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Final Report

SRA	Closing the loop between agriculture and wastewater discharge: A novel technique for turning wastewater into fertiliser in the Pacific
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Acronyms

ACIAR: Australian Centre for International Agricultural Research
DFAT: Department of Foreign Affairs and Trade's (DFAT)'s
FAO: Food and Agriculture Organisation of the United Nations
GPML: Global Partnership on Marine Litter
GDP: Gross Domestic Product
HTC: Hydrothermal Carbonisation
JICA: Japanese International Cooperation Agency
J-PRISM: Japanese Technical Cooperation Project for Promotion of Regional Initiative on Solid Waste Management in Pacific Island Countries
LDC: Least Developed Country
MLAP: Pacific Marine Action Plan: Marine Litter
NBSAP: National Biodiversity Strategy and Action Plans
NEPIP: National Environment Policy and Action Plans 2030
NSDP: National Sustainable Development Plan (2016-2030)
NWMPCSIP: National Waste Management and Pollution Control Strategy and Implementation Plan 2016-2020
NWT: National Wastewater Taskforce
PICT: Pacific Island Countries and Territories
PALM: Japan-Pacific Leaders' Meeting
PAR: Participatory Action Research
PVMC: Port Vila Municipal Council
RANP: Rapid Assessment of Needs and Perceptions
SPREP: Secretariat of the Pacific Regional Environment Programme
SRA: Small Research Activity
SWAT: Solid Waste Agency of Tuvalu
TIWPAP: Tuvalu Integrated Waste Policy and Action Plan (2017 to 2026)
UNDP: United Nations Development Fund
UNEP: United Nations Environmental Program
VCCDRRP: Vanuatu Climate Change and Disaster Risk Reduction Policy (2016-2030)
NNOP: Vanuatu National Oceans Policy (2016)
VRWMASP: Vanuatu Recyclers and Waste Management Association Strategic Plan (2021-2024)
VSTP: Vanuatu Sustainable Tourism Policy (2019-2030)

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1. Executive Summary

This ACIAR funded Small Research Activity (SRA) aimed to assess the feasibility of a 'Closing the Loop' concept in Pacific Island agriculture by assessing the feasibility of converting human waste into stable, pathogen-free, organic fertilisers in two developing Pacific Island countries (Vanuatu and Tuvalu). Both countries are dominated by small-scale subsistence-based agriculture, lack some basic services, suffer from degraded groundwater and coastal water quality, are spread over vast distances and are severally threatened by climate change. Despite the critical need for local solutions to improve agricultural systems, affordable, small scale, low maintenance technologies that help increase crop yields and improve sanitation problems have yet to be developed and applied.

To address these problems, this SRA aimed to; 1) undertake extensive stakeholder engagement in a range of contrasting communities using interviews, surveys, and storian sessions to determine community needs, opportunities, and perceptions of using treated human waste in agriculture, 2) test the capability of traditional and novel treatment technologies to produce a pathogen-free, nutrient-dense, organic fertiliser, 3) conduct a feasibility study to determine potential waste feedstocks, energy sources, benefits to farmers, governance structures and project partners that affect the rollout of full-scale reuse projects, 4) create a model to rapidly assess the needs, suitability and opportunities for implementing full-scale reuse projects in other Pacific communities, and 5) create opportunities for women in Pacific Island agricultural communities. This project directly aligns with both countries' key agricultural research priorities, including sustainable agriculture development, increased agricultural resilience, and adding value to agricultural products.

This SRA found that most survey and workshop participants have experienced a loss of productivity in their farming or backyard gardening systems. Declining crop yields are particularly problematic because most people within these communities rely on subsistence or smallholder farming to meet their daily food and economic needs. Decreasing productivity has been attributed to reduced soil health following a shift to more intensive farming practices and planting of crops with high nutrient demand. Additionally, efforts to increase productivity have been hampered by the high cost and lack of awareness of synthetic fertilizers, the importance of organic certification and in the case of Tuvalu, a ban on fertiliser imports since 2000. Reduced crop yield has subsequently led to food shortages in some sections of communities and further compounded by extreme events such as COVID 19 travel restrictions and increasingly prevalent tropical cyclones.

Human and organic waste management is also extremely problematic, with nutrient-rich domestic wastewaters often discharged directly into groundwater and coastal lagoons. This leads to degraded water quality and is a significant threat to human and environmental health. Although progress has been made in the last few decades moving communities to better sanitation with the installation of improved wastewater treatment systems, these systems are almost universally poorly maintained and serviced. Importantly, without any incentive to collect waste, it remains a ‘problem’ rather than a potential asset to improve livelihoods in the communities. As well as human wastes, organic waste disposal is also problematic, with much of the total volume of wastes collected for landfill consisting of organic material (i.e. household food scraps and agricultural wastes).

Social, cultural, and environmental considerations contrasted between countries and communities within countries, showing the importance of developing site-specific models for the rollout of wastewater reuse projects in the wider Pacific. For example, communities in Tuvalu were generally more open to reusing human waste than communities in Vanuatu. This was attributed to Tuvaluans having more exposure to composting toilets and a greater awareness of the need to conserve water and limited access to fertile land, among other social and cultural factors. Significant limitations were also found in specific communities, such as Tanna (Vanuatu), where cultural factors led to the low acceptance of using human waste. Additionally, there is a lack of available sites to conduct a pilot project in the Tanna due to significant land tenure disputes.

The project found that in more peri-urban settings such as Mele, Vanuatu and Funafuti in Tuvalu, a large proportion of waste feedstock is wet waste (septic tank waste) which requires dewatering through sand drying beds before further treatment or treatment via hydrothermal carbonization (HTC). In contrast, the more rural communities on Vanuatu’s outer islands and, to a lesser degree in Funafuti, had a greater prevalence of dry wastes that could be treated directly with anaerobic composting and/or pyrolysis after collection. A small number of composting toilets have been trailed in Tuvalu and could provide an easily accessible source of dry wastes if sufficient volumes were available. Another option that requires further exploration is the collection and use of cruise ships wastes. Cruise ship waste is a significant management and environmental problem in countries like Vanuatu and represents a large untapped nutrient source for larger-scale agriculture if it could be adequately collected and treated. The study also found abundant renewable energy sources for more advanced treatment technologies (pyrolysis and HTC), including forest biomass, coconut husks, copra and Biogas (methane captured from stored wastes).

To assess the viability of turning human waste and wastewater into organic fertilisers, we tested several human waste types, treatment options (pyrolysis, HTC, and anaerobic composting), and final product types. The treatment options all effectively retained the bulk of primary (N, P, K), intermediate (S, Mg, Ca) macronutrients and all micronutrients. For pyrolysis and HTC treatments, phosphorus concentrations were enriched 1.4 and ~2 fold, respectively. Initial dewatering processes also effectively reduced pathogen loads (>90% reduction), but levels were still greater than thresholds considered safe for unrestricted use on food crops. Anaerobic composting of dried septic tank sludges reduced faecal coliforms and E. coli concentrations to below Australian EPA to 'Stabilisation Grade Product' safety limits, and end products could be used safely on food crops if the piles were turned regularly to increase homogeneity. Both the pyrolysis and HTC treatments removed 100% of pathogens. Analysis of the differences between treatment technologies clearly showed that there is not a 'one size fits all' solution for communities. Factors such as the type of waste available, level of technical expertise, capital investment, and the type and scale of agricultural use determine the suitability of each particular process for different communities.

The project found that if all household human wastes were treated and reused, the produced fertilisers could meet more than double the nitrogen and about 60% of the phosphorus needs of subsistence farming households. However, as capturing 100% of waste matter from on-site systems is challenging, further research is needed to quantify on-ground recovery rates. Due to the volume of wastes required, broadacre or plantation farming would likely necessitate access to centralised wastewater facilities (or potential cruise ship wastes) and up-scaled treatment systems.

Many of the smallholders surveyed indicated there is a growing market for organically certified products, and there was a significant opportunity to increase the profitability of markets gardens. With synthetic fertilisers either banned or in limited use, the smallholders also indicated there is little opportunity to improve their soil health and overall yields while still producing an organic product. The fertilisers produced in this study have the potential to meet this growing need for organic produce. Wastes treated via anaerobic composting, pyrolysis and HTC all met the standards for organic certification and unrestricted use according to the Pacific Organic Standard, National Standard for Organic & Biodynamic Produce and The Australian National Export Standard for Organics. However, once full-scale projects are developed, individual assessments would need to be conducted.

A range of potential governance structures are possible for developing full-scale wastewater reuse projects in Pacific Island communities depending on the needs, limitations, partners and type of wastes available. These include; 1) a fully supported funding model where donors fund a larger initial capital expenditure, ongoing project costs and the product is provided free of charge, 2) a blended model where project costs are split between donors and project partners and the product is sold at a subsidised rate, and 3) a commercial funding model where project costs are covered by partners and product sales.

Because wastewater reuse projects cover a broad range of different sectors (wastewater management, groundwater resources, marine management, agriculture, and commercial interests), there is substantial opportunity for a number of project partners to be involved. This includes global partners such as the World Bank and United Nations Development Program, major regional organisations like the Secretariat of the Pacific Regional Environment Programme, and the Japanese International Cooperation Agency aid organisations like Australia’s Development Program and ACIAR, universities and research institutions, NGOs like Live and Learn in the Pacific, and most importantly Pacific Island governments and councils.

To determine the feasibility of developing Closing the Loop wastewater reuse projects in Pacific communities other than those already surveyed, we developed the *Rapid Assessment of Needs and Perceptions (RANP)* tool. This tool incorporates lessons learned during this SRA to efficiently assess new communities' suitability for reuse projects and identifies the most appropriate governance structure, partnerships, opportunities, limitations, and suitable treatment systems before on-ground works occur.

Importantly, this project found there are significant opportunities for women in future wastewater reuse projects. Specific opportunities identified for women include working with female market stallholders, capacity building female waste pickers at Bouffa landfill in Vanuatu, ensuring an equal representation of female and male technical staff, and exploring private sector opportunities for the development and sale of fertiliser with female entrepreneurs. Academic scholarships are also available to female applicants through ACIAR Pacific Agriculture and Southern Cross Universities scholarship schemes.

This study found wastewater reuse represents a significant opportunity for Pacific communities. Not only can it help improve food security, economic opportunities and increase crop yields, it may also promote better human waste management by shifting the perception of human waste from a ‘problem’ to an ‘opportunity’. Importantly, the study found there is no ‘one size fits all’ solution, and the needs, perceptions and limitations of each community must be assessed before any on ground works take place.

The key recommendations of this project are:

- That full scale Closing the Loop reuse projects be developed in Mele, Vanuatu and Alapi, Tuvalu.
- That measures are taken in Vanuatu to reduce the significant amounts of organic waste entering Bouffa Landfill from markets, kava bars and households.
- That full scale Closing the Loop reuse projects also be developed in other Pacific communities using the RANP model.
- That an education program be developed to support the mindset shift in certain communities to seeing human waste as a resource rather than taboo.
- That further research be conducted to determine the feasibility of collecting and treating human wastes from cruise ships, the amount of recoverable human

waste from different household waste treatment types and incorporating animal wastes into future RANP processes.

- That opportunities for greater engagement of women in Pacific agricultural communities through improving supply and quality of produce for markets and value addition continue to be explored.

2. Background

2.1 Regional Level

Waste management and the pollution of groundwater and coastal ecosystems is a significant problem for South Pacific nations. Poor waste management arising from a lack of knowledge and resources has led to significant social and environmental impacts. Developing effective waste management practices that incorporate nutrient capture may build South Pacific community resilience with improved agricultural yields and a cleaner, healthier environment.

In the Pacific at the Regional level, the following policies address issues around waste management and pollution control:

- The Cleaner Pacific 2025 - Pacific Regional Waste and Pollution Management Strategy 2016-2025
- Pacific Marine Action Plan: Marine Litter (MLAP) 2018-2025 that was developed as part of the Regional Seas Programme and the Global Partnership on Marine Litter (GPML)
- SAMOA Pathway for Sustainable Development Goals

The two key regional organisations supporting waste and pollution management in the Pacific are the Secretariat of the Pacific Regional Environment Programme (SPREP) and the Japanese International Cooperation Agency (JICA). SPREP is an inter-governmental organisation that provides technical assistance to twenty-one Pacific Island Countries and Territories (PICT's) in several priority environmental areas, including waste management and pollution control (Secretariat of the Pacific Regional Environment Programme, 2011). JICA started assisting PICTs in terms of solid waste management in collaboration with SPREP in 2000 to realize the commitment of the

Government of Japan at the 2nd PALM (Japan-Pacific Leaders' Meeting). The outcome of this collaboration was the adoption of the Pacific Regional Solid Waste Management Strategy 2010-2015.

In partnership with SPREP, JICA initiated the Japanese Technical Cooperation Project for Promotion of Regional Initiative on Solid Waste Management in Pacific Island Countries (J-PRISM) in 2011 (SPREP, 2011). The J-PRISM was implemented in 11 PICTs: Federated States of Micronesia, Republic of the Fiji Islands, Republic of Kiribati, Republic of Marshall Islands, Republic of Palau, Independent State of Papua New Guinea, Independent State of Samoa, Solomon Islands, Kingdom of Tonga, Tuvalu and Republic of Vanuatu (SPREP, 2011). The objective of J-PRISM was to develop/increase the capacity of the counterparts and the recipient countries as a whole by implementing priority actions listed in the Regional Solid Waste Management Strategy 2010-2015 to respond to any issues/challenges and provide better solid waste management.

In 2017, in partnership with SPREP, JICA launched the Japanese Technical Cooperation Project for Promotion of Regional Initiative on Solid Waste Management in Pacific Island Countries Phase 2 (J-PRISM II). This program targeted the *"human and institutional capacity base for sustainable Solid Waste Management in the Pacific region is strengthened through implementation of Cleaner Pacific 2025 - Pacific Regional Waste and Pollution Management Strategy 2016-2025"* (JICA, 2019).

Regional initiatives such as these rely heavily on fundamental change at the community level. Therefore, it is vital to engage communities in the design and development of waste management projects. Under the SPREP Clean Pacific 2021 Campaign (Secretariat of the Pacific Regional Environment Programme, 2012), successful community-based case studies were provided to replicate in other communities. Activities included: composting, waste reduction, recycling, litter prevention, and better waste disposal solutions. However, while progress has been made in the development of regional initiatives and national programs, poor solid and hazardous waste continues to escalate in the region. In terms of waste streams, PICT's are dominated by organic waste, which accounts for up to 50% of all waste disposal, thus reflecting the largely agricultural-based economy in the majority of PICT's. This indicates the significant potential that waste reuse could deliver in reducing the waste burden in PICT's.

PICTs are generally classified into three sub-regions, Melanesia, Polynesia, and Micronesia, based on their ethnic, linguistic, and cultural differences. Across these three sub-regions, the land masses, populations, economic prospects, natural resources, and political systems can vary widely. Two PICT's were selected for this SRA based on contrasting attributes to assess the feasibility of recovering wastewater nutrients in contrasting communities. The Polynesian country of Tuvalu and the Melanesian country of Vanuatu were selected as they demonstrated significant differences in population and population density, population growth, land area and exclusive economic zone (see Table 1). Interestingly both Vanuatu and Tuvalu are amongst the few countries in the world to have evaded the COVID 19 pandemic. However, border restrictions presented several socio-economic challenges food shortages, limited movement between islands, and limits on imported goods.

Table 1. Population and Size of Pacific Islands (Source: Richards & Haynes, 2016, p. 256).

Country	**Exclusive economic zone (km^2)**	**Land area (km^2)**	**Population**	**Population density (people/km^2)**	**Population growth rate (%)**
Melanesia					
Vanuatu	710,000	12,281	307,150	20	2.5
Polynesia					
Tuvalu	1,300,000	26	11,149	429	0.5

Poor municipal solid waste management is a significant threat to sustainable development in PICTs, with potentially damaging consequences to public health, environmental quality, water resources, fisheries, agriculture, tourism, trade, and other areas of national development (SPREP, 2010).

The threats arising from poor solid waste management are made worse due to:

- Increasing rates of waste generation arising from economic and population growth
- The limited availability of suitable land for landfills on small islands and atolls, exacerbated by customary land tenures and ‘‘not-in-my-backyard’’ attitudes
- The remoteness of many PICTs resulting in high capital and operating costs

- The small and sometimes sparse populations which limit any potential economies of scale, and
- The limited institutional and human resources capacity and the fact that solid waste financing has not kept pace with the growth in waste volumes

At the country and territory levels, solid waste management is sometimes allocated to several agencies, or in some cases, one entity bears all the responsibility. The majority of PICT's have limited human, financial and institutional resources available to address waste management issues. Typically, the agencies responsible for managing waste services in both Vanuatu and Tuvalu are poorly managed and resourced, resulting in inconsistent and unreliable services.

2.2 Vanuatu Country Profile

Vanuatu is a geographically isolated country located in the South-West Pacific, consisting of more than 80 dispersed islands with a total land area of 12,2812 km^2 and a combined coastline of 2,530 km^2 (Figure 1). Approximately 74% of Vanuatu's 307,150 people live in rural areas, with many members of these rural households reliant on traditional subsistence agriculture for their livelihoods (ADB, 2019a).

Vanuatu recently graduated from the least developed country status in 2020. This is highly commendable considering they are ranked first on the World Risk index due to the high frequency of cyclones and earthquakes (CEPF, 2012). Additionally, its narrow economic base (rated the 7^{th} most tourism-dependent country in the world; Frost, 2019) has been severely impacted by strict border restrictions due to the COVID 19 pandemic and widespread damage by a category five cyclone in April 2020. In light of the impacts of COVID 19 on the tourism industry, the Vanuatu Government has shifted its focus to rural and agricultural development and food production as a priority to improve the livelihoods of the Ni-Vanuatu people (Coco, 2020). Drawing on recent economic data from Vanuatu there is evidence to suggest that Vanuatu has performed better than expected without international tourism with reference to the ability of Ni Vanuatu to adapt and return to their land while also relying on social reciprocal systems. This data also leads to question the real economic contribution from international tourism to Vanuatu, and the issue surrounding leakage of tourism revenue (ACIAR, 2021; Howes & Surandiran, 2021).

2.2.1 Community descriptions

Research activities in Vanuatu were conducted on three islands: Tanna in Tafea province, Santo in Sanma province and Efate in Shefa province (Figure 1). The study locations were selected to provide contrasting geographic locations, waste availabilities, and socio-economic attributes in a wide range of communities to best assess the feasibility of implementing waste reuse in the wider Pacific.

