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Research Report

Resource Recovery from Livestock Waste: Cases and Business Models from the Global South

Avinandan Taron, Abinaya Sathiskumar, Javier Mateo-Sagasta, Rajdeep Singha, Zeleke Agide Dejen, Guillermo Peña Chipatecua and Rosa Ruiz Bastidas

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Acronyms and Abbreviations

ABPP	Africa Biogas Partnership Programme
AGOA	African Growth and Opportunity Act
BCR	Benefit-cost ratio
BOD	Biochemical oxygen demand
BPAHS	Biogas Programme for the Animal Husbandry Sector
CBE	Circular bioeconomy
CBG	Compressed biogas
CFA	Central Financial Assistance
CFU	Colony Forming Unit
CIISA	Centro Internacional de Inversiones S.A.
CIMNE	International Centre for Numerical Methods in Engineering
CNG	Compressed natural gas
COD	Chemical oxygen demand
CSR	Corporate social responsibility
CTCN	Climate Technology Centre & Network
D.R.C	Democratic Republic of the Congo
ESG	Environmental, Social and Governance
EU	European Union
FITs	Feed-in tariff
FPO	Farmer Producer Organization
FQBC	First Quezon Biogas Corporation
GDP	Gross domestic product
GEDA	Gujarat Energy Development Agency
GHG	Greenhouse gas
GIZ	German Development Cooperation
GSBTM	Gujarat State Biotechnology Mission
IAA	Integrated Agriculture and Aquaculture System
IDCOL	Infrastructure Development Company Limited
IFS	Integrated farming system
IIGE	Institute for Geological and Energy Research Ecuador
INIAP	National Institute of Agricultural Research Ecuador
IRESA	Integrated Renewable Energy and Sustainable Agriculture
IRR	Internal rate of return
IWMI	International Water Management Institute
KCIC	Kenya Climate Innovation Center
KCV	Kenya Climate Ventures
Kg	Kilogram
KIRIDI	Kenya Industrial Research and Development Institute
KW	Kilowatt
kWh	Kilowatt-hour

LAC	Latin American and Caribbean region
LMICs	Low- and medium-income countries
LOF	Liquid organic fertilizer
LPG	Liquefied petroleum gas
MARD	Ministry of Agriculture and Rural Development
MCA	Multicriteria assessment
MNRE	Ministry of New and Renewable Energy
MoEWRI	Ministry of Energy, Water Resources and Irrigation
MT	Metric ton
NABARD	National Bank for Agriculture and Rural Development
NBMMP	National Biogas and Manure Management Programme
NDBP	National Domestic Biogas Program
NDDB	National Dairy Development Board
NEMA	National Environmental Management Authority
NGO	Non-governmental organization
NPV	Net present value
NTS	Non-typhoidal Salmonella
O&M cost	Operation and maintenance cost
OFMB	Organic Fertilizer Manufacturers Botswana
ONGC	Oil and Natural Gas Corporation Ltd
PPA	Power purchase agreement
PROM	Phosphate rich organic manure
PSI	Private Investor Program
RBB	Agriculture Development Bank of Nepal and Rastriya Banijya Bank
RE	Renewable energy
ROI	Return on investments
RRR	Resource, Recovery and Reuse
SAGARPA	Secretariat of Agriculture, Livestock, Rural Development, Fishing, and Food
SDG	Sustainable Development Goals
SHG	Self-help group
SMEs	Small and medium-sized enterprises
SSA	Sub-Saharan Africa
TELOS	Technical, economic, legal, operational, and scheduling
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
VCA	Value chain approach

Summary

Livestock waste presents significant environmental and public health risks in low- and middle-income countries (LMICs), particularly through water pollution and the transmission of infectious diseases. Rich in nutrients (nitrogen and phosphorus), this waste can lead to eutrophication of water bodies through runoff. Additionally, livestock waste contains pathogens, including *Escherichia coli, Salmonella,* and various viruses, which contaminate surface waters posing health hazards to humans and animals.

Despite these risks, livestock waste creates opportunities for a circular bioeconomy. Conversion of waste into biogas, organic fertilizer, and aquaculture feed can mitigate environmental harms while generating socioeconomic co-benefits. However, limited awareness, infrastructure, financing mechanisms, and access to appropriate technologies impede widespread adoption in LMICs. These barriers may be overcome through targeted training at the farm level, supportive policy frameworks, and the creation of an enabling environment for investments.

A global review of 135 livestock waste resource recovery cases highlights varied approaches across LMICs. Private-sector adoption of biodigestion is particularly prominent, with regional differences in focus. In Latin America and Sub-Saharan Africa, biodigestion is primarily aimed at energy and revenue generation, while South and Southeast Asian countries prioritize aquaculture feed production and vermicomposting. Government support (like subsidies, incentives, and technical assistance) often underpins success in these regions. In some cases, these are in collaboration with the private sector.

An analysis of 26 cases identifies three generic business models: (i) **energy and biofertilizer recovery**, (ii) **soil nutrient and organic matter recovery**, and (iii) **food nutrient recovery for aquaculture**. Government-led household and community-level initiatives tend to achieve higher economic feasibility and replicability. In contrast, private enterprises tend to operate more effectively at a larger commercial scale. These models vary in complexity, scale, and profitability. Energy and feed recovery models typically ensure cost recovery through self-consumption and diversified product sales. Soil nutrient recovery models depend more on the organic fertilizer market commercialization. Energy and biofertilizer models require multi-stakeholder involvement and rely on more sophisticated technologies, often sourced externally. In comparison, soil and feed recovery models are technically simpler but face financial limitations, which can be mitigated through support from governments, NGOs, and international organizations.

The average payback period for these enterprises ranges between five to six years, with cost-benefit ratios typically between 1 and 2. To ensure sustainability and impact, enterprises must adhere to operational guidelines that ensure environmental compliance, economic viability, and regulatory alignment. Feasibility assessments are critical and should consider local institutional settings, resource availability, market conditions, and community priorities that guide strategic planning, production, finance, and risk management, promoting sustainability and effectively addressing critical environmental and public health challenges.

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Introduction

Key findings

- The livestock sector is experiencing a significant growth in developing countries with increased demand for meat and dairy products, driven by rising per capita incomes and population growth.
- However, the tremendous increase in livestock production results in the generation of millions of metric tons of waste globally which leads to significant environmental impacts such as greenhouse gas emissions, land degradation, water pollution, food safety and health concerns.
- This phenomenon has created a necessity to develop an effective livestock waste management strategy focusing on recovering resources and reducing waste disposal.
- The developing economies present significant opportunities for recovering valuable resources from livestock waste, including energy in the form of biogas, soil nutrients and feed for aquaculture which offers numerous environmental, social and economic benefits.
- Nevertheless, a lack of awareness, infrastructural barriers and technological limitations continue to pose challenges to resource recovery from livestock waste. These obstacles can be addressed through enhanced training at the farm level and the formulation of new policies at the national level. Furthermore, foreign investment is instrumental in facilitating these efforts.

Livestock waste as part of the problem and part of the solution to the global environmental crisis

The livestock sector supports food and nutrition security, livelihood promotion and poverty reduction and agricultural development. Livestock production supports the livelihoods and food and nutrition security of almost 1.3 billion people (FAO 2023)[1], supplies approximately 17% of the available food calories and contributes over 40% of the agricultural GDP globally (Robinson et al. 2015). The growth of the sector is modest in high-income countries but in the developing world is growing fast (World Bank 2022), particularly in Asia and Africa where it is among the fastest growing subsectors of agriculture.

Livestock production growth has been attributed to dietary changes with rising demand for meat and dairy products driven by increasing per capita income and population growth (FAO 2024a).

[1] https://www.fao.org/animal-production/en/

In Africa, the total meat production has increased from 12 million tons in 2002 to 22 million tons in 2021 and the total milk production has increased from 9 million tons in 2002 to 53 million tons in 2021. In Asia, while population growth in much of the continent has begun to stabilize, incomes are growing, maintaining a rising demand for high quality livestock-derived food. The total meat production of Asia has grown from 95 million tons in 2002 to 151 million tons in 2021 and the total milk production has grown from 42 million tons in 2002 to 401 million tons in 2021 (FAO 2024b). It is projected that demand for livestock derived products in Asia will continue to grow rapidly to more than 600 million metric tons per year by 2030 (OECD 2021).

Nevertheless, the growth of the sector comes with environmental concerns. The livestock industry uses significant amounts of land, water, biomass and other resources and releases a substantial quantity of undesirable substances into the environment (Sohil and Kichloo 2023). FAO (2006) points out three significant environmental impacts – greenhouse gas emissions, land degradation and water pollution. Manure management and enteric fermentation are the major sources of greenhouse gas emissions from livestock industry which contribute to 0.7% and 5% of global GHG emissions in 2019 respectively (IPCC 2022). Moreover, the increase in livestock production results in overgrazing, which can lead to deterioration of physical, chemical, biological properties of soil causing soil erosion, desertification and drought.

Livestock production also results in the global generation of millions of metric tons of waste annually (Tarafdar et al. 2021), including animal manure, feed residue, bedding materials, litter, hair, feathers and animal carcasses (Parihar et al. 2019; Shakya et al. 2022). Manure is the most important category and contains a number of potential hazards to the environment and human health. It contains nutrients such as phosphorus or nitrogen that in excess can lead to water eutrophication, algal blooms and hypoxia. It has organic matter that can deplete oxygen in waters. It has pathogens that can pose health risks and also emerging pollutants such as endocrine disruptors, antibiotics or antibiotic resistant bacteria and resistance genes (Brusseau and Artiola 2019; Mateo-Sagasta et al. 2018).

Livestock waste also has resources that, if recovered, can bring economic opportunities, restrict pollution and reduce risks related to public health. Livestock manure applied to soil helps in increasing the soil nutrient retention capacity and the physical condition by increasing the water holding capacity. Manure is a source of biofuels (such as biogas, dry manure or organic briquettes), which is increasingly gaining value to cope with increasing demand for energy, and rising fossil fuel prices. Waste management techniques like composting, vermicomposting or biodigestion are some of the practices that generate valuable resources and minimize disposal of waste and the negative impacts it brings (Sohil and Kichloo 2023).

In addition to the environmental benefits, resource recovery from livestock waste leads to other socio-economic benefits. It provides new business opportunities from the sale of resources and helps in cost recovery and cost savings during waste management. Economic benefits like improvements in the environment (regulation and provisional ecosystem services) and human health (e.g. lower medical costs) can be accrued in the long term. Social benefits include the generation of employment across the waste management and reuse value chain.

This study is focused on the identification of businesses cases[2] that recover resources from livestock waste across different countries. These cases are categorized and described in the third chapter of the report. The following sections of the present chapter elaborate more on the waste generated from the livestock sector, adverse impacts and about resource recovery and reuse from the waste management practices.

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[2] The term 'business model' used in the report follows the definition by Osterwalder and Pigneur (2010) and applied to the waste management sector by Otoo and Drechsel (2018), Rao et al. (2020). The term is defined to describe and articulate the value propositions served to the customers and the operational aspects (inputs, stakeholders, costs, revenues) of the business. These businesses can also be termed as social enterprises with different motives like profit making, cost recovery, cost savings and can be a private or a public initiative or a cooperative or jointly by public and private.

Characteristics of livestock waste

Some of the components of livestock waste, such as nutrients or organic carbon, can become resources or hazards depending on how waste is managed. It is important to understand the composition of livestock waste to appreciate the potential for resource recovery or to pose risks for the environment or human health. There are different wastes produced by the livestock sector – mostly feces and urine, wasted feeding material (food lost as it is discarded or uneaten), and soiled bedding material like straw, saw dust and wood shavings. Slaughterhouses also generate waste like animal carcasses or viscera that need to be managed. Polluted water used for washing is also generated in livestock farms and slaughterhouses.

Animal manure can be categorized based on its consistency or moisture content into liquid manure (up to 5% solids), slurry and semi-solid manure (between 5 and 25% solids) and solid manure (more than 25% solids) (Romney et al. 1994). Table 1 reports about manure production and characteristics of different animal species. These approximate figures are mainly for developed regions for semi-solid manure. Actual properties of a given manure can vary by 20% from average based on the waste management process of adding water, bedding, etc.

