment of the whole food system where the waste is produced, which includes the description of the mass of, characteristics of, and the reason for the generation of food waste to create a baseline data that will serve as a basis in conducting food waste prevention strategies.

This paper examines the material flows of rice at an organizational level, specifically in a private higher education institution in the Philippines, to aid in the data gap regarding food waste studies in the whole food value chain. This study provides a more holistic understanding of rice flows through the analysis of rice procurement, handling, storage, preparation (cooking), consumption (service and dining), and waste management using material flow analysis (MFA) and system dynamics (SD) approaches (see conceptual framework in Figure 1). Universities are important organizations to focus on because of their centralized food waste generation. This presents a good opportunity for food waste reduction and quantifies potential diversion for composting and other more appropriate disposal and treatment methods. In addition, this also offers an opportunity to support student formation activities for more responsible rice consumption.

MATERIALS AND METHODS

Analytical Techniques

MFA has been proven as a useful tool in understanding food flows and wastage (Leray *et al.* 2016; Ju *et al.* 2017; Amicarelli *et al.* 2020) and supporting waste management

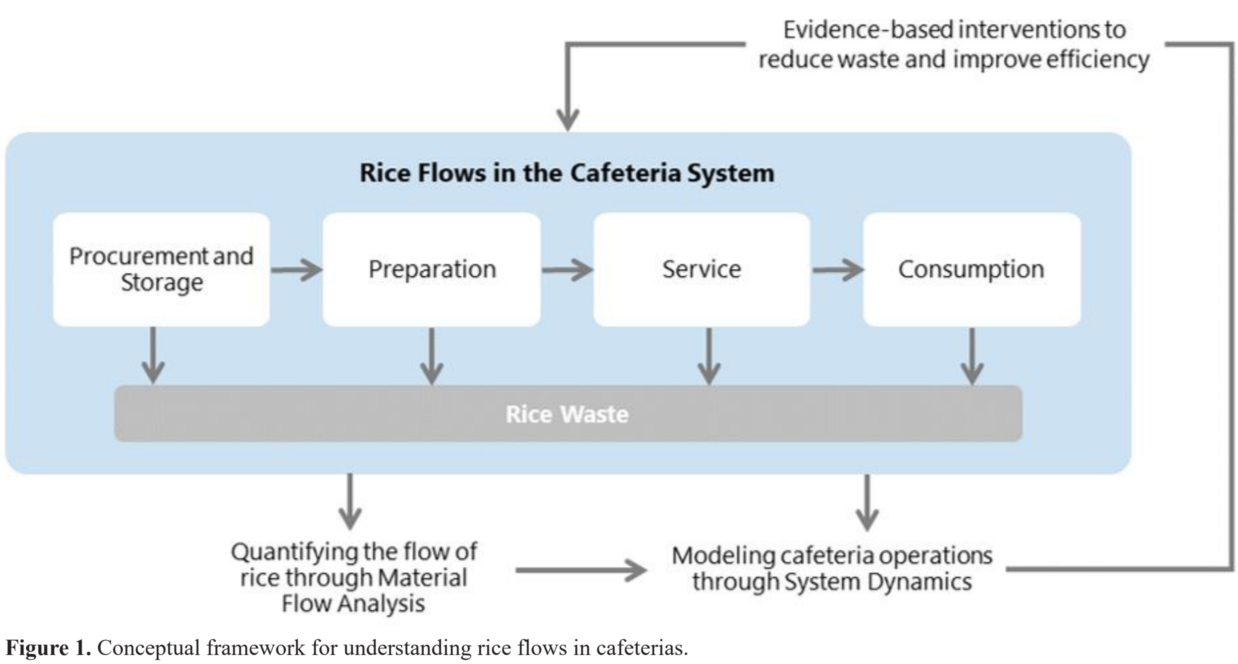

Figure 1. Conceptual framework for understanding rice flows in cafeterias.

decisions and interventions (Makarichi *et al.* 2018; Wang *et al.* 2018; Fiore *et al.* 2019). Through the principle of mass balancing, MFA delivers a consistent set of information that is comprehensive yet verifiable by transparently accounting for stocks and flows within the system. It also identifies the accumulation and depletion of material stocks, which points to the key factors or relevant flows and processes within the system. Complimenting the MFA results with SD techniques enhances the understanding, as it provides opportunities for qualitative mapping of causal relationships and quantitative computer modeling of the behaviors of stocks and flows over time. SD modeling has been applied to higher education institutions to facilitate strategy formation (Sahay and Kuldeep 2014) and to promote sustainability competencies in the student body (Faham *et al.* 2017). In the food systems sector, SD has been used to study the impacts of food waste and evaluate food waste management in a larger urban context and even at the country level (Lee *et al.* 2019; Zhu *et al.* 2020; Mobaseri *et al.* 2021; Chinda and Thay 2022).

System Description

This study looks at the flow of rice in the cafeterias of a higher education institution in the Philippines – the Loyola Schools (LS), which is the tertiary level of the Ateneo de Manila University (Ateneo). The LS has an undergraduate and graduate student population of around 10,000 individuals. Food waste audits have been conducted since 2014, as part of the efforts to establish a sustainable food program to promote health and nutrition, resource efficiency, and environmental responsibility (Favis and Estanislao 2016). Two main campus cafeterias and two dormitory cafeterias were included in the study. The selected campus cafeterias represent the two biggest and most well-established cafeterias found at the center of the LS campus, which house sub-concessionaires and cater to most of the LS population. The two dormitory cafeterias are smaller, with no sub-concessionaires, but cater to the fraction of the population living on-campus. The rice processes were summarized into four stages: [1] the procurement and storage stage involves purchase activities from delivery of rice to onsite storage; [2] the preparation stage involves the rice being transferred from storage to the preparation area where it is cooked, with wastes due to the overcooking and burning of the rice referred to as "preparation waste"; [3] during the service stage, in which the cooked rice is sold, rice that was not sold at the end of the day and not reprocessed and sold as another product the next working day is considered "service waste", and service waste was considered indicative of a surplus of cooked rice compared to customer demand; and [4] in the consumption stage, "consumer waste" refers to purchased but leftover rice from the customers, with several factors (deemed "soft variables") affecting this (*e.g.* serving size, taste, *etc.*) not yet considered in the MFA and SD model construction due to the limitations of the study.

Data Collection

The mass of rice at each stage was measured by direct weighing and recording all data in kg. Sampling was conducted from Mondays–Fridays. Saturdays were not included due to the difference in the following variables as compared to other weekdays: population difference, the number of cafeteria operational hours, and production procedures. The duration of the data gathering lasted for at least 12 h/d – from 06:00 AM (start of service) to 06:00 PM. A total of 15 d were sampled, with each day of the week being sampled three times. Consultations with cafeteria staff were also conducted to investigate the standard methods and operating procedures inside each cafeteria, and the technologies that are currently in use for rice procurement, preparation, and service. This included the following: processes involved in each of the four stages and in waste management; materials and equipment used in the preparation stage; processes involving the disposal of plate rice wastes, preparation wastes, and service wastes or unsold leftovers; and details about rice and its inflow and outflow in the system, including the associated water consumed. Customer consumption patterns were also investigated based on the sales of the cafeteria and its sub-concessionaires (if applicable) of rice. Data on rice sales also included information on the estimated number of cups of rice purchased per hour and the percentage of the total number of customers that availed of half (white) rice servings. More details may be found in Appendix I.

Material Flow Analysis (MFA)

The MFA construction began with the definition of the system boundaries, after which key factors such as stocks and flows at each of the stages (procurement and storage, preparation, service, and consumption) were identified. Inflows and outflows were balanced to account for the stocks and sinks that were not directly observed. The following stocks were identified: STORAGE (mass of purchased rice in storage), WASHING (mass of rice as it is washed prior to cooking), COOKING (mass of rice after cooking), SERVING (mass of rice as it is available for diners to purchase and mass of rice leftover), DINING (mass of rice consumed and mass of rice leftover), and WASTE (mass of rice losses). The MFA was applied to each cafeteria individually at first and then consolidated to create a model to represent all cafeterias. The results were organized into Sankey diagrams, illustrated using STAN version 2.5.1302.

System Dynamics (SD) Modeling

Using a dormitory cafeteria as a case study, a causal loop diagram (CLD) was developed based on the understanding of the system as gleaned from the data-gathering and consultations. Then, two SD models were created, using VENSIM Personal Learning Edition (PLE), based on the MFA. The first was an hourly model, while the second was a daily model. The hourly model runs on a half-hourly time step for 24 h. It included delivery and batching schedules, additional batch conditions, and a buying profile. The buying profile gave explicit details on the changes in stock and flow rates of rice throughout the day. The estimated number of cups of rice sold for each hour of each time block was used to build the buying profile. This captured the slow hours and peak hours of the cafeteria and how they affected the cooked rice stock and the additional rice preparation. Two different buying profiles (one for full servings, one for half servings) were constructed.