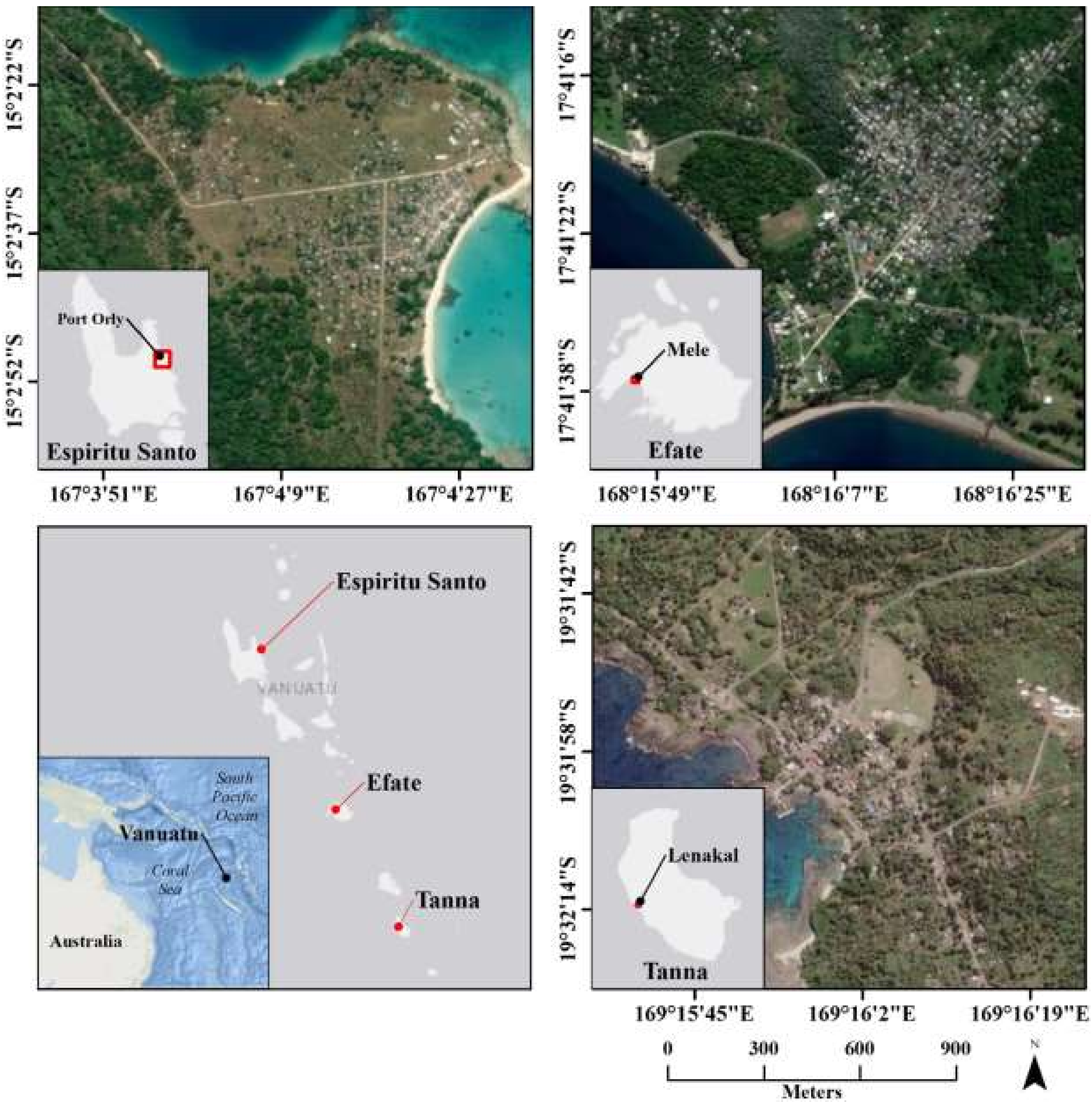

Figure 1. Location and maps of selected communities in Vanuatu where feasibility studies were undertaken.

Port Orly, Santo

Research activities were conducted within the East Santo Area Council with smallholder farming households in the village of Port Olry (Figure 1). Port Orly has a population of 1,931 (VNSO, 2021) and encompasses coastal, upland and drier regions. In addition to the relatively high density and high numbers of households, smallholders in East Santo have access to several diverse market channels and large areas of land classified as suitable for further development for agriculture, plantations and pastures (Quantin, 1982; Simeon & Lebot, 2012).

Mele, Efate

Research activities were also conducted within the Mele Area Council on Efate just outside of the national capital of Port Vila (Figure 1). Mele Area Council has a high population density with 6,437 people residing within an area of 69 km^2. The region is also experiencing rapid population growth of 8.0% per annum. Whereas 51 mostly agricultural leases were granted in the decade between 1980 and 1990, between 1993 and 1996, 147 mostly residential and commercial leases were granted. Many of these leases have been converted into coastal subdivisions, limiting the access of Mele villagers to nearby beaches and marine resources. Consequently, Mele villagers are planning to move the village to a further inland location. Recently, the Mele village board unsuccessfully invested in ventures that included a rubbish collection service to diversify the revenue base. However, the service was sold to meet the costs of a land dispute and a failed community fishing venture (Fingleton et al., 2008).

Ipai, Tanna

Ipai village is located in West Tanna (Figure 1). Tanna Island is 40 km long and 19 km wide, with a total area of 550 km^2. Its highest point is the 1,084 m summit of Mount Tukosmera in the south of the island. Tanna has a population of about 44,000, with seven different Indigenous languages spoken and Bislama and English. Tanna's almost entirely Melanesian population follow a more traditional lifestyle than many other islands. The island is one of the most fertile in Vanuatu and produces kava, coffee, coconut, copra, and other fruits and vegetables. Ipai village is a 'Kastom Village', which are typically located at higher altitudes on Tanna, and typically restrict many modern services and conveniences. The village has a population of 139 spread across 26 households. Most housing is traditionally built with thatch roofing and dirt floors. Poor farming practices in the region have led to severe erosion, which has significantly impacted the community and surrounding ecosystems. The governance system across the island is complex and includes customary landholders, Tanna Area Councils and Area Secretaries, Tanna Council of Chiefs, Tafea Provincial Government, Lenakal Municipal Council.

2.2.2 Socio-economic conditions

The Gross Domestic Product (GDP) of Vanuatu before the COVID 19 pandemic grew year on year for more than ten consecutive years led by the industry sector, while both service and agriculture sectors declined. Tourism contributed 34.7% of GDP before strict COVID 19 border restrictions (ADB, 2020) however recent economic data questions the actual direct contribution of tourism revenue to GDP (Howes & Surandiran, 2021). In 2018, Vanuatu experienced a negative trade balance, with exports totaling US$167 million compared to imports of $268 million (BACI, 2020). Between 20 and 25% of GDP in Vanuatu is derived from agriculture, with kava, copra and beef being the highest value export commodities. With the recent announcement of commercial importation of kava into Australia as a food, demand for kava is expected to increase significantly. Copra production continues to increase despite the drop in the average price from VT 59,000 to VT 35,000 per ton in mid-2018. Cocoa prices have been more stable than in previous years; however, production has decreased due to low yields from plantations where trees were old and unproductive. Approximately 50% of rural households in Vanuatu keep some form of livestock (15,500 smallholder and 1500 semi-commercial households; Cardno, 2014; VNSO, 2011).

Approximately 70 to 80% of households rely on subsistence/semi-subsistence agriculture (traditional economy) to support their livelihoods (income, social obligations, nutrition). This high percentage means that the GDP does not reflect all production and consumption (VNSO, 2010). For traditional landholders in rural areas of Vanuatu, subsistence agriculture is still the predominant mainstay of socio-economic life (Ratuva, 2010). A large majority of Melanesian people (including Vanuatu) live on land that has remained under customary title and is controlled by clans and families (Anderson & Lee 2010). Anderson (2011) identifies traditional Melanesian land systems as ‘vehicles for food security, housing, widespread employment, social security, biodiversity protection and ecological stability; they are also a store of natural medicines, as well as a source of social cohesion, inclusion and cultural reproduction'. A previous study found that Vanuatu's economy was already more circular than most other countries and exceeded the global average of approximately 9% (UNDP, 2021).

2.2.3 Key challenges

Key challenges facing agriculture in Vanuatu include; significant population growth, urbanisation, increasing land tenure disputes, contamination of catchments, unsustainable waste disposal, depletion of biodiversity (particularly key species such as coconut crab, mangroves, prawns), the transition to monoculture farming practices, unsustainable land management, erosion problems, decreasing soil health, logging of primary and secondary forests, increasing prevalence of crop pests and disease, disruptions to imported food supply and climate change.

Climate change modelling for Vanuatu predicts the main impact areas will be on coastal areas, food security (both land and fisheries based), catchment management and water resources, tourism and commercial agriculture (SPREP, 2019). Because of Vanuatu's relatively small land area and small inland-to-coastline ratios, there is strong topographical connectivity between ecosystems. The general pattern on Vanuatu is one of upland forested catchments connecting directly to the coastal zone and inshore marine environment through riparian waterways. It follows that the health of marine ecosystems is often directly linked to the health of riparian and forest ecosystems. This recognition has led more organisations to adopt a Ridge-to- Reef approach in addressing environmental issues, such as sedimentation of coral reefs.

2.3 Tuvalu Country Profile

Tuvalu is located approximately halfway between Hawaii and Australia in the South Pacific Ocean. It comprises nine islands (four fringing reef islands and five coral atolls) (Figure 2). Tuvalu has a total land area of 26 sq. km. and 750,000 sq. km of maritime space due to its large exclusive economic zone. The population size is small, 11,149 (2012 Population & Housing Census, Preliminary Analytical Report), with a low growth rate of 0.5%. More than half the population resides on the main island of Funafuti.

Tuvalu gained independence from the United Kingdom in October 1978. The political system consists of a constitutional monarchy with a 15-member unicameral parliament elected every four years. The United Nations Development Programme classifies Tuvalu as a resource-poor, “least-developed country” that is “extremely vulnerable” to the effects of climate change. Most of the islands sit barely three metres above sea level, and at its narrowest point, Fongafale stretches just 20 m across. Some of these islands are made up of many tiny islets, such as Funafuti Atoll, which consists of the two main inhabited islands (Fongafale and Amatuku) and around two dozen other islets which are mostly uninhabited (Ainge Roy, 2019). The intrusion of saltwater has already impacted porous and salty soils, making it increasingly difficult to grow key staples and decreasing the yields of various fruits and vegetables (World Bank, 2015).

2.3.1 Community description

All of the research activities in Tuvalu were conducted in the Funafuti Islets, which is the capital of the island nation (Figure 2). Two sites were on the island of Fongafale, which is the largest of Funafuti's islets, while one site is an islet of Funafuti. Fongafale has a population of 6,320 people (2017 census) and is 12 kilometres long and between 10 and 400 metres wide. The South Pacific Ocean and reef fringes on the east, and the protected atoll lagoon is on the west of the island. The study locations were limited to Funafuti due to COVID 19 restricting the movement to the outer islands during data collection.

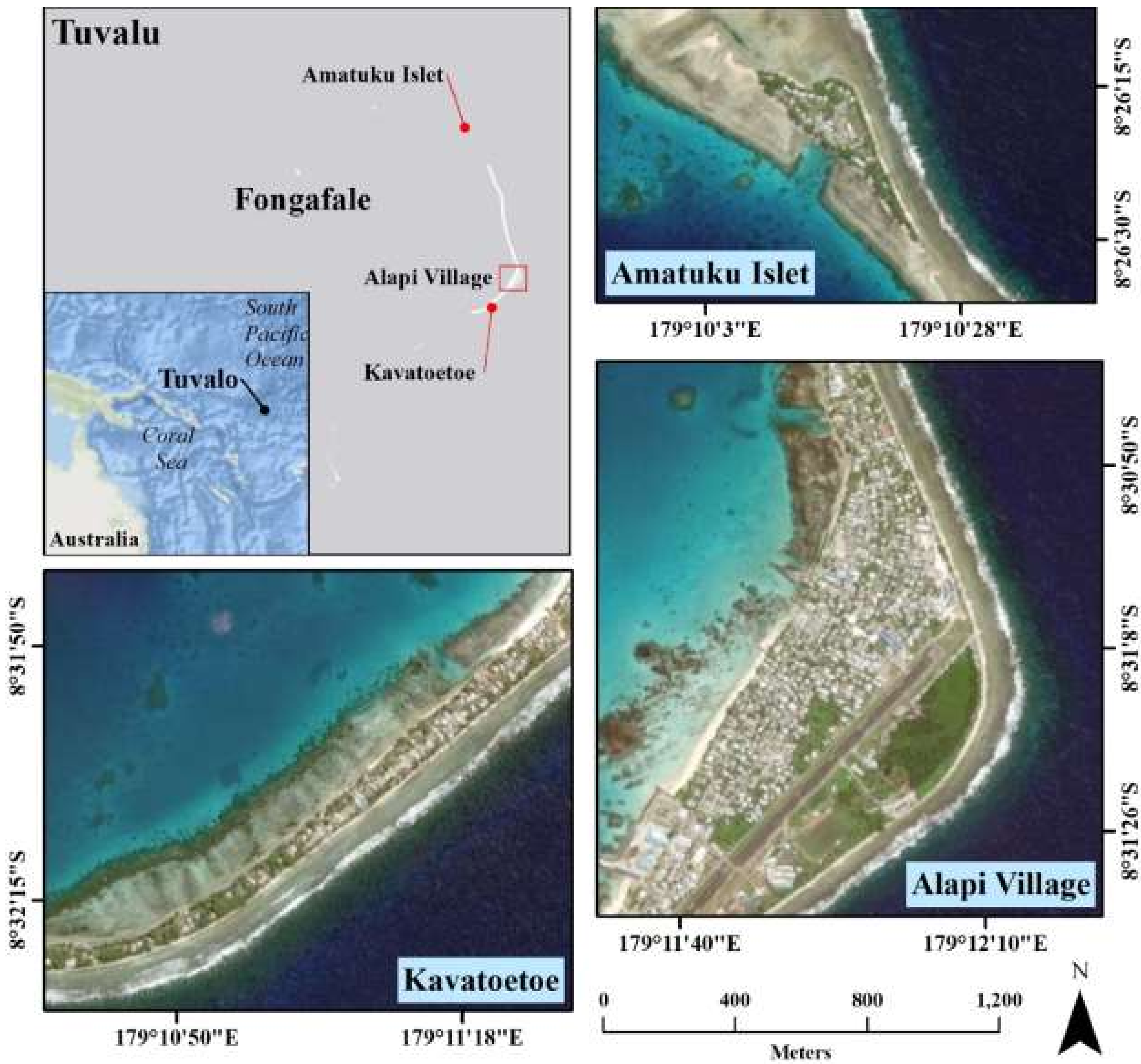

Figure 2. Location and maps of selected communities in Tuvalu where feasibility studies were undertaken.

Amatuku Islet

Amatuku Islet is located at the north end of Fongafale islets and is home to the Tuvalu Maritime Training Institute, which consists of government staff houses, school classrooms and dormitories. It has a population of fewer than 150 people and is fully leased by the Tuvalu Government. Breadfruit trees, coconuts, banana plantations, pulaka pit, home gardens and pig fodder trees such as cordia are grown.

Alapi Village

Alapi Village is located in the centre of Fongafale and is home to approximately 1020 residents in medium-density agriculture and housing. Most land is owned by private landowners and consists of between half an acre and one-acre plots with a house site, a small animal enclosure (mostly pigs), a household garden and approximately a 50 m x 50 m plot for growing breadfruit, coconuts, pulaka pit and pandanus.

Kavatoetoe Village

Kavatoetoe Village is located on the southern coast of Fongafale Island. Half of the village land is leased by the government and half by private landowners. Most plots are between half an acre and one acre in size and consist of a house site, a small animal enclosure (mostly pigs), a household garden and approximately a 50 m x 50 m plot for growing sweet potatoes, breadfruit, bananas, coconuts, pandanus or other broadleaf plants.

2.3.2 Socio-economic conditions

In terms of resident population and access to natural resources, Tuvalu is classified as the World's smallest developing nation and recognised by the United Nations as being a 'least developed country'. Tuvalu's economy is highly dependent on foreign income sources and thus vulnerable to global sources of volatility.

There are several constraints to domestic economic activity as well as limitations on the capacity to participate in global markets, including:

- A small domestic market size which makes products for the domestic market non-profitable
- Its remote location, long-distance from markets and high sea freight costs make imports, exports, tourism and circular migration costly
- The limited domestic natural resources (minerals, oil, land, soil, agriculture)
- The limited land resources and poor soil limits the potential for agricultural and timber production

Despite these limitations, Tuvalu is a lower-middle-income country, performing well on human indicators. This can be attributed to a high degree of family and community obligations, respect and connection felt by its citizens. The country is a peaceful democracy, with negligible crime or substance abuse. Island-based community councils, the Fulekaupule, exercise considerable community and political influence.

The subsistence economy also plays a significant role in the economic structure of the country and provides an element of resilience. Agriculture and fisheries are the main subsistence activity (accounting for about 60% of GDP and 75% of the labour force). Unemployment is essentially non-existent in Tuvalu, as effectively all citizens can move between subsistence and formal employment in the absence of opportunities for cash-earning activities. Tuvalu has a deeply entrenched and effective cooperative movement, particularly in the retail sector and good quality and accessible health and education systems. Mellor (2003) suggests that in Tuvalu, the strong “tradition of guarding and promoting the social welfare of the nation could well provide useful lessons for other developing nations, not to mention the so-called developed nations of the world”.

Employment in the private sector is limited, with the public sector being the primary employer (66% of the population working in the formal sector). There are five main sources of externally derived income: maritime employment; remittances from Tuvaluans working abroad; income from a range of unique activities such as Dot TV; international aid; and income from Tuvalu’s national reserves, in particular the Tuvalu Trust Fund. In addition, Tuvalu has several smaller external income sources such as copra, philatelic products, tourism, foreign private investment, and various other minor sources such as international church and ecumenical groups (Mellor, 2003).

Tuvalu is classified as a classical MIRAB economy (Migration, Remittances, Aid and Bureaucracy), a rent-based economy that can be sustained through income from remittances and aid flows rather than productive activities (Bedford & Graeme, 2012). Tuvalu is heavily reliant on foreign aid, with most of its GDP made up from donations from the UN and neighbouring countries. Since 1970, the average annual aid flow per capita to Tuvalu has been estimated at around US$650 (1998), the highest of all the independent nations. Economic performance has been volatile in the last few years due to the high dependence on overseas sources of income, reducing income from overseas seafarers, and high dependence on imports of food and fuel. Tuvalu’s economy is considered one of the most vulnerable in the Pacific due to the global economic crisis (ADB, 2019b).

2.3.3 Key Challenges

Food security and nutritional deficiency is an increasing issue for atolls countries such as Tuvalu. Many factors restrict agricultural production, including the lack of seed stock, water shortages, increasing groundwater and soil salinity, and poor soil health. Since sea-level rise has contaminated groundwater resources, Tuvalu is now totally reliant on rainwater which is further impacted by droughts occurring with increasing frequency. Even if the locals could plant successfully, there is often insufficient rain to water simple kitchen gardens (Ainge Roy, 2019). As a result of low agricultural production, people in Tuvalu are heavily reliant on imported food. Staple starchy Pacific Island foods such as taro and cassava now have to be imported at great expense, along with most other food. However, increased vulnerability due to the reliance on imported food has been highlighted by the COVID 19 pandemic, which caused restrictions on food supply chains. To ensure households are able to produce starchy staples, nutritious food and achieve better food and nutritional security, there is a need to improve the quality of soils in Tuvalu while building the capacity of key stakeholders (ACIAR, 2019).

3. Objectives

The aim of this project was to:

Determine the feasibility of providing inexpensive and locally available organic fertilizer from treated human and agricultural wastes by conducting detailed scoping studies in Tuvalu and Vanuatu. The project also sought to test a range of traditional and novel treatment systems to determine the feasibility of capturing wastewater nutrients and converting them into organic fertilisers for crop production.

The project objectives were to:

Objective 1. Engage with agricultural communities and key stakeholders in Vanuatu and Tuvalu to determine the need, scale (farm, community and region), available waste streams (pit toilet, agricultural, septic, municipal), challenges, and agricultural benefits of novel wastewater reuse and nutrient recovery facilities.

Objective 2. Foster collaborative relationships with the Live and Learn Pacific Network, local councils and relevant government departments in both countries to support communities in sustaining their environment and improving food security.

Objective 3. Characterise wastes and test novel nutrient recovery wastewater technologies to produce a stable, pathogen-free, organic fertilizer from agriculture and domestic wastewater.

Objective 4. Engage women in Pacific Island communities by creating opportunities for female community members to better engage in the project, where possible employing female project officers and providing a Southern Cross University co-funded scholarship for a suitable female applicant.

4. Methodology

The social research component of the project consisted of collective discussion, interaction and meetings with smallholder households and key stakeholders. A Critical Participatory Action Research (CPAR) methodology was used as it is an approach that entails meaningful involvement from the participants in all phases of the research process and mutual respect for different knowledge systems (Dawn et al., 2013). PAR was used to inform the project's research priorities, aims, and questions in preparation for the research. This is important to ensure the research was participatory in the design and application, ensuring validity and sustainability of the intervention being evaluated. The CPAR process comprises four phases: (i) diagnosis/analysis, (ii) planning, (iii) implementation and (iv) evaluation. After the diagnostic phase, the planning – implementation – evaluation continuum was repeated with key stakeholders throughout the research (Defoer et al., 1998).

4.1 Case Study Locations

The project sought to gather data from six diverse agricultural communities in both Vanuatu and Tuvalu with different wastewater treatment and socio-economic attributes. The purpose was to assess the viability of implementing wastewater reuse techniques in contrasting community settings (i.e. a community adjacent to a centralized treatment plant, a community with composting toilets, a community with septic tanks, remote vs urban, a community with open defecation) to gather specific data on the need, limitations and opportunities that exist in distinct community settings.