Table 1. Average manure production and characteristics of different animal species

Animal		Size (kg)	Manure production (kg/day)	Water (%)	BOD (kg/day)	Nutrient content		
						N (kg/day)	P_2O_5 (kg/day)	K_2O (kg/day)
Dairy cattle	Dairy cattle	68	6	88	0.09	0.023	0.005	0.018
		113	10	88	0.15	0.036	0.009	0.032
	Heifer	340	29	88	0.45	0.104	0.032	0.100
	Lactating cow	454	48	88	0.73	0.263	0.136	0.141
		635	67	88	1.02	0.372	0.191	0.218
	Dry cow	454	37	88	0.54	0.163	0.050	0.127
		635	52	88	0.77	0.227	0.091	0.181
	Veal	113	4	96	0.1	0.018	0.014	0.027
Beef cattle	Calf	204	12	92	0.26	0.064	0.045	0.050
	High forage	340	28	92	0.48	0.186	0.064	0.113
		499	42	92	0.68	0.277	0.095	0.163
	High energy	340	24	92	0.45	0.172	0.064	0.100
		499	36	92	0.68	0.245	0.095	0.145
	Cow	454	29	88	0.64	0.141	0.082	0.118
Swine	Nursery	11	1.2	89	0.04	0.009	0.005	0.005
	Grow – Finish	68	4.3	89	0.14	0.036	0.023	0.018
	Gestating	125	3.4	91	0.10	0.023	0.018	0.018
	Lactating	170	10.2	90	0.34	0.082	0.059	0.064
	Boar	159	3.3	91	0.10	0.023	0.018	0.018
Sheep	Sheep	45	1.8	75	0.05	0.018	0.009	0.018
Poultry	Layer	2	0.12	75	0.01	0.002	0.001	0.001
	Broiler	1	0.08	74	0.0	0.001	0.001	0.0005
	Turkey	9	0.41	75	0.30	0.006	0.005	0.002
	Duck	3	0.15	73	0.01	0.002	0.002	0.001
Horse		454	23	78	0.64	0.127	0.050	0.104

Source: Martin-Marroquin and Hidalgo 2014

Animal waste or manure contains high concentrations of bacterial or parasitic pathogens, which can be released during irrigation events on lands where manure has been applied and can be transported through flowing water to contaminate surface or ground water used for human supply, recreation and food production. Table 2 provides a summary of data on levels and prevalence of zoonotic pathogens measured in livestock manures obtained from different studies.

Table 2. Reported levels and prevalence (in average) of zoonotic pathogens in livestock manures

Pathogen	Cattle		Swine		Sheep		Poultry	
	Prevalence (%)	**Level** (CFU/g)	**Prevalence** (%)	**Level** (CFU/g)	**Prevalence** (%)	**Level** (CFU/g)	**Prevalence** (%)	**Level** (CFU/g)
E. coli O157	16	1.2×10^3	0-22	3.9×10^3	20.8	7.8×10^2	NA	NA
Salmonella spp.	0-13	2.1×10^3	7.9-100	6.0×10^2	8.3	7.1×10^2	17.9	2.2×10^2
Listeria spp.	24.4	1.1×10^3	16-19.8	3.1×10^3	29.2	2.0×10^2	19.4	8.3×10^2
Campylobacter spp.	31.1	3.2×10^2	13.5-73.9	3.1×10^2	20.8	3.9×10^2	19.4	2.6×10^2
C. parvum	1-100	1.9×10^1	13.5	5.8×10^1	29.2	1.0×10^1	NA	NA

Source: Manyi-Loh et al. 2016, CAST 2008, Hutchison et al. 2005

Notes: Data are not available for prevalence and levels of *E. coli* and *C. parvum* in poultry manure

Liquid waste generated from livestock farms has a complex composition (Vaishnav et al. 2023). Livestock wastewater, which is produced by livestock farms, is typically composed of manure and feed residue, urine, washing wastewater and wastewater generated during the life and production process of workers (Hu et al. 2020). Parihar et al. (2019) estimated that water required for washing animals such as cattle, buffalo, horse and pigs vary between 25–70 liters/animal/day.

For cattle and buffalo the requirement is 45–70 liters/animal/day, for horse 36 liters/animal/day and for pigs 25–28 liters/animal/day. The average volume per urination event reported by Selbie et al. (2015) is 2.1 L for dairy cattle and 1.2 L for beef cattle. Reece (2015) suggests the urine volume for different livestock as follows: (i) cow – 17–45 (mL/kg body weight per day); (ii) goat and sheep – 10–40 (mL/kg body weight per day); (iii) horse – 3–18 (mL/kg body weight per day); and (iv) pigs – 5–30 (mL/kg body weight per day).

Table 3 provides the composition of dairy wastewater, swine wastewater and poultry wastewater as reviewed by Vaishnav et al. (2023), which comprehensively highlights the data collected from different sources that analyze different countries globally including Scotland, India, Brazil and Uzbekistan.

Table 3. Typical composition and characteristics of livestock wastewater

Parameters	Dairy wastewater	Swine wastewater	Poultry wastewater	Reference
pH	4.7–11	6.4–6.8	7.1–7.3	Daneshvar et al. 2019; Oliveira et al. 2020; Artukmetov et al. 2021
COD (mg/L)	10,000–50,000	14,532–15,965	480–850	Daneshvar et al. 2019; Oliveira et al. 2020; Artukmetov et al. 2021
BOD (mg/L)	40,000–48,000	5,806–8,451	0.39–0.74	Daneshvar et al. 2019; Oliveira et al. 2020; Artukmetov et al. 2021
Total Solids (mg/L)	–	7,631–10,657	430–720	Oliveira et al. 2020; Artukmetov et al. 2021
TSS (mg/L)	2.8	1,349–5,075	–	Chokshi et al. 2016; Oliveira et al. 2020
TN (mg/L)	14–830	–	56.5–70.7	Daneshvar et al. 2019; Artukmetov et al. 2021
TP (mg/L)	9–280	329–476	0.2–0.6	Daneshvar et al. 2019; Oliveira et al. 2020; Artukmetov et al. 2021
Total K (mg/L)	–	–	11.1–23.7	Arukmetov et al. 2021
Total Ca (mg/L)	–	–	50–69.2	Arukmetov et al. 2021
Bicarbonates (mg/L)	–	–	326–434	Arukmetov et al. 2021
Salinity (g/L)	1.33	–	–	Chokshi et al. 2016
Conductivity (ds/m)	1.87	9.88–10.99	–	Chokshi et al. 2016; Oliveira et al. 2020
Wastewater production (per year)	4–11 million tons	1,300 tons per farm (China)	–	Ahmad et al. 2019; Nagarajan et al. 2019

Source: Adapted from Vaishnav et al. (2023)

Another important source of livestock waste is from abattoirs and slaughterhouses. By-products that are in solid form and not further processed accumulate as solid waste. It includes the remaining material that is in non-edible form, including bones, hoofs, horns, integuments, skin, ligaments, and cartilage tendons, the contents of the gastrointestinal tract and internal body organs (Nauman et al. 2023). Liquid waste from slaughterhouses includes urine, oils, wastewater, fats, sludge, used oil and grease. Table 4 provides the details of waste generation from slaughterhouses.

Table 4. Waste generation (percentage of the total waste) from animal slaughtering processes

Type of waste	Waste generation (% of the total waste)
Chicken slaughtering process	
Skin and feathers	57.37
Legs	14.8
Intestines	20.35
Other waste	< 1
Lambs/cattle slaughtering process	
Manure	12
Ruminal contents	80
Blood	5
Other waste	3

Source: Adapted from Nauman et al. 2023, Adhikari et al. 2018; Mozhiarasi and Natarajan 2022; Jayathilakan et al. 2012; Meeker and Hamilton 2006

The livestock sector is also a major source of emerging pollutants such as veterinary pharmaceuticals, animal hormones or pesticides, which can concentrate in livestock excreta. In recent years, emerging pollutants have been a significant concern for both developed and developing countries due to their potential adverse impacts on human health and environment. Animal antibiotics are a case in point. The use of antibiotics (such as tetracycline, rifampicin and vancomycin) for therapeutics and as growth promoters has increased in the livestock sector to ensure animal health and high production. The excess use and misuse of antibiotics has led to the emergence of antibiotic-resistant bacteria. In the coming decades many common antibiotics could stop curing both minor and fatal infections due to antibiotic resistance (Zandaryaa and Mateo-Sagasta 2018; Cook and Wright 2022).

Adverse impacts of livestock waste on ecosystems

Livestock waste, especially animal manure, is a growing source for a wide range of environmental impacts. It adversely affects the ecosystem by contamination of drinking water, eutrophication of surface water, particulate pollution, antimicrobial resistance, loss of soil fertility leading to loss of farm productivity, increased food safety risks and diseases, thereby highly contributing to water, soil and air Table 5 shows the adverse impacts of livestock wastes on environment, food safety and health.

Table 5. Examples of negative impacts of livestock wastes on environment, food safety and human health

Impacts on	Examples
Water	• Contamination of drinking water with nitrates, pathogens, hormones and pesticides. • Eutrophication of surface water leading to toxicity and loss of biodiversity.
Soil	• Over application of manure on soil causes accumulation of heavy metals which affect the growth of plants. • Calcium and magnesium present in the manure alters soil pH causing soil acidification. • Intensive use of antibiotics in the livestock industry releases antibiotic resistant microorganisms on to the soil which can potentially enter food chain.
Air	• Emission of ammonia from livestock waste causes particulate pollution and acid rain. • Emission of powerful greenhouse gases such as nitrous oxide and ammonia, leading to climate change.
Food safety and health	• Zoonotic pathogens from the manure can be released on the croplands and drinking water which can result in food and water borne illnesses in human and animals. • Release of toxic gases into the air can lead to respiratory diseases in humans.

Source: Authors' creation

Soil and water pollution

Manure is generally used as organic fertilizer for crops. When livestock manure is applied to the fields or croplands, nutrients (primarily nitrogen and phosphorus), organic matter, nutrients, pathogens, heavy metals and emerging pollutants may be released from the soil to groundwater and surface waters through leaching or runoff. These pollutants pose a significant challenge in water quality in many developing countries (USEPA 2023; Mateo-Sagasta et al. 2018). Table 6 reports the estimated N and P loss to freshwater ecosystem from agricultural lands applied with manure in selected regions.

Table 6. Estimated N and P loss to freshwater courses from manured agricultural lands (in thousand tons) in selected regions

Region	N from animal manure		N losses to freshwater courses	P from animal manure		P losses to freshwater courses
	Crop	Pasture		Crop	Pasture	
South America	1052.0	1051.0	526.0	576.8	59.0	76.3
West Africa	140.0	148.0	72.0	71.9	26.0	11.7
East Africa	148.0	78.0	57.0	76.0	24.0	12.0
South Africa	79.0	3085.0	791.0	40.6	50.0	10.9
North Africa	36.0	34.0	18.0	18.5	10.0	3.4
South Asia	3816.0	425.0	1060.0	1920.9	10.0	231.7
Southeast Asia	941.0	477.0	355.0	512.0	15.0	63.2

Source: Adapted from FAO 2006; Sakadevan and Nguyen 2017; Mekonnen and Hoekstra 2017

Organic matter from livestock can also pollute water. Organic matter may come from animal manure, uneaten animal feed and effluents from animal processing industries. When organic matter is decomposed in water it can consume dissolved oxygen leading to hypoxic conditions. The accumulation of nutrients in water bodies can lead to eutrophication and accelerate the growth of plants and algae. When these plants and algae die off, they consume dissolved oxygen in water bodies, which can negatively affect the aquatic ecosystems and biodiversity.

Livestock waste also contains zoonotic pathogens and parasites which can survive for days or weeks in animal waste which, if applied onto land, can contaminate water resources via runoff. The overuse and misuse of veterinary medicines such as antibiotics and artificial growth hormones in livestock farms causes the release of medicine residues into soil, groundwater and surface water through leakage from animal waste storage tanks and with the use of animal manure as fertilizer (Mateo-Sagasta et al. 2018).

Excess application of manure on soil can lead to accumulation of heavy metals such as copper or zinc, which causes health issues in animals that rely on gazing and crop feeding and can lead to crop or pasture productivity loss (Ogbuewu et al. 2012; Elena et al. 2015).

Greenhouse gas emissions and air pollution

Livestock waste is one of the key factors contributing to air pollution due to the release of ammonia and major greenhouse gases such as carbon dioxide, nitrous oxide or methane. Manure management is one of the major sources of greenhouse gas emissions from livestock industry which contribute to 0.7% global GHG emissions in 2019 (IPCC 2022).

The livestock sector is an important emitter of nitrous oxide, which remains in the atmosphere for about 150 years and has a higher potential for global warming and depletion of ozone layer than carbon dioxide. Over 64% of the total ammonia emission is from livestock waste, which is a major contributor to acid rain and acidification of the ecosystem. Livestock manure is a significant source of methane emission which has a 23-fold greater potential for global warming compared to carbon dioxide. In the last 15 years, methane emissions have increased by 50% from cattle waste and 37% from pigs. Exposure to these gases can cause airway diseases such as asthma, bronchitis, mucous membrane irritation and chronic obstructive pulmonary disease. Generation and accumulation of odorous volatile compounds including ammonia and hydrogen sulfide from fresh animal manure, when exceeding the exposure limit (Park et al. 2020) can cause acute poisoning and respiratory issues for farm workers and animals (Elena et al. 2015; Dopelt et al. 2019). Organic aerosols along with endotoxins and irritants released from swine waste can lead to respiratory illness among farm workers and people around the farm.

Food safety and health concerns

Health risks represent the likelihood that harm will actually occur and are the combination of hazard and exposure. There may be multiple hazards in livestock waste including pathogens, endocrine disruptors, and other toxins that can pollute air, water, soil and food when livestock waste is not safely managed. Poorly treated manure is frequently used as a soil amendment and organic fertilizer in agriculture and constitutes a key mechanism for zoonotic pathogens transmission into the food chain. Humans can be exposed to livestock waste hazards through inhalation of polluted air, dermal absorption or ingestion of polluted food, water or even accidental soil ingestion. Occupational risks by farmers or waste managers directly exposed to waste can also occur. Excess use of various antibiotics and drugs as preventive medicine in livestock farms also contributes to antimicrobial resistance, which is a major health concern.