The daily model used the daily stocks and flows to aggregate them into totals at the end of the month. Values were expressed in terms of daily quantities and the simulation was run for 1 mo. The model includes other factors in the rice processing system such as gross revenues, operational costs, waste disposal conditions, and losses in rice waste. Monthly values were useful from a management perspective given that resources such as water are billed monthly.

Two sets of simulations were conducted: The first simulation is a baseline case that uses the collected data. The second is a simulation in which a policy change specifically for the rice preparation stage was tested to reduce rice waste while still meeting customer demand. These scenarios were run with both the hourly and the daily models.

RESULTS

Cafeteria Rice Flows

The consolidated MFA of the university cafeterias is shown in Figure 2 (the individual MFAs of the four university cafeterias, along with a description of their operations and equipment, are detailed in Appendix II). The analysis shows that burnt rice from the cooking process (33.90 ± 10.65 kg) is a greater source of waste compared to the rice purchased but not consumed by diners (15.58 ± 3.11 kg). However, the "unknown" flow is comparable in magnitude (44.52 ± 15.93 kg) and represents processes that are currently not well-accounted for. This flow comprises mainly of cooked rice that was served in catering functions and, hence, taken out of the scope of this system analysis; unsold rice that was re-processed and sold the next day as another product; and unsold rice that was consumed by employees or shared with staff.

The exception to this is the dormitory cafeteria in this case study (Figure 3). Overall, this dormitory cafeteria produces 10.80 ± 3.61 kg of known rice waste. Rice

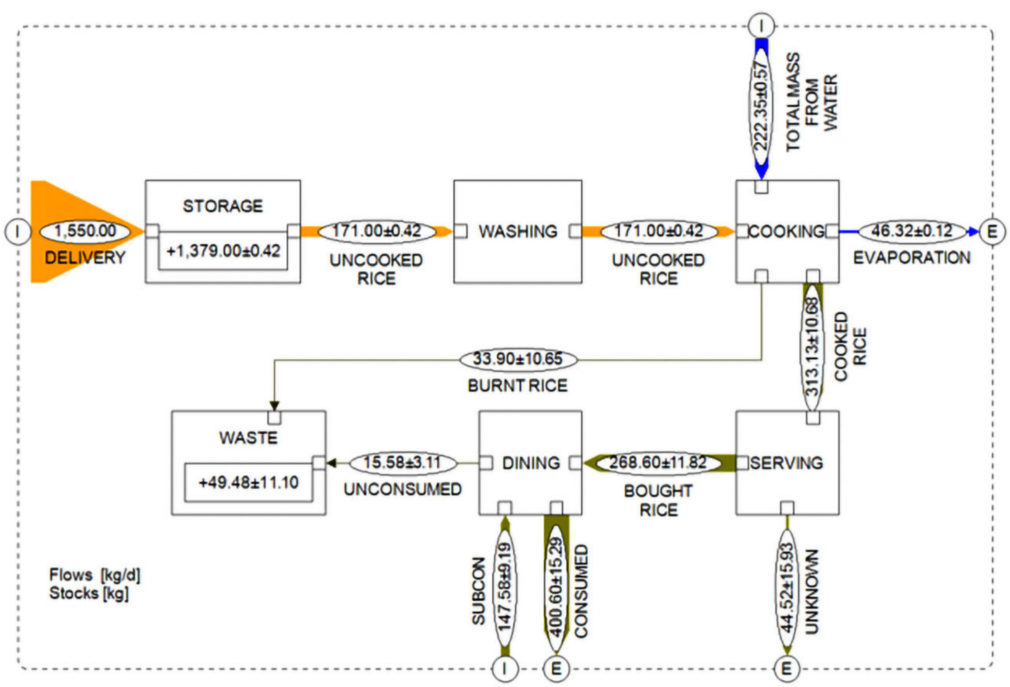

Figure 2. Total MFA of university cafeterias.

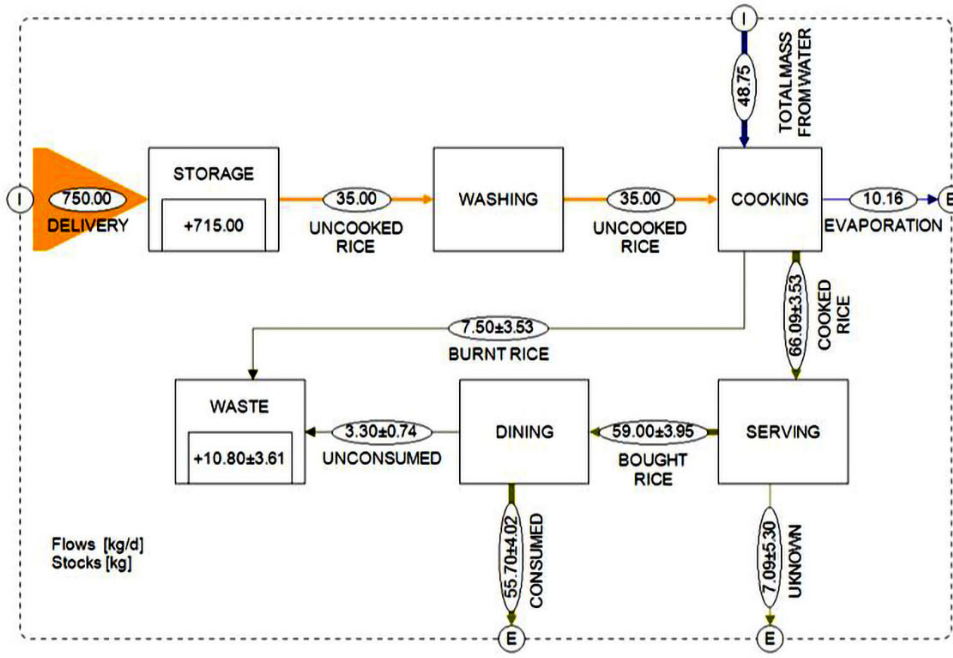

Figure 3. MFA of the dormitory cafeteria.

wastes are collected with the leftover viands in one bin, to be sold (*e.g.* as feed for pig farms). A total of PHP 600 additional income is generated monthly. This cafeteria has no catering services and claims not to recycle or reheat leftover rice for the next day. They do allow employees to consume service leftovers, but this flow has not been measured. Thus, the unknown flows – which amount to 7.09 ± 5.30 kg – are considered mainly as waste and as financial losses.

Modeling the Rice System

The inputs from the dormitory cafeteria were developed into a CLD (Figure 4) to visualize the rice system of this cafeteria. Reinforcing Loop #1 (R1: A-B-C-D-E-F-A) illustrates the impact of burnt rice on the overall system. Lost revenue due to burnt rice leads to preparation waste and lost opportunities to invest in better equipment, which could potentially lead to more burnt rice and lost revenue. Balancing Loop #1 (B1: A-B-G-H-D-E-F) also related to burnt rice. Efforts to procure and produce more rice for revenue are offset by losses due to burnt rice. Balancing Loop #2 (B2: A-B-G-H-I-J-F-A) refers to lost revenue due to service waste. Efforts to cook more rice will lead to lost revenue if these are not sold. Reinforcing Loop #3 (R3: A-B-G-H-K-L-M-N-O-A) considers the scenario in which the cooked rice is bought – meaning, no revenue is lost, and additional income may even be gained from selling bought but unconsumed rice (*i.e.* as animal feed). It should be noted, however, that while this scenario results in more revenue for the cafeteria, not all the rice may be collected, which still leads to rice wastage. Balancing Loop #3 (B3: A-B-G-H-P-A) and Reinforcing Loop #3 (R3: A-B-G-H-K-A) represent the typical structures for expenses and income, respectively. In B3, the process of procuring and cooking rice adds to operational costs; whereas in R3, the process of selling the cooked rice leads to revenue.

Based on the diagram, the mass of cooked rice is a key variable that is incorporated into the different feedback loops. It affects both the preparation waste (through burnt rice) and the potential service waste (the unknown flows of the MFAs in Figures 2 and 3). The supply of cooked rice is dependent on the number of rice batches prepared for the day and the amount of rice per batch, which may vary according to forecasted demand. In the case of this dormitory cafeteria, the normal number of rice batches/d is four, at 7 kg of rice per batch. However, if the cafeteria anticipates that the supply of cooked rice may not meet the demand during peak hours, an additional batch of rice is prepared. By increasing the number of batches by one more than the regular, the cafeteria is able to increase its supply of cooked rice in response to the high demand by the customers. However, this, in turn, increases the total operational costs of the cafeteria, which leads to a decrease in the gross revenue. It also increases the probability of service waste at the end of the day.