Secondary data was gathered through available data and reports on community wastewater treatment and agricultural wastes in Vanuatu and Tuvalu to assess available waste streams. On-ground assessment of the wastewater treatment techniques was not possible due to COVID 19 border restrictions in both countries.

4.2 Methods

For sustainable development approaches to succeed in the Pacific, they need to be adapted to suit local conditions and cultures. Research must be based on Pacific ways of knowing, and research paradigms must be appropriate to Pacific epistemological methods. Thus, a holistic, value-rich, and action-orientated education is essential to generate the "*positive societal transformation*" that is needed for the Pacific Island countries to manage their resources prudently and to develop sustainably (Deo, 2005). Therefore, this project incorporated this approach into a CPAR methodology in both countries. This approach is particularly effective when the research aims to understand complex social phenomena (Yin, 2012). It enables an empirical enquiry of the context of the case study by gathering knowledge from several direct and indirect sources.

CPAR is outcome orientated and seeks action 'if required' in addition to contributing knowledge. Addinsall (2017) highlights the importance of seeking action only '*if required*', cautioning researchers operating in this context not to assume participants need assistance or even want to change their circumstances, or that the researchers have the level of understanding required to facilitate this for the benefit of the participants. CPAR blends theory and a critical perspective with action and places more importance on real tangible outcomes over knowledge for knowledge's sake (O'Donoghue, 2001). These factors have led to approaches like CPAR to be the preferred methodology with many Indigenous people (Rigney, 1997). Participatory research approaches such as CPAR have been applied effectively in Vanuatu in recent years (Addinsall et al., 2015; Addinsall, 2017; Warrick, 2009; Wilson, 2013) and as such have resulted in increased engagement of local communities in addressing local goals concerning development and management of local resources. By using this technique, this project can ensure that a diverse range of stakeholders have contributed to the recommendations for a larger wastewater reuse project.

This first stage of this project consisted of collective discussion and interaction with relevant government, NGO's and private industry stakeholders through a CPAR process. The flexibility of the CPAR process enables the use of multiple methods without compromising the principles of equality, participation and collaboration (McTaggart, 1991). These discussions took place as one-on-one unstructured interviews using criteria sampling and small stakeholder information workshops to collect information from stakeholders operating in waste reuse and represent data collected from the case study sites.

To respectfully engage with communities and rural households in most Pacific Island countries, it is necessary to firstly engage with the chief, area secretary and community leaders which often takes place in the Nakamal. This process is usually male-dominated and takes place over several occasions before wider engagement with the rest of the community. While following these cultural protocols are particularly important for long-term engagement with communities, sometimes this information is not properly disseminated wider in the community and particularly to women.

With this in mind and having gained cultural entry into the community, awareness sessions with the wider community then took place. This was led by local Live and Learn teams in both countries. From there, storian sessions using a Rapid Assessment of Needs and Perceptions (RANP) methodology (see section 5.3.5) were used to determine the feasibility of a Closing the Loop project for each specific community. The method allowed the project team to rank the communities needs and perceptions using survey questions, identifying key project partnerships, determining the types of waste feedstocks available and what limitations and opportunities exist in the community. The storian sessions were again conducted by the local Live and Learn team in addition to an experienced female Ni Vanuatu agricultural and social scientist in Vanuatu and an experienced Agricultural Government employee in Tuvalu. These sessions took place in groups of three to four people in a mixed-gender setting. The central feature of these sessions was 'storian sessions' (chatting, yarning or swapping stories; Crowley, 1995). This involves building relationships between the participant and researchers, which enables a collaborative environment to address the research problem (Warrick, 2009), and allows the community to be better empowered (Beeton, 2006). This style of research is also known as 'Talaona groups' in Fiji (Nabobo-Baba, 2008). Storian sessions and Talanoa groups are seen as culturally appropriate Oceanic research methods. Nabobo-Baba (2008) describes such methods as a movement towards decolonisation from 'western ideology of subjective empathy to an inter-subjective empathy.' These storian sessions enabled participants to express thoughts that they may not have considered in the community information sessions.

Figure 3. Community workshop Tuvalu (Kavatoetoe).

Figure 4. Stakeholder workshop Vanuatu (Tanna).

Figure 5. Stakeholder workshop Vanuatu.

Agricultural extension systems in the South Pacific are often biased towards men, as male-dominated state agencies largely control information and communications. This project recognised that the basic principle in addressing gender inequality in agricultural development is to enable female input to decision making across all levels. We, therefore, developed stakeholder engagement strategies that promoted women's voices to be heard. To address potential gender bias, a female social scientist and female research assistants conducted storian sessions with female-only groups as well as mixed-gender groups to ensure women felt safe and comfortable to engage in the workshop process. Due to travel restrictions, the female social scientist was not able to travel to Tuvalu, but the research team in Tuvalu was still heavily represented by female project officers. A female Southern Cross University co-funded scholarship student in Vanuatu assisted throughout the project with data collection and analysis. The student received training from some of the leading social scientists involved in Pacific Island research equipping them to be a future leader in the field at the end of their studies.

4.3 Key Questions

Several key research questions were addressed throughout the project, including:

- Is there a need to improve soil health and productivity using a locally produced organic fertilizer?
- Are current wastewater treatment practices sufficient to protect valuable groundwater and coastal water resources?
- What potential organic and human waste sources are available?
- Would a human waste-based fertilizer be socially acceptable?

- What are the incentives for a community to uptake waste-based fertilizers?
- What is the best technique to produce a safe and economical fertilizer?
- What is the importance of organic certification in Pacific communities?
- What are potential funding models for Closing the Loop projects?
- Can we develop a method to efficiently gauge the potential value and acceptance of a Closing the Loop project in other Pacific Island that were not assed during this study?

5. Results and Discussion

5.1 Undertake a series of workshops in a range of communities in both Vanuatu and Tuvalu to determine need, scale and key problem areas (Activity 1.1)

This section of the SRA was informed by a number of methods applied in stages through a CPAR process which included: unstructured interviews with relevant government, NGO's and private industry stakeholders; initial engagement with chiefs, area secretaries and community leaders; awareness workshops with the wider community and storian sessions guided by the RANP surveys with small groups of both mixed and same genders. These methods were applied in order to assess key stakeholders and communities' needs and the perceptions of re-using wastes as an organic fertilizer. The process uncovered several key areas of community needs, opportunities and concerns that need to be incorporated into any future on-ground implementation of a Closing the Loop project.

5.1.1 The growing need for improved soil health

Throughout the Pacific Islands, there is growing attention on the need to maintain good soil health for sustained productivity and increased yields. However, movement to non-traditional cropping, more intensive farming, and climate change-induced changes to soil health and rainfall have seen soil health degrade markedly. As such, there is growing recognition that soil amendments such as composting and fertilizers may be helpful to increase the amount of organic matter in the soil, its water-holding capabilities and the amount of nutrients available to help with plant growth.

Vanuatu

Agriculture forms the backbone of Vanuatu's formal and informal economies. While it only contributes 20% to Vanuatu's GDP, the contribution from subsistence agriculture to the traditional economy ensures the wellbeing of over 80% of the population. Subsistence and semi-subsistence and what Vanuatu terms the 'Traditional Economy' provides an important safety net and safeguard against extreme (food) poverty. However, urban migration (mostly fueled by the tourism enclaves and the desire for better access to education) is leading to a significant internal migration flow which is fuelling unsustainable urbanization, increasing urban poverty and exacerbating strains on urban infrastructure. Higher incidence of poverty in urban areas compounds and interacts with higher food poverty in urban areas compared to rural areas. In certain areas, malnutrition (particularly stunting, anaemia, iodine deficiency and NCDs; hypertension, diabetes, obesity and heart failure) has been identified. A key challenge for Vanuatu is developing pathways for the commercialisation of traditional farming systems over monoculture high input farming techniques. This would allow for increased income while continuing to support social support networks, reciprocal networks of exchange, environmental sustainability and food security (Addinsall et al., 2016).

This study found that due to the prevalence of subsistence farming, food security was on average higher in the rural communities of Port Orly and Ipai, where households have customary access to land for subsistence. In contrast, in Mele food nutrition is more of an issue, with higher consumption of unhealthy imported foods being almost double that of Ipai and Port Orly participants. This is driven by higher population densities which limits access to customary land (due to significant land alienation) and less healthy imported food being relatively cheaper than fresh produce. One participant from Mele stated, *"We are an urban settlement with not many gardens, but we produce a lot of waste".*

While most participants interviewed stated they had not purchased fertilizers for their farms or home gardens, many expressed a growing need for fertiliser, highlighting noticeable decreases in productivity, particularly participants from Port Orly and Ipai. A smallholder farmer from Port Orly commented, *"We have noticed when we first clear forest the garden is really productive, but then the next time we plant, it isn't as productive. Since we have been focusing more on kava, we are seeing the soil lose productivity. Where we plant kava we are noticing a big decline in the quality of soil".* A larger landholder from Port Orly also supported this, stating, *"Before cyclone Harold, people did not see the need to improve productivity, but after Harold, farmers see the need to improve productivity not just in food but also cattle. This is because a lot of us experienced food shortages after the cyclone, especially tubers as a food source post-cyclone. Consumption of beef in Port Olry has increased a lot. Agriculture has recently been expanded even with vegetables. Farmers do big farms now. EDF 11* [an agreement between the European Commission and the Vanuatu Government to promote sustainable development in Vanuatu] *has stepped in to help restock livestock. In regards to the garden, farmers are doing more gardening now and people are eating more local food compared to rice".* A smallholder farmer from Ipai stated, *"Previous year's garden was good but now not good anymore. Before high yield, now very low yield. During the early days harvest was good big tubers; now sizes go smaller. Productivity is getting smaller and smaller".*

However, in all three communities, there was very little chemical fertilizer use, use of manure or composting. No one from Ipai had ever used fertilisers to increase productivity. According to the Vanuatu Agriculture Supplies agronomist Aaron Pendergast, "*the amount of fertilizer used in Vanuatu is still very low compared to other Pacific Island countries*". Roughly, Vanuatu used around 5 tonnes of nitrate per year for the whole country compared to 1.5 million tonnes per year in Australia (Fertilizer Australia, 2017). Mr Pendergast went on to suggest, *"Most of the inorganic or synthesized fertilizers used in Vanuatu are imported from Australia. The buyers are mainly people from Efate and a few from Santo who are doing backyard gardening. Of that usage, the leaching is unknown, but with low usage rates probably unlikely significant".*

A larger farmer in Port Orly highlighted the growing interest in using fertiliser for market gardens, *"There is a big interest in fertiliser if it's organic, but I'm a leading farmer. Some farmers still don't understand its purpose as we haven't had the problems that we are experiencing now with the loss of productivity and overpopulation.*" He went on to state that women could be particularly interested, "*I think women are going to be more interested in using fertiliser than men. Because the biggest need for it is for food gardens where we are seeing the loss of productivity. I can see the use for it in kava too, which is more managed by men, but I think women would take it up first for their* *home gardens. We would need demonstration gardens for farmers to come and see how the fertiliser improves the soil".*

The UN Food and Agriculture Organisation (FAO) indicated that in 2012 crop yields in Vanuatu were stable and that agricultural practices were sustainable in general, with a few exceptional examples of soil erosion due to monocultures and deforestation due to land clearing for cropping (UNESCAP, 2012). However, the report went on to suggest that population growth and development of large commercial plantations and farms could change this in the future. Junior Salong from the Department of Agriculture stated, *"Fallow* [land that is left to restore its fertility] *is becoming an issue now as we are experiencing population growth and intensification of farming with the transition from subsistence to cash cropping".* Participants in this study indicated a growing sentiment of decreased productivity, with several participants suggesting that the transition from relatively diverse subsistence farming to monoculture kava plantations had led to a decrease in productivity. *"Yes, I've noticed loss of productivity now that I'm growing kava. The first plot I planted grew really well, but now this second rotation is growing very slow*". The rural communities surveyed in this study were mostly made up of smallholder farmers with a few large scale farmers.

There was a noticeable awareness of the use of fertilisers to improve productivity from many of the smallholder respondents, particularly from Port Orly, *"I have never purchased fertiliser, but we use horse and cow manure for kava plantations to raise productivity. It performs really well. Everyone in the village is coming around to see how we use manure from our animals for our kava plantations".* In general, smallholder farmers in Ipai and Tanna already had a good understanding of the role of fertilizers, with one respondent suggesting that "*the Yasur volcano was Tannas fertiliser"*. Tanna is regarded as is one of the most fertile islands in Vanuatu and produces the widest range of commodities, including kava, coffee, peanuts, copra, and other fruits and vegetables.

Michel Raikatalau, the owner of V-Organic fertilizer, has produced a liquid organic fertiliser made from 100% organic materials on his farm in North Efate. The product has been tested in New Zealand and approved by the Vanuatu Bureau of Standards. He spoke about the importance of creating an organic product for Vanuatu, *"I am working on organic products as farmers in Vanuatu have had a lot of awareness in this area and know they can get better returns if they are certified. I have been to most farms in Fiji,* *and many are not organic. The population is rapidly growing, and we need organic fertilizer. Most times, we talk about export, but money is in Vanuatu. We can use the Organic product in Vanuatu and sell it to our farmers".* V-Organic have been trailing a biochar oven using organic and human waste with products being tested by the Vanuatu Bureau of Standards. Next year they will be working with the Department of Environmental Protection and Conservation to collect municipal organic waste for fertilizer. They are also designing a new compost toilet that can be easily accessed by waste collectors as there is a reluctance in communities to empty the compost toilets.

Tuvalu

Unlike Vanuatu with its rich volcanic, ash and basaltic soils, Tuvalu soils are largely infertile and calcareous. This infertility has been compounded by the loss of nutrients due to manual tillage, deep drainage and intensive domestic crop production. While the potential for high-value crop exports from Tuvalu is limited, the production of fruit and vegetables for local urban markets is an important source of cash for smallholder farmers (White et al., 2007). A further issue for Tuvalu is the maintenance of groundwater quality for domestic supply. Agriculture is a major source of excess nutrient and faecal contamination of groundwater lenses (White and Falkland 2010; van der Velde et al., 2007). Because of this, synthetic fertilisers have been banned in Tuvalu since 2000, leading to the development of organic agricultural production systems.

As a result of these factors, Tuvalu has had much more exposure to the use of organic fertilizers and composting than Vanuatu. This can be seen in the participant responses, with over 78% of people across the three communities suggesting that they compost compared to only 20% in Vanuatu. Typically, organic nutrients are sourced from household or animal wastes. However, other materials can be collected from nearby locations, including forest material and harvested seaweed. Responses across the three communities were very similar, indicating the benefits of mixing animal and plant waste to fertilize home gardens, *"Yes, I use compost for the home garden, I used animal manure, rotten logs, coconut husk and dry leaves".*

In Tuvalu, subsistence farming provides a significant proportion of food to families, with 82% of survey respondents indicating family household crops and gardens provide 30% of food or more and 27% of respondents indicating they rely on home produce for more than 50% of their food. 43% of respondents indicated there had been a decrease in productivity in household crops and gardens. A workshop participant noted, "*Yes, we have noticed a decrease of 3% in the productivity in my garden and the farm, but it keeps increasing, and there is no possible solution for it*." and "*Yes, we noticed the drop of yield in most of the farms in the community and the islands. The decline is caused by poor soil, soil salinity, pests and diseases*". Contrary to Vanuatu, where very little composting occurs, 78% of respondents indicated that they compost. With food shortages a problem and decreasing productivity, project partner Live and Learn has been working with community members on new production methods in the Funafala Food Garden and also collaborated with the Tuvalu Department of Education in the development of an educational curriculum on incorporating traditional knowledge into Tuvalu's agriculture production.

5.1.2 The need for better wastewater management

The management of human waste in the Pacific Islands has received significant attention in the last few decades, with a shift from traditional waste management techniques (open defecation and pit toilets) to more modern technologies (septic tanks). However, in order to work effectively and stop impacts to human health, groundwater resources and coastal ecosystems, they must be properly monitored and maintained. Importantly, human effluent remains categorised mainly as "waste" despite being high in organic and nutrients which soils in many Pacific Islands desperately lack. A Closing, the Loop project, has the potential to change this perception and put a value on human wastes that facilitates greater attention on its management and collection in Pacific communities.

Vanuatu

In Vanuatu, many groundwater resources are affected by pollution and, increasingly, sea-water intrusion. Much of Vanuatu's significant infrastructure and highest density communities have been developed within metres of the shoreline. Pollution in Port Vila Harbour from land-based activities and ineffective wastewater treatment has become increasingly evident. Prior to the development of the National Wastewater Taskforce (NWT), which was appointed by the Department of Environmental Protection and Conservation in 2020, no government department had taken a lead role to address the management of wastewater, with most initiatives driven by NGOs and religious institutions. The Pollution Control Act, which governs the NWT, gives power to authorised officers to enter any premises to inspect the sewage treatment/disposal systems. The NWT then advises proper authorities for penalty or advisory notices.

The NWT consists of various government departments, including the Department of Health, Department of Environmental Protection & Conservation, Port Vila Municipality, Ports and Harbor, Shefa province, Public Works Department and Department of Water Resources, and private sector partners, including KPC Elevate Vanuatu Ltd and UNELCO. Upon commencing inspections, NWT found that many resorts and hotels as well as the Port Vila hospital, were operating wastewater treatment plants beyond their capacity. The NWT suggested that most water contamination issues are believed to be predominantly from domestic and commercial wastewater management. Ionie Bolenga, Waste Officer for the Department of Environment Protection and Conservation, stated, *"The NWT has done some inspections in businesses around Port Vila in 2020 including the Grand Hotel, the Port, LJ Hooker and Calvo Store due to high level of bacteria in the Port Vila* Harbor". Port Vila Municipal Council (PVMC) were also found to be responsible for the discharge of sewage water into the harbour from toilets from the Port Vila main market. The PVMC was issued with a penalty notice and closed down the public toilets until they could be repaired. In response, PVMC stressed to all businesses operating in the central business district to properly manage their sewage.

Even with these measures, there is still little evidence of monitoring taking place at the community level. Mele households predominately have septic systems. However, 91% of survey respondents indicated that their septic system had never been de-sludged. A community representative from Mele suggested, *"most septics have never been emptied in the community because it's too expensive"*. Outside of the municipalities, around 80% of households use water-sealed pit loos or Ventilation Improved Pit toilets (VIP; a traditional pit toilet with increased airflow to reduce odours) with largely only schools and businesses such as banks, butcheries, cooperatives, tourism bungalows and restaurants using septic systems.

Tourism Standards have been developed under a program titled Vanuatu Tourism Permit and Accreditation Program (VTPAP), launched in 2015 by the Vanuatu Department of Tourism (DoT) to ensure tourism operators are operating at, or above, minimum standards throughout Vanuatu's tourism sector. A focus of the program is to improve wastewater treatment by rural tourism businesses and ensure they meet health and safety standards. Septic tanks have now been recommended for all developments in urban areas of Vanuatu. Of those businesses in Port Orly that were on septic, the project team was informed, "*that none of these systems had been emptied, and up to 300 people can use one septic toilet in a day in the local restaurants during festivities*".

Water supply to Mele is provided by a private company, UNELCO, from a shallow aquifer. Water supply infrastructure in Ipai and Port Orly is donor-funded and community operated and managed. Water quality testing has indicated "hotspots" for water pollution showing high levels of bacteria, COD and nitrogen from human waste (IWRM, 2007, Pg. 19). Coastal water monitoring has shown specific "hotspots" where pit latrines and septic tanks are located in significant numbers close to the coast, such as Mele Bay and Erakor Lagoon. These uncontrolled nutrient and pathogen discharges combined with poor natural flushing are pushing coastal waters towards the limits of world standards (IWRM, 2007).