Table 7. Potential pathogens and illness caused among humans

Organism	Types of Organism	Illness caused in humans	Routes of infections
Escherichia coli	Bacteria	Bloody diarrhea, severe anemia, kidney failure or even death	Direct contact with feces and through water contaminated with feces
Campylobacter	Bacteria	Diarrhea and systemic illness	Through fecal contaminated water or food
Salmonella	Bacteria	Diarrhea, fever and abdominal cramp	Through fecal contaminated water or food
Leptospira	Bacteria	Leptospirosis with symptoms such as high fever, kidney or liver failure, meningitis or even death	Directly through animal urine or soil containing animal urine contacting breaks in the eyes, skin, mouth or nose
Listeria	Bacteria	Listeriosis characterized by fever, chills, headache, upset stomach and vomiting, most likely to affect pregnant women and unborn babies	Manure contaminated food
Shigella	Bacteria	Bloody diarrhea	Direct contact with feces
Cryptosporidium	Parasite	Watery diarrhea, may be life-threatening to peoples with poor immune system	Soil, water, food, or surfaces contaminated with feces of infected animal
Hepatitis A	Virus	Viral liver disease causing mild to severe illness, flu-like symptom, diarrhea, fever, discomfort, decreased appetite, tiredness	Fecal, or by indirect contact through contaminated food and water

Rotavirus	Virus	Gastroenteritis. Symptoms include severe diarrhea, vomiting, fever, and dehydration	Contamination of hands, objects, food, or water with infected feces
Nipah virus	Virus	Severe illness in both animals and humans. Asymptomatic infection to acute respiratory syndrome and fatal encephalitis	Eating food contaminated by feces of infected animal
Avian influenza	Virus	Conjunctivitis, fever, cough, sore throat, muscle aches, pneumonia	Contact with contaminated droppings

Source: Fong 2017; Murcia et al. 2009

Delahoy et al. (2018) conducted a review to identify pathogens that may substantially contribute to the global burden of disease in humans through their spread in animal feces in the domestic environment in low- and middle-income countries. Of the 65 potentially pathogenic organisms considered, four pathogens that are also hosted by livestock were considered of highest concern based on a substantial burden of disease for which transmission in animal feces is potentially important: *Campylobacter*, non-typhoidal salmonella (NTS), Cryptosporidium and *Toxoplasma gondii*. Combined, these four pathogens (together with Lassa virus, which is spread through the feces of rats indigenous to Sub-Saharan Africa) cause close to one million deaths annually. More than half of these deaths are attributed to invasive NTS. Additionally, these examples and those shown in Table 7, *Escherichia coli* 0157:H7, *Clostridium botulinum*, *Giardia lambia* and microsporidia are frequently cited as zoonotic pathogens with relevant health effects.

High levels of nitrous oxide (25–100 ppm) in the environment causes respiratory illness (Brender 2020). Excessive nitrate in water can cause cancer (Said et al. 2022) or blue baby syndrome in humans. Because it concentrates residues of antimicrobials, antimicrobial resistance genes and resistant pathogens, manure application on farms can further spread antimicrobial resistance in the environment (Zalewska et al. 2021; Checcucci et al. 2020). Use of contaminated water in irrigation and production of vegetables can add to the problem and be a major health concern for humans.

Resource recovery from livestock wastes in developing countries

It has been estimated that approximately one billion smallholder farmers in developing countries depend on livestock contributing to over 40% of total agricultural GDP (IFAD 2015). However, they often lack support, resources and technologies to mitigate the negative impacts of livestock waste on the environment.

Livestock waste management through circular economy can improve food security and control soil, water and air pollution leading to the development of healthy, efficient and resilient communities. It aims to provide revenue streams and generate millions of job opportunities for smallholder farmers in developing countries, thereby reducing poverty. Nutrients and energy recovery from livestock waste can address several Sustainable Development Goals including food security (SDG 2), good health and wellbeing (SDG 3), the provision of clean water and sanitation (SDG 6), the provision of affordable and clean energy (SDG 7), responsible consumption and production (SDG 12) and reduction of GHG emissions and climate change (SDG 13) (UN 2021).

Energy production from animal manure

Many developing countries are dependent on external sources of fossil fuels for energy production, which makes them vulnerable to global shortages or raising prices. Fossil fuels are also a primary source of greenhouse gas emissions leading to climate change.

Bioenergy production from endogenous renewable resources is considered as part of the solution for mitigating the external dependence, and the negative effects of fossil fuels. Biomass recovered from livestock wastes, especially from animal manure, can be used to produce biogas, which can offer remarkable opportunities in developing countries, particularly where intensive livestock farming is practiced. Another potential output of biogas digesters is slurry, which is more stable than raw manure, and can be used as biofertilizer to improve physical and chemical fertility of soils. The average biogas production potential of animal manure varies depending on different species of livestock as follows: 0.25 Nm^3/kg of biogas production from buffaloes and cattle; 0.31 Nm^3/kg of dry matter from chickens and ducks; 0.37 Nm^3/kg of dry matter from pigs and 0.35 Nm^3/kg of matter from sheep (Surendra et al. 2014). However, the volume of manure required must be both consistent and sufficient to generate an adequate amount of methane. In certain instances, it may be necessary to supplement the feedstock with additional carbon sources to achieve the desired yield of biogas. Table 8 reports the animal waste availability and biogas production potential of developing regions.

The recovery, distribution and use of biogas can create substantial employment opportunities in rural areas. Full recovery of the carbon embedded in the manure produced globally can mitigate 418 million metric tons CO_2 equivalent of greenhouse gas emissions in the developing regions (Surendra et al. 2014).

A survey conducted in Bangladesh suggests that only 4.8% of animal manure is used to produce biogas and slurry through anaerobic digestion while the rest is kept as solid storage and burned as fuel. The findings of the survey suggest that the poor manure management is due to lack of awareness, less trading infrastructures and unavailability of equipment and machinery. According to the study, broadening current efforts of Bangladesh government on promoting the installation of biodigesters, enhancing the existing farm-level training and developing new policies have been identified as an opportunity for improvement in manure management (Huque et al. 2017). A steady increase is observed in the installation of biodigesters in small-scale farms of Costa Rica due to incoming foreign investment in renewable energy, urbanization and public health and environmental concerns (Jenet et al. 2018).

Dry manure and bio briquettes produced from manure can also be used as an alternative source of fuel for replacing firewood. Dry manure is used as heating and cooking fuel in rural areas. On the other hand, producing bio briquettes from animal manure serves as an affordable and sustainable solution for meeting the increasing energy demand. For instance, cow dung with a bulk density of 2.85 g/cm^3 can produce bio briquettes with gross energy of 3,490 Kcal/kg (Sathiyabarathi et al. 2022). Moreover, solid fuel pellets produced from cow and swine manure had a gross energy of 4,084.33 Kcal/kg and 2,986.37 Kcal/kg, respectively (Wzorek et al. 2021; Budsaereechai et al. 2016).

Table 8. Animal waste availability and biogas production potential

Region	**Animal waste availability (million dry metric tons/year)**	**Biogas potential (million Nm^3/year)**
Africa	215	54,671
South America	233	56,200
South Asia	289	73,700
Southeast Asia	95	26,338

Source: Surendra et al. 2014

Nutrients recovery and composting

The global market demand for fertilizer has increased over the last decades reaching 194.4 Mt in 2018. The continuous application of chemical fertilizers in the soil can result in groundwater pollution and loss of soil fertility. Therefore, several countries are moving towards a green revolution which mandates the use of biofertilizers. Biofertilizers produced from the biomass of animal manure not only improve soil fertility but also promote sustainable development in agricultural ecosystems. Proper nutrient recovery technique from livestock manure is required to prevent oversaturation of nutrient supply which in the long term can affect the environment in several ways as mentioned earlier (Dadrasnia et al. 2021). Composting facilitates the production of pathogen-free solid manure, which has gained much attention in developing countries due to its simplicity in production and low capital cost. In recent years, developing countries such as Myanmar and Thailand have shown a relatively high production of compost using solid manure. Installation of biodigesters for energy production and composting are widely promoted in large scale farms of India, Vietnam, Brazil and Sri Lanka (Huong et al. 2020).

Challenges in promoting livestock waste management

Lack of knowledge on nutrient and economic value of livestock manure is a major drawback in promoting resource recovery among smallholder farmers in developing countries. The illiteracy of farmers in rural areas is a major concern in accessing available information related to livestock management and pollution control. Providing training on proper manure management practices for farmers with the development of policies involving key stakeholders including the ministries of agriculture, water and energy can be an opportunity for improvement.

Scope and objectives of the study

This study identifies and analyzes resource recovery business cases utilizing livestock waste across several low- and medium-income countries. Chapter 2 provides the details of the identified cases. The subsequent chapter develops business models based on the different cases categorized as per the resources used or products derived, global availability, institutional arrangements or motivations.

This chapter discusses strengths and weaknesses of business models. The scalability of these business models is further adjudged based on the enabling environment of promoting such business. The enabling environment for entrepreneurs investing in livestock waste for safe management practices in different countries is presented in Chapter 4.

An overview of business cases for safe resource recovery from livestock waste in the Global South

Key findings

- Although the development of resource recovery initiatives remains in its infancy across the Global South, this study identified a number of cases that have successfully operated for over five years from Latin America and the Caribbean, Sub-Saharan Africa, South Asia and East Asia and Pacific regions between 2015-2022.
- Biodigestion remains the most significant valorization technique employed for the recovery of energy in the form of biogas and soil nutrients as bio slurry across all four regions. Additionally, notable instances of soil nutrient recovery through composting and food nutrient recovery though direct application of manure on aquaculture ponds were prominently observed in cases from South Asia and Sub-Saharan Africa.
- The majority of the observed cases are private businesses operating with an aim of cost recovery through self-processing of waste or generating profits through the treatment of externally supplied waste.
- Government departments and agencies play a crucial role in promoting resource recovery in the Global South by providing substantial financial support. Meanwhile, technical assistance is predominantly supplied by the private sector, with a remarkable number of cases receiving additional guidance from international organizations focused on capacity building.

As discussed in the previous chapter, resource recovery from livestock waste can prevent environmental pollution and generate valuable economic resources at once. There are multiple examples all over the world where valuable resources, such as biogas, nutrients or organic matter, have been recovered safely from livestock waste and used for beneficial purposes such as energy generation or agriculture or aquaculture production.

This chapter summarizes the characteristics of 135 resource recovery cases identified for safe utilization of livestock waste across different countries. These characteristics include the geographical location, age of the business case, type of waste generated, type of treatment used, resources recovered, financial objective of the business cases, primary stakeholders involved, along with the analysis on the economics of the resource recovery businesses.

This chapter is based on data analysis of global practices obtained from the following sources: (i) books, articles, databases, documents and documentaries related to safe livestock waste management and resource recovery; and (ii) an online survey[3] circulated among academics, researchers, practitioners and professionals managing and working in the livestock sector.

Analysis of the identified business cases

Geographic distribution of the identified cases

We collected data from 135 cases from the Global South. 22% of the cases are from Latin America and the Caribbean (LAC), particularly from Mexico, Argentina, Colombia, Peru and Brazil. South Asia is represented by cases from Bangladesh, India and Nepal, collectively constituting 30% of the total cases. About 12% of the cases are from Southeast Asia including Cambodia, Indonesia, Laos, the Philippines and Vietnam. Thirty-five percent of the cases are from Sub-Saharan Africa (SSA) including Botswana, Burkina Faso, Ethiopia, Ghana, Ivory Coast, Kenya, Mali, Rwanda, South Africa, Tanzania, Uganda and Zambia. Figure 1 shows a geographical distribution of the 135 cases, classified by the different products recovered from livestock waste.

[3] https://docs.google.com/forms/d/1FaRxtBpNHroCrf7zLobclqEOrKITFHFePONau4pFcmM/edit?ts=643eaf33

Figure 1. Types of products recovered from the analyzed resource recovery cases in different regions

Source: Authors' creation

Age of business

The number of years of operation of a resource recovery case is a key indicator of success, because non feasible cases tend to run out of business with time. 74% of the cases have been reported with a successful operation for more than five years, whereas only 5% of cases were identified to be at a nascent stage, operating for less than a year (Figure 2). Most successful resource recovery business cases were observed to be private organizations targeting primarily on energy recovery through biodigestion, especially for profit and cost recovery.