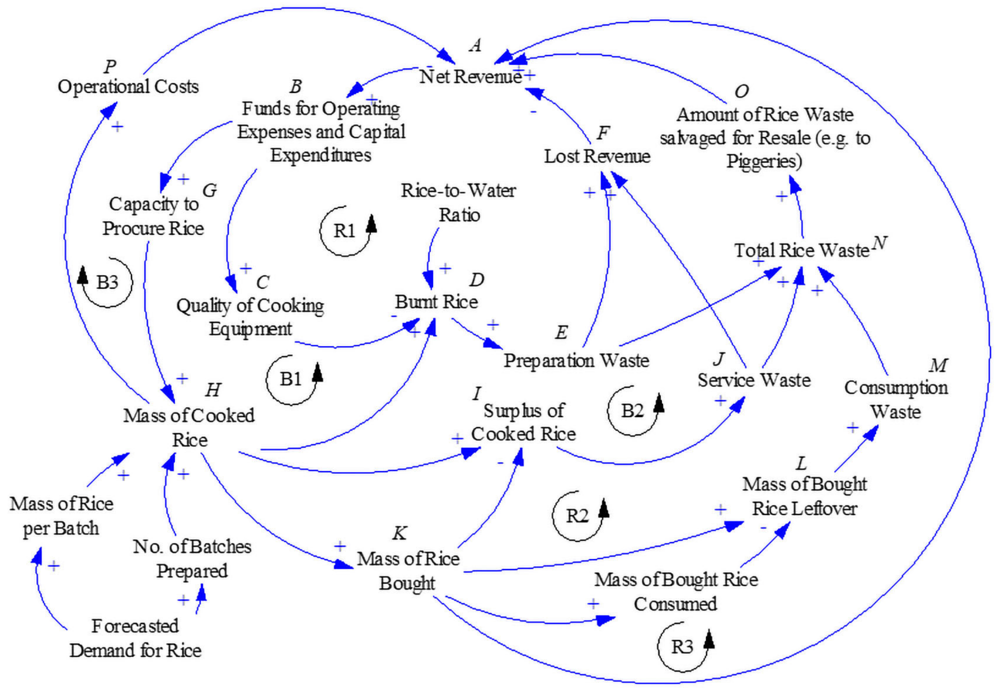

Figure 4. Dormitory cafeteria system CLD.

This CLD and the MFA model of Dormitory Cafeteria A were then used as the bases for the construction of the SD hourly and daily models. The hourly model (see details in Appendix III) captured the major rice stocks (rice in storage, cooked rice, bought rice, total consumed rice, preparation waste, service waste, and consumer waste) and the flows linking these stocks (preparation and cooking, buying, and losses due to burnt rice and unsold or unconsumed rice diverted to waste by the end of the day) (Figure 5).

Figure 6 compares selected stock variables in the daily model: total cooked (accumulated total mass of cooked rice, regardless of whether bought or wasted), total bought (accumulated total mass of sold rice), total consumed (accumulated total mass of rice consumed by diners), and total wasted (accumulated total mass of rice waste, which the model calculates by the end of the day). In the baseline simulation, the total mass of cooked rice amounts to 67.00 kg/d of rice. Out of 67.00 kg of cooked rice, only 59.03 kg is bought, 55.73 kg of which is consumed.

The total mass of wasted rice (Figure 7) includes the different types of rice wastes coming from the different stages of rice preparation: preparation wastes, service wastes, and consumer wastes. In the MFA for the dormitory cafeteria, service waste was treated as an unknown value because it was not directly measured, and no records were kept of the amount that employees might have consumed. The SD model provides a calculation for that unknown but with the assumption that all the unsold cooked rice becomes service waste. With this caveat, the service waste becomes the largest contributor to rice waste, averaging 7.97 kg of rice at the end of the day. The second-largest source of rice waste is burnt rice, which represents preparation waste, with a total amount of 6.59 kg. Consumer waste is the least source of rice waste at the end of the day with a total of 3.30 kg, which is estimated to be 5% of the total bought rice.

In total, the daily waste predicted by the model is estimated at 17.48 kg. This is in general agreement with the values derived from observations and the development of the MFA, which estimate the combined total known waste and the unknown flows at 17.89 kg. The small discrepancies can be attributed to various factors such as measurement uncertainties and roundoff in the calculations.

The SD hourly model was then adapted into the SD daily model using the same basic stocks and flows for the rice system but aggregated at the daily level and with additional calculations for the financial implications by the end of a month-long simulation (Figure 8). The "net revenue," with a value of PHP 81,260.50 at the end of the month, represents the difference in the gross revenue and operational costs. The "gross revenue" is the total income generated from the mass of bought rice and sold rice waste; whereas the "costs" is another stock variable that represents the total costs spent

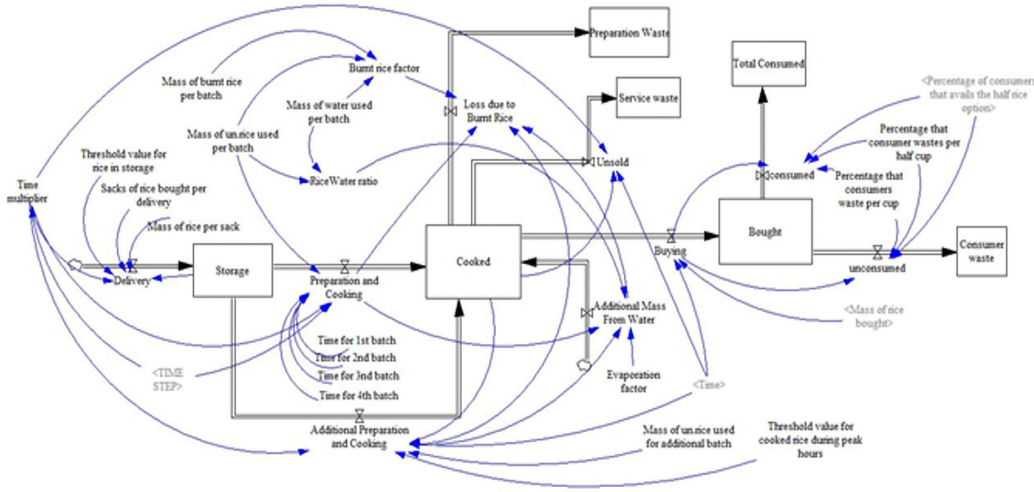

Figure 5. Main stocks and flows of the SD hourly model of the dormitory cafeteria.

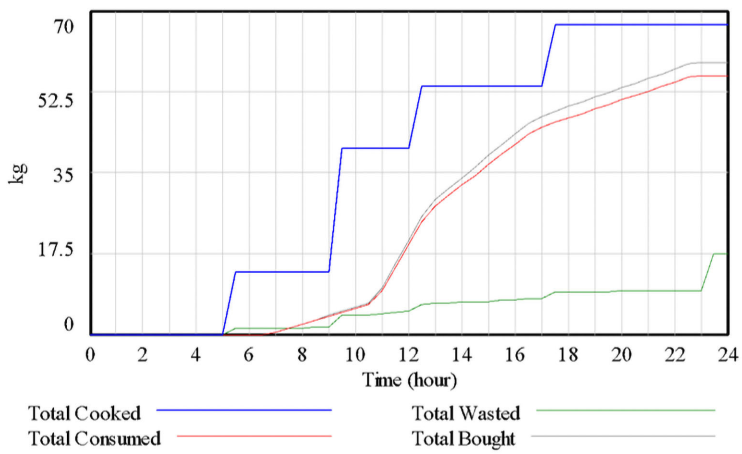

Figure 6. Comparison of total mass (kg) of rice cooked, bought, consumed, and wasted from the SD hourly model of the dormitory cafeteria, baseline simulation.

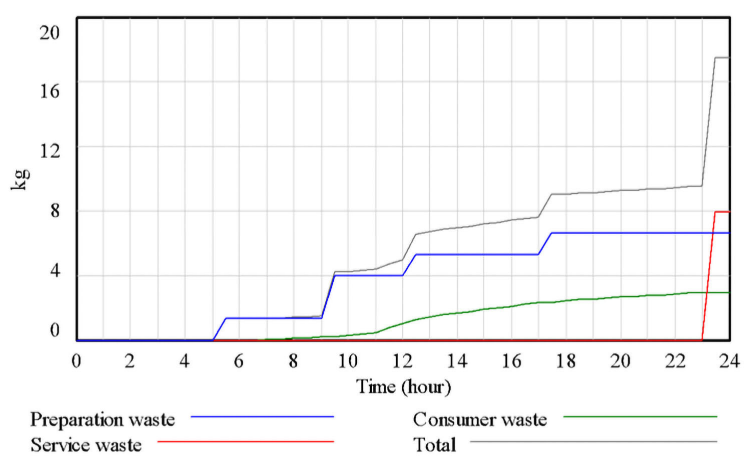

Figure 7. Comparison of rice wastes from preparation, service, and consumption stages of the dormitory cafeteria.