Many participants from Port Orly suggested they had used the same pit latrine for over 15 years and that this could be impacting environmental and human health. One participant suggested, *"When the water supply isn't working in some houses in Port Orly, they use wells around the house which are located so close to the pit loos. I know they are releasing wastewater into the well when the toilet fills up, because they dig the well next to the toilet and drill the drum to release the wastewater. We won't use the well water because of this".* This was supported by another participant, *"When there is big rain, we notice that our pit loos do contaminate well water. Our community water source is high up on the hill, so our drinking water doesn't get contaminated. We do have wells around the village for an emergency when the water supply doesn't work or in the dry season, and that's when we would need to drink that water".*

Human waste management is under the jurisdiction of the municipalities. It is currently operated in urban Port Vila and the surrounding peri-urban communities by private companies DJ repair and DJ Septic. Despite there being *"over 10,990 households on septic in the PVMC" (*David Talo, Dissemination Officer for the Statistical Leadership Coordination (SLC) Section), David Joseph, owner of DJ Repairs and DJ Septic stated, *"We pump out at least 30-40 septic tanks within the PVMC in a month. This includes households, companies, business houses, resorts and schools. Large* *companies like the Au Bon Marche supermarket are serviced once a month due to the high number of employees"* indicating a vast discrepancy between the maintenance requirements of septic systems and what is actually happening (an average septic tank should be inspected and pumped every 2-5 years; www.epa.gov/septic). The prices of waste removal vary according to the sizes of the septic. The 2,000 -2,500 L tanks cost VT 18,000 while 5,000 L tanks cost VT 36,000.

Septic waste from Port Vila is disposed of at the Bouffa landfill site. In 2018, the Asian Development Bank funded a project to better manage human waste at the Bouffa landfill site. The project saw the development of two large treatment ponds to filter and dry wastewater before it leaches into the soil. David Joseph owner of DJ Septic stated, *"Before, human waste was just dumped into a hole which would fill up full really fast, and when it rained, the waste would just overflow everywhere. However, the current set up of the two larger ponds is more manageable where all the waste goes into the ponds".* The PVMC waste officer stated, *"The initial plan is to filter out the wastewater and the dried waste so it can be collected and mixed later with the market waste to help decompose faster. Pond one is anticipated to be full in 6-7 years' time, but with a change in practice where waste is dried up and used with organic waste, this could help maintain the ponds for a much longer period*".

Tuvalu

In Tuvalu, the coordinating agency responsible for waste management is the Ministry of Internal Affairs, while the monitoring agency is the Solid Waste Agency of Tuvalu (SWAT). The agency for managing waste services is the Kaupule (Island Council). Household and business wastes in Funafuti are collected by the Kaupule and taken directly to the dumpsite manned by SWAT. A separate collection of green wastes is the responsibility of SWAT and are deposited and shredded at a central location.

The *Tuvalu Integrated Waste Policy and Action Plan 2017-2026* guides the management of waste in the country with the vision of having "A cleaner and healthier Tuvalu for today and future generations." A review of the policy showed that despite challenges to the implementation of the plan, there is evidence of "significant progress" against some key indicators (UNEP, 2020). However, the review also highlighted weaknesses in a number of areas related to a lack of enforcement, public awareness and education programmes and, in particular, sewage and sludge management. To mitigate these emergent issues, the review recommended putting in place a proper healthcare waste management system, installation of appropriate treatment systems for sewage and sludge and women's groups taking the lead on addressing illegal waste disposal.

The majority of the households surveyed across all three communities had septic systems for treating wastes, with only 10% of respondents in Alapi having composting toilets. Only half of the respondents have had their septic tanks emptied since they had been installed. Septic tank systems have been promoted as the most hygienic and safe way to dispose of human wastes and a significant improvement on the use of the beach for human waste disposal. However, the septic tank based system was introduced without regard to the geophysical characteristics of the atoll system or a well thought out policy on inspecting and maintaining such systems (Lal, Saloa & Uili, 2006). Poorly constructed septic systems and improper maintenance are causing overflow into adjacent areas and the groundwater table, particularly during high tides and heavy rains. This is particularly problematic at the groundwater table is extremely shallow (generally 1 to 1.3 m below the surface), allowing pollutants from leaking septic tanks to easily contaminate groundwater resources and move into coastal lagoons. Similar to Vanuatu, compounding this problem is the lack of monitoring and enforcement and an absence of coordination and harmonisation of "management" of water and sanitation between national government agencies and the local government (the *Kaupule*). In addition, there is a rapidly growing population and limited land space, resulting in septic tanks being located too close to each other, wells and homes.

5.1.3 Organic waste management

Combining organic and human waste stocks can be valuable in helping with some forms of waste treatment and composting. However, the amount and collection of organic waste in many Pacific Islands have been problematic, emphasising organics as a "waste" with little or no value rather than a "resource". A closing the Loop project has the potential to shift this paradigm and turn household and agricultural wastes into a valuable commodity that can be used to improve agricultural productivity.

Vanuatu

Much of the organic waste produced in Mele is dumped at the Bouffa landfill site in designated yellow garbage bags. Besides the considerable loss of value of the organic material that is dumped, it decays under anaerobic conditions, which creates methane emissions, a potent greenhouse gas (UNDP, 2021). Wander et al. (2019) suggested it is vital that any future business plan for the management of waste in Vanuatu should consider the segregation of organic waste either for composting or merely using it as a landfill cover as no landfill sites in Vanuatu have cover material. Having a landfill cover reduces greenhouse gas emissions and improves landfill management.

Organic waste from Port Vila central market has also recently started to be collected and dumped separately from the other waste. The PVMC Waste Officer stated: *"We have so much market waste, from six markets all up. We have one small vehicle for market waste, and the truck is busy every day. We want to designate an area for organic waste. The initial plan is to have it collected and dumped in a separate place so that it can be used later for backyard gardening. We have a new officer in charge of market waste to make sure that the market waste isn't mixed with yellow bag waste. We won't be sending the market waste to the Bouffa landfill, we will be bringing it to the waste office. We are building a factory to make compost from market waste. Then we will sell the compost".* While this has started on a small scale, there is still a significant amount of green waste being disposed of through the plastic rubbish bag collection system and being dumped in landfill. Kava waste from the kava bars (Nakamals) also represents a significant organic waste source and is collected along with the domestic waste.

With landfill space being at a premium in every location of this study, the removal of organics from the incoming waste stream to the landfill not only solves an environmental issue, but it also has the potential to reduce the requirement of landfill space resulting in a substantial monetary saving. A 2017 JICA study indicated that 50% or 24 tonnes of waste per day coming to the Bouffa landfill is household waste. Of this, 49% or 12 tonnes is organic in nature. Assuming a minimum of 60% of this waste can be successfully recovered for composting or processing, that equates to 1,826 tonnes of organic waste recovered per year and almost 3,000 cubic metres of saved space in landfill (based on EPA Victoria guidelines). APWC research shows that in Luganville, the central market generates an average of 1.1 tonnes of pure green and food waste every day, which is being sent to landfill. In addition, an average of 250 kilograms per day is being composted on-site using a small-scale composting system. This trial stops almost 350 tonnes of organics from entering the landfill each year and saves 550 cubic metres of landfill space.

Tuvalu

Due to limited land availability for landfill in Tuvalu, the communities surveyed have had a much higher degree of exposure to projects that reuse human, animal and plant waste for agricultural use than communities in Vanuatu. This includes projects such as the 'Food Cube' which was designed and produced by Biofilta, an Australian company developing modular urban farming systems. Biofilta claims that the Food Cubes are able to produce up to 150 kilograms of vegetables and greens a year and that "*the system is raised, so there is no risk of saltwater inundation, and our wicking technology is extremely water-efficient, using only a fraction of the water needed in conventional agriculture*." Further, Food Cubes use compost, specifically tailored to the country's soil needs by the Australian Centre for International Agricultural Research (ACIAR) Improving Soil Health, Agricultural Productivity and Food Security on Atolls project (SMCN/2014/089), Soil Management in Pacific Islands: Investigating Nutrient Cycling and Development of the Soils Portal project (SMCN/2016/111) and the Australian Department of Foreign Affairs and Trade's Tuvalu Food Futures project. The project also draws on ingredients from the island's green waste treatment facility (Wilson, 2021).

5.1.4 Community perceptions of using human waste

Despite being a ready source of organic matter and nutrients, human (or animal) waste is often seen as taboo in many communities. This is often influenced by the communities location, the urban/rural setting, level of affluence, cultural traditions and the degree of subsistence farming. To determine the beliefs and values underlying this bias, to determine the scope of change in these beliefs, and ultimately the uptake and success of a project like Closing the Loop, a detailed social assessment is necessary.

Vanuatu

Across the three communities in Vanuatu, the use of animal waste seemed to be much more accepted than the use of human waste, with widely held perceptions that human waste has diseases and is not safe. The pastor for the Port Orly community stated, *“People don’t talk about human or animal waste; food waste is ok. Human waste is not healthy because people may have diseases, and they are not 100% healthy. It's ok to do animal and kitchen waste composting, but it's not safe to use human waste. If you work on the scale of a women's group to improve produce or access to markets, you will get success, but large scale projects are harder to get success. It's important to manage waste, but I wouldn't do it at the community level”.* A large farmer from Port Orly stated, *“The collection of cattle manure will work out if you give cattle farmers some sort of incentive for that*”, however, he was not interested in talking about using human waste.

The island of Tanna is known for its rigorous cultural preservation, including the issues surrounding menstruation in females. For example, the sharing of a bed with a menstruating wife is forbidden even during catastrophic situations. Atkinson (2010) states that *“the traditional practice of women retreating to separate huts during the time of menstruation still occurs in many parts of Tanna (particularly in Middle Bush)*”. Despite a ritual celebrating when a young Tannese woman reaches puberty, when she is bathed and anointed and “*dressed in holiday attire, consisting of a profusion of gay beads*”, menstruating women are viewed as “*unclean*”, “*shut out of the village*”, and “*unable to touch anything belonging to men*” (Jolly, 2001). As such, the cultural appropriateness of converting human waste to fertilizer was viewed with much scepticism. According to the chief representative of the Ipai community, *“in our culture, we do not have our women touch our foods or use the same toilet as us as they are considered unclean during that period”*. During the menstruation period of a female member of the family, they are strictly forbidden to come in contact with food and anything that they share with the males. Thus, the question raised was; is it possible to use treated human wastes as a fertilizer in the gardens where food is grown? When this was put to a council of chiefs, there was in-principle support for the idea of improved soil health, but that human waste would not be accepted.

Compost toilets have been trailed in the peri-urban communities of Port Vila and Luganville with little success. A former WASH officer for Live and Learn who was part of the compost toilet trials stated, *“Compost toilets are a viable option for Vanuatu. However, they would require a significant amount of investment in education and* *awareness, particularly around maintenance".* The project team interviewed an older woman with disabilities from Mele Village on Efate that was part of the compost toilet trail. She stated, *"My toilet hasn't been emptied since it was built, and both chambers are nearly full now. It's because people in the community are too embarrassed to be seen emptying it. Maybe it would have worked better if the toilet was not in the middle of the community where everyone can see you emptying it?".* This sentiment was shared by many participants when the team discussed the need to empty the compost toilet. Participants suggested that they are used to either pit loos or septics that do not require them to deal with human waste as it was seen as taboo.

Tuvalu

Compared to Vanuatu, the participants surveyed in Tuvalu had much less reluctance towards the idea of using human waste in fertiliser. A participant from Amatuku stated, "*Yes, this could be accepted [the use of human waste in fertiliser] if people fully understand that it is safe*". This could be attributed to the much higher rates of composting in the community (78% of participants composted), the already poor soil health in Tuvalu and moderate uptake of composting toilets in the community (10% of respondents in Alapi). When asked if they would use a safe fertilizer made from human waste to grow food, only 7% of respondents indicated they would not, while 83% were not adverse but would want to know more information. Interestingly, of that 83%, 97% of respondents said they would be willing to pay for it.

5.1.5 The growing importance of organic agriculture

Organic certification of produce can open valuable pathways for market gardeners and farmers in Pacific communities as the tourist market for organic meat and vegetables increases. However, at the moment, there are few opportunities to improve soil health outside of chemical fertilizers. The potential of a human waste-based organically certified fertilizer like that produced via a Closing the Loop project may provide a valuable opportunity for entrepreneurial farmers in agricultural communities.

Vanuatu

Many participants across the three communities highlighted the importance of developing an organic fertilizer to improve soil health. One farmer stated, "*We would be* *very interested in using fertiliser if it was organic".* This growing awareness of organics is driven by an increasing number of companies being certified as organic under a Participatory Guarantee System (PGS) such as Tanna Coffee, Tanna Farms, Lapita Cafe Ltd, ACTIV and Teoma Group.

A major policy endorsed by the Pacific High-Level Group at the Pacific Island Forum in 2008 was the Pacific Organic Standard (Bell, 2009). The Pacific Organic Standard was created as a foundational body to support strengthening and growing organic agriculture capacity and production in the Pacific region (Regional Organic Task Force, 2008). The standard provides consultations, promotion and capacity development; yet, it intentionally does not cover conformity assessments, seeking to allow local stakeholders the opportunity to develop their organic systems that adhere to local, regional and international standards. In 2008, IFOAM provided training support to POETCom members on meeting the challenges of organic certification in the region using a Pacific Organic Standard.

The Pacific Organic Standard outlines the requirements for meeting organic production and covers plant production, animal husbandry, beekeeping, collection of wild products and aquaculture, and also processing and labelling of products derived from these activities (POETCom, 2020). By working with local socially responsible companies in Vanuatu, program partners including the Farm Support Association, POETCom, SPC, Pacific Horticultural and Agricultural Market Access Program (PHAMA) and the Vanuatu Organic Certification Committee were able to support the organic certification of product lines, including coffee, dry roasted peanuts, and cassava flour through the development of Participatory Organic Guarantee System (POGS) that met POETCom's Organic Pacifika Mark (Addinsall et al., 2020). Through the development of the POGS, technical assistance was given to smallholder farmers, including women and youth, to train in organic and sustainable farming practices based on traditional knowledge such as intercropping to help avoid the adverse effects of monoculture cash cropping while also ensuring food security (Wong, 2019).

Tuvalu

In Tuvalu, much like Vanuatu, there is a growing market for organically certified products to meet growing tourism demand. Improving soil health and crop productivity would have several benefits to community members, including increased income, the potential for better product branding and improved farming practices.

5.2 Testing the treatment capabilities of a range of traditional and novel treatment options (Activity 1.2)

To assess the viability of turning human wastewater into organic fertilisers, we tested several different treatment options using a series of field, laboratory and processing options (Figure 6). We tested waste types that were typical across the Pacific, including wet wastes (sludges) that can originate from centralised treatment facilities or septic tanks and dry wastes from composting toilets or pit loos. For wet wastes, we firstly reduced their water content below 80% through the use of sand drying beds. From there, the waste was treated either biologically through anaerobic composting or thermally through hydrothermal carbonisation and pyrolysis. The treated products from these processes were then either sieved, granulated or pelletised depending on the community needs. At all stages, we assessed the pathogen load and the major and minor nutrient content. As well, we also assessed the viability of organic certification of the final products. Green wastes were also included as a supplement as they are generally abundant, of little value and aid the different treatment processes, particularly in balancing nutrient ratios in anaerobic composting.

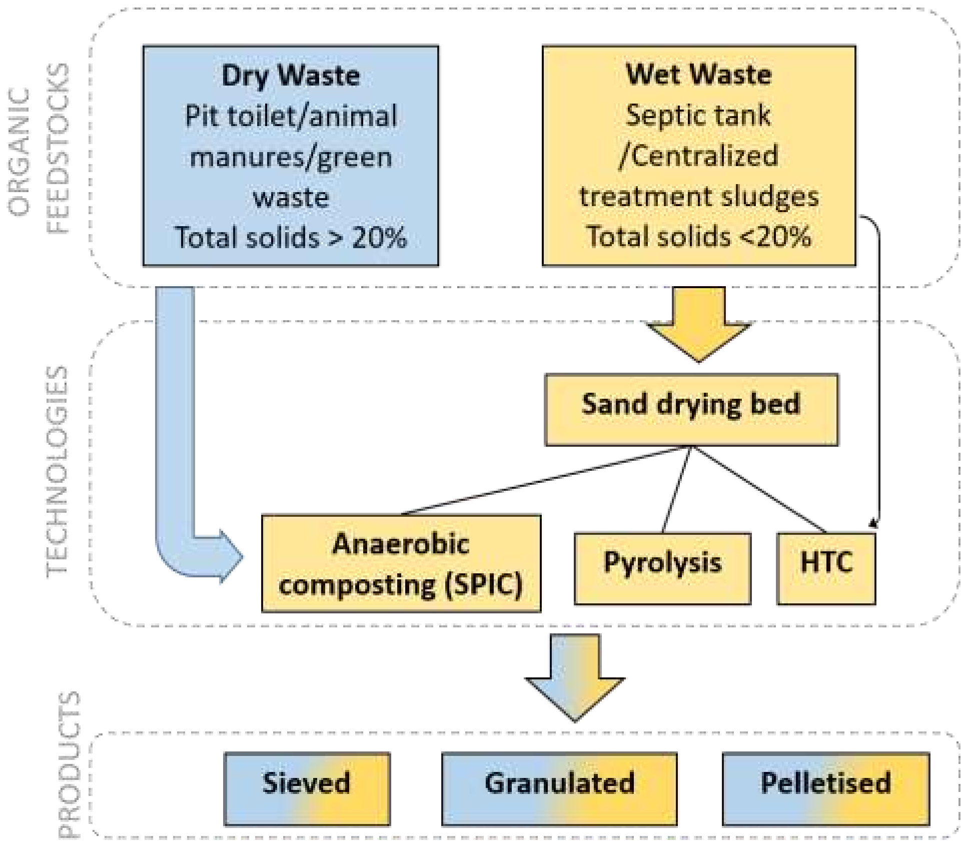

Figure 6. Schematic of organic waste conversion technologies and potential products.

5.2.1 Sludge drying beds

Decentralised human wastewater treatment using domestic septic tanks as collection and pre-treatment vessels is common across Pacific island communities. However, the high water content of the generated septic sludge presents a significant challenge in its handling, disposal or downstream utilisation. Sludge drying beds are an effective means of dewatering and providing further stabilisation of faecal sludges, which is especially important for transportation and improved end-user utility (Nikiema and Cofie, 2014).

Sludge drying beds are simple, shallow, permeable beds filled with sand and gravel with under-drainage to collect the leachate. Many design configurations exist, including different shapes, sizes, drainage systems, and types of gravel and sand layers. Drying beds require no electrical energy or chemical addition but are land-intensive and subject to climatic fluctuations. When the bed's surface is loaded with septic sludge, the drying process utilises the percolation of leachate through the sand and gravel and solar evaporation at the sludge surface (Figure 7). Approximately 50% to 80% of the sludge volume evaporates or drains off as liquid leachate, which needs to be collected and further treated through systems like reed beds before environmental discharge. When dry sludges are removed manually or mechanically, the dried sludge is not entirely stable or pathogen-free (Harrison et al., 2000) and may require further processing depending on its intended end use (discussed in section 5.2.6). In this crude form, dried sludge materials (often referred to as biosolids) are nutrient-rich (N, P, K and S) and can be beneficially used as soil amendments and fertiliser substitutes (McLaughlin et al., 2008). The fact that faecal pathogens are still present means applications may be limited to crops that are not directly consumed (i.e. sugarcane, kava, coffee, pawpaw, forestry). Moreover, land application of sludges that are not completely stabilised may contribute to excessive nutrient leaching and environmental degradation.