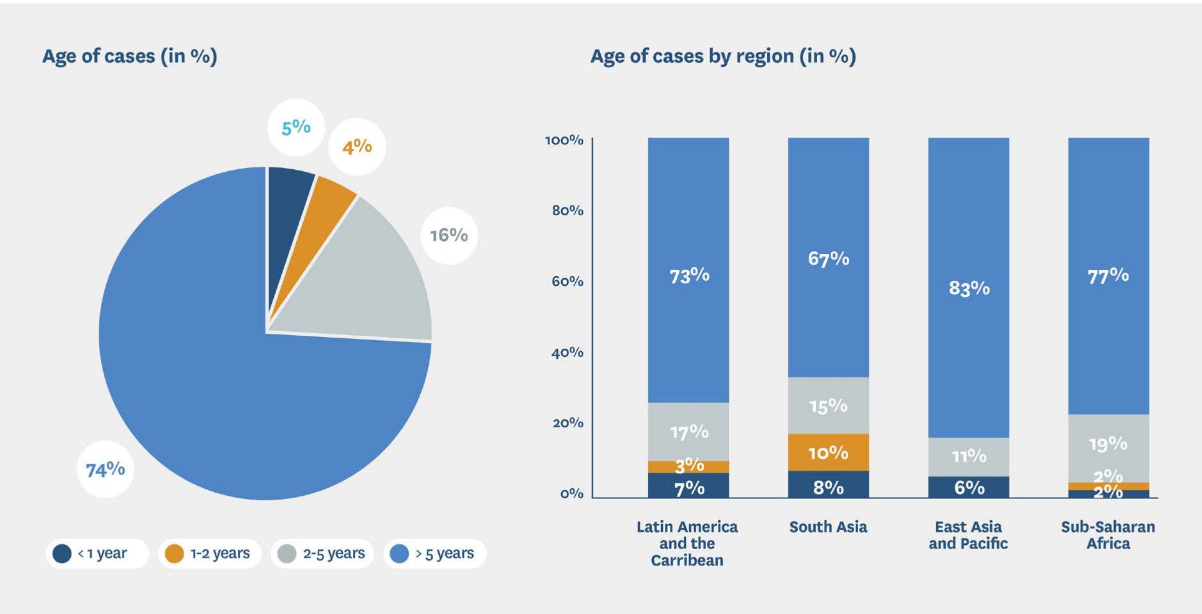

Figure 2. Age of different cases and distribution across regions

Source: Authors' calculation

Typology of wastes used for resource recovery

When effectively managed and processed, livestock waste can be turned into valuable resources, contributing to sustainable agricultural practices and environmental conservation. The data collected shows following livestock wastes being used for resource recovery across different countries:

Livestock waste: Livestock manure, including waste from animals like cows, is rich in nutrients like nitrogen and phosphorus. It can be processed into organic fertilizers for crop cultivation. Thirty-six percent of the cases use manure from livestock.

Poultry waste: Poultry waste originating primarily from chicken constitutes 9% of the total cases observed.

Pig waste: 7% of the cases use pig waste (primarily fecal matter) for resource recovery.

Slaughterhouse waste: By-products from the slaughter process, such as blood, bones and offal, can be processed into animal feed, organic fertilizers or bioenergy. There are eight cases of slaughterhouse waste, making up 6% of the total cases.

Combination of different wastes: Some resource recovery systems involve the combination of various organic wastes, including crop residues, industrial by-products, and animal waste, to create a synergy for resource recovery. The combination of different waste types represents a significant portion, with 47 cases contributing to 35% of the total cases.

The types of waste used by the analyzed resource recovery cases in different regions are shown in Figure 3. A higher percentage of cases (65%) is identified for use of manure from livestock farms as primary raw material for resource recovery in India of South Asia. The use of a combination of organic derivatives of wastes from other sources along with the livestock waste is prominent among cases identified from Kenya of Sub-Saharan Africa and Colombia of Latin America and the Caribbean region contributing to 60% and 37.5% of the total cases, respectively.

The data indicates that apart from using farm waste, the utilization of slaughterhouse waste is restricted to cases from LAC and Africa, especially in Mexico, Kenya, Burkina Faso and Colombia. Bangladesh of South Asia reported most cases in use of poultry waste while cases for use of pig waste from pig farms are comparatively higher in countries of LAC and East Asia such as Brazil and Vietnam.

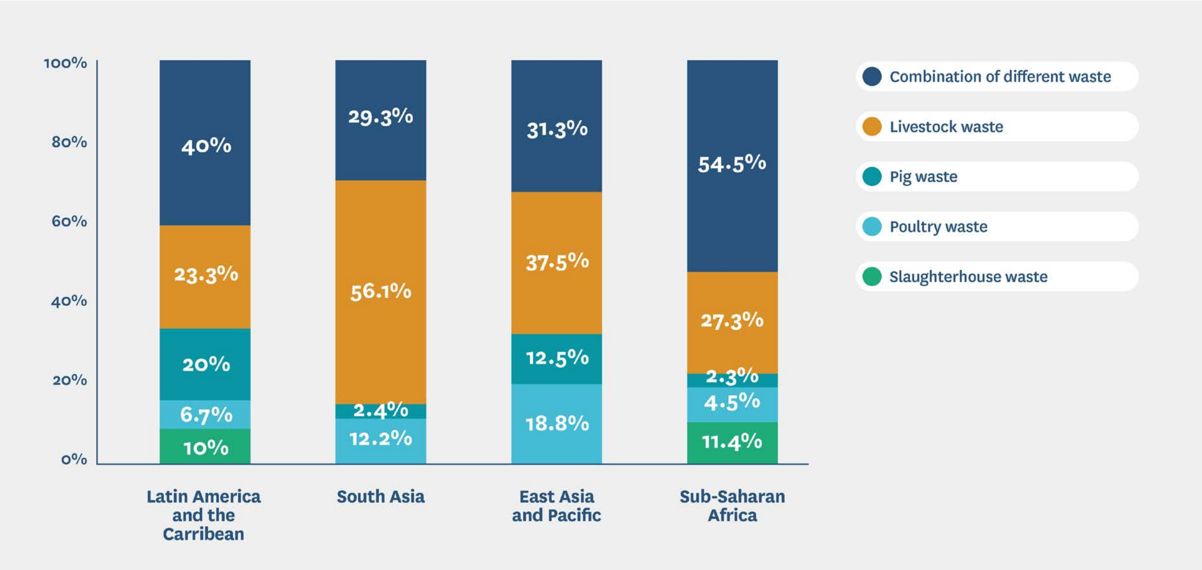

Figure 3. Types of wastes used in the analyzed resource recovery cases in different regions

Source: Authors' creation

Waste treatment processes

Waste treatment methods play a crucial role in managing and mitigating the environmental impact of various types of waste. The choice of treatment method depends on the nature of the waste, environmental considerations, regulatory requirements and the desired outcomes. Some of the common waste treatment methods are:

Composting: Composting is a natural and environmentally friendly method for decomposing livestock waste. It reduces methane generation (a potent greenhouse gas) compared to anaerobic decomposition. There are different techniques used for composting that are identified in the global literature: (i) simple composting (in form of piles/windrows, in-vessel, crib-composting), (ii) aerated/aerobic composting, and (iii) vermicomposting. About 35% of cases found in different countries cited composting as a method to derive soil conditioner.

Aerobic composting: Aerobic composting involves the controlled and slow decomposition of organic waste with the help of oxygen. The fermenting cycle is long with a low decomposition rate (Qian et al. 2016). This method helps reduce the volume of waste, improves soil structure and promotes sustainable agriculture. About 13% of the global cases (related to composting) stated aerobic composting as a means of treatment.

Vermicomposting: Vermicomposting involves using worms to decompose organic waste. It accelerates the composting process and produces nutrient-rich vermicompost. This method is valuable for small-scale waste management, requiring less space and producing a high-quality soil conditioner. About 53% of the composting cases were represented by vermicomposting methods.

Biodigestion: Biodigestion, particularly anaerobic digestion, is the most widely used valorization technique (Samoraj et al. 2022). It produces biogas, a renewable energy source, and a nutrient-rich digestate that can be used as fertilizer. This method contributes to waste reduction, energy recovery and sustainable agriculture. Both the liquid and solid fractions of digestate are high in nitrogen, making them a valuable source for plants (Czekała 2022). A review by Shi et al. (2018) focused on nutrient recovery from the digestate mentioning different possible technologies like ammonia stripping, chemical precipitation, thermal hydrolysis, ion exchange adsorption, and pressure-driven and non-pressure membrane technologies. The study shows that nutrient recovery from digestate is facing practical challenges especially in small farms, since farmers are reluctant to increase the cost of treating animal manure and direct land-spreading is their highest priority. The review of the global cases confirmed that biodigestion is most prominent with 50% of cases, and 5% of cases recovering and reusing both biogas and digestate as soil ameliorants.

Along with composting and biodigestion, cases of no treatment and direct application to ponds (for aquaculture), farmlands or sundried briquette making has also been reported in about 11% cases. Using livestock waste for recovering feed for aquaculture are mostly observed in South Asian countries (India and Bangladesh) which comprises the majority of the “no treatment” categorization.

Biodigestion is considered as the primary waste treatment technique among the cases from LAC (80%), South Asia (43.9%), SSA (36.2%) and East Asia and Pacific (33.3%) (Figure 4). Mexico and Colombia provided the highest number of cases observed for the utilization of the biodigestion technique in Latin America. The technique is widely used in India (among Asian countries) and Ethiopia (among SSA). From the study, it was evident that vermicomposting is the second most prevalent waste treatment process. India and Bangladesh reported five cases each for vermicomposting contributing to 50% and 19.2% of total cases, respectively, while Kenya and Uganda of Sub-Saharan Africa have identified with three cases each contributing to 30% and 42.9% of total cases, respectively.

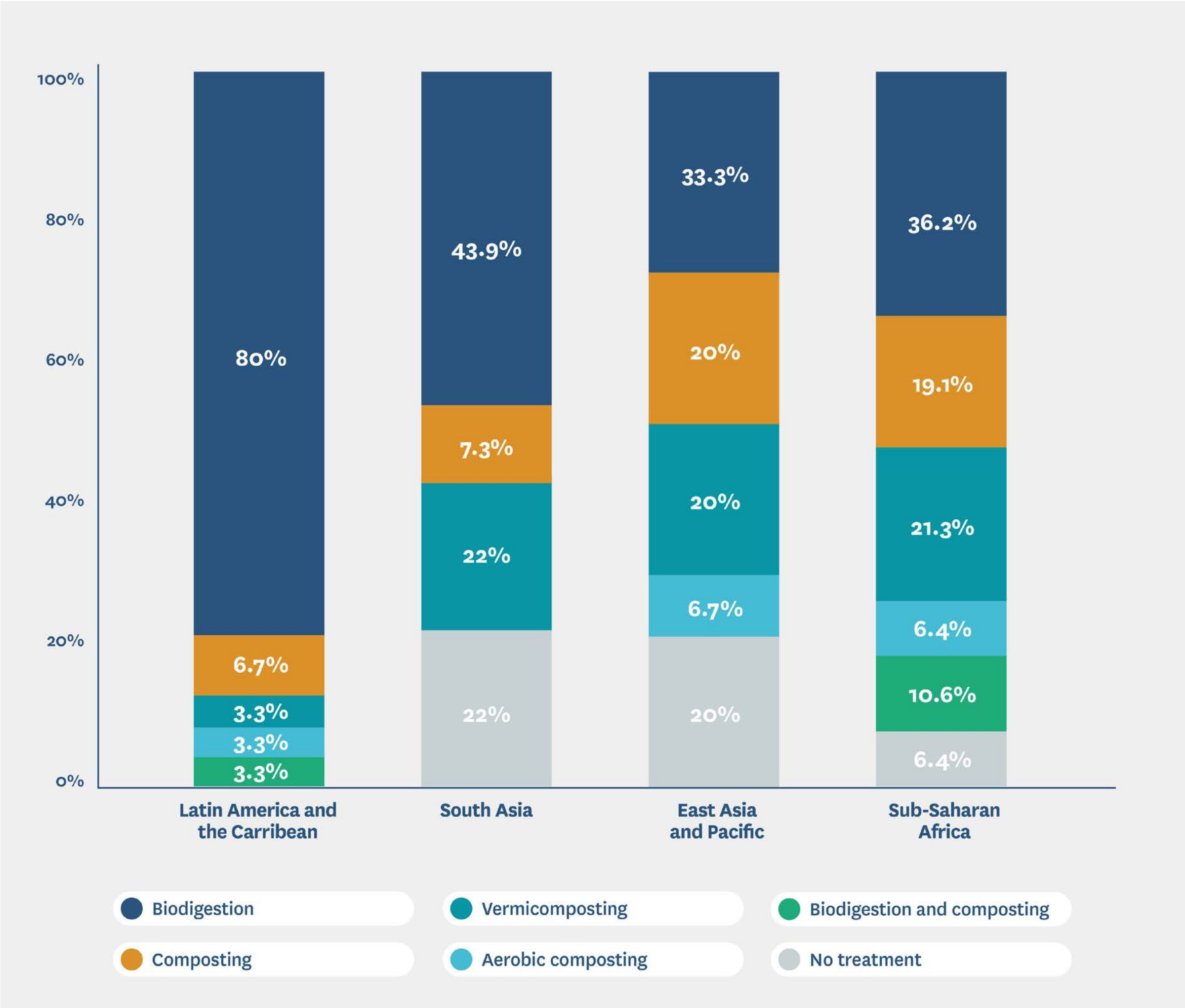

Figure 4. Waste treatment methods used by the analyzed resource recovery cases across different regions

Source: Authors' creation

Typology of products recovered

The recovery of valuable products from waste treatment processes is a fundamental aspect of sustainable waste management. As reported earlier, biodigestion is the predominant treatment process, which recovers energy and the digestate derived acts as soil conditioner. Analysis of the global data provides several insights about the trends in the recovered products across the different regions (Figure 5).

About 34% of cases from the global survey showed energy and use of digestate as the main products recovered followed by systems where energy is the sole product recovered and reused (about 28%).