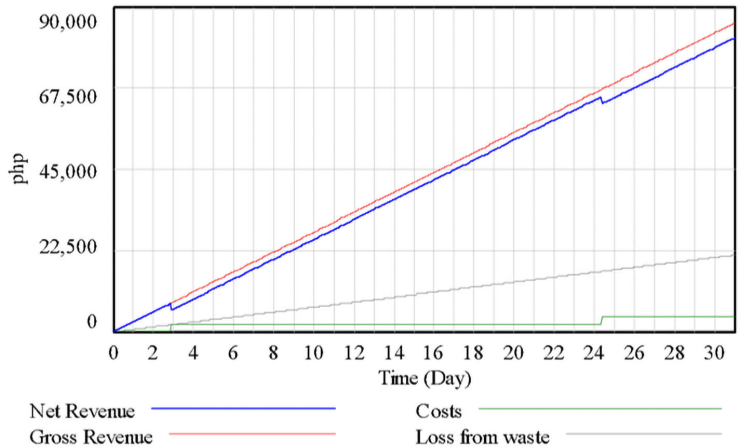

Figure 8. Baseline rice net revenue in comparison to gross revenue, costs, and loss from rice waste in the dormitory cafeteria.

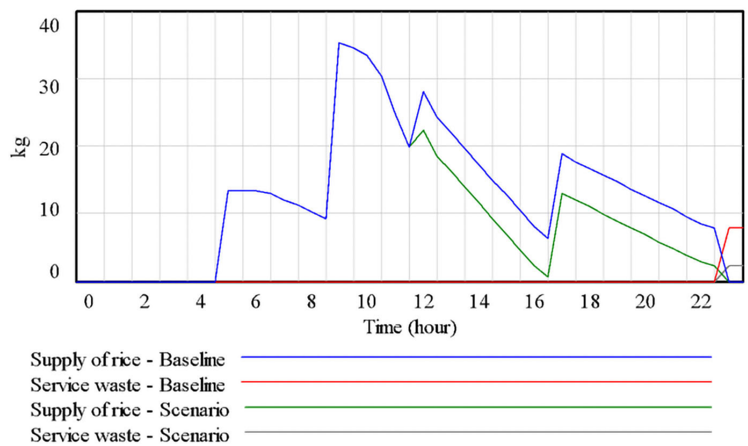

Figure 9. Comparison of the supply of rice and service waste in the dormitory cafeteria, baseline *vs.* scenario simulations.

for the procurement of rice and water consumption only. Notably, the "loss from rice waste" represents lost revenue due to preparation waste, and service waste totals PHP 21,226.30 at the end of the month, which is bigger than the operational costs at PHP 4,120.62.

Given that service waste is potentially the largest contributor to rice waste and financial loss, the scenario implemented for the dormitory cafeteria represents a protocol change aimed at decreasing the amount of service waste. The calculation of service waste is dependent on the amount of the remaining stock of unsold rice by the end of the day. The surplus rice indicates opportunities for waste avoidance through reduction at the source, a key insight consistent with the diagram in Figure 4. Among the inputs to the "cooked" rice stock is the flow of rice from the additional rice batch (as seen in Figure 5) when the management observes that the supply of cooked rice may not be enough. Thus, the scenario simulation reduces the mass of cooked rice by decreasing the amount of rice in the additional batch prepared when the cafeteria anticipates higher demand. However, a constraint is that the supply should still be able to meet the current demand based on the data gathered on the buying profile. In the scenario simulation, instead of the normal 7 kg, the additional batch was reduced to 4 kg.

Figure 9 shows the baseline trend supply of cooked rice, which is available for purchase throughout the day. At the end of the day, the cooked rice is "converted" to service waste. The baseline value for the service waste is 7.97 kg. In the scenario simulation, the cooked rice supply is lower than the baseline after reducing the additional batch. This generated less service waste at the end of the day. The 4 kg value for the additional batch yields the least amount of service waste without the supply of rice reaching zero.

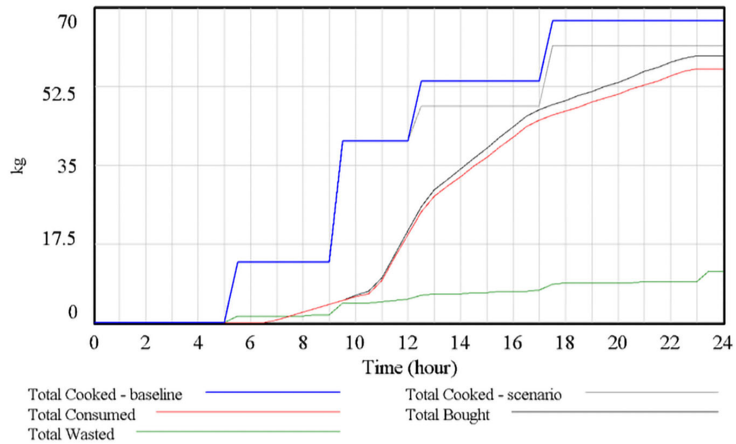

Figure 10. Rice mass totals in the dormitory cafeteria, baseline *vs.* scenario simulations.

Figure 10 shows that despite the decrease in the supply of cooked rice, there is still enough supply to provide for the demand. The amount of bought rice (based on the collected baseline data) is lower than the scenario value of cooked rice throughout the simulation. The value of the bought rice on the 17^{th} hour is 47.22 kg, whereas the cooked rice is 47.86 kg. Applying the same protocol change (reducing the additional batch from 7 kg to 4 kg) to the daily model and simulating for one month shows that the reduction of service wastes lowered the revenue lost due to rice wastes from PHP 21,226.30 to PHP 12,044.8 at the end of the month, indicating potential savings of PHP 9,181.50 monthly.

DISCUSSION

The overall MFA analysis highlighted the magnitude of the rice wastes generated from the upstream kitchen processes compared to the downstream consumption end. These results show that there is room for improvement, especially in processes upstream of consumption, to make the rice flow more efficient. The largest contributor to rice waste was not the plate leftovers of the consumers but rather the burnt rice coming from the kitchens. This is echoed in other studies, which found that food waste generation is higher at the meal preparation and cooking stage rather than at the consumption stage (Parry *et al.* 2015; Kasavan *et al.* 2021). This emphasizes the need to put more focus on adjusting food preparation practices in the kitchens, aside from just influencing consumer behavior. Based on the interviews conducted (details in Appendix I), the burning of rice could be attributed to the rice to water ratio used and to the equipment available for cooking. This may be reduced by either finding the appropriate ratio of rice and water when cooking or increasing the quality of rice cooking equipment, *e.g.* through investing in capital expenditures.

However, another key gap is accounting for the "unknown" flows that might potentially be contributing to service waste. The case of the dormitory cafeteria suggests that service waste could be a bigger or comparable contributor to preparation waste in terms of both mass and revenue loss. Thus, interventions need to be instituted to better quantify these unknown flows and then redirect them. For example, while keeping food safety in mind, unsold cooked rice may be safely stored and recooked as fried rice or it may be added to the food waste sold as fodder, both for additional income.

The prototype SD models for the dormitory cafeteria demonstrate how policy changes can be tested and their potential impacts on key variables of concern can be explored. In the scenario tested in this study, the simulations show how service waste and lost revenue can be reduced by a simple change in their additional batching policy. Other policy options identified from the MFA can likewise be implemented to test their efficacy.

There are limitations, however, to the model developed: factors that affected consumer preferences and would hence influence service waste were not yet included. Consumer behaviors (*e.g.* rice waste per cup) were assumed to be constant through time when demand and buying profiles might actually change throughout the month, and throughout the year depending on the activities on campus. Sampling was only conducted over the weekdays when in fact, there are still diners on campus on weekends. Whereas the values of specific variables in the SD model can be adjusted to reflect variations in consumer demands, further model development will be needed to quantify and incorporate the soft variables.

Nevertheless, the findings suggest that the pre-consumer stage of food production is more, if not equally, important than the post-consumer stage in terms of waste generation. Current approaches to food waste reduction in the university are focused on consumer behavior and preferences through advocacy campaigns for food waste avoidance such as sticker reminders and posters in the cafeterias and social media campaigns. However, these only address post-consumer waste. As such, collaborating with cafeteria management and finding alternative procedures to reduce waste and improve efficiency in the kitchen is key in addressing the overall food waste problem. Providing evidence-based recommendations for logistics and operations, as well as environmental education opportunities for management and staff, will also be helpful. As previous studies have shown, the success of food waste reduction and management within the hospitality and foodservice sector is dependent on the attitudes and pro-environment behavioral change of management (Munir 2022).

CONCLUSION

Sources of rice waste in the university can be summarized according to the four stages of the rice system: First is the procurement and storage stage, which is the only stage in the procedure where no rice waste was observed during the data gathering. The second is the preparation stage – where rice is wasted when it is not cooked properly – resulting in inedible, burnt rice. The third stage is the service stage, and rice that was not sold at the end of the day is considered service waste. The last stage is the consumption stage: rice plate leftovers are called consumption wastes and are the smallest contributor to the total waste produced in cafeterias. The MFA analysis showed that the largest source of known rice waste is the preparation stage. This provides valuable information to improve the sustainability of the campus food system. Most of the current campaigns focus on the consumer level of rice wastage when there is much to be done on the upstream rice life stages in the institution, specifically in the preparation and service stages. Therefore, this approach needs to be re-strategized to address the bulk of rice losses within the university food system.