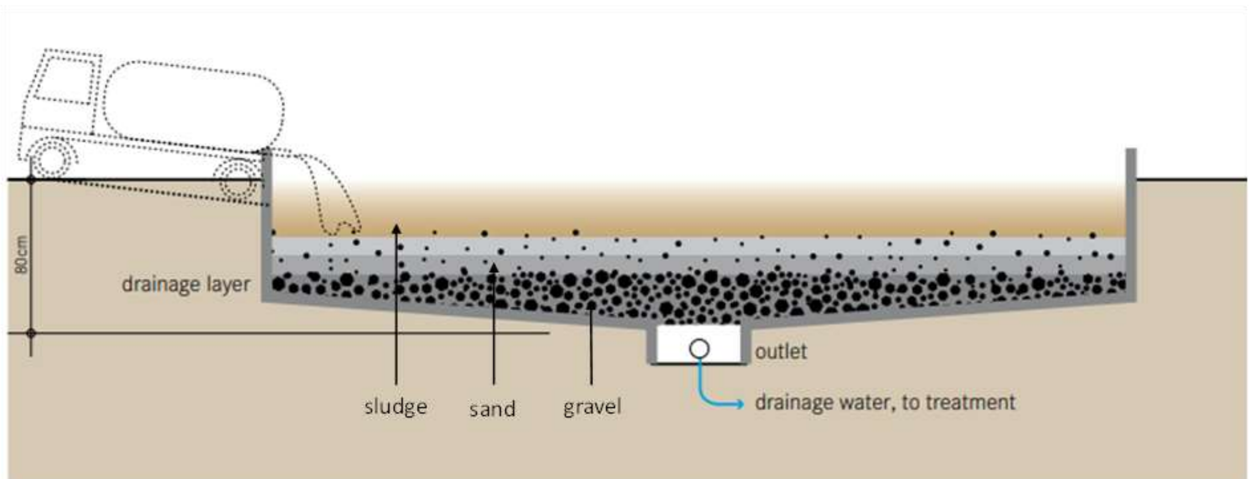

Figure 7. Schematic representation of a sludge drying bed (Tilley, 2014).

Leachates collated from dewatering processes typically represent 40-70% of the initial sludge volume and generally require additional treatments (nutrient and pathogen reduction) to meet environmental discharge quality standards. Effective, low-cost, low-tech options for treating leachates are constructed reed beds and wetlands (Davison et al., 2005). Simply, reed beds are lined beds or troughs (to prevent seepage), filled with gravel and planted with various local macrophytes (Figure 8). Multiple reed beds may be used continuously in series or in a batch mode, as long as a required hydraulic holding period (typically five days) in the reed bed is achieved. The resulting wastewaters may be used for irrigation, and the reed bed plants can be harvested and used for animal fodder or composted.

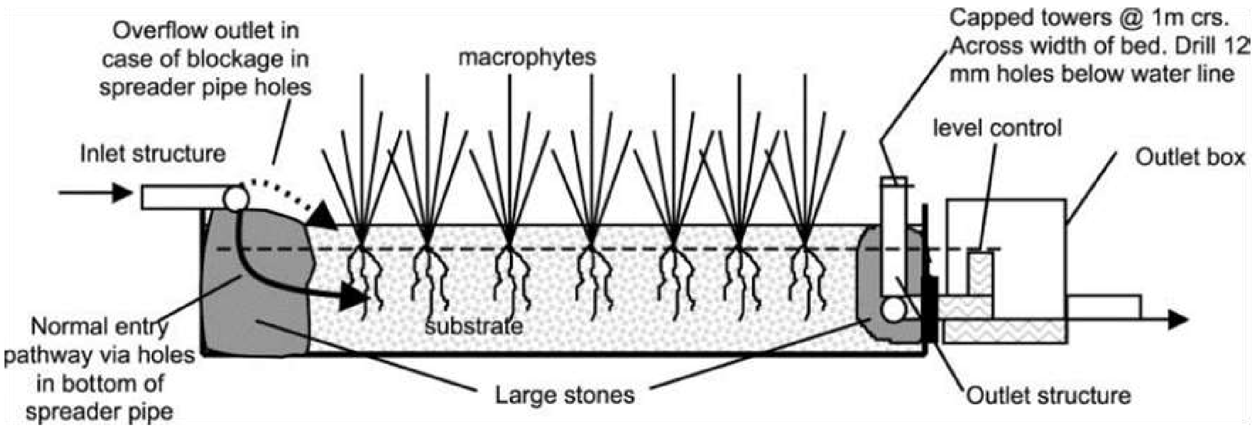

Figure 8. Schematic of typical reed bed construction showing major components.

5.2.2 Anaerobic composting

Composting is a simple biological approach to manage all types of organic wastes, including human faecal waste (septic tank sludges), animal manures and garden or agricultural green waste. Composting allows you to turn waste materials into a valuable soil conditioner for agriculture and gardens. The general composting process involves mixing organic materials, pushing the mixture into a pile or windrow, adding water and then letting the pile decompose in a controlled manner. The composting process can be performed under turned /aerobic (with oxygen), or no turn anaerobic (oxygen-free) conditions and has four core phases; mesophilic, thermophilic, cooling and curing stages (Wang et al., 2015). Through these phases, a plethora of microorganisms, especially bacteria and fungi, can decompose organic wastes into a stable humus-like material (Lohri et al., 2017). Importantly, during the thermophilic stage, if internal temperatures are maintained at prolonged elevated temperatures (a minimum of 55°C for ≥15 days), even high-risk materials like animal manures and human effluents can be pasteurised and considered safe for use. When composting manures and human effluents, co-composting with green wastes improves the nutrient balance and aids in achieving these elevated thermophilic temperatures.

The anaerobic composting method or static pile inoculated covered compost (SPIC) uses a simple no-turn technique to achieve effective composting. Instead of regular turning, the compost pile is inoculated with specialised microbes, then covered with plastic tarps and left to decompose (as shown in Figure 9) (Walker et al., 2009). Anaerobic composting is a low cost and easy method for effectively composting at a large or small scale. It can offer several advantages over traditional aerated/turned composting methods.

Figure 9. Preparing the anaerobic composting windrows before covering, covered windrows and composted material after 12 weeks incubation.

As the anaerobic composting method does not need to be regularly turned, it results in significant savings in time, machinery and labour when compared to standard aerated methods. Covering the compost piles means it requires much less water to achieve a final compost product. The anaerobic composting process is applicable in high rainfall zones as there are no additional requirements for a cover/roof to keep excess rain off compost piles. In addition, problematic odours are greatly reduced or eliminated. Finally, the need to cover piles with tarps or plastic sheeting significantly increases the thermal and moisture efficiency from the piles and reduces the risk of contaminated run-off from the composting site to the local environment. The resultant composted material retains the bulk of the nutrient content and typically provides improved agricultural productivity when applied as a soil amendment. The beneficial effect of compost on soil health and crop ultimately yield can be variable, but soil aggregation, soil bulk density and water holding capacity have consistently been reported to improve with compost addition (Kranz et al., 2020).

5.2.3 Pyrolysis and biochar

Pyrolysis is the thermal decomposition of organic materials at elevated temperatures under a limited oxygen environment. The resulting material termed biochar is a carbon-rich, nutrient-dense charcoal-like material. The ‘Slow Pyrolysis’ process, which significantly favours biochar production, involves indirectly heating dry biomass using an external heat source to temperatures of between 400-600°C for around one hour. The external heat source can be fuelled by wood, charcoal, gas or any other combustible material. Once cooled, the biochar is recovered and can be used as-is or processed into pellet and briquette forms for easier transportation and use. The pyrolysis process is scalable from easily constructed small-batch units to large-scale kilns (Figure 10). However, the process is limited to dry or low moisture (ideally >20% total solids) material, hence feedstocks like septic tank sludge require pre-drying (i.e. over sand drying beds) before use. The blending of various organic wastes is also an option to achieve the desired moisture content. Many potential benefits in the application of biochar to agricultural soils have been demonstrated, and include enhanced soil fertility, improved soil water retention, enhanced microbial composition and act as slower release N and P fertilisers, which reduces environmental leaching (Leng et al., 2019; Zhang et al., 2016). Moreover, the fact that high temperatures are used during pyrolysis, processed human wastes and animal manures are 100% pathogen-free and safe for direct application to edible crops.

Figure 10. Typical kilns used to produce biochar.

5.2.4 Hydrothermal carbonisation (HTC) and hydrochar

An emerging alternative thermal treatment technology is Hydrothermal Carbonisation (HTC), where high moisture materials like septic sludges can be directly carbonised with substantially lower energy inputs than pyrolysis (Kambo and Dutta, 2015). Similar to pyrolysis, the HTC process produces a carbon and nutrient-rich, coal-like material called hydrochar with similar soil amendment, carbon sequestration and fertiliser attributes as biochars. Typically the HTC process differs from pyrolysis in that wet biomass is directly heated under mild reaction temperatures (180-260°C) and pressures for longer periods (0.5 to 7 hours depending on the feedstock). Again, this process is scalable, but a pressure vessel requires a higher capital investment and a greater technical knowledge base (Figure 11) than other biowaste processing technologies. The HTC process is advantageous because a greater feedstock diversity can be carbonised and is lower in energy consumption than biochar production because no prior drying of organic wastes is required, and the process is exothermic. The application of hydrochars has positive changes to soil physical properties through decreased bulk density and increased total porosity, improved soil aeration and water holding capacity following hydrochar addition. Hydrochars are also 100% pathogen-free and act as slower release N and P fertilisers.

Figure 11. Hydrothermal carbonisation (HTC) of wet organic wastes in a low-temperature pressure reaction vessel.

5.2.5 Nutrient and pathogen analysis

In the conversion of biowastes into useable soil amendments and fertilisers, three main aims were assessed 1) the recovery and/or concentration of composite nutrients in the final products, 2) the reduction of pathogens to safe levels, and 3) the ability of the final product to be organically certified.

Nutrient retention

Human biowastes, including septic tank sludges and composted toilet wastes, are generally rich in essential nutrients, particularly nitrogen (N), phosphorus (P), potassium (K) and other minerals. In contrast, these faecal wastes are generally poor in carbon (C), hence, the addition of green plant wastes generally aids in the conversion process and helps nutrient balances in the final product.

As summarised in Figure 12, all of the 12 essential plant elements which are generally managed by growers and farmers are present in the raw feedstocks. The primary macronutrients N, P and K (Figure 12a) were approximately 3.4%, 1.3% and 0.7% (5:2:1) of total weight, respectively. All four treatment processes were effective at retaining the bulk of these composite primary macronutrients. While minor losses of N were observed in end products (<30%), both pyrolysis and HTC chars showed P levels were enriched 1.4 and ~2 fold respectively, over levels found in the raw feedstocks.

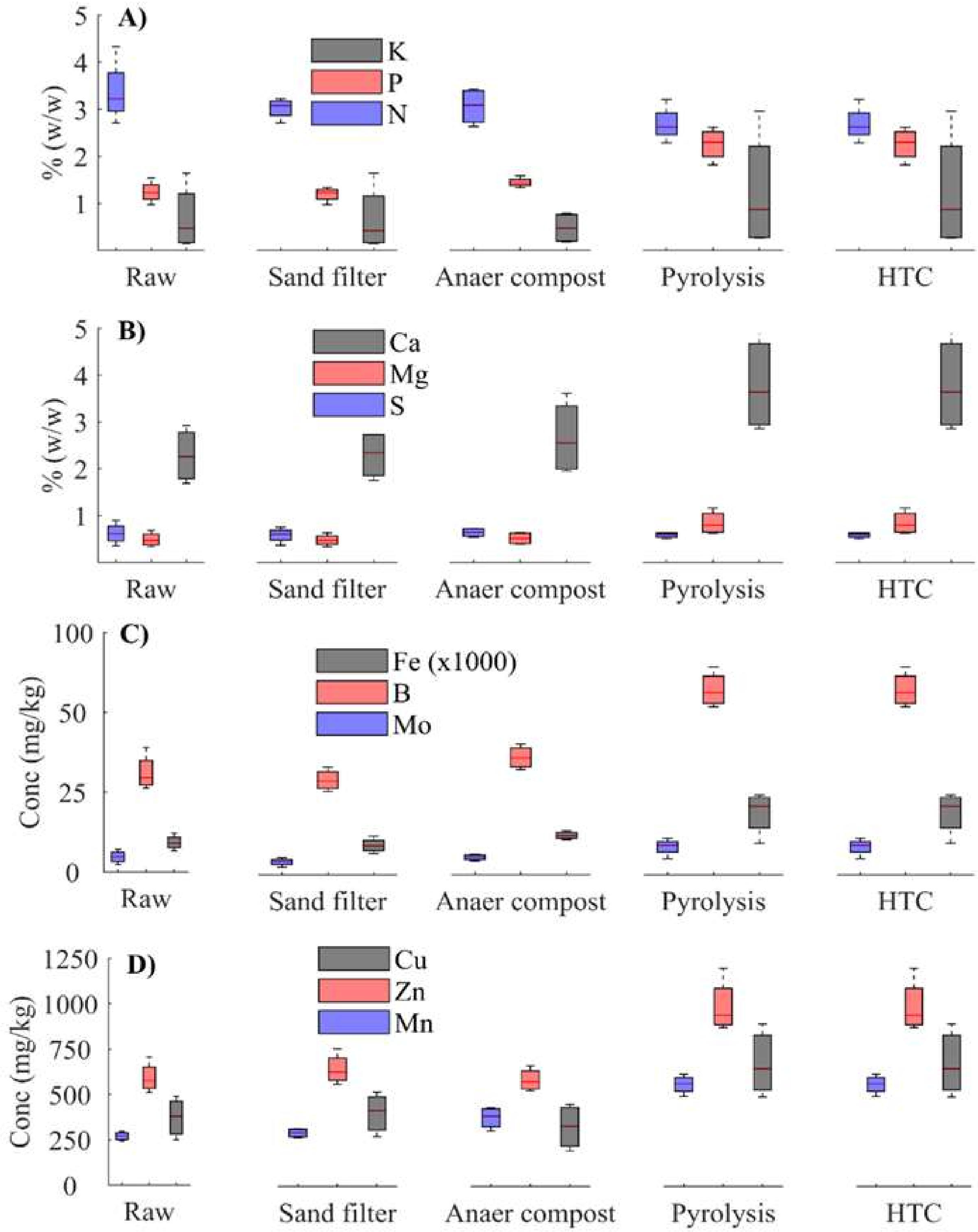

Figure 12. Analysis of major nutrients (N, P and K), intermediate macronutrients (Ca, Mg and S) and essential micronutrients (Fe, B, Mo, Cu, Zn and Mn). Note Fe is shown in g/kg.

The intermediate plant macronutrients sulphur (S), magnesium (Mg), and calcium (Ca) were abundant in the raw feedstocks and were recovered at high yields in all the four treatment products (Figure 12b). Again, the pyrolysis and HTC processes effectively enriched these nutrients, particularly Ca, representing nearly 4 wt% of the final char weight. An abundance of Ca in these soil amendment products has additional benefits in promoting healthy soil structure and stabilising organic matter, which increases soil water- and nutrient-holding capacity.

The remaining essential micronutrients required in very small quantities were effectively recovered by all treatments (Figure 7c and d). Pyrolysis and HTC concentrated all micronutrients in the final products, except for boron, which decreased in HTC chars. It is worth noting that the source of the high iron concentrations in the raw materials (~9 g/kg) is likely a product of assessing Australian wastes (as sampling Vanuatu or Tuvalu wastes was not possible due to COVID19 travel restrictions). Australian wastes can be affected by the local municipal drinking water supply network, which relies on iron pipes. Such iron levels are not expected in sludges where households/communities have a non-reticulated water supply.

Pathogen reduction

Potentially disease-causing pathogen loads in septic tank sludges are generally high in Faecal coliforms and E.coli being in the order of 107 and 105 CFU/L respectively (Appling et al., 2013; Harrison et al., 2000) with Salmonella spp. often detected (Figure 13). In contrast, the pit toilet waste was relatively free of all three pathogens tested and most likely reflects the mature age and stability of the pit toilet waste used in this study. However, it could be assumed that such waste materials would generally contain considerable pathogen loads if used in an immature state. All four treatment processes were successful in significantly reducing the overall pathogen content of septic tank sludges. Sand drying beds were an effective pathogen reduction process (>90% reduction), which agrees with the range reported in previous studies (98% reduction) (Harrison et al., 2000). However, despite this high disinfection rate, the pathogen levels were still greater than what is considered safe for their unrestricted use on food crops (AS4454-2012 guidelines; Appendix B). Consequently, primary treated sludges from sand drying beds require additional treatments (mainly heat) before being considered safe for unrestricted use. The fact that faecal pathogens are still present means applications may be limited to crops that are not directly consumed (i.e. sugarcane, coffee, fruit trees, coconut and forestry).

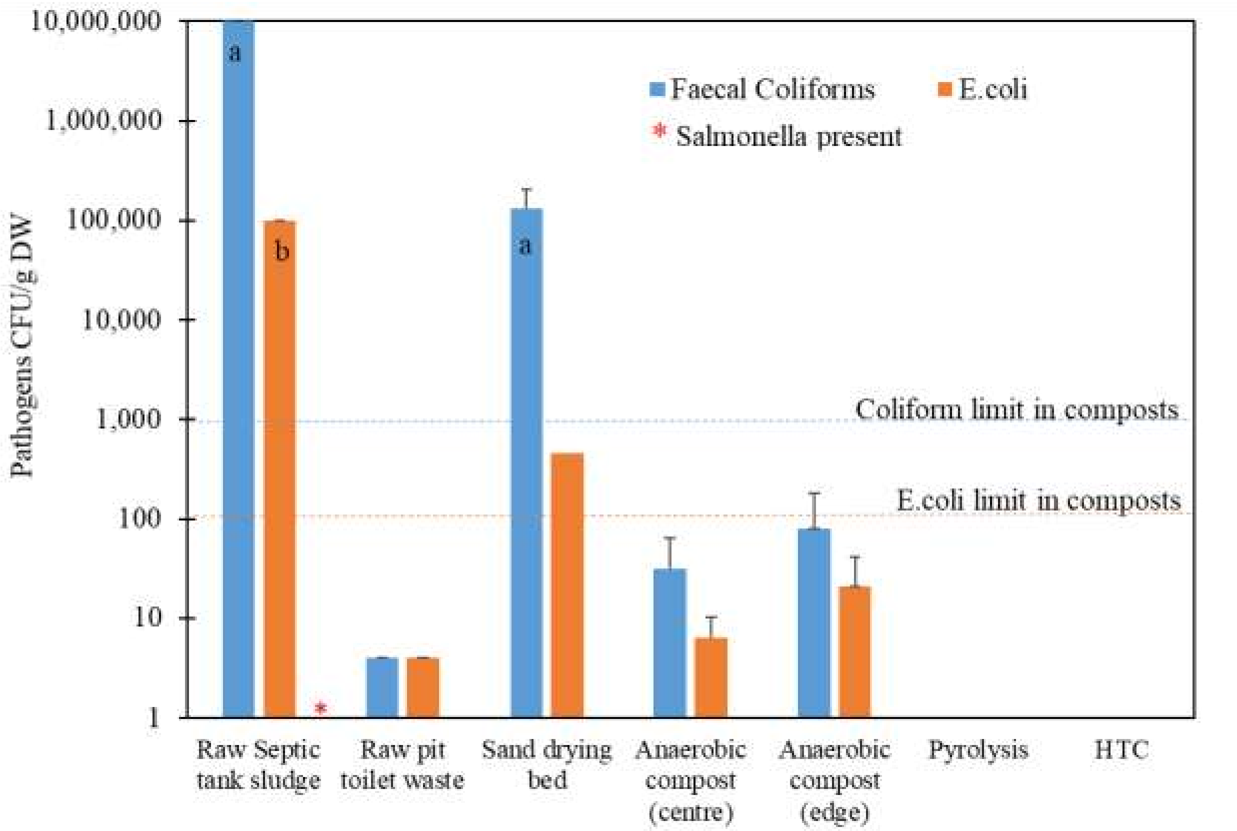

Figure 13. Pathogen reduction by treatment. Faecal coliforms, E.coli and Salmonella limits in composted products set at <1000 MPN/g DW, <100 MPN/g DW and absent in 25 g, respectively (according to AS4454-2012 guidelines). Values with a and b notation were taken from published literature (Appling et al., 2013; Harrison et al., 2000).

Anaerobic composting of the dried septic tank sludges was found to provide the required heat necessary to partially pasteurise the material with the concentrations of both faecal coliforms and E.coli below the safety limits detailed in the Australian composting standards for a 'Mature Compost' (AS4454-2012 guidelines) (Figure 13). Moreover, with this level of pathogen reduction, it would also be classified as 'Stabilisation Grade A Product' according to the Australian EPA 2000 guidelines (EPA, 2000). This was confirmed by the continuous monitoring of temperature profiles within the compost piles (Appendix A) with a temperature of >60°C maintained over 15 days (maximum of 70°C). However, there was some variability in pathogen levels and that there could be the potential for higher pathogen content in some portions of the unhomogenised anaerobically composted piles, particularly the outer surface where adequate heating was not sustained. Repetitive turning of the pile (as described in the AS4454-2012 standards) could be added to the process to better reduce pathogen content if direct application to food crops is planned. Both the pyrolysis and HTC treatments removed 100% of pathogens and would be considered safe for unrestricted use.