Business cases for energy and organic matter (digestate) recovery were observed mainly in Mexico, Columbia and Brazil of LAC region, India and Nepal in South Asia and Ethiopia and South Africa in SSA. Sole recovery of energy is more noticeable than deriving soil organics in cases from Southeast Asia, especially in Vietnam.

About 25% of cases indicated the use of livestock manure for soil conditioning/organics. SSA countries shows a higher representation of such cases present in Uganda and Kenya. About 10% of the global cases (mainly in Asian countries) mentioned about use of livestock waste for fish feed through integrated farming.

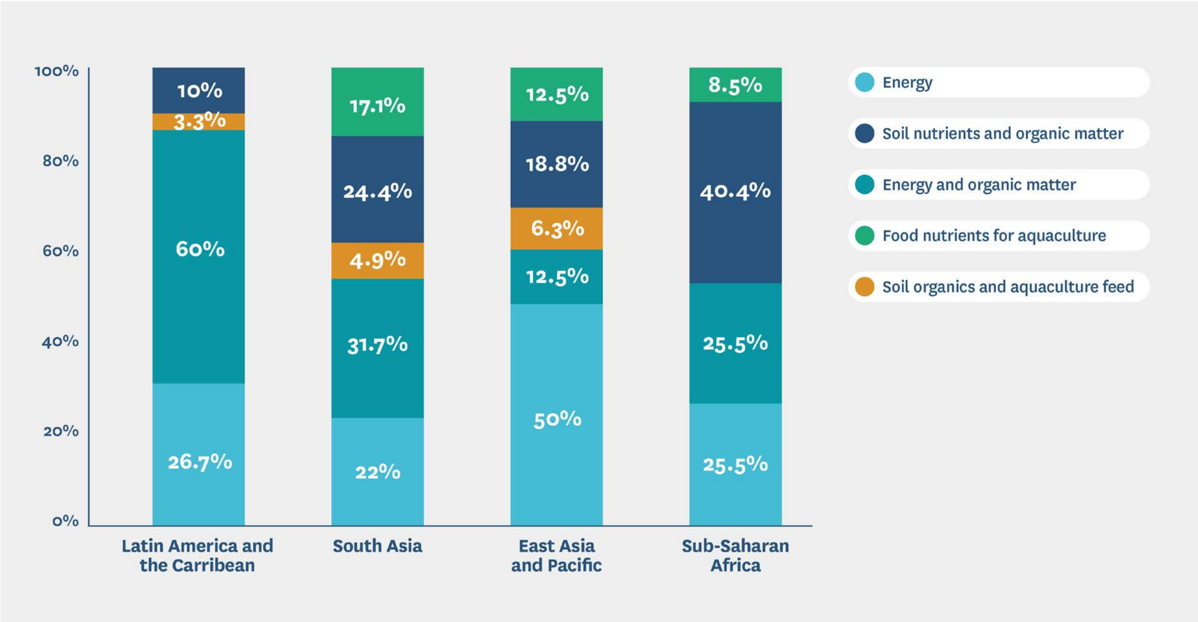

Figure 5. Various recovery products across selected regions

Source: Authors' creation

Organizational forms and financial objectives of the businesses

The organizational form and financial objectives associated with resource recovery initiatives are critical catalysts in driving economic viability and success of these businesses. These objectives encapsulate a diverse range of aims, each contributing to the overarching goal of aligning economic interests with environmental stewardship. Analysis of the global cases shows that 70% of cases are private businesses while 13% are public entities (including those controlled by local governments), and about 5% are public-private partnerships. Cooperatives and farmer organizations leading such organizations is limited to 8%. While 3% of the cases are initiated by the non-for-profit organizations, fewer than 2% of the cases have been established by universities (Figure 6).

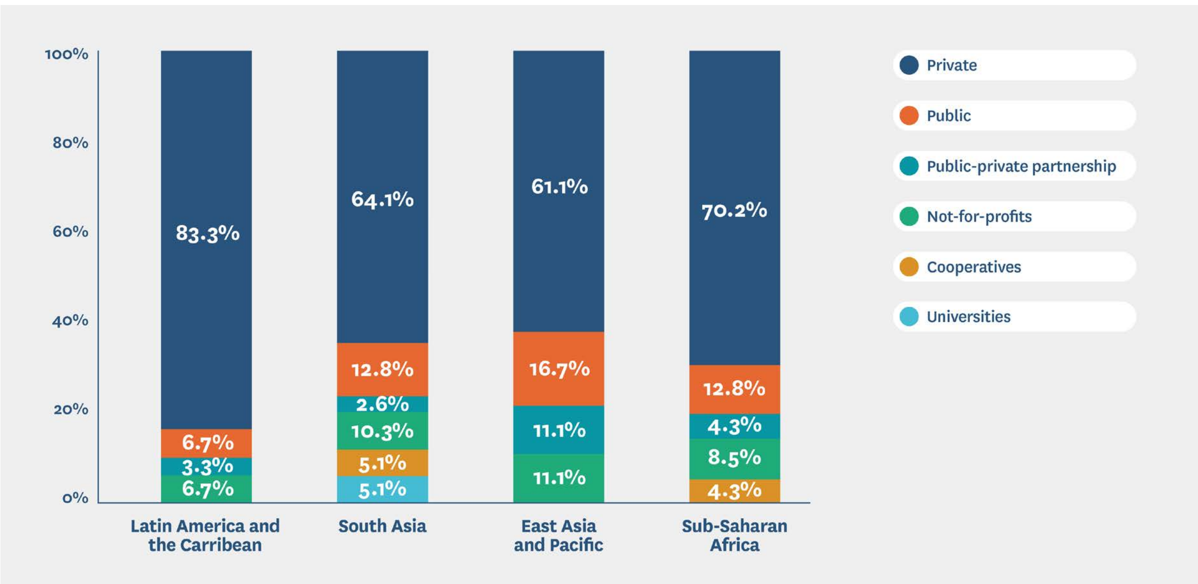

Figure 6. Organizational forms and financial objectives of the resource recovery businesses across selected regions

Source: Authors' creation

A predominant financial goal revolves around cost recovery (26.8%) in cases from South Asia with eight identified cases in India which is followed by Bangladesh with two identified cases. This entails efforts to recoup expenditures related to waste treatment and resource recovery. In most of the cases of Sub-Saharan Africa, financial objectives extend beyond mere cost recovery, encompassing the dual aim of recouping expenses and generating profits (25.5%), especially in countries namely, Kenya and South Africa with 50% and 66.7% of total cases, respectively. A cumulative financial objective involving both cost recovery and addressing regular energy demands was predominant in Mexico of Latin America with four identified cases (out of nine cases). A distinct focus on financial sustainability and profitability emerges in cases from LAC (53.3%) and SSA (25.5%). Especially, Colombia of LAC (six out of eight cases) and Uganda of SSA (three out of seven cases) are leading their regional peers in the financial objective of gaining profit. A financial objective rooted in social enterprise principles was observed to be prevalent among cases from South Asian countries such India and Bangladesh. This underscores a concerted effort to balance financial goals with a social and environmental impact commitment.

Supplier and consumer

In the intricate landscape of waste management, understanding the origins of waste is pivotal for devising effective strategies and sustainable practices. The following breakdown sheds light on the diverse sources of waste, considering whether it is externally supplied or self-generated.

Self-supply, where the entity generates its waste internally, is predominant among cases from all four regions (74.6% of total cases). The cases indicate that the waste is a by-product of the entity's operations or activities. This self-supplied waste offers an opportunity for the entity to exercise greater control over waste generation, fostering potential avenues for waste reduction and sustainable resource management.

However, most countries of Sub-Saharan Africa such as Kenya, Burkina Faso, South Africa and Uganda, the majority of the countries of Latin America such as Colombia, Brazil and Chile, and South Asian countries such as India and Bangladesh were identified with cases of external supply of waste such as from the municipality.

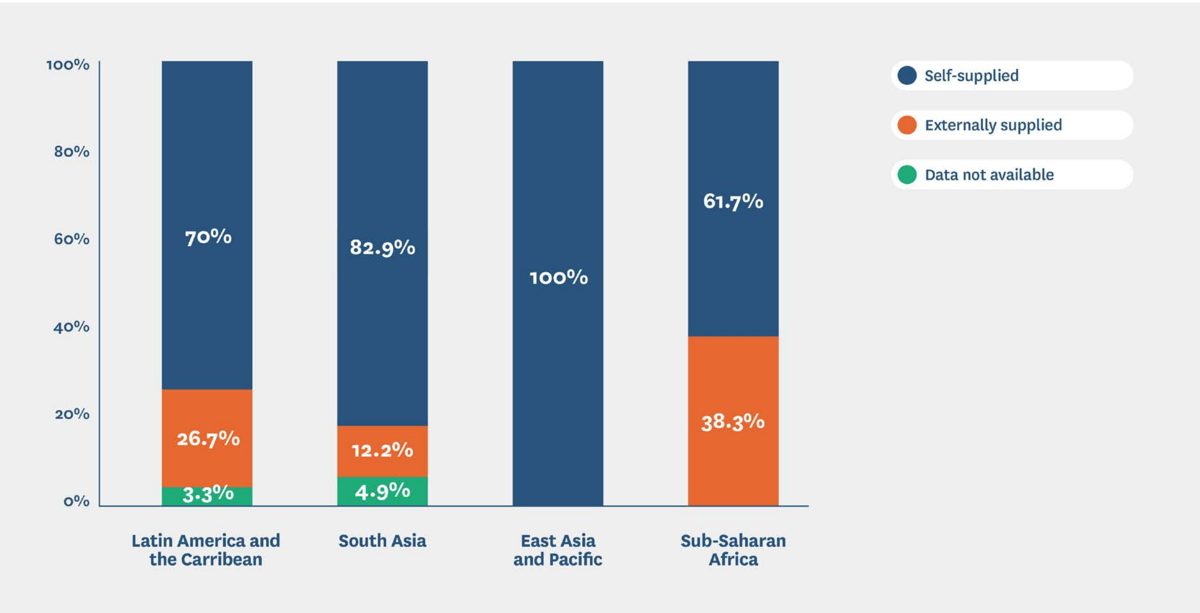

Figure 7. Livestock waste suppliers for resource recovery across selected regions

Source: Authors' creation

This signifies that a portion of the waste originates from sources beyond the immediate control or ownership of the entity. Including externally supplied waste introduces complexities in waste management strategies, necessitating collaboration and coordination with external suppliers (Figure 7).

The prevalence of self-supplied waste emphasizes the importance of internal processes and practices in waste management. Entities producing waste internally have the potential to implement tailored solutions to minimize waste generation and enhance resource recovery.

Understanding the diverse array of customers involved in waste management is essential for tailoring effective strategies that address the specific needs and challenges of different sectors. This breakdown provides insights into the distribution of customers engaged in waste management practices, highlighting the varied stakeholders contributing to responsible waste handling.

The predominant category involves self-consumption where the entities directly consume the product recovered from their waste, contributing to more than 50% of total cases (Figure 8). Few cases of South Africa, Tanzania and Uganda were identified where the utilization of resources recovery approach is localized within the community, with a primary focus on households. This community-centric approach reflects the active involvement of residents in conscientious resource recovery practices. Chile and Colombia of LAC, Nepal of South Asia, Indonesia of East Asia and Pacific, Botswana, Mali, Rwanda and Uganda of SSA were identified with cases where the farmers emerge as the central figures in waste management, emphasizing the crucial role played by agricultural communities in fostering sustainable waste practices. There were also few cases identified where both the community and farmers play a role as consumers in Brazil of LAC, India and Bangladesh of South Asia, Vietnam of East Asia and Pacific, Kenya, Ghana and Burkina Faso of SSA.