The MFA models have proved useful in presenting a visual analysis of the cafeteria systems, whereas the SD models can facilitate the testing of the impacts of policy changes over time. Both the MFA and SD models show that interventions to minimize rice wastes are needed for the upstream processes specifically for the preparation and service stages of rice systems in the LS cafeterias. The key factors that affect the generation of rice wastes include the choice of cooking equipment, rice-to-water ratio, and modifications in the batching system. Revisions of the standard operating procedures made in the processes of the cafeterias and maintenance or updating the equipment are recommended. Rice directed to other purposes (*e.g.* to catering functions, to employees, for re-processing into a different product) need to be measured to better estimate the amount of service waste.

The prototype SD models for the dormitory cafeteria found that the service wastes are potentially the largest contributor to this cafeteria's rice wastes. Modifications to the rice batching system were simulated, effectively reducing the service wastes and financial losses that trigger undesirable feedback in the cafeteria system, as seen in the CLD. The model can also be adopted according to the specifics of other cafeterias and used as a tool to aid in decision-making for creating policy changes within the cafeteria.

The SD model was developed using data and insights from the MFA and was intended as a complementary tool. Currently, however, the SD model is limited to the quantifiable aspects of the operations in the larger rice waste system in university cafeterias. This prototype can be enhanced to include soft variables such as consumer behaviors and preferences that affect the rice consumption patterns. This can help cafeterias explore interventions to reduce consumption waste alongside service and preparation wastes.

The study helps fill the data gap regarding food waste studies in the food value chain at an institutional level. It also shows the potential of using MFA and SD as tools for creating and enhancing sustainable food systems to better address problems regarding food loss and waste. Implementing this in an educational institution that has centralized food waste generation offers opportunities to divert large quantities of food waste from landfills. Moving forward, rice sampling methods can be standardized based on the pilot efforts described in this study, and institutionalized as part of a larger food waste monitoring and evaluation initiative. Rice waste generation – and the larger food system, in general – represents a dynamic system influenced by several factors such as population on campus, consumer preferences, cafeteria technologies and protocols, *etc.* Data-gathering over time will be crucial to regularly validate and adjust the prototype models developed here, as well as to enhance these as decision support tools in service of the university sustainability agenda.

Finally, this study prompts us to rethink the way universities and other institutions should approach environmental issues such as waste generation. Downstream, consumer-focused interventions targeting changes in attitudes and behaviors must be complemented by upstream changes in operations and management approaches to support both a structural and cultural transformation for sustainability.

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NOTES ON APPENDICES

The complete appendices section of the study is accessible at https://philjournsci.dost.gov.ph

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APPENDIX I: DATA COLLECTION

Data collection for inputs to system characterization and system analysis and simulation was conducted *via* [1] consultation with cafeteria management and [2] actual observation and sampling.

1. Consultation

1.1. Standard Operating Procedures

A staff management consultation was conducted to investigate the standard methods and operating procedures inside the cafeteria, as well as the technologies that are currently in use for rice procurement, preparation, and service. This includes the following:

1. Processes involved in each stage: the procurement and storage stage, preparation stage, service stage, consumption stage, and waste management stage

2. Materials and equipment used in the preparation stage

3. Processes involving the disposal of the following:
    a. Plate rice wastes
    b. Preparation wastes
    c. Service wastes or unsold leftovers

4. Details about rice and its inflow and outflow in the system
    a. Rice characteristics (type of rice)
    b. Mass and frequency of rice delivery (including conditions for delivery)
    c. Rice to water ratio (ratio of the mass of uncooked rice and water used per batch)
    d. Amount of cooked rice produced/d
    e. Rice serving size
    f. Rice prices

5. Amount of water and energy consumed during rice preparation

The consultation was conducted only once during the data gathering period under the working assumption that the methods and operation procedures in the cafeteria kitchen remained consistent. The results of this were used as an additional input to construct the MFA and SD model.

1.2. Customer Consumption Patterns

The customer consumption patterns are heavily based on the sales of the cafeteria and its sub-concessionaires (if applicable) of rice. This aims to identify the consumption patterns of the consumers and their preferences. The rice sales also reflect the following information: [i] estimated number of cups of rice purchased/h based on the sales records and [ii] percentage of the total number of customers that availed of half (white) rice servings. These details were used for constructing the SD model. As for the MFA models, the aggregate rice sales were used.

2. Sampling of Rice Flow and Waste Generation

During the sampling period, the mass (kg) of rice moving from procurement through consumption was determined using a weighing scale. The sampling was conducted during representative days, when there was no major university event being held. The duration of the data gathering lasted for at least 12 h/d – from 06:00 AM (start of service) to 06:00 PM. A total of 15 d were sampled, with each day of the week being sampled three times. During sampling, weighing stations were created for each cafeteria using their readily available weighing scales and rice waste containers. Data sheets are provided and are all kept by the data gatherer.

The sampling method for determining the food losses and waste is divided according to the following stages:

2.1. Procurement and Storage Stage

Rice may be lost during the procurement and storage stage due to spillage, infestation, contamination, or weather exposure. In the event of any such incidents, information such as the date and time of the incident, the mass of the wasted rice, and the reason why the rice was lost is recorded.

2.2 Preparation Stage

Rice may be wasted during the preparation stage due to spillage or improper cooking methods resulting in burnt rice. Since the preparation procedure is standardized, the sampling and interview were only conducted once throughout the sampling duration. These parameters were assumed to be constant. In instances where rice preparation fails and the rice is rendered inedible, the wasted rice was also weighed.

The evaporation of water used in cooking the rice was estimated by obtaining the difference between the rice and water before and after it was cooked. This difference was divided by the initial mass of water to get the fraction of water evaporated. This is used as the evaporation factor in the SD model.

2.3 Service Stage

Service wastes are the rice that was cooked but was left unsold to the consumers for that day. The data for service wastes were taken from the difference between the total mass of rice cooked/d and the total mass of rice sold/d. The total mass of rice sold/d was taken from the sales records with permission from the cafeteria management. For cafeterias with sub-concessionaires, data on their rice sales were also taken either through daily monitoring of the sales or through the sales records of the cafeteria management.

Cafeteria practices related to unsold rice were observed and recorded. This includes whether the unsold rice is donated to the kitchen employees, stored for recycling (cooked as garlic rice or fried rice) and resold, or immediately thrown away.

2.4 Consumption Stage

Plate wastes are the rice wastes gathered from the leftovers of the diners. The plate waste data gathering procedure was conducted as follows:

1. The assigned collector for the day segregated the rice from plate wastes into the provided containers at the weighing stations.
2. The collected plate rice wastes were weighed and recorded on the data sheets provided.
3. After weighing, the rice waste was disposed of according to the standard operating procedures of the kitchen.
4. The mass of the rice waste collected was recorded in kg as plate wastes.

A separate set of data sheets was provided to tally the number of rice cups, full or half portion, served within the day. For other cafeterias, the data for the amount of sold cups of rice were taken from the record of the cafeteria management. Additional information about other variables collected is provided in Table AI.1 below.

Table AI.1. List of variables collected from sampling and key informant interview/consultation from various stages of the life cycle of rice.

APPENDIX II: MFA DIAGRAMS OF INDIVIDUAL CAFETERIAS

Two main campus cafeterias (designated as Campus Cafeteria A and Campus Cafeteria B) and two dormitory cafeterias (designated as Dormitory Cafeteria A and Dormitory Cafeteria B) were included in the study. Dormitory Cafeteria A was used as the case study for the SD modeling.

The MFA of Campus Cafeteria A is summarized in Figure AII.1. Campus Cafeteria A received 10 sacks of rice in each delivery, which was equivalent to a total of five 500 kg of rice, delivered only when there are less than two sacks of rice left in the storage area. The estimated number of batches of rice prepared every day ranged from 7–10 batches, each weighing 6 kg/batch. Thus, the daily total was equivalent to 60 kg of uncooked rice, which also included rice cooked for a portion of their catering services. For the sake of the model, the number of batches that was used was set to 10 batches to account for the unmeasured portion of rice for catering (outside the cafeteria).