5.2.6 Final products

Following the treatment processes described above, a range of pathogen-free, nutrient-dense end products were developed for direct application into different agricultural systems, including sieved, granulated and pelletised products (Figure 14). Sieved products are easily produced by sieving material through wire or plastic mesh, typically with a 20 mm mesh size. Oversized material can be reused for further composting or thermal treatments. Granulated pyrolysis and HTC products are generated by the grinding of the charcoal-like material (i.e. using a pan granulator). For both sieved and granulated products, the starting material should be relatively dry to reduce clogging. Pelletised products are generated via several machine configurations, including extruders and flat die pelletisers. The size and power of the pelletisers varies according to the production level and can be electric, petrol or tractor PTO driven. Here, pelletised products were produced using a flat die with a tractor PTO drive (a similar system is shown in this video www.youtube.com/watch?v=MX4fwmSmf5U). Although granules and pellets require additional equipment and subsequent costs, these products ultimately improve handling and transport and increase the marketability of manure and human waste-based products by addressing technical and social challenges linked with these wastes. Pelletised products improve mechanical spreading options and applications where greater nutrient densities are required. Moreover, it is likely that pelletised products would command a higher value with broader applications, which could offset the additional production costs.

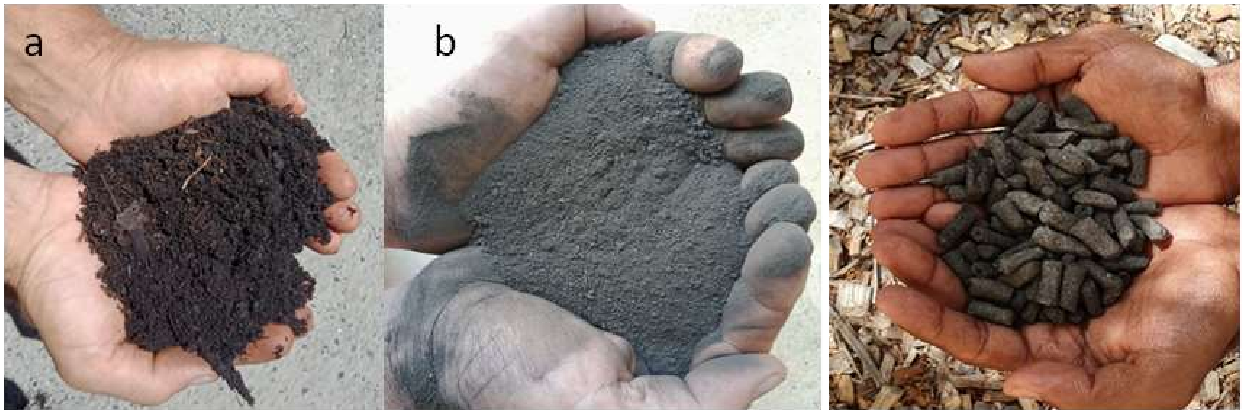

Figure 14. Product options to improve handling and marketability include; (a) sieved, (b) granulated, and (c) pelletised products.

5.2.7 Compost and organic certification

For composting certification, the products generated from anaerobic composting, pyrolysis and HTC were evaluated against the Australian standards for composts, soil conditioners and mulches (AS4454:2012). All the final products largely met the minimum requirements of a 'mature' compost classification in the Australian standard (Appendix B) and would be suitable for unrestricted use. One exception was that HTC and anaerobic composted products which were slightly above the 100 mg/L threshold for ammonium nitrogen. For composted products, this could be mitigated by introducing periodic turning of the compost during stabilisation. The addition of lime to HTC and anaerobic composted products can also be used to reduce ammonium nitrogen levels. Another exception was that all treatments were over the 50 mg/kg copper limits. Similar to the higher iron content mentioned earlier due to the Australian drinking water supply networks, copper is similarly affected. The elevated copper is unlikely to be an issue in sludges from households and or communities using non-reticulated water supplies. High copper and /or metal levels in final products may also be mitigated by changing the feedstock to include mixed green wastes.

For organic certification, the products generated from anaerobic composting, pyrolysis and HTC were evaluated against organic certification guidelines (Pacific Organic Standard, National Standard for Organic & Biodynamic Produce and The Australian National Export Standard for Organics) (Department of Agriculture Water and the Environment, 2016). As stated, for the use of animal manures and human wastes (i.e. biosolids), the material must meet the highest ‘Classification A’ for ‘Stabilisation and Contamination’ for consideration in organic composted products. For stabilisation, products which meet the pathogen reduction (i.e. ‘composting at 55°C for three consecutive days’) and vector attraction reduction requirements (‘treated in an aerobic process for at least 14 days with average temperature >45°C’) and the microbiological standards (tables 3-4 and 3-5 in Use and Disposal of Biosolids Products 2000 (See Appendix C) (EPA, 2000) are classified as ‘Stabilisation Grade A’. Likewise, contaminant grading is established by determining the contaminant concentrations in the product and comparing these with the contaminant acceptance concentrations listed in Table 3-1 in Use and Disposal of Biosolids Products 2000 (EPA, 2000). Once the contaminant and stabilisation grades have been determined, the biosolids product is classified as either ‘Unrestricted Use’, ‘Restricted Use’ or ‘Not Suitable for Use’ based on the assigned grades. The minimum quality grades corresponding to each product classification and allowable applications (uses) and disposal methods of classified biosolids are described in Table 3-6 of the standards (See Appendix C) (EPA, 2000). Treated human wastes (biosolids) meeting both ‘Stabilisation Grade A’ and ‘Contamination Grade A’ are classified as ‘Unrestricted Use’, which includes allowable uses including home lawns and gardens, public contact sites, agriculture, forestry and urban landscaping.

Further investigation into the possibility of organic certification for the produced fertiliser was done through discussion with Southern Cross Certifiers, an Australian based Organic Certification company that works closely with POETCom (Pacific Organic and Ethical Trade Community Pacific Community, www.organicpasifika.com). According to the National Standard for Organic & Biodynamic Produce (or The Australian National Export Standard for Organics) and AS6000 (Department of Agriculture Water and the Environment, 2016), there is no explicit terminology stating that you can or cannot use human waste materials. In fact, Appendix M of the National Standard and Appendix F of the AS6000 (See Appendix D) state the following highlighted criteria “... *a decision will be based on environmental safety, ecological protection, landscape and human and animal welfare*”. Southern Cross Certifiers concluded, “*Our opinion is that providing the compost is produced in compliance with*

AS4454-2012 or an equivalent Standard, and specifically compliant with Table 3.1(A), Pathogen Indicators/Composted Product, then we believe the product would be eligible for certification as an Allowed Input for Organic Production under most global standards".

5.2.8 Treatment advantages & disadvantages

Given the differences between the biowaste feedstocks, processing technologies, and end products demonstrated in this study, it is imperative to evaluate and quantify the key advantages and disadvantages of each process before establishing their suitability for a particular community. A summary of key features are compared in Table 2.

Table 2. Comparisons between selected waste feedstocks, treatment processes and end products.

	Feature	Advantages	Disadvantages
Waste feedstocks	Septic tank and centralised sludge	• Low intrinsic value • High nutrient (N,P,K) composition • Large volumes available • Reduced environmental impact when recycled	• High moisture content requires drying before use • High transportation costs • High pathogen content. • Requires transport infrastructure for centralised collection • Potentially having to deal with leachate from drying
	Compost/pit toilet waste	• Low intrinsic value • Good balance of nutrients and fibre (carbon). • Drying is generally not required • Partially stabilized and pasteurized	• Labour intensive recovery from pit toilets • Moderate pathogen content • May require drying before use. • Generally low volumes
	Mixed green waste	• Readily available in most locations • Generally low value • High carbon content for improved soils	• Bulky for transportation • Low pathogen content • Competing uses (already used for other applications)
Treatments	Sand drying beds	• Applicable to high moisture sludges • Low capital and operating costs • Minimal operator attention and skill needed • No electricity required • Low to no chemical consumption • Pathogen removal (~80-90%).	• Land intensive • Potential odours and climatic fluctuations • Incomplete sterilisation (may require further treatment for food crop use) • Leachates require further treatment prior to environmental discharge (i.e. use of planted reed beds to reduce nutrients and pathogens)
	Anaerobic composting (SPIC)	• Applicable to most organic waste. • A small amount of operator attention, machinery and skill is required • Low cost, low odour and low water usage • Compatible with high rainfall areas • Pathogen reduction meets compost standards • High nutrient retention. • Safe for direct use on food crops with repetitive turning • Potential for organic certification	• Land intensive • A mixture of feedstocks require for efficient co-composting (i.e. septic tank sludge with green waste) • Training is required to establish a consistent process • Periodic monitoring of pathogens and maturity required to meet regulatory requirements • Variability in pathogen content, particularly near edges

Table 2 Cont.

	Feature	Advantages	Disadvantages
Treatments cont.	Pyrolysis (biochar)	• Applicable to all types of organic waste • Only a moderate amount of operator attention, machinery and skill is required. • Basic low-cost systems can be constructed, suitable for individual households and small communities • Process scalable to larger centralised systems with off-the-shelf technology • Nutrient-dense slow-release fertiliser • 100% pathogen-free	• The process is limited to dry or low moisture (ideally <20%) material • Capital costs increase with scale • Does require some level of training and expertise to produce a quality product • Requires an external heat source (wood, gas, oil etc.)
	HTC (hydrochar)	• Applicable to all types of organic waste, including high moisture material • Nutrient-dense, slow-release fertiliser • 100% pathogen-free	• High capital and operating costs • A high level of training and expertise required • Applicable to centralised systems with infrastructure • Requires an external energy source
Products	Sieved	• Simple process • Low cost • High organic load	• Bulky for handling and transport • Less marketable
	Granulated	• Increased bulk density • Improved handling • High nutrient concentration • Slow-release fertilise	• Additional machinery • Higher production costs • Additional technical expertise
	Pelletised	• High density • Improved handling, marketability and application • High nutrient concentration • Slow-release fertiliser	• Additional machinery • Higher production costs • Additional technical expertise and product development required

5.3 Conduct a feasibility study to determine the governance structures, health considerations, likely community uptake and cost-benefit analysis that might affect the rollout of a full-scale wastewater reuse project (Activity 1.3)

It is essential to determine the feasibility of a project before there is a significant commitment of energy and funds. To do this, it is necessary to gauge the potential government buy in of the project and assess the community's needs, values and perceptions and also the projects restraints, costs, opportunities and potential benefits. This allows projects to be developed around government and community priorities rather than countries adjusting to the needs of the project or funding body. When these factors are considered early in the project design phase, this leads to more efficient, less costly and community-owned and government supported projects that hopefully run well past when any initial funding has been spent.

5.3.1 The challenges and needs of different communities

Vanuatu

Acquiring land at the community level is fraught with challenges, often making it more feasible to work with municipalities. However, they are not without their own set of challenges. The landfill site at Tanna, currently managed under the municipality, is too small to service the increasing population and expansion of the tourism industry. Negotiations are underway to relocate the site outside of the municipality. However, there are ongoing disputes between stakeholders claiming to be landholders of the proposed site. The landfill site in Luganville municipality is located too close to the main road, and rubbish is not properly contained, leading to litter being seen for km's down the main road. However, the Bouffa landfill in Port Villa has enough space and secure tenure to allow a Closing the Loop type project to operate from there.

Many participants in Port Orly commented on the lack of infrastructure to undertake the collection of animal or human waste with comments such as "*Because we don't have a truck, I think my household would prefer if someone picked up our waste and dropped off the fertiliser pellets to us as it's very expensive to get all the way to town to buy fertiliser*".

Tuvalu

The situation for many communities surveyed in Tuvalu is quite different to Vanuatu. Many respondents noted how they have little to no access to farming land, which leaves them reliant on backyard gardens, markets or imported food. The lack of access to land would mean that a roll-out of an organic fertiliser project in Tuvalu must be focused on highly productive backyard gardening in small spaces. Access to water was also a key concern for communities as they were experiencing longer dry periods. These significant factors have led to a greater awareness of composting and water-efficient small space farming in Tuvalu. This awareness would support a wastewater reuse project that works with developing fertiliser at the household/community level.

It is advisable that any fertiliser related projects work alongside projects such as the "Tuvalu Food Futures" project. This project produces healthy food in small spaces by establishing highly productive, water-efficient food gardens with special compost recipes using local biomass to increase nutrients in the soil. Commodities that were particularly important to the participants were coconut, breadfruit and banana.

Communities in Tuvalu already support the notion of circular economies and resource use with the concepts of *Fale pilli* and *kaitasi,* and any future projects needs to value these concepts highly. The Honourable Simon Kofe discussed the concept of *fale pili* which translates to 'my neighbour'. He described *fale pili* as having a deep and unique meaning to Tuvaluans around social reciprocity. Then there is *kaitasi* (sharing everything amongst family members, sharing of land, decisions, development, resources etc.). Mr Kofe suggested, "*most importantly, we need to ensure that our values are not lost in our dealings with regional and international partners. Tuvaluans have always and will always believe in their strong values, culture and tradition* (Kitara, 2020)".

5.3.2 Potential benefit to farmers

If all household human wastes are treated and reused, the produced fertilisers can meet more than double the nitrogen and meet about 60% of the phosphorus needs of subsistence farming households in Vanuatu and Tuvalu (Table 3). This is based on approximate application rates of 90 kg per ha of nitrogen and 70 kg per ha of phosphorous for breadfruit, taro and coconut and an average household cropping area of 0.07 ha (a third of the average household land area). The average household (4.6

family members) would produce approximately 3.2 Kg nitrogen per year from faecal matter and 19.3 kg of nitrogen per year from urine, and 1.4 kg of phosphorous from both faecal matter and urine. However, it must be noted that capturing 100% of a household's waste matter from on-site systems is challenging, and it is likely the amount of nutrient that could be captured per household is closer to one-third of this. Further study is needed to quantify actual recovery rates in Pacific households.

Other Pacific Island crops like Kava can have slightly higher fertilizer needs (16.5 kg/ha nitrogen in NPK and 150 kg/ha urea) (Source: www.pafpnet.spc.int/attachments/article/779/Fiji-Kava-Quality-Manual). As such, producing a sufficient amount of reused human waste fertiliser could be problematic for broadacre applications unless a large supply of human waste is available from sources such as a centralised sewage treatment plant.

Table 3. Potential nutrient recovery and use by households in Vanuatu and Tuvalu.

Variable	**Amount**
Household and waste	
Average land size (ha)	0.2
Estimate of crop/garden area (ha)	0.07
Ave household size (members)[2]	4.6
Faecal matter dry weight (kg/yr/person)[1]	13.9
Urine (L/yr/person)[1]	518
Nitrogen	
Faecal matter dry weight (kg N/yr/person)[1]	0.7
Urine (kg N/yr/person)[1]	5.2
Approximate application rate (kg N/ha/yr)[3]	90
Household needs (kg N/yr)	6.0
Household available from faecal reuse (kg N/yr)	3.2
Household available from urine reuse (kg N/yr)	19.3
Phosphorous	
Faecal matter dry weight (kg P/yr/person)[1]	0.3
Urine (kg P/yr/person)[1]	0.3
Approximate application rate (kg P/ha/yr)[3]	70
Household needs (kg P/yr)	4.7
Household available from faecal reuse (kg P/yr)	1.4
Household available from urine reuse (kg P/yr)	1.4

[1]Source: Rose et al., (2015) average for low income countries.
[2]Source: United Nations Population Division (www.un.org/development/desa/pd/data/household-size-and-composition), average household size for Fiji.
[3]Approximate average for breadfruit, taro and coconut (Sources: Lee et al., 2016, Nathanael 1967 and University of Queensland www.uq.edu.au/_School_Science_Lessons/BrProj.html#15.0)

5.3.3 Access to waste feedstocks

Determining the available waste feedstocks in communities is vital to deciding on which treatment systems would be best suited (Table 4). In more peri-urban settings such as Mele, Vanuatu and Funafuti in Tuvalu, a large proportion of waste feedstock is wet waste (septic tank waste). It requires dewatering through sand drying beds before further treatment or direct HTC treatment (See Figure 6). In contrast to this, the more rural communities in the outer islands of Vanuatu and, to a lesser degree in Funafuti, had a greater prevalence of dry wastes and can be treated directly with anaerobic composting and/or pyrolysis after collection. A small number of composting toilets have been trailed in Tuvalu (only 1.4% of toilets), but it would provide a good source of easily accessible dry wastes if a sufficient volume could be sourced. Wet wastes (septic waste) must be collected with a pump truck which is either done by local government or by private contractors. Once the waste is removed from the septic tank, it needs to be transported to a larger area with sand drying beds for dewatering or direct HTC treatment. Waste from pit toilets needs to be excavated (either by hand or mechanically) and waste from composting toilets removed before being transported to a central location for further treatment.

Table 4. Available waste feedstocks from study sites in Vanuatu and Tuvalu. Percentages of total toilets are shown in brackets.

Location	Pit toilet	Pour toilets to pit	Ventilated Improved Toilet (VIP)	Compost	Flush toilet to septic	Total
Vanuatu[1]						
Mele, Efate	181 (14.9%)	483 (39.8%)	17 (1.4%)		534 (44.0%)	1215
East Santo	454 (36.1%)	456 (36.2%)	307 (24.4%)		41 (3.3%)	1258
West Tanna	1354 (65.4%)	17 (0.8%)	537 (25.9%)		163 (7.9%)	2071
Tuvalu[2]						
Funafuti	43 (6.7%)	163 (25.5%)		9 (1.4%)	424 (66.4%)	639

[1] Source: 2020 Population and Housing Census for Vanuatu (www.sdd.spc.int/vu)
[2] Lal et al. 2007.

In addition to household wastes, there are several other sources of waste that require further research to determine their viability in future reuse projects. Cruise ships represent a significant source of untapped nutrient reuse in Pacific countries. For example, in Vanuatu, in the ten years leading to 2014, cruise ship arrivals increased

15% to 230 cruise ships, with each ship averaging more than 2,000 passengers (SPTO, 2017). Despite growing international cooperation prohibiting the dumping of sewage at sea (www.imo.org) and an upgrade to the Lapetasi Wharf in Port Villa, Vanuatu has no international pump-out facilities to manage sewage from international vessels (Asia Pacific Waste Consultants, 2019). In contrast, domestic shipping sewage wastes are discharged on private property on Santo (Asia Pacific Waste Consultants, 2019). Based on the environmental problems caused by cruise ship wastes and the potential for reuse, there is a need for future research focusing on the potential for cruise ship waste to be reused in Pacific countries.

Animal wastes, such as manure from pigs, cows and chickens, also represent a potentially significant nutrient source and are already widely used in Pacific countries to improve soil health. Although assessing the viability of re-using animal wastes was beyond the scope of this study, we believe animal wastes could easily be incorporated into Closing the Loop technologies. However, future research quantifying nutrient content, waste volumes and collection mechanisms needs to take place to assess these wastes further.

5.3.4 Energy requirements

More advanced treatment techniques such as pyrolysis and HTC require an external energy source to heat wastes to the necessary temperature and pressure. There are three primary sources of this energy available that can be available on pacific islands; petroleum-based electricity, biomass burning and biogas.

Petroleum

Imported petroleum products often make up a significant proportion of Pacific Island energy sources. Currently, non-renewable sources account for 81% of Vanuatu's electricity generation, with a target to be 100% renewable by 2030 set by the government (Griffith University, 2020). In Tuvalu, 77% of the country's installed energy capacity comes from a power station on Funafuti. On outer islands, antiquated and inefficient diesel-run generators with no capacity to store energy often run 12 to 18 hours per day, meaning that blackouts (most often the result of shortages of fuel and spare parts) are a frequent occurrence (ESMAP 2017). As such, and with the growing impacts of climate change, the Tuvalu Government has committed to sourcing 100%

of electricity from renewable energy (mostly solar PV) by 2025. As such, any treatment system that relies on petroleum energy would likely not be accepted widely by government project partners or the community, particularly when other much more inexpensive and readily available sources of energy are available.