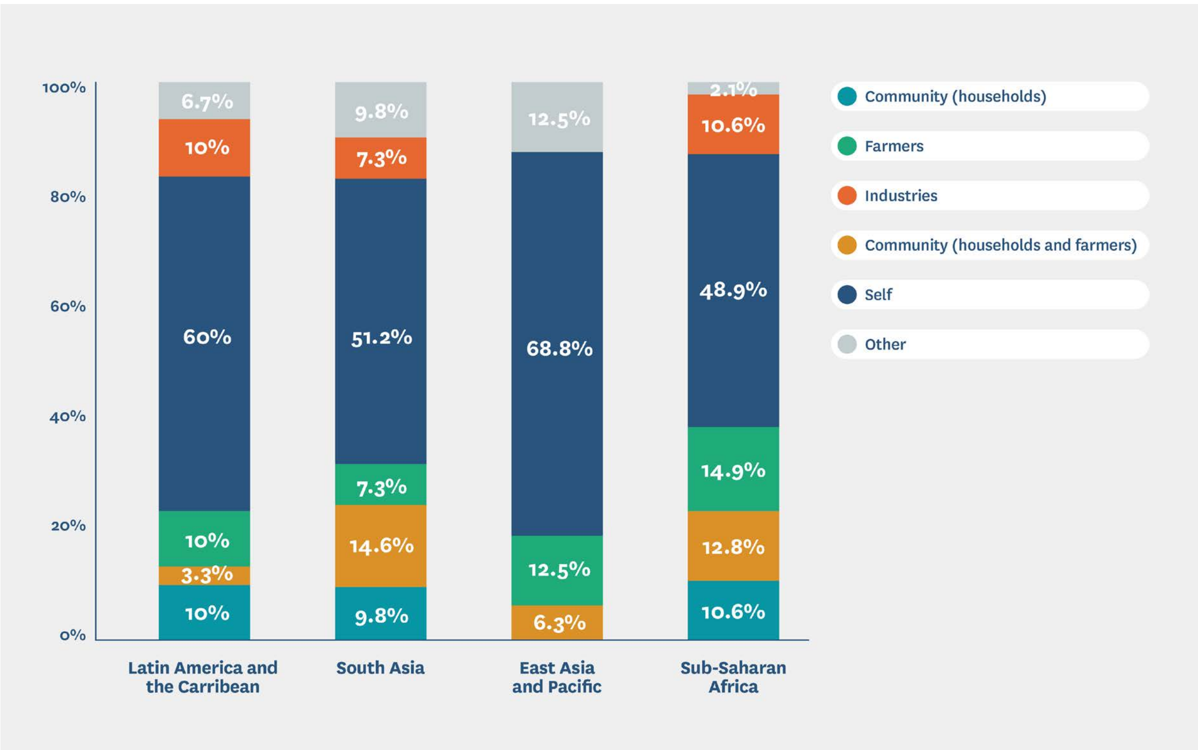

Figure 8. Consumers of recovery products across selected regions

Source: Authors' creation

Financial and technological partners

Government agencies or departments, international organizations, donor agencies and private companies play a crucial role in providing financial and technical support for functioning of resource recovery and reuse systems from livestock waste across different regions. For instance, the Punjab Development Agency, a state-owned agency of India has signed an agreement with a natural gas company named GAIL (India) Limited to set up 10 compress biogas projects using animal manure with an investment of USD 71 million.[4]

From the study, 24% and 34% of data were obtained for financial and technical partners supporting resource recovery businesses from livestock waste, respectively, across South Asian, East Asia, Sub-Saharan African and Latin American regions. The majority of the cases (48%) were funded by government agencies or departments such as Ministry of New and Renewable Energy of India, Regional Government of San Martin, etc. (Figure 9). About 27% of cases were operating through funds from private organizations, corporate social responsibility projects, loans from private banks or self-financed, while the rest of the cases were funded by international organizations and NGOs such as the Asian Development Bank and Netherlands Development Organization, etc.

As for technical partners, more than 50% of cases were obtaining technical support from private organizations such as Afrisol Energy Limited, EnviTec Biogas AG, etc. It was evident that majority of the funds (more than 75% of cases) from government departments or private organizations were primarily allocated to biogas production which is a crucial factor in attracting more private companies to invest in biodigestion technology across the regions.

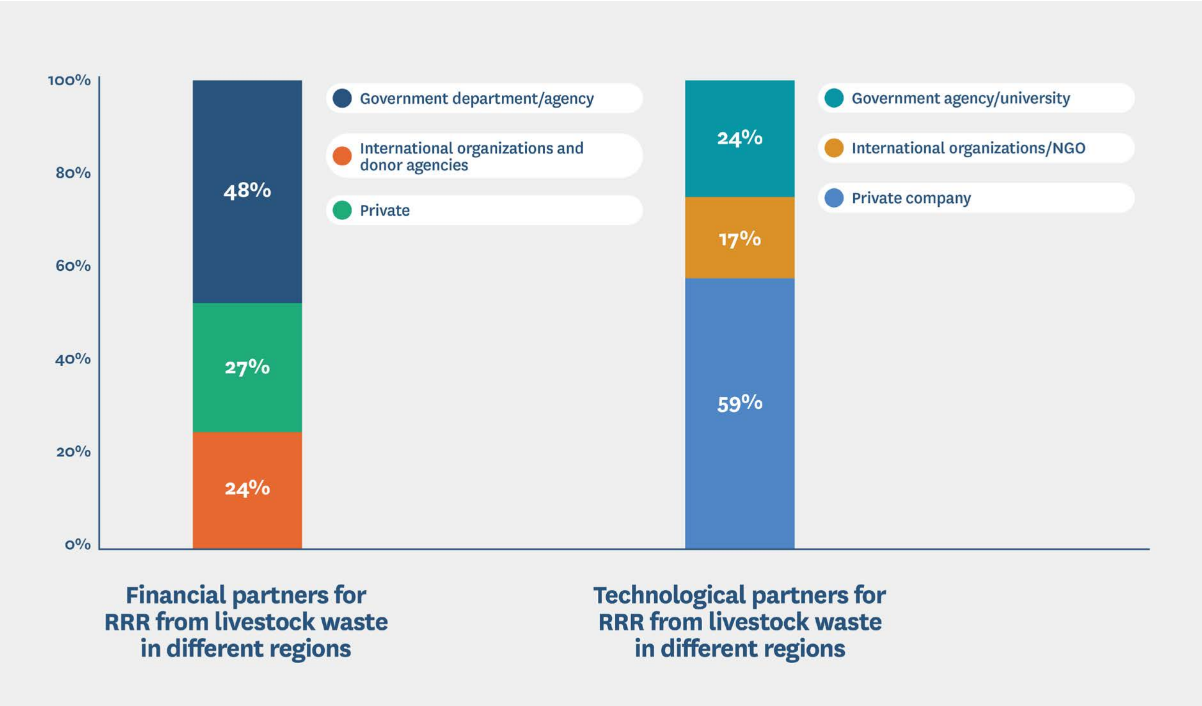

Figure 9. Financial and technological partners for resource recovery from livestock waste in different regions

Source: Authors' creation

[4] https://www.bioenergy-news.com/news/punjab-to-set-up-10-cbg-projects/

Economics of the resource recovery businesses

This section evaluates the financial viability and economics of resource recovery businesses that use various livestock waste treatment processes. The financial analysis includes the interpretation of total capital (or initial) investment, annual operation and maintenance cost and annual revenue generation through recovery of value-added products. Table 9 provides a summary of data obtained from the online survey on total capital (USD), operation and maintenance (O&M) costs and annual revenue of several resource recovery business cases from livestock waste which are analyzed based on the quantity of livestock waste and treatment processes. Small-, medium- and large-scale business cases were taken into account for a regional comparison. However, it should be noted that standardization of data cannot be performed considering the variations in the quantity of waste used in different resource recovery business cases. To validate the findings of the global survey, a literature survey was conducted on economic and financial feasibility of resource recovery from livestock waste across different regions. The findings provided from the global survey correlate with secondary data obtained from different studies. For example, study conducted in India (Jagtap and Dalvi 2021) estimates the total capital and O&M cost of biogas production through biodigestion technique using combination of animal waste as USD 22,000 and USD 7,000 which validates the findings of this report for biodigestion in South Asia. Similarly, Ashfaq et al. (2017) shows that annual revenue generated from vermicomposting of cow dung in Bangladesh varies from USD 110 to 460 which corresponds to the data obtained from the survey for vermicomposting in cases from South Asia. In SSA such equivalence is also observed in studies like Meyer et al. (2021), which estimated the initial investment cost for biogas production from cattle manure through the biodigestion technique as USD 940, and Galgani et al. (2014) on anaerobic digestion and composting in Ghana, which shows total capital for initiating biodigestion and composting of animal manure is USD 161,200. However, data obtained (from the survey) for Latin American region on total capital, O&M cost and annual revenue of biodigestion technique varies with the data obtained from the study conducted by Montoro et al. (2017). The study reports the total capital, O&M cost and annual revenue as USD 887,300, USD 46,400 and USD 350,700, respectively, which is much greater than the values obtained from the survey.

The total capital (or initial) investment includes the cost of technology development, equipment and machinery, acquisition of land, on-site infrastructure, and market research, whereas the O&M costs for running a business unit includes the wages/salaries of staff, transportation, utilities (water and electricity bills) and other costs required for maintenance. The resource recovery sector, in general, is of particular interest as the initial cost and operation costs of technology and processes are low compared to their benefits. As for resource recovery from livestock waste, the cost effectiveness and the ability to generate high annual revenue varies according to the region where the case is operating, and the complexity of livestock waste treatment technologies found across various scales of the resource recovery sector within the region.

According to Table 9, the estimated total capital investment for conducting biodigestion treatment for livestock waste on small to medium scale is higher in South Asian cases, while cases from other regions such as LAC and SSA required a higher total capital investment for carrying out the treatment technique on a large-scale. Besides initial investment, the operation and maintenance cost for performing biodigestion treatment for livestock waste was also higher in cases from SSA. However, higher annual revenue is generated from resource recovery products recovered through biodigestion of livestock waste in cases from LAC to that of SSA.

As for vermicomposting, a lower capital investment is required by cases identified from SSA compared to LAC where the operation and maintenance cost is lower. It was also observed that the annual revenue generated through vermicomposting of livestock waste in Southeast Asian cases is significantly higher compared to cases from South Asia.

Table 9. Total capital, O&M costs and annual revenue of the resource recovery businesses from livestock waste across selected regions

Region	Quantity of waste	Treatment process	Total capital in thousand USD	Annual O&M costs in thousand USD	Annual revenue in thousand USD	Payback period in years (Benefit-cost ratio)**	References
Latin America	10–108.26 ton/day	Biodigestion	2.2–36.9	0.7	44.8	2–5.7 (2.55)	Online survey
	33–150 m³/day	Biodigestion	1.3–50.6	0.4	16.4		Guares et al. 2021
	1150 tons/day	Vermicomposting	4.9	5.6	2.2	2.7 (1.48)	Reynoso-Lobo et al. 2018
South Asia	3.6–36 m³/day	Biodigestion	11.7–30.6	1.5–4.2	8.6	1–6.5 (1.79)	Garkoti and Thengane 2024
	20 tons/day	Vermicomposting	12.2	8.2	20.4	5.1 (1.95)	Thirunavukkarasu at al. 2022
	0.6 tons/day	Vermicomposting	28.5	6.9	45.3		Beg et al. 2024
	0.3 tons/day	Integrated Farming system (No treatment)	1.3	9.9	49.3	1.6 (1.49)	Banerjee and Barat 2016
Sub-Saharan Africa	0.25–98.42 tons/day	Biodigestion	1.6–80.0	2.0–9.6	5.9–25.0	2.38–6 (1.00)	Online survey
	40–60 m³/day	Vermicomposting	30.0	15.0	74.9	1.78 (3.60)	Geyo 2024
	0.3–175.19 tons/day	Biodigestion and composting	15.0–20.0	3.3	5.0–13.3	3–10 (1.25)	Online survey
	4.92 tons/day	Aerobic composting	#5.8	3.0	6.1	5 (1.48)	Online survey
	0.005 tons/day	Integrated Farming system (No treatment)	3.4	22.3	51.7	1.0 (1.99)	Mulokozia et al. 2021
East Asia and Pacific	0.04 tons/day	Vermicomposting	#41.7	#3.7	26.4	1.8 (1.95)	Online survey

Source: Authors' creation

Note: Total capital, O&M costs, and Revenue are unit costs of waste handled

Estimated using the costs and revenues of treatment technology for processing other organic wastes – Niwagaba et al. 2018; Pandyaswargo and Premakumara 2014

**Generalized and estimated payback periods and cost benefit ratio are given due to existing data limitations.

Conclusion

The present chapter presents an analysis of the 135 cases obtained from different literature survey and online survey canvassed to different academics, practitioners, networks working on livestock waste management. The analysis of global review indicates that 74% of the resource recovery cases have reported a successful operation for more than five years. These business cases utilize different livestock wastes as well as combination of livestock and other organic fractions to recover products like energy, soil nutrients and fish feed. For example, businesses use manure from livestock (36%), poultry waste (9%), pig waste (7%), slaughterhouse waste (6%), and combination of different waste (35%) for resource recovery. Different forms of composting (like aerobic composting, vermicomposting, traditional box and pile composting), and biodigestion are prevalent (around 36% and 53%, respectively), there exist cases that use natural treatment by direct use of the livestock waste as fish feed or obtaining soil nutrients. Since biodigestion is a prominent recovery technique, most cases reported energy and soil organics as the main product utilized with regional variations. Most cases in LAC, showed energy recovery and soil organics (from digestate) are the main recovered products. In contrast, cases from Asian and African countries have lesser representation of such recovered products. In Southeast Asian cases, sole recovery of energy is more noticeable than deriving soil organics. In SSA, a greater number of cases use of livestock for composting and recovering soil conditioners. Cases using livestock waste for fish feed are observed in Asia with few cases reported in Africa.

The review shows that most cases are privately owned, with 48% of cases reflecting that financial help has been obtained from governmental sources, while other private players were technical supporters. The data reveals that about 50% of private businesses runs with a profit motive, while 37% is motivated by cost recovery model. About 13% mentioned that they are social enterprises without elaborating on the financial motivation. The study also provides the unit cost of capital cost, O&M and revenue for different treatment processes, and these data were triangulated with the secondary literature. The next chapter complements the economic findings and provides an elaborate study on the business operational aspects.

Business models for resource recovery from livestock waste based on case studies from the Global South

Key findings

- Based on their value propositions, business cases were categorized into three primary business models: energy and biofertilizer recovery; soil nutrient and organic matter recovery; and food nutrient recovery for aquaculture. These business models exhibit significant diversity in terms of operational landscape, performance levels, regulatory approaches, and potential for replicability, contingent upon the underlying business cases.