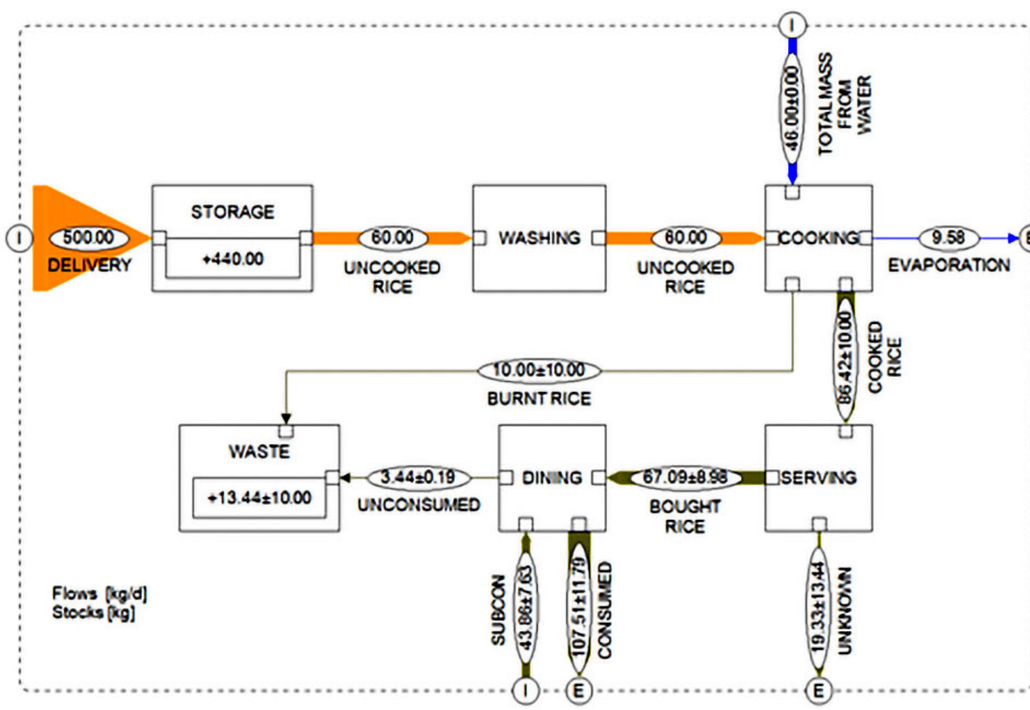

Figure AII.1. MFA of Campus Cafeteria A.

The value of the BURNT RICE flow in this model was attributed to the equipment used in cooking rice, which is an industrial rice cooker. However, the amount of burnt rice can be reduced by adjusting the rice-to-water ratio. The UNKNOWN flow in Figure AII.1 was taken to represent, though not exclusively, the percentage of the COOKED RICE that was served for catering. This flow also includes the amount of rice that was not sold during the day. Either way, the unknown flow for this model is assumed to be 100% consumed since the mass of prepared rice meant for catering is taken out of the system boundaries. The unsold rice was reprocessed using a different procedure and is resold as another product the next working day. Thus, this rice is not considered waste.

In total, Campus Cafeteria A generated 13.44 ± 10.00 kg of rice waste, 10 kg of which originated from kitchen waste or burnt rice. The total waste collected is sold to outside partners for additional profit where it was found that Cafeteria A gains an additional PHP 1000.00 for eight barrels of collected food waste. Water loss of 9.58 kg during the cooking of rice was also noted.

The MFA of Campus Cafeteria B is summarized in Figure AII.2. The rice delivery occurred daily, bringing 50 kg of rice into the system every day, where 27.70 ± 0.42 kg of it was prepared by the cafeteria. Similar to Campus Cafeteria A, Campus Cafeteria B also offered catering services, and the rice that was served for the catering was also taken from the daily preparations of rice for the cafeteria. To account for the rice demand for the cafeteria and partially for the catering, the assumed number of batches used for the model is eight.

During consultations, leftover cooked rice in the service area was found to be consumed by the employees. These leftover service wastes were included in the UNKNOWN flow of the model. Aside from these, the remaining percentage of the UNKNOWN flow represents the amount of rice that was served or added to the catering services.

Campus Cafeteria B has the least value of BURNT RICE of all the cafeterias. It is also the only cafeteria where the value of the BURNT RICE flow is lower than the UNCONSUMED flow. Campus Cafeteria B also uses industrial rice cookers but with more water in relation to rice, which could have contributed to the lower amount BURNT RICE. Daily, Campus Cafeteria B loses 9.08 ± 0.12 kg of water due to evaporation during the cooking stage. The total rice waste was 8.32 ± 3.16 kg of rice, of which 7.32 ± 3.00 kg came from the UNCONSUMED flow. However, this may be a slight overestimate as some viands were mixed into the rice wastes and were difficult to separate prior to weighing.

The MFA of Dormitory Cafeteria A is represented in Figure AII.3. Dormitory Cafeteria A received 15 sacks of 50 kg rice whenever only two sacks of rice (100 kg) remained in storage. This café is the newest establishment among the four cafeterias of the LS campus and does not

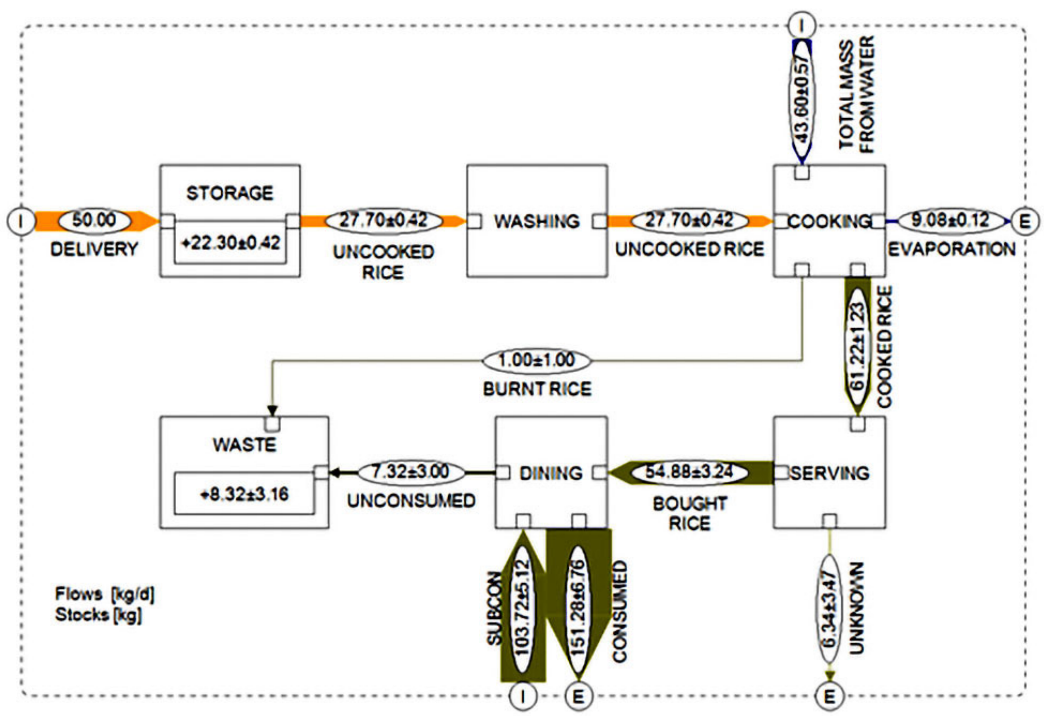

Figure AII.2. MFA of Campus Cafeteria B.

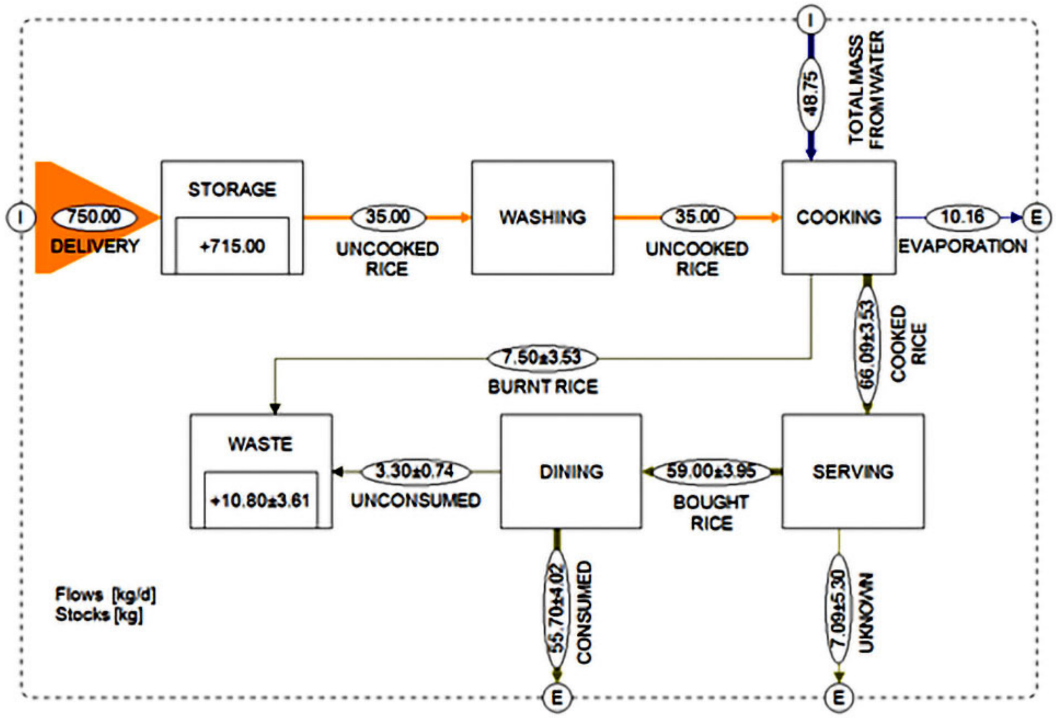

Figure AII.3. MFA of Dormitory Cafeteria A.

offer any catering services. This is also the only cafeteria that still prepares rice by boiling the grains in a large pot instead of using industrial or commercial rice cookers.