Biomass

Besides petroleum, biomass burning meets a substantial part of Pacific Islands energy needs. Biomass typically can consist of forestry products, copra, coconut husks or other agricultural wastes. Biomass is used primarily for residential purposes, such as cooking and crop drying. Mostly rural (and some urban) households use biomass as their primary energy source, mainly for cooking. In Vanuatu, approximately 85% of households use wood and coconut shells as an energy source. However, little accurate information is available on biomass produced and utilized in Vanuatu. According to IRENA, forest biomass in Vanuatu accounts for about 60% of the country's energy supply and more than 90% of household energy consumption. In Tuvalu, copra is a large untapped biomass energy source with preliminary evidence suggesting at least 200-300 t of copra per year available that currently goes unused.

Biogas

Another alternative energy source is biogas. Recently, 40 biogas digesters were installed in Tuvalu to reduce the countries dependence on imported petroleum and to reduce the health impacts of burning kerosene indoors (The Pacific Community, 2019). The digesters rely on animal waste and organic material composted in a sealed container to produce methane. This methane can then be used for cooking or other energy-intensive applications. Additionally, the composted material can then be used in household gardens to improve soil health. A series of digestors could easily be added to the processing site of a Closing the Loop project, and organic waste and/or human waste used as feedstock. The captured methane could then be used to run the pyrolysis or HTC treatment units. At the end of the digesting process, the composted material from the digestor could then be treated in the pyrolysis or HTC treatment units.

5.3.5 Project partners and legislative frameworks

The project identified a broad range of potential project partners and collaborators that can help ensure future Closing the Loop projects are successful. Global partners such as the World Bank and United Nations Development Program can provide a range of technical advice and funding options. International organisations like the Secretariat of the Pacific Regional Environment Programme (SPREP) or aid organisations like Australia's Development Program administered through the Department of Foreign Affairs and Trade can provide funding through various grants. In-country governments and councils can provide funding and valuable resources (technical staff and/or services like pumping vehicles). NGOs like Live and Learn and public universities can provide hands-on management of projects and create opportunities for students to study both in-country and abroad.

Potential international partner organisations in Vanuatu and Tuvalu

- **The Australian Centre for International Agricultural Research (ACIAR)**, which founded this initial Small Research Activity has an extensive track record of funding cross-sector initiatives such as this one that delivers specific development outcomes. To date, ACIAR has commissioned and managed more than 1,500 research projects in 36 countries, partnering with 150 institutions along with more than 50 Australian research organisations.
- **The Japanese Technical Cooperation Project for Promotion of Regional Initiative on Solid Waste Management in Pacific Island Countries Phase II** (J-PRISM II) project focuses on sustainable waste management in the municipalities (Lenakel, Luganville and Port Vila) and Tuvalu. It supports capacity building in waste management, improving governance and human resource development and encouraging waste separation at the household level.
- **The Secretariat of the Pacific Regional Environment Programme (SPREP)** is an inter-governmental organisation providing technical assistance to 21 PICT's in several priority environmental areas, including waste management and pollution control.
- **The United Nations Development Program (UNDP)** has developed a solution-orientated concise analysis of circular economy opportunities aligned to government policy and plans in both Vanuatu and Tuvalu. The main opportunities listed include applying anaerobic digestion for municipal, industrial and agricultural organic waste (and where waste volumes are small, composting can be used instead) and collecting and sorting recyclable materials.

Vanuatu project partners

The main project partner would be local governments. In Vanuatu, this would be provincial governments and municipalities that have responsibility for waste management. Local governments play an important role in providing household waste collection and recycling services, managing and operating landfill sites, delivering education and awareness programmes, and providing and maintaining litter infrastructure. However, the local Governments in Vanuatu lack financial support and capacity. A PVMC waste officer stated, *"Most of our staff have not been educated past year three in school. We have a huge capacity issue and need more technically trained people to work with us".*

Principal waste management control officer Ionie Bolenga stated, *"For any project to do with waste in general, we would recommend that they work closely with the government. If the project lapsed, the National Waste Water Task Force would then take over after considerable capacity building from the project team. The government department responsible would be the Department of E*nvironmental *Protection and Conservation, in collaboration with the Department of Health and the Department of Water Resources"*. The Department of Agriculture also showed enthusiasm to be part of a full-scale wastewater reuse project suggesting that they would be more interested in the end product and could use existing networks in the islands to get this product out to rural communities and educate farmers around the use of organic fertilizer.

Other Vanuatu project partners

- **The Department of Environmental Protection and Conservation** in the Ministry of Climate Change, Environment, Energy, Meteorology and Disaster Management. The department administers the Waste Management Act 2014 and is also responsible for both groundwater and coastal water health
- **The National Wastewater Taskforce (NWT)** is a newly formed organisation appointed by the Department of Environmental Protection and Conservation in 2020. NWT has the responsibility to oversee the construction and inspection of sewage treatment/disposal systems.
- **The Farm Support Association (FSA)** provides support to assist small-holders in establishing animal farming systems (i.e. chicken, goats and pigs) and vegetable, fruit and root crop gardens. In terms of fresh produce, the FSA works

with local Ni Vanuatu growers to run trials of fruit and vegetable crops and provide advice in aspects of nursery techniques, disease and pest prevention and provision of seeds. The FSA is also trying to raise awareness of growers around quality issues, an extension of the growing season, and the management and packaging of produce during transport to markets.

- **Live and learn Vanuatu** has a long history and experience in Water and Sanitation Hygiene (WASH) and other waste activities. They have been working with schools and communities in Port Vila and peri-urban communities around Port Vila, promoting safe access to water, sanitation and promoting good hygiene practices as well as advocating for menstrual hygiene management. They have been funded to undertake several consultancies to carry out research in schools around Vanuatu.
- **Vanuatu Environmental Science Society (VESS)** aims to promote science in the fields of conservation, environmental protection and sustainable development within Vanuatu. VESS is an ambassador for the Australia, New Zealand and Pacific Islands Plastics Pact (ANZPAC), which brings together key players in the region behind a shared vision of a circular economy for wastes such as plastics.
- **The Vanuatu Recyclers and Waste Management Association (VRWMA)** consists of businesses and organisations from Vanuatu that have had a demonstrable association with recycling, waste management, waste minimization or commercial waste production for at least 12 months.
- **Won Smol Bag** is a Port Vila-based NGO that promotes awareness in waste management, particularly composting toilets and is also engaged in a community initiative to collect plastics, cans, scrap steel, packaging waste and diapers from seven communities in Port Vila. The recyclable material collected is transported to the recycler (Recycle Corp), and the remainder goes to the Bouffa Landfill.
- **Vorganic** has produced a liquid organic fertiliser made from 100% organic materials on his farm in North Efate. The product has been tested in New Zealand and is recognised by the Vanuatu Bureau of Standards. The biggest client for his product is the Department of Agriculture.

- **Vanuatu Agricultural Supplies (VAS)** has been a big part of the agricultural development in Vanuatu since 1983. Some of their key focus of work includes ground grown herbs, a nursery for hydroponic salad leaves and assisting Ni Vanuatu growers with crop husbandry advice and managing crop disease. They see an increasing trend in local growers developing non-traditional crops such as watermelon, potatoes and rice partially driven by better financial returns on the crop.

Recommended policy and legislation alignment for a full-scale wastewater reuse project in Vanuatu

- National Sustainable Development Plan (2016-2030) (NSDP)
- National Environment Policy and Action Plans 2030 (NEPIP)
- National Waste Policy
- Vanuatu Recyclers and Waste Management Association Strategic Plan 2021-2024
- National Waste Management and Pollution Control strategy and Implementation Plan 2016-2020
- National Biodiversity Strategy and Action Plans (NBSAP)
- Vanuatu Climate Change and Disaster Risk Reduction Policy (2016-2030)
- Vanuatu National Oceans Policy (2016)
- The Vanuatu National Plastics Strategy (2020-2030)
- Vanuatu Sustainable Tourism Policy (2019-2030)
- Waste Management Act. No 24 of 2014
- Pollution Control Act. No. 10 of 2013
- Environmental Protection and Conservation and Conservation Act [Cap 283]

Potential project partners in Tuvalu

- **The Solid Waste Agency of Tuvalu (SWAT)** within the Ministry of Home Affairs and Rural Development and is mandated to oversee the management of wastes both in the main island of Funafuti and the outer islands. SWAT is guided by the Tuvalu Integrated Waste Policy (2017 to 2026) and Action Plan (2017 to 2021), which was funded by the European Union (EDF10). It is responsible for a number of activities such as implementing waste reduction and resource recovery programmes, promoting the recovery of green wastes from the waste stream, implementing composting programmes, and encouraging stakeholders to utilise compost produced from processed green wastes.

- **The Kaupule** is the local government unit on each island and is responsible for waste management in their particular area. The Kaupule sits under the Department of Rural Development within the Ministry of Home Affairs and Rural Development. The Kaupule may make by-laws regarding waste management under the Falekaupule Act 1997 and specifically section 15(2) of the Waste Operations and Services Act 2009.
- **The Ministry of Finance and Department of Trade** in collaboration with SWAT, develops waste business opportunities to ensure sustainable waste systems, including financial mechanisms to support efficient delivery of waste services.
- **The Department of Public Works,** in collaboration with the SWAT and private contractors, are responsible for undertaking detailed infrastructure (including maintenance) management programmes to ensure that waste facilities and equipment are properly acquired and looked after. This includes designs incorporating climate-proofing, ensuring facilities are operated within a reasonable standard for effective and efficient waste services, and with due consideration to the occupational health and safety of the waste workers and the health and well-being of the community.
- **The Ministry of Health and Department of Environment** cooperates with SWAT to handle, store and dispose of hazardous wastes (chemicals, asbestos, healthcare wastes, used oil, e-wastes, etc.) according to international convention regulations and best practice management approaches that will minimise health and environmental impacts.
- **The Department of Energy** has partnered with the Biogas Facility project run in collaboration with SPC (through an EU funded project) and UNDP to reduce the impacts of piggery wastes (Lifuka, 2016). SWAT facilitates the provision of piggery waste and runs the processing plant.

- **The Ridge 2 Reef project** investigates the use of pig manure for compost which is aligned with a recent cost-benefit analysis for green waste processing.
- **Live and Learn Tuvalu** has experience in Water and Sanitation Hygiene (WASH) and Waste Activities. It has recently undertaken extensive education campaigns on WASH in the central islands of Tuvalu, as well as being a key manager on exploring new production methods in the Funafala Food Garden. Live and Learn has also collaborated with the Tuvalu Department of Education in the development of an educational curriculum on incorporating traditional knowledge into Tuvalu's agriculture production.

Recommended policy and legislation alignment for a full-scale wastewater reuse project in Tuvalu

- Te Kakeega III National Strategy for Sustainable Development 2016 to 2020
- Falekaupule Act 1997
- Tuvalu Integrated Waste Policy and Action Plan (2017 to 2026)
- The Environment Protection Act (2008)
- Waste Services and Operations Act (2009)
- Customs Act (Cap. 55)

5.3.6 A Rapid Assessment of Needs and Perceptions (RANP)

This SRA shows that there is potential for the *Closing the Loop Project* which turns human waste into organic fertilizer to bring a range of benefits to Pacific Island communities. However, it is necessary to consider several important factors before implementing such a project. In particular, it is first necessary to assess the community's needs, opportunities, limitations and which treatment type is most applicable to a specific community. Undertaking this assessment before on ground works commence will help facilitate greater community acceptance and engagement with the project, which communities are best suited to such a project and where it is likely to have the greatest return.

To do this, we have developed the Rapid Assessment of Needs and Perceptions (RANP) methodology to determine. Figure 15 shows what information is necessary to attain to determine the feasibility of a Closing the Loop project for a specific community. The method allows project officers to quickly rank the communities needs and perceptions using survey questions, identifying key project partnerships, determining the types of waste feedstocks available and what limitations and opportunities exist in the community (Appendix E).

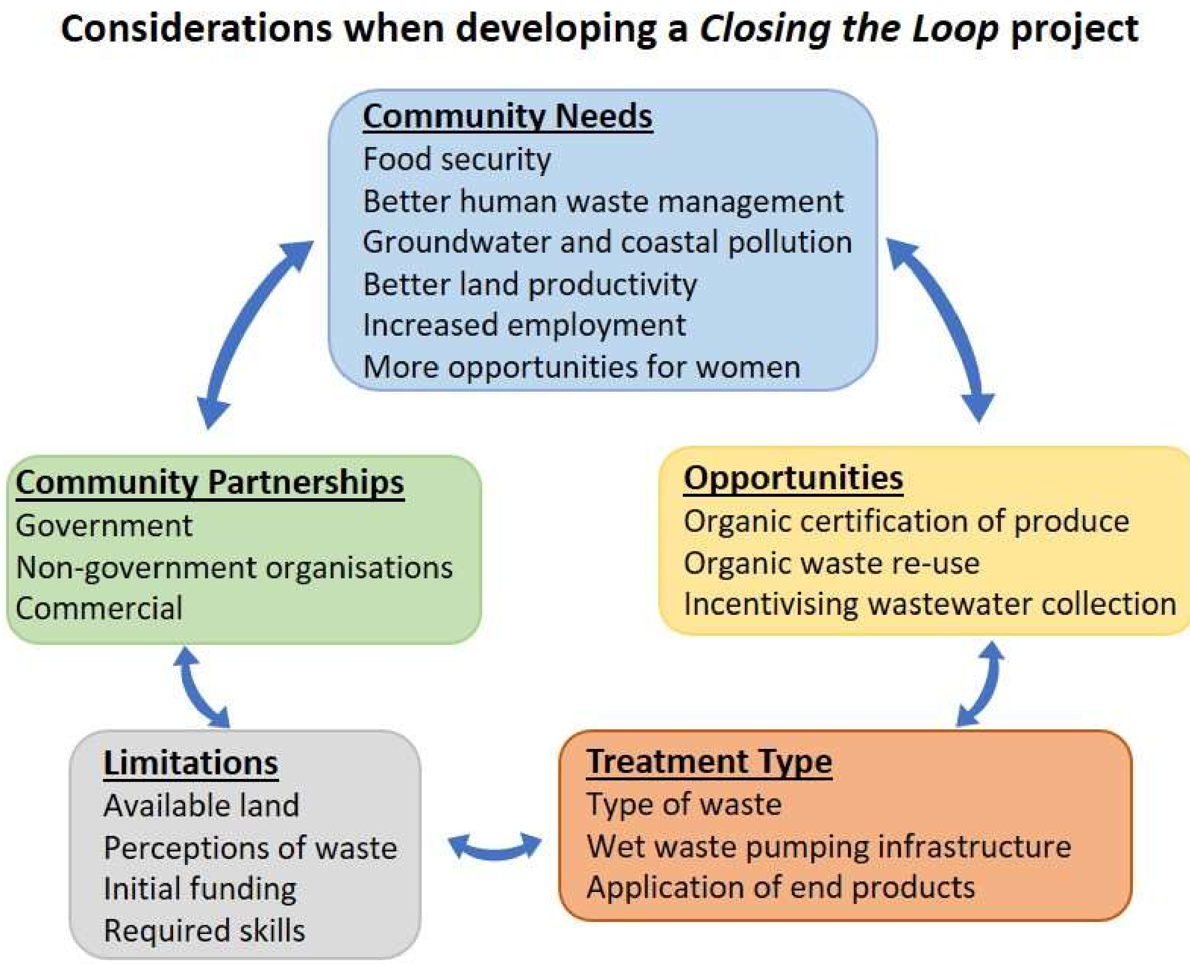

Figure 15. Considerations when developing a Closing the Loop project in Pacific Islands.

5.3.7 Project governance structures

A range of potential models are possible for developing a full-scale wastewater reuse project in Pacific Islands depending on the needs, limitations, partners and type of wastes available. The below figure (Figure 16) outlines three possible scenarios: 1) a fully supported funding model where donors fund a larger initial capital expenditure, ongoing project costs and the product is provided free of charge, 2) a blended model where project costs are split between donors and project partners and the product is sold at a subsidised rate, and 3) a commercial funding model where project costs are covered by partners and product sales.

Supported funding model

- External donors are sought to fund the initial and ongoing project costs fully
- Sizeable initial capital costs (i.e. waste collection vehicle)
- External sources finance treatment equipment
- Three full-time equivalent staff (collection, processing and administrative)
- The local council provides the processing facilities
- The product is provided for free

Blended funding model

- Projects costs are split between donors and partners
- The local government provide the collection vehicle and employee
- Two full-time positions (processing and administrative)
- Treatment equipment is funded from external sources
- The local council provides processing facilities
- The product is sold at a subsidised cost

Commercial funding model

- Project costs are covered by partners (i.e. local government), and product sales
- Local government or private business provides collection vehicle
- Salaried positions are funded through the sale of products
- External sources finance treatment equipment
- Processing is done at commercial premises
- Product is sold at commercial rates

Figure 16. Potential Closing the Loop project funding models.

5.4 Engage women in Pacific Island agricultural communities through gender-aware stakeholder engagement, employing female in-country research assistants and providing a co-funded PhD/Masters scholarship (Activity 1.4)

Women in both Vanuatu and Tuvalu have a strong vested interest in water resource management as they are the key stakeholders responsible for market and backyard gardens. However, projects endeavouring to facilitate greater participation of women in this sector have met with variable results. It is important that any further project is managed in such a way that it does not erode away traditional systems and practices that support women and children. Anderson (2011) suggests many western ‘growth’ strategies favour formal economies and private businesses, in particular export industries, while devaluing and often displacing more traditional ‘hybrid’ livelihoods that combine formal, informal and subsistence economies. It is these ‘hybrid’ traditional economies where many rural women in the Pacific play a significant role (Addinsall et al., 2015). Indeed, strategies solely relying on capital and growth can significantly redirect and alter smallholder livelihood futures and ultimately place an additional burden on women through reinforcing patriarchal lines (Ife, 2013). There are other preferred methods of increasing agricultural productivity, which are more likely to yield sustainable increases in community living standards without entailing serious social disruption. Therefore, work is needed to explore these ‘preferable methods’ that can enhance access for women without displacing or eroding customary tenure and the traditional economy, which constitutes the political, economic and social foundation of contemporary Pacific Island society (Regenvanu, 2009).

Significant opportunities exist for women in Pacific agricultural communities in future Closing the Loop wastewater reuse projects, including employing female waste pickers at Bouffa landfill in Vanuatu as project officers, ensuring an equal representation of female and male technical and administrative staff, exploring private sector opportunities for the development and sale of fertilizer with female entrepreneurs and opportunities for female market stallholders to sell the products.

This is where an intersectional approach becomes imperative as often, the needs of Pacific Islander women are seen as being met by services and projects which are ultimately designed for the male population (Crenshaw, 1989). Mistaken assumptions are made in decolonisation and development discourse and practice about the ‘shared’ experiences of all Pacific Islanders, ultimately resulting in projects and services which negatively affect women. This project puts forward the need to treat every community as having its own specific needs and challenges and thus recommends that any future wastewater reuse project conducts a RANP with a balanced gender representation and the reporting the information back to both male and female participants for verification.

In order to further support greater representation of Pacific Island women as leaders in future projects, academic opportunities for women can be developed through ACIAR Pacific Agriculture and Southern Cross Universities scholarship schemes. As part of this project, Southern Cross University project officers are supervising a female Ni Vanuatu PhD student Ms Norah Rihai who’s research is seeking to merge multiple discourses by firstly reviewing the development model that is driving agricultural and tourism linkages with a gender focus. The outcomes of this study aim to support the further development of regenerative agriculture incorporating traditional knowledge and using agritourism as an educational platform. Much like this project, a Participatory Action Research approach is being applied to define and develop a sustainable and regenerative agritourism model for Pacific Islands countries.