- The engagement of stakeholders is comparatively less in the food nutrient recovery business since it is more farm-specific and requires fewer technicalities and skilled labor. In contrast, the stakeholder engagement increases with recovery of soil nutrients to biogas and biofertilizer recovery requiring an additional layer of participation of stakeholders.

- The financial analysis reveals that the energy and biofertilizer recovery model achieves cost recovery through self-consumption of end products and the sale of surplus to local markets. However, the soil nutrient and organic matter recovery model generates profits solely through the commercialization of end products, whereas the food nutrient recovery model emphasizes recouping expenditures through effective waste recycling and efficient utilization of available resources.

- The payback period of these models varies between 5–6 years with a cost-benefit ratio between 1–2 for most of these businesses.

- Government-initiated households (in Southeast Asia) and community-based energy recovery projects (in South Asia) from animal farms exhibit higher economic feasibility and replicability. Privately operated models are suitable for large-scale operations, enabling the commercialization of products to increase revenue. These types of businesses are observed in Latin America and depend on financial support from the government and technical support from other private players.

- Models related to soil-nutrient recovery (in Sub-Saharan Africa) and food nutrient recovery for aquaculture (in South Asia) also show higher replicability in low- and medium-income countries due to less technical and skill requirements.

Selection of featured cases for deeper analysis and business modelling

Based on the cases obtained through online surveys and literature, some cases were selected for deep characterization to understand the underlying business model involved in the cases. To ensure representative, diverse and relevant cases, the selection of the cases for classifying the business models was based on the following criteria:

1. Availability of data for the business cases — either from the online source or collaborator helping in data collection and in some cases, data provided by the organizations on request.

2. Business diversity — while selecting the cases, it was ensured that regional representation of cases representing waste management technologies, institutions, and adaption and scaling was ensured, given the business and cultural context of the priority countries, India and Ethiopia.

3. Replicability in low- and middle-income countries at scale — selection of business cases with a high representation of cases related to readily available technologies that are cost-efficient and easily replicable given the country context (institutions and regulations).

The business cases selected for the deep characterization were assessed based on a template that included the following aspects:

1. Context and background — describing the initiation of the business, location, and reuse activities.

2. Business and institutional environment — brief description of the market condition explaining the need for the product catered by the business; critical institutional framework (regulations) that incentivize or constrain the business's operations.

3. Business model — using a business canvas explain the customers, value proposition, stakeholders, resources and key operations required, costs and revenue to the business, environmental and health costs and benefits.

4. Value chain and stakeholders related to the livestock waste management process.

5. Technology used for the recovery process; quantity and quality of waste; quantity and quality of product recovered.

6. Financial outlook — CAPEX, OPEX, revenue flow, net profit and payback of the business

7. Business model assessment — parameters used for assessment include scalability and replicability, profitability and cost recovery, social impact, environmental and health impact, innovation; SWOT analysis of the business.

Relating value propositions with business models for resource recovery

From the deep characterization and analysis of selected business cases, a generic resource recovery business model utilizing livestock waste (i.e. animal manure and abattoir waste) was developed. Different value prepositions of the resource recovery business model are presented in the business canvas (Figure 10), which includes:

- **Value proposition 1 (VP1):** Reuse through Energy and Soil Nutrient Recovery

- **Value proposition 2 (VP2):** Reuse through Soil Nutrient Recovery

- **Value proposition 3 (VP3):** Reuse through Recovery of feed for Aquaculture

The other elements of the business canvas can be interpreted with respect to the value proposition and are specified with different color codes. According to the value proposition offered, the revenue streams and customer segments will vary. For example, energy and biofertilizer recovery businesses generate revenue through a) self-consumption of biogas, thereby reducing grid electricity costs; b) sale of surplus biogas to the local community, households, small energy-intensive businesses as well as national power grids; and c) sale of biofertilizer to the local farmers and local markets.

Soil nutrient recovery businesses generate revenue through a) self-consumption of liquid organic fertilizer, and b) sale of granulated organic fertilizers to the local farmers, farmer producer organizations, fertilizer distributors as well as export markets.

As for fish-feed recovery, the businesses generate revenue through integration of livestock farming with aquaculture which involves sale of fish and livestock products to the local farmers and markets.

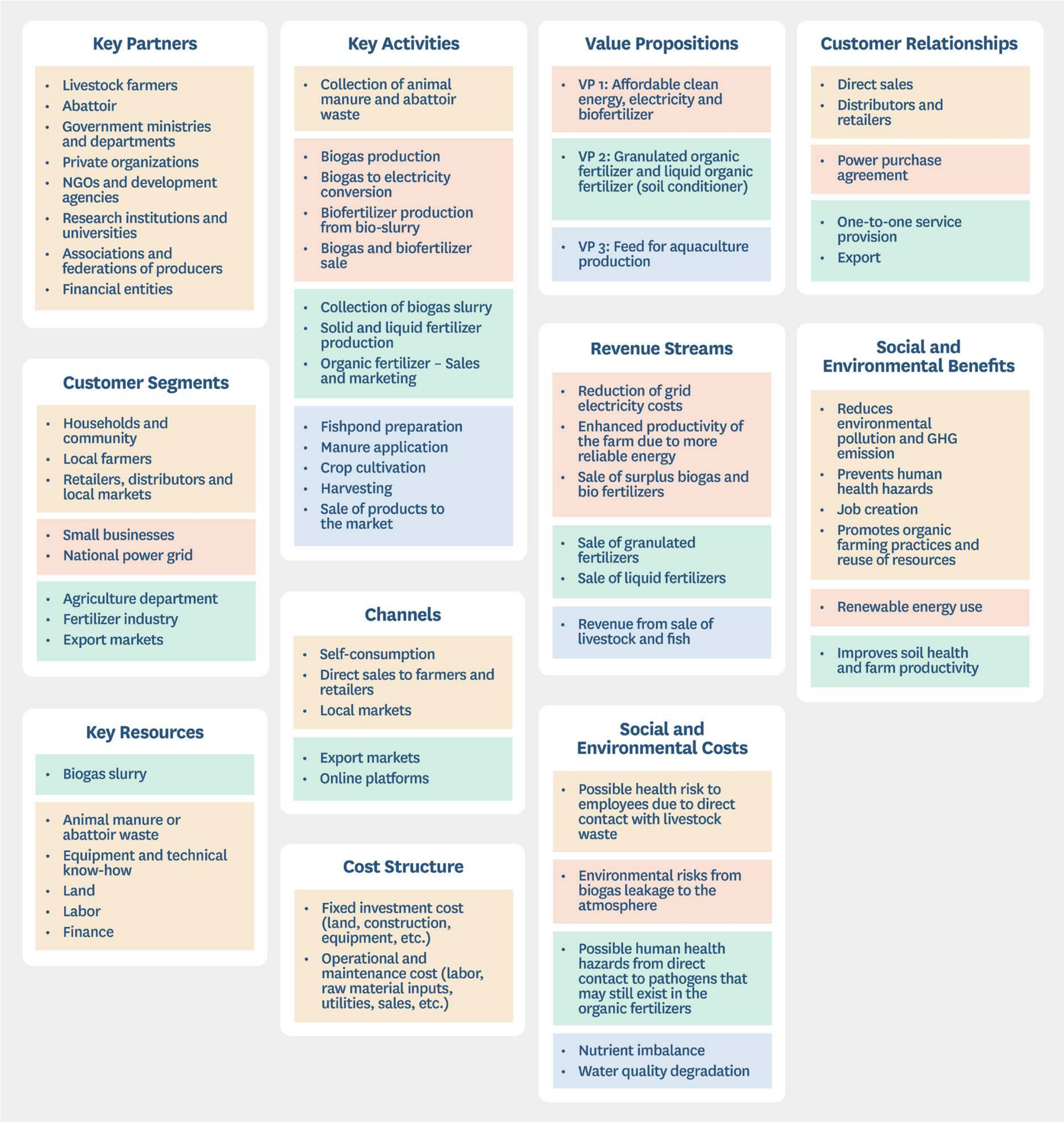

Figure 10. Generic business model canvas for resource recovery from livestock waste

Source: Authors' creation

Note: The canvas's color codes represent the value propositions mentioned above. The generic points are highlighted with a different color.

Having understood the generic business model for resource recovery from livestock waste, the selected business cases from Latin America (five cases), South Asia (eight cases), East Asia and Pacific (three cases) and Sub-Saharan Africa (10 cases) were clustered into three different business models based on the value prepositions offered (Figures 11, 12 and 13), which includes:

- Model for recovering energy and biofertilizer from animal manure and abattoir waste
- Model for recovering soil nutrients and organic matter for agriculture from animal manure and abattoir waste
- Model for recovering feed for aquaculture from animal manure and abattoir waste