It was observed that Dormitory Cafeteria A did not recycle or recook leftover rice. Therefore, all of the UNKNOWN was assumed to be immediately disposed of, although it was claimed that employees may take and consume the service leftovers. Although the UNKNOWN flow was not connected to WASTE stock, a large percentage of it represents financial loss. Rice wastes are collected with the leftover viands in one bin, to be sold (*e.g.* to piggeries). A total of PHP 600 additional income is generated monthly. Overall, Dormitory Cafeteria A produces 10.80 ± 3.61 kg of known rice waste and 10.60 kg of water loss due to evaporation.

The MFA of Dormitory Cafeteria B is represented in Figure AII.4. Rice delivery here occurred twice a month with 10 sacks of rice, each weighing 25 kg. Every day, 48.30 kg of rice was prepared. Like the campus cafeterias, Dormitory Cafeteria B also provided catering services, which accounted for most of the UNKNOWN flow. Included in the UNKNOWN was the mass of rice that the cafeteria gave for free to the Residence Halls staff. This free rice came from the donated sack of rice from the residence hall director and was not reflected in the sales record; it was, therefore, added to the flow for catering. The impacts of this additional sack on profits were unknown and this additional rice sack was not included in the DELIVERY flow. Lastly, the UNKNOWN flow also included service wastes or leftover unsold rice at the end of the day. These are stored by the management and are reheated the next morning to be sold and served. Therefore, these are assumed to be 100% consumed and are not wasted

The BURNT rice flow of Dormitory Cafeteria B was the largest value compared to the other cafeterias, despite having the highest water-to-rice ratio. Commercial rice cookers were being utilized by the cafeteria. Dormitory Cafeteria B, in total, generated 16.92 ± 0.24 kg of rice waste from UNCONSUMED and BURNT RICE and lost 17.50 kg of water/d.

APPENDIX III: SD HOURLY MODEL OF DORMITORY CAFETERIA RICE SYSTEM

The hourly model captured the major rice stocks (rice in storage, cooked rice, bought rice, total consumed rice, preparation waste, service waste, and consumer waste) and the processes linking these stocks.

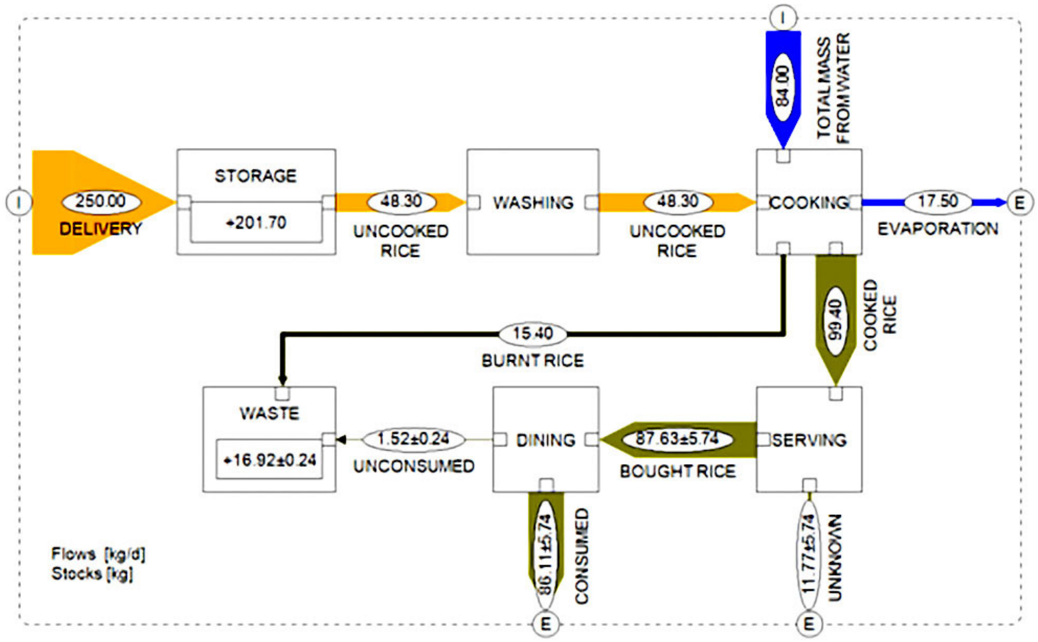

Figure AII.4. MFA of Dormitory Cafeteria B.

Based on the interviews, an influx of rice is created in the model whenever the mass of rice in the storage area is less than 100 kg. This limits the inflow of rice into the system without risking running out of rice stock while still having a continuous inflow of rice.

The hourly model also shows the changes in the cooked stock. Cooked stock is the remaining supply of cooked rice that is available throughout the day as it is affected by the rice preparation and rice demand. For rice preparation or batching, it is divided into two inflows in an hourly model: "preparation and cooking" and "additional preparation and cooking." These variables include the time the batches are made and the mass of rice utilized for each batch. The "additional mass from water" is the added mass due to the absorbed water in the cooking process. The value of this flow is dependent on the value of the rice inputs and the current rice-to-water ratio used by the cafeteria.

The output of "cooked" stock or available supply of rice, on the other hand, is the buying and the outflow of the preparation waste and service waste. The "buying" flow is the mass of rice bought. The buying profile is used as an input for this flow to show the per hour demand for bought rice. In doing so, the value of the buying flow or demand for rice changes for each hour of the day, capturing the change in the rates during peak hours. The other outputs are the "loss due to burnt rice" and the "unsold." These flows take a portion of the cooked rice per batch and all the remaining stock of rice in the "cooked" stock at the end of the day and consider them as rice waste in the model.

The succeeding table details all the variables in the model. Values are based on observations during data-gathering.

Table AIII.1. Variables in the SD hourly model for the dormitory cafeteria.

Model settings	
Unit time	h
Time start	0
Time end	24
Time step	0.5

Table of variables:

Note: the column "value" refers to the initial value in the case of stock variables (*i.e.* the amount in the stock at time = zero) and to a constant value in the case of static auxiliary variables. No fixed value is indicated for ("N/A" = not applicable) flow variables in this model and other auxiliary variables, which are computed from the given equations.

Name	Type	Unit	Value	Equation	Remarks
Additional mass from water	Flow	kg/h	N/A	((Preparation and Cooking/RiceWater ratio))+((Additional Preparation and Cooking/RiceWater ratio))-((((Preparation and Cooking/RiceWater ratio))+((Additional Preparation and Cooking/RiceWater ratio)))*Evaporation factor)	
Additional preparation and cooking	Flow	kg/h	N/A	IF THEN ELSE(Time>=10:AND:-Time<=12:AND:Cooked<=Threshold value for cooked rice during peak hours,"Mass of un.rice used for additional batch"*Time multiplier,0)	If the cooked rice during peak hours (10 AM–12 NN) is equivalent to 1 and 1/2 batches of rice (22.078125 kg), then an additional batch is prepared)
Average half cups sold/d	Auxiliary	cup	N/A	"Total no. of consumers per day"*Percentage of consumers that avails the half rice option	
Average whole cups sold/d	Auxiliary	cup	N/A	Total no. of consumers per day*(1-Percentage of consumers that avails the half rice option)	
Bought	Stock	kg	0	INTEG(Buying-Consumed-Unconsumed,0)	
Burnt rice factor	Auxiliary	dmnl	N/A	Mass of burnt rice per batch/(Mass of un.rice used per batch + Mass of water used per batch)	
Buying	Flow	kg/h	N/A	IF THEN ELSE(Time>=6:AND:Time<23,Mass of rice bought,0)	
Consumed	Flow	kg/h	N/A	(Buying*Percentage of consumers that avails the half rice option)*(1-Percentage that consumer wastes per half cup)+(Buying*(1-Percentage of consumers that avails the half rice option))*(1-Percentage that consumers waste per cup)	
Consumer waste	Stock	kg	0	INTEG(Unconsumed,0)	
Cooked	Stock	kg	0	INTEG(Additional Mass From Water+Additional Preparation and Cooking+Preparation and Cooking-Buying-Loss Due to Burnt Rice-Unsold,0)	
Delivery	Flow	kg/h	N/A	IF THEN ELSE(Storage<=(Threshold value for rice in storage-35),Mass of rice per sack*Sacks of rice bought per delivery*Time multiplier,0)	Rice is delivered if two sacks (100 kg) of rice remains in the storage; delivery is timed for 09:30 AM
Evaporation factor	Auxiliary	dmnl	0.208333333		
Half cups buying profile	Auxiliary	1/h	N/A	WITH LOOKUP (Time, ([(0,0)-(24,0.2)],(0,0),(6,0),(7,0.047619), (8,0.047619),(9,0.047619),(10,0.047619), (11,0.158263),(12,0.158263),(13,0.0616246), (14,0.0616246),(15,0.0616246),(16,0.0616246), (17,0.0410831),(18,0.0410831), (19,0.0410831),(20,0.0410831), (21,0.0410831), (22,0.0410831),(24,0)))	Lookup graph based on the sales record on the cafeteria on how many half cups of rice were sold/d
Half cups sold/h	Auxiliary	cup/h	N/A	Half cups buying profile*Average half cups sold/d	
Inflow of rice and water	Flow	kg/h	N/A	Additional Mass from Water+Additional Preparation and Cooking+Preparation and Cooking	
Inflow of waste	Flow	kg/h	N/A	Loss Due to Burnt Rice+unconsumed+Unsold	
Loss	Flow	kg/h	N/A	Loss Due to Burnt Rice	