6. Conclusion and Recommendations

This study found the wastewater reuse represents a significant opportunity for Pacific communities. Not only can it help improve food security, economic opportunities and increase crop yields, it can also promote better human waste management by helping shift the perception of human waste from being a 'problem' to an 'opportunity'. Importantly, the study found there is not a 'one size fits all' solution to implementing wastewater reuse projects with sometimes contrasting beliefs and community structures, including perceptions around reusing waste (particularly human waste), government policy in waste management, exposure to alternative waste management systems and agricultural and environmental challenges. This suggests the need for a detailed understanding of the communities needs, perceptions and limitations before any on ground works takes place. Therefore, this project puts forward a range of recommendations:

Recommendations

1. In Vanuatu, that a pilot project takes place with the Mele community in partnership with the Department of Environmental Protection and Conservation, Department of Agriculture, Department of Industry, Shefa Provincial Government Council, Port Vila Municipal Council, National Wastewater Taskforce (NWT), Japanese International Cooperation Agency (JICA), Secretariat of the Pacific Regional Environment Programme (SPREP), Live and Learn Vanuatu, Wan Small Bag, DJ repair and DJ Septic Waste, Vanuatu Agricultural Supplies, V-Organic and the Vanuatu Bureau of Standards. The project focus would be on a combination of septic and organic waste from Mele and the markets and kava bars in Port Vila using drying beds, anaerobic composting and pelletising. Processing would be done at the Bouffa Landfill site in Port Vila where there is sufficient space and

secure land tenure. The project would need to subsidize the collection of septic waste from Mele and provide bins for separating organic waste.

2. In Vanuatu, the development of a waste management plan at the provincial and council levels is a requirement under the current National Waste Management Strategies of Vanuatu. The provincial and municipal councils are ill-equipped to develop such waste plans on their own, ACIAR in collaboration with JICA and SPREP should support the development of waste management plans in other provinces.
3. A pilot project should be developed In Alapi, Tuvalu, with septic and pit/composting toilet waste processed using drying beds, pyrolysis and both granulating and pelletising. The project will partner with Live and Learn Tuvalu and the Funafuti Council with treatment facilities on Funafuti Council land.
4. A Rapid Assessment of Needs and Perceptions (RANP) be undertaken in a range of new communities with different cultural, economic and agricultural contexts and where suitable, pilot Closing the Loop projects be developed.
5. The project develops working groups in each pilot site to support project rollout. The working groups would incorporate government, non-government, community representatives and commercial project partners to ensure the long-term support and financial viability of the project.
6. Further research on the amount of recoverable human waste from different household waste treatment types (septic tank, pit toilet, composting toilet) be undertaken to determine the amount of organic fertiliser that can be produced.
7. That a further SRA be developed determining the feasibility of collecting and processing wastes from cruise ships in Vanuatu.
8. The availability, current uses, perception, collection, treatment and reuse of animal wastes be incorporated into the RANP process, and where suitable, animal wastes be incorporated into future pilot projects.
9. An education program would need to be developed to support the mindset shift to seeing human waste as a resource and not a taboo. Also, continued work on educating Pacific Islanders on the benefits of composting and building soil health

and how treated human waste is safe, inexpensive, and can improve crop productivity. This will build upon past projects, including ACIAR's Improving Soil Health, Agricultural Productivity and Food Security on Atolls project, and ACIAR's Soil Management in Pacific Islands: Investigating Nutrient Cycling and Development of the Soils Portal and also DFAT's Tuvalu Food Futures project.

9. Opportunities for women continue to be developed in future Closing the Loop projects by working with female market stallholders, capacity building female waste pickers at Bouffa landfill in Vanuatu, ensuring an equal representation of female and male technical staff, and exploring private sector opportunities for the development and sale of fertilizer with female entrepreneurs. Academic opportunities for women can also be developed through ACIAR Pacific Agriculture and Southern Cross Universities scholarship schemes.

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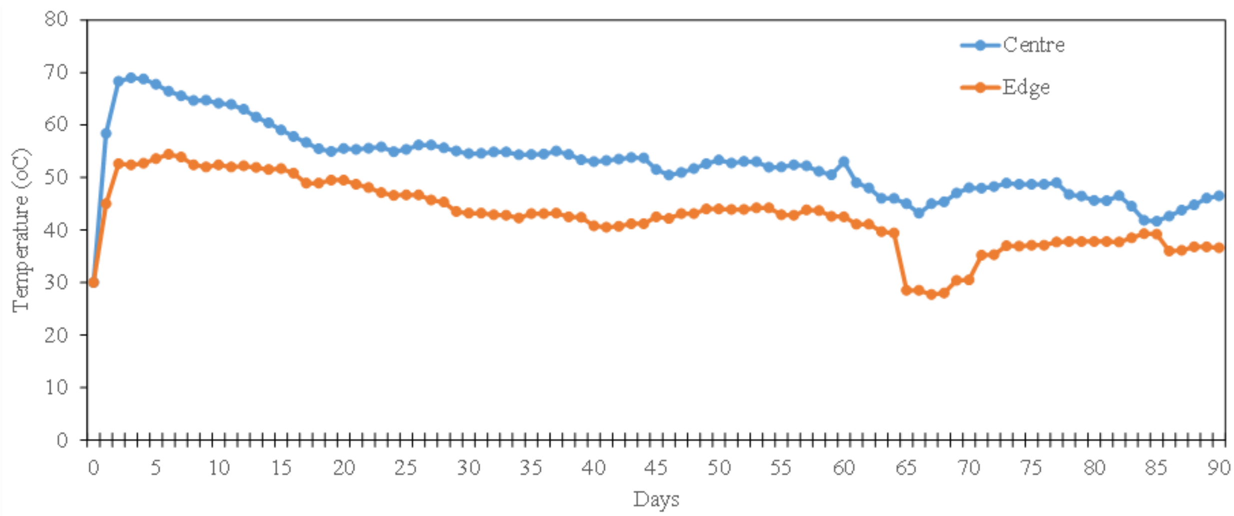
8. Appendixes

Appendix A. Temperature profiles of anaerobically co-composted (SPIC) septic tank sludge and mixed green waste.



Appendix B. Physical and chemical characterisation of wastes after various treatment processes.

	Biochar (pyrolysis)				Hydrochar (HTC)				SPIC Composted material		AS4454:2012 Mature Compost
	Septic tank sludge + green waste	Compost toilet waste + Septic tank sludge	Septic tank sludge	Compost toilet waste	Septic tank sludge + green waste	Compost toilet waste + Septic tank sludge	Septic tank sludge	Compost toilet waste	Septic tank sludge + green waste	Compost toilet waste + Septic tank sludge	
pH	7.46	9.18	7.37	10.48	5.06	5.88	5.35	5.90	6.87	6.27	*> 5*
Electrical Conductivity (dS/m)	2.49	4.79	2.68	11.30	3.72	3.82	3.24	6.13	5.33	6.03	*< 10*
Total Carbon (%)	26.0	34.2	23.8	47.3	26.5	29.9	22.6	42.7	24.48	28.72	*≥ 20*
Total Nitrogen (%)	2.62	2.63	3.21	2.29	2.33	2.28	2.88	1.84	3.43	2.82	*≥ 0.8* see note 7
Estimated Organic Matter (%)	44.2	58.1	40.5	80.4	45.1	50.8	38.4	72.6	42.11	48.82	..
Ammonium Nitrogen (mg/L N)	8.8	2.2	11.2	1.0	264.0	197.0	346.0	148.5	625.67	6.41	*< 100*
Ammonium Nitrogen (mg/kg N)	44.2	11.0	56.0	5.0	1,320.0	985.0	1,730.0	742.5	3128.33	32.05	..
Nitrate Nitrogen (mg/L N)	<LOR	0.5	<LOR	<LOR	1.5	140.0	53.5	590.0	228.00	558.00	..
Nitrate Nitrogen (mg/kg N)	<LOR	2.7	<LOR	<LOR	7.4	700.0	267.5	2,950.0	1140.00	2790.00	*≥ 10* see note 7
Phosphate Phosphorus (mg/L P)	3.9	1.7	5.2	2.0	9.5	7.1	8.1	10.9	27.31	53.27	*≤ 5* see note 7
Phosphate Phosphorus (mg/kg P)	19.6	8.5	25.8	10.0	47.6	35.5	40.3	54.3	136.54	266.33	..
Ammonium/Nitrate Ratio	na	4.1	na	na	177.8	1.4	6.5	0.3	3.22	0.01	*< 0.5*
Total Calcium (%)	3.10	4.36	2.93	5.22	2.01	3.31	2.21	3.07	2.07	3.70	..
Total Magnesium (%)	0.64	0.96	0.68	1.20	0.32	0.51	0.42	0.46	0.42	0.66	..
Total Potassium (%)	0.28	1.46	0.27	2.96	0.09	0.33	0.11	0.54	0.18	0.74	..
Total Sodium (%)	0.16	0.49	0.17	1.14	0.04	0.10	0.04	0.21	0.11	0.29	*<1 Na*
Total Sulphur (%)	0.59	0.65	0.65	0.48	0.45	0.41	0.57	0.26	0.73	0.59	..
Total Phosphorus (%)	2.17	2.43	2.62	1.81	1.49	1.88	2.13	1.26	1.43	1.59	*≤ 0.1 P* see note 10
Total Zinc (mg/kg)	936	863	1,145	835	663	661	947	551	634	520	*< 300 Zn*
Total Manganese (mg/kg)	524	556	474	589	324	405	385	367	291	414	..
Total Iron (mg/kg)	25,075	19,484	23,680	9,905	12,640	12,767	18,076	6,124	12,571	10,777	..
Total Copper (mg/kg)	619	470	853	93	469	342	656	76.3	431	236.5	*< 150 Cu*
Total Boron (mg/kg)	53	60	55	66	11.7	14.1	12.3	23.3	41	38.0	*< 100 B*
Total Silicon (mg/kg)	877	745	657	592	679	788	701	1,302	1,147	1,290	..
Total Aluminium (mg/kg)	25,584	19,368	27,550	4,047	13,807	10,480	20,701	2,792	13,433	8,509	..

Appendix B Cont.

Total Molybdenum (mg/kg)	9.33	9.20	11.56	5.04	6.36	5.67	8.60	3.63	6.37	5.08	*..*
Total Cobalt (mg/kg)	9.24	8.04	8.25	3.53	4.75	4.71	5.25	2.14	4.34	4.95	*..*
Total Selenium (mg/kg)	4.56	3.70	6.28	<1	3.91	3.47	5.83	1.22	4.04	2.63	*< 5 Se*
Total Cadmium (mg/kg)	0.6	>0.5	0.9	<0.5	1.0	0.9	1.4	<0.5	0.8	0.6	*< 1 Cd*
Total Lead (mg/kg)	50.7	47.0	61.2	36.4	39.8	36.4	54.6	25.8	35.5	40.4	*< 150 Pb*
Total Arsenic (mg/kg)	4.1	4.9	3.9	5.7	2.7	3.0	3.5	2.9	2.7	4.5	*< 20 As*
Total Chromium (mg/kg)	138.8	73.0	86.7	27.2	50.3	37.3	67.1	10.5	44.4	28.0	*< 100 Cr*
Total Nickel (mg/kg)	43.4	33.8	46.6	14.4	27.0	22.2	35.2	11.1	25.9	20.5	*< 60 Ni*
Total Mercury (mg/kg)	<0.1	<0.1	<0.1	<0.1	1.6	0.9	2.4	0.3	1.8	1.0	*< 1 Hg*
Total Silver (mg/kg)	3.1	2.7	4.2	<1	2.8	2.2	3.9	1.0	1.8	<1	*..*
Solvita Compost Maturity Index											
Solvita NH3									5.00	5.0	
Solvita CO2									6.50	7.0	
Solvita Maturity Index	NA	NA	NA	NA	NA	NA	NA	NA	6.67	7.0	*5-8*
Path test											
Salmonella spp (Absent in 25 g)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	*Absent in 25 g*
E. coli (MPN/g DW)	ND	ND	ND	ND	ND	ND	ND	ND	0- 9.2	0	*< 100 MPN/g*
Faecal Coliforms (MPN/g DW)	ND	ND	ND	ND	ND	ND	ND	ND	0-93	0	*< 1000 MPN/g*

Appendix C. Environmental Guidelines: Use and Disposal of Biosolids Products 2000 (Sourced from EPA, 2000).

TABLE 3-3

Biosolids Stabilisation Requirements

A biosolids product must meet at least one ***pathogen reduction*** *requirement* *and* *at least one* ***vector attraction reduction*** *requirement.*

Pathogen Reduction Process

Stabilisation Grade A

1. Thermally treated biosolids

a) Biosolids > 7% solids with temperature at least 50° C. The equation (1) for the time -temperature requirement is:

$$D = \frac{(131,700,000)}{(10^{0.1400t})}$$ where D = time required in days, t = temperature in degrees Celsius

This option includes pasteurisation at 70°C for 30 mins;

b) Biosolids > 7% solids. This option includes composting at 55°C for 3 consecutive days.

c) Biosolids > 7% solids that are small particles heated by contact with either warmed gases or an immiscible liquid. The temperature should be at least 50°C for at least 15 seconds using the equation above. This option includes biosolids in contact with a hot gas stream in a rotary drier or biosolids dried in a multiple-effect evaporator system.

d) Biosolids < 7% solids and less than 30 minutes contact time. Use equation 1 for contact times > 15 seconds and < 30 minutes.

e) Biosolids < 7% solids and > 30 minutes contact time at 50° C or higher use equation (2) below:

$$D = \frac{(50,070,000)}{(10^{0.1400t})}$$

This option includes thermophilic aerobic digestion.

2. High pH—high temperature process

The pH of the biosolids product is to be raised to greater than or equal to pH 12 and remain above pH 12 for 72 hours. During at least 12 hours of the 72-hour period, temperature of the biosolids product has to be greater than 52°C. After 72 hours biosolids product must be air dried to a solids content of more than 50%.

3. Biosolids from unknown processes

For biosolids where the history of processing is not known, the product will be subject to a program of testing for the parameters contained in tables 3-4 and 3-5.The testing regime must be accepted by the EPA. This option includes stockpiles of "dewatered" or dried biosolids which have been stored for a minimum of three years.

Vector Attraction Reduction Requirements

1. Mass of volatile solids in the biosolids shall be reduced by a minimum of 38%.

2. Anaerobically digested biosolids which do not meet requirement 1. above must have no more than 17% further volatile solids reduction when incubated under anaerobic conditions in a bench scale reactor for an additional 40 days at 30-37° C.

3. Aerobically digested biosolids which do not meet requirement 1. above must have no more than 15% further volatile solids reduction when incubated under aerobic conditions in a bench scale reactor for an additional 30 days at 20°C (typically used for extended aeration processes).

4. Specific oxygen uptake rate for biosolids treated by an aerobic process shall be less than 1.5 mg O_2/hour/g total solids at 20°C.

5. The pH value of the biosolids shall be raised to 12 and without the addition of further alkali shall remain at 12 or higher for two hours and then at 11.5 or higher for an additional 22 hours.

6. For biosolids which contain stabilised solids only, the proportion of dry solids shall be at least 75%.

7. For biosolids which contain unstabilised solids generated in a primary wastewater treatment process the proportion of dry solids shall be at least 90%.

8. Biosolids shall be treated in an aerobic process for at least 14 days. During that time, the temperature of the biosolids shall be >40°C and the average temperature >45° C. This option relates primarily to composted biosolids.

Appendix C. Cont.

TABLE 3-4

Initial Process Verification Standards

Parameter	Standard
Enteric viruses	< 1 PFU per 4 grams total dry solids
Helminth ova (*Ascaris* sp. and *Taenia* sp.)	< 1 per 4 grams total dry solids

PFU = plaque-forming unit

TABLE 3-5

Stabilisation Grade A Microbiological Standards

Parameter	Standard
E. coli	<100 MPN per gram (dry weight)
Faecal coliforms	<1,000 MPN per gram (dry weight)
Salmonella sp.	Not Detected / 50 grams of final product (dry weight)

MPN = most probable number.

TABLE 3-6

Classification of Biosolids Products

Biosolids Classification	Allowable Land Application Use	Minimum Quality Grades	
		Contaminant Grade	Stabilisation Grade
Unrestricted Use	i) Home lawns and gardens. ii) Public contact sites. iii) Urban landscaping. iv) Agriculture. v) Forestry. vi) Soil and site rehabilitation. vii) Landfill disposal. viii)Surface land disposal[2].	A	A
Restricted Use 1	i) Public contact sites. ii) Urban landscaping. iii) Agriculture. iv) Forestry. v) Soil and site rehabilitation. vi) Landfill disposal. vii) Surface land disposal[2].	B	A
Restricted Use 2	i) Agriculture. ii) Forestry. iii) Soil and site rehabilitation. iv) Landfill disposal. v) Surface land disposal[2].	C	B
Restricted Use 3	i) Forestry. ii) Soil and site rehabilitation. iv) Landfill disposal. iv) Surface land disposal[2]	D	B
Not Suitable For Use	i) Landfill disposal. ii) Surface land disposal[2].	E[1]	C[1]

Notes:
1. Biosolids products which are not contaminant or stabilisation graded are automatically classified Not Suitable For Use.
2. To be applied within the boundaries of sewage treatment plant site.

Appendix D. National Standards for Organic and Bio-Dynamic Produce (Source: Department of Agriculture Water and the Environment, 2016).

Appendix M Criteria to evaluate input substances for inclusion in this standard.

Evaluation criteria

- The lists of substances in the Appendices include products of established use in organic and biodynamic agriculture.

Standards

- For any products to be included in this Standard the following must be provided to allow product assessment.
  - Inputs must satisfy the principles of organic production as outlined in this Standard.
  - The input is considered necessary/essential when evaluated in the context in which the product will be used.
  -
    - This decision will be based on arguments/evidence to prove the necessity of an input and will be based on environmental safety, ecological protection, landscape and, human and animal welfare; and
    - Such an evaluation will consider the product in the context of available alternatives already in use in organic production, including management and husbandry practices; and
    - The use of an input may be restricted to specific conditions, specific regions or specific commodities.

Appendix E. A Rapid Assessment of Needs and Perceptions

This Rapid Assessment of Needs and Perceptions is a survey tool to determine the feasibility of a Closing the Loop project for key stakeholders and community members. The surveys can be done remotely or through community workshops (or ideally both).

Question
1. Name
2. Age
3. Gender
4. Education level
5. Village name
6. The village where you were born
7. Number of people in your household
8. Household construction
9. The water source for household and condition
10. Type of human waste system for your household (septic, pit loo, composting toilet)
11. How many households does this waste system service?
12. Is your septic tank ever de-sludged? How often? Is de-sludging done manually/or pump truck? How much does it cost?
13. What is done with the sludge from your septic tank or waste from composting toilet?
14. What is your primary source of off-farm income?
15. On average, how much do you make from this activity?
16. Do you receive financial support from family overseas? If so, on average, how much per year?
17. Have you taken out any loans recently? If so, from where and for what purpose?
18. Are you a member of an organisations? What is its purpose? What contributions do you make?
19. Does your household have access to customary land? If yes, how many hectares?
20. Does your household lease land? If yes, how many hectares?
21. What is the primary function of this land? (determine if they grow crops, livestock, agroforestry, trees, etc.)
22. Is this land primarily for household subsistence, formal markets of both?
23. How much of the food consumed in your home is from subsistence? (compared to store brought food)
24. Has your household ever experienced any food shortages? If so, how often, what was the cause? How did you respond?
25. Have you noticed a decrease in productivity on your land?
26. Do you purchase any fertilisers to raise productivity? If yes, describe how much? Where does it come from? How much does it cost?
27. Do you compost? What do you compost? What do you use it for?
28. What type of human waste systems have been introduced in your village? And what were the challenges?
29. Is it socially acceptable to manage human waste? What challenges would need to be overcome for it to be collected or used for agriculture?
30. Is there groundwater or coastal contamination from waste in your village? If so, where and why?
31. What is the biggest source of waste in your village? Where does it go?
32. Would you be open to having human waste from your land collected by others?
33. Would you be open to collecting the human waste from your land (i.e. emptying pit or composting toilet) and receiving a small payment for it?
34. If you could produce a safe fertiliser (compost material) from human waste products, would you use it to grow food? If not, what would it take for you to use it (i.e. information on crop benefit, safety information etc.)?
35. Would you be willing to pay for a fertiliser made from human waste?

Further considerations

Partners

What international, national, NGO, academic, and commercial partners can collaborate on the project and contribute funding, technical advice, services, scholarships and on-ground management?

Waste and treatment types

What type of waste is available, and what type of treatment system best suits the community's needs?

Limitations

What are the challenges that might interfere with the project meeting its objectives?

Opportunities

What other opportunities or problems could a Closing the Loop problem solve?