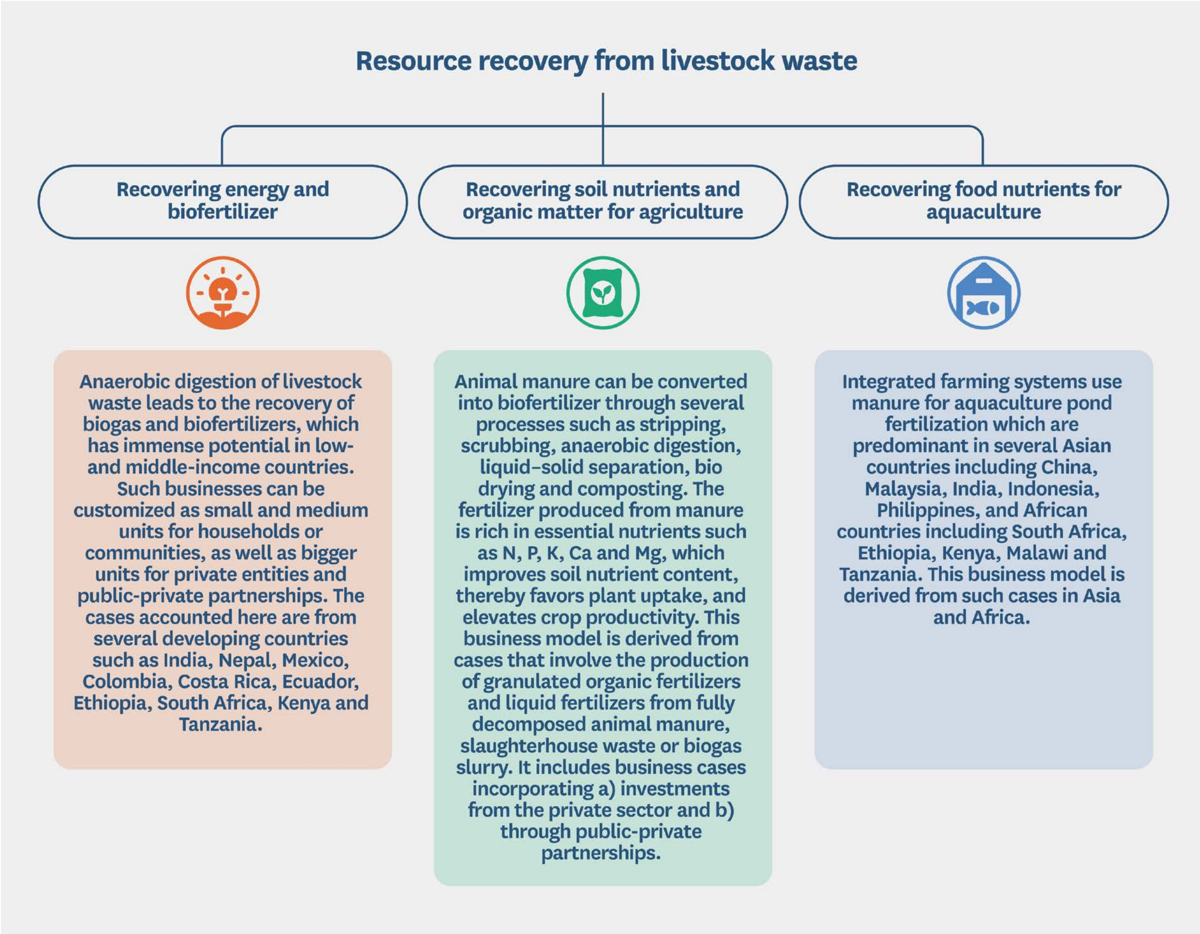

Figure 11. Three types of resource recovery business models

Source: Authors' creation

Figure 12. Geographical diversity of resource recovery business cases

Source: Authors' creation

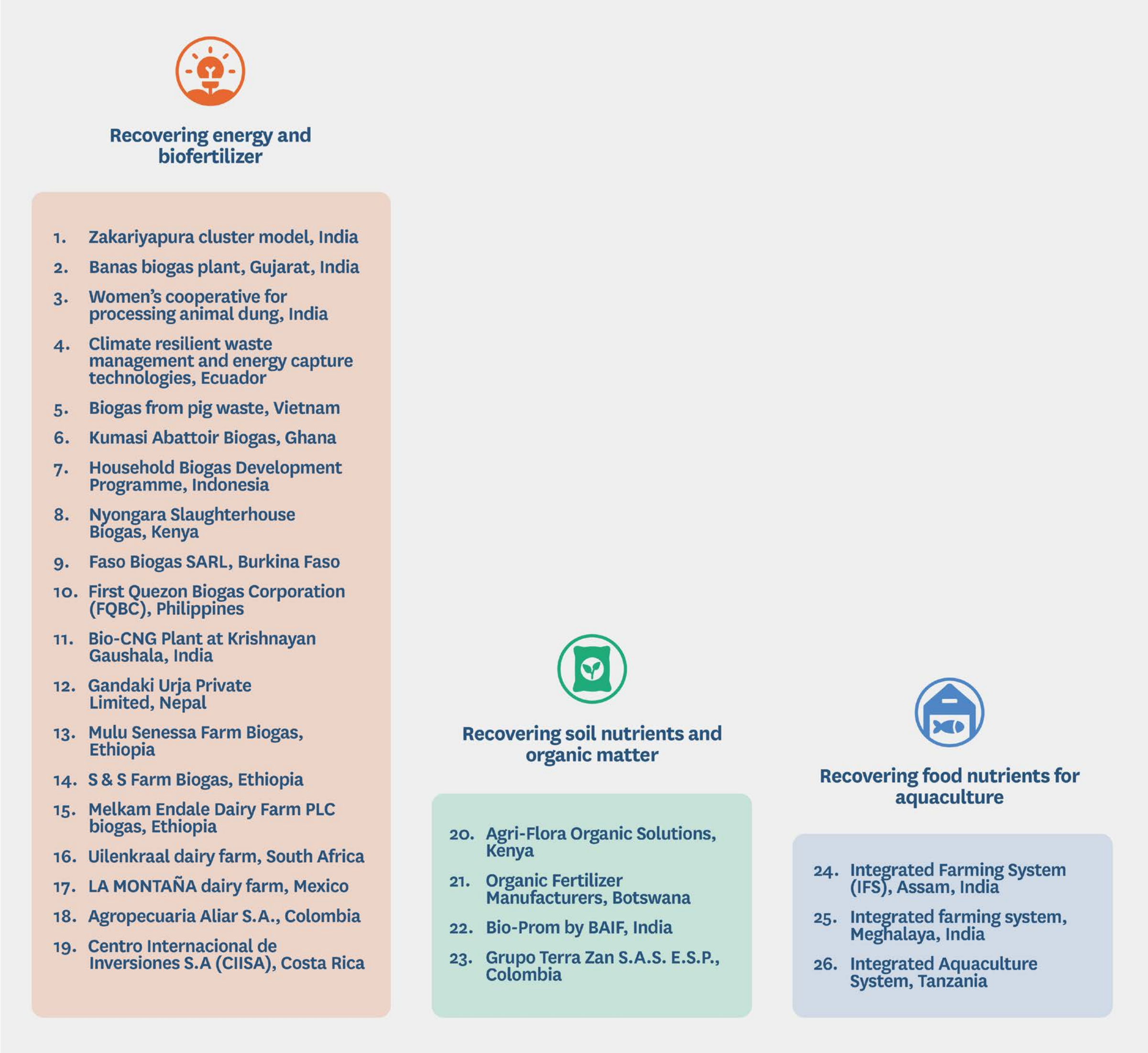

Figure 13. List of selected resource recovery business case

Source: Authors' creation

Engagement of stakeholders in the resource recovery business models utilizing livestock waste

The success of any business depends on the stakeholder's active participation. Therefore, this section aims to highlight the role of key stakeholders in the different business models. Generally, the national, federal and regional governments are the major stakeholders playing a crucial role in developing strategies and initiatives to promote resource recovery from livestock waste and providing strong financial support in terms of subsidies, tax exemptions, green bonds, loans, grants and public credit guarantees. Besides governmental support, technical assistance from private organizations, research institutes, universities, NGOs and international agencies can significantly support the implementation of these business models by providing installation, capacity building and training. These stakeholders can collectively enhance the enabling environment for resource recovery.

As for raw materials, both energy and biofertilizer recovery and food nutrient recovery business models often use waste collected from own farms and abattoirs, whereas soil nutrients and organic matter recovery models depend on external livestock farms or biogas units (for bio-slurry).

Notably, the engagement of stakeholders is less in the food nutrient recovery business model as it is more farm-specific and involves less technical and skill requirements, while the energy and biofertilizer recovery model requires a higher participation of stakeholders due to increased complexity in technology (Figure 14). Institutional arrangements of a business highly affect stakeholder engagement; for instance, within the energy and biofertilizer recovery business model, the cases operating under public-private partnerships (PPPs) exhibit higher stakeholder engagement compared to cases operating under private enterprises or at household or community levels.

Figure 14. Increasing complexity of stakeholders involved in different business models

Source: Authors' creation

Financial analysis of resource recovery business models

Following the stakeholder analysis, a comparative financial assessment of countries such as India, Mexico, Costa Rica, Ethiopia, Kenya, Tanzania and Botswana was performed using the data collected from selected business cases to recognize the financial feasibility of resource recovery business models across different regions.

Figures 15 and 16 illustrate the (percentage) cost breakdown of resource recovery models under different criteria. According to the business cases, most of the capital cost (CAPEX) of energy and biofertilizer recovery and soil nutrients and organic matter recovery business models is towards cost of machinery and equipment, installation of biodigesters and cost of construction materials, while most of the CAPEX of feed recovery business model is allocated towards acquisition of land, pond construction and cost of inputs such as fish fingerlings and feed. Energy consumption contributes to a larger proportion of annual operation and maintenance cost (OPEX) for the conversion of biogas to electricity (using generators) in energy and biofertilizer recovery business model and for blending, granulation and packaging of commercially produced organic fertilizer in soil nutrient and organic matter recovery business model. Moreover, cost of labor, maintenance and regular monitoring holds a significant share of OPEX in all three business models, while a smaller proportion of OPEX is allocated towards consumption of chemicals and inputs in both energy and biofertilizer recovery and soil nutrients and organic matter recovery business models.

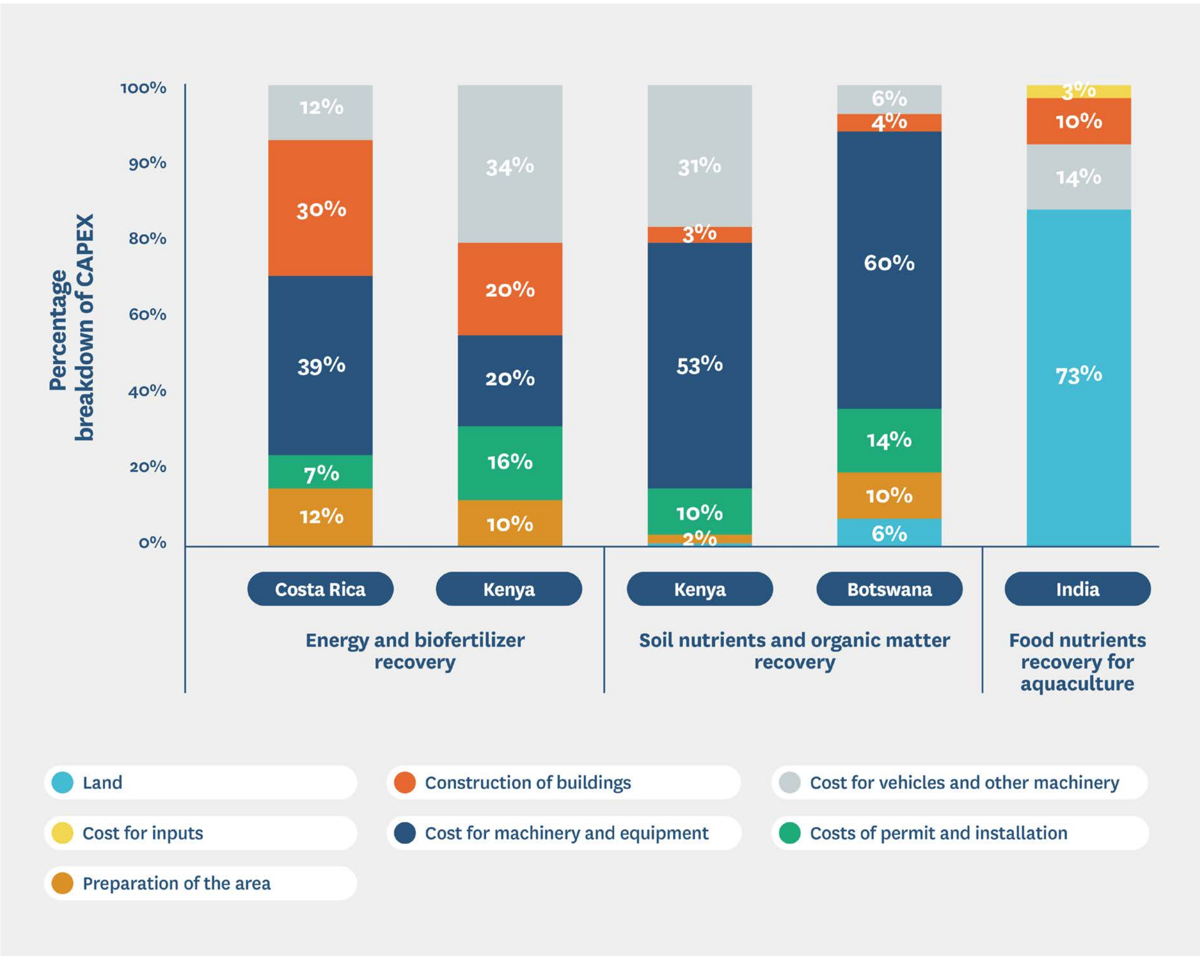

Figure 15. Breakdown of capital costs of different resource recovery business models

Source: Authors' creation

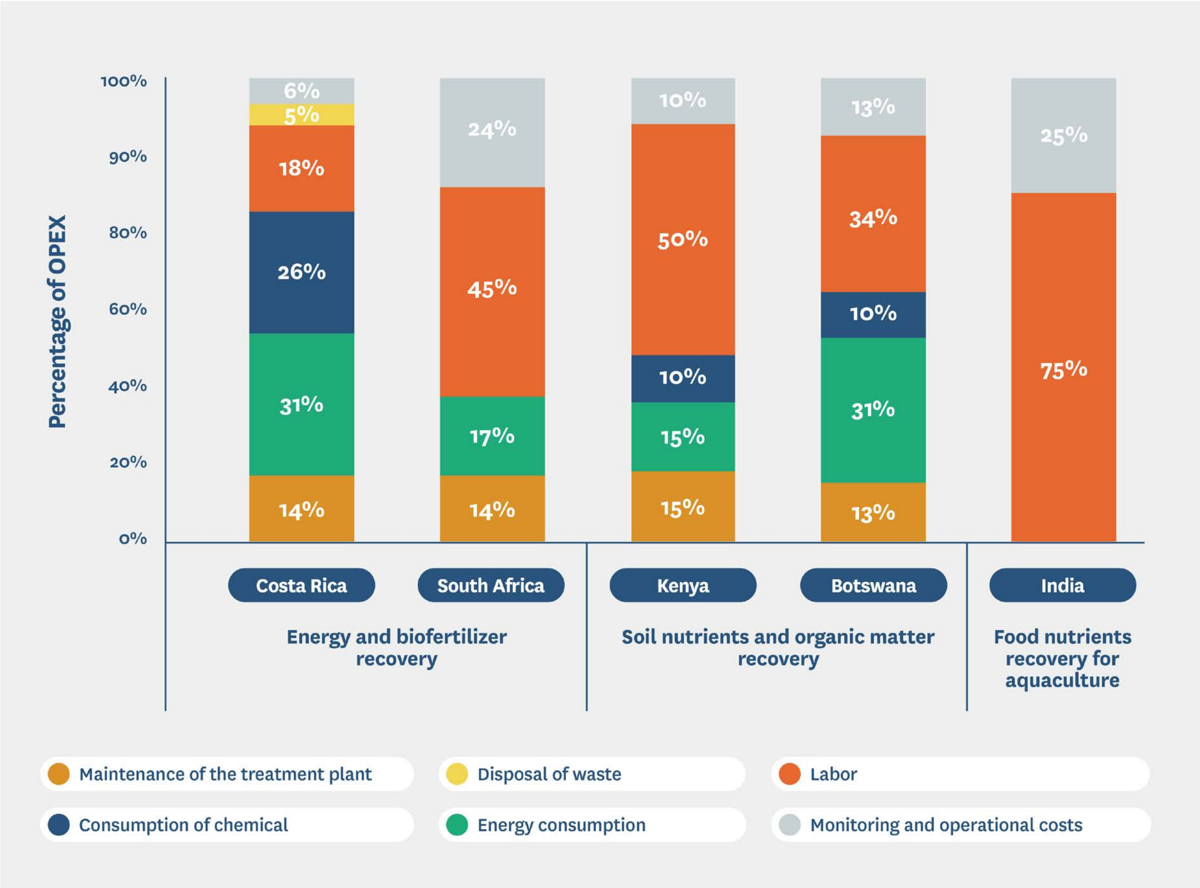

Figure 16. Breakdown of annual O&M costs of different resource recovery business models

Source: Authors' creation

However, costs (total capital and annual O&M) and annual revenue can vary for each country where the business cases are operating (Figure 17). For example, biogas and biofertilizer production exhibited a higher revenue with higher capital cost in Latin American cases such as El Arreo Slaughterhouse of Costa Rica and LA MONTAÑA dairy farm of Mexico compared to cases from India (women's cooperative for