Name	Type	Unit	Value	Equation	Remarks
Loss due to burnt rice	Flow	kg/h	N/A	Burnt rice factor*(Preparation and Cooking + Additional Preparation and Cooking + Additional Mass from Water)	
Mass of burnt rice/batch	Auxiliary	kg	1.5		
Mass of rice bought	Auxiliary	kg/h	N/A	(Whole cups sold per hour*Mass per cup of rice)+(Half cups sold per hour*Mass per half cup of rice)	
Mass of rice/sack	Auxiliary	kg/sack	50	Constant	
Mass of un.rice used for additional batch	Auxiliary	kg	7	Constant	
Mass of un.rice used/batch	Auxiliary	kg	7	Constant	
Mass of water used/batch	Auxiliary	kg	9.75	Constant	
Mass/cup of rice	Auxiliary	kg/cup	0.21298	Constant	
Mass/half cup of rice	Auxiliary	kg/cup	0.117456	Constant	
Outflow of rice from the service area	Flow	kg/hour	N/A	Buying	
Percentage of consumers that avails the half rice option	Auxiliary	dmnl	0.117392	Constant	
Percentage that consumer wastes/half cup	Auxiliary	dmnl	N/A	3.3/59	Based on rice waste *vs.* rice bought
Percentage that consumers waste/cup	Auxiliary	dmnl	N/A	3.3/59	Based on rice waste *vs.* rice bought
Preparation and cooking	Flow	kg/hour	N/A	("Mass of un.rice used per batch"*Time multiplier*PULSE(Time for 1st batch,TIME STEP))+ ("Mass of un.rice used per batch"*Time multiplier*PULSE(Time for 4th batch,TIME STEP))+ ("Mass of un.rice used per batch"*Time multiplier*PULSE(Time for 2nd batch,TIME STEP))+ ("Mass of un.rice used per batch"*Time multiplier*PULSE(Time for 3nd batch,TIME STEP))	4 batches are prepared/d (1 at 5 AM; 2 at 9 AM and 1 at 5 PM)
Preparation waste	Stock	kg	0	INTEG(Loss Due to Burnt Rice,0)	
Rice-to-water ratio	Auxiliary	dmnl	N/A	"Mass of un.rice used per batch"/Mass of water used per batch	
Sacks of rice bought per delivery	Auxiliary	sack	15	Constant	
Service waste	Stock	kg	0	INTEG(Unsold,0)	
Storage	Stock	kg	75	INTEG (Delivery-Additional Preparation and Cooking-Preparation and Cooking,75)	
Threshold value for cooked rice during peak hours	Auxiliary	kg	22.0781	Constant	Equivalent to 1 and 1/2 batches of rice
Threshold value for rice in storage	Auxiliary	kg	100	Constant	
Time for 1st batch	Auxiliary	hour	5	Constant	4 batches are prepared/d (1 at 5 AM; 2 at 9 AM and 1 at 5 PM)

Name	Type	Unit	Value	Equation	Remarks
Time for 2nd batch	Auxiliary	hour	9	Constant	4 batches are prepared/d (1 at 5 AM; 2 at 9 AM and 1 at 5 PM)
Time for 3rd batch	Auxiliary	h	9	Constant	4 batches are prepared/d (1 at 5 AM; 2 at 9 AM and 1 at 5 PM)
Time for 4th batch	Auxiliary	h	17	Constant	4 batches are prepared/d (1 at 5 AM; 2 at 9 AM and 1 at 5 PM)
Time multiplier	Auxiliary	1/h	N/A	1/TIME STEP	
Total bought	Stock	kg	0	INTEG(Outflow of rice from the service area,0)	
Total consumed	Flow	kg/h	0	INTEG(Consumed,0)	
Total cooked	Stock	kg	0	INTEG(Inflow of rice and water-Loss,0)	
Total no. of consumers/d	Auxiliary	cup	292.47	Constant	Based on the no. of cups (whole and half) ordered
Total waste	Stock	kg	0	INTEG(Inflow of waste,0)	
Unconsumed	Flow	kg/h	N/A	(Buying*Percentage of consumers that avails the half rice option)*(Percentage that consumer wastes per half cup) +(Buying*(1-Percentage of consumers that avails the half rice option))*(Percentage that consumers waste per cup)	
Unsold	Flow	kg/h	N/A	IF THEN ELSE(Time=23,Cooked*Time multiplier,0)	Unsold rice is automatically disposed
Whole cups buying profile	Auxiliary	1/h	N/A	WITH LOOKUP (Time, ([(0,0)-(24,0.2)], (0,0),(5,0),(6,0),(7,0.0291605),(8,0.0291605), (9,0.0291605),(10,0.0291605),(11,0.179421), (12,0.179421),(13,0.0796805),(14,0.0796805), (15,0.0796805),(16,0.079685),(17,0.0342992), (18,0.0342992),(19,0.034292),(20,0.0342992), (21,0.0342992),(22,0.0342992),(23,0),(24,0)))(24,0.2)],(0,0),(5,0),(6,0),(7,0.0291605),(8,0.0291605),(9,0.0291605),(10,0.0291605),(11,0.179421),(12,0.179421),(13,0.0796805),(14,0.0796805), (15,0.0796805),(16,0.0796805),(17,0.0342992),(18,0.0342992),(19,0.0342992),(20,0.0342992),(21,0.0342992),(22,0.0342992),(23,0), (24,0)))	Lookup graph based on the sales record on the cafeteria on how many cups of rice were sold/d
Whole cups sold/h	Auxiliary	cup/h	N/A	Average whole cups sold/d *Whole cups buying profile	

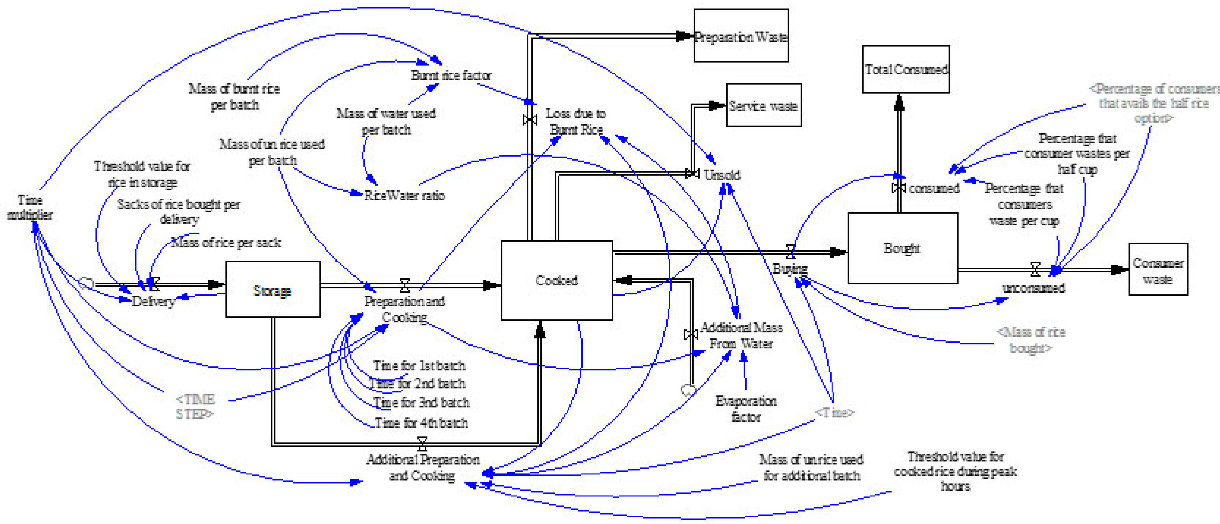

Figure AIII.1. SD hourly model: main stocks and flows.

Figure AIII.2. SD hourly model: calculations of buying profile (left) and totals (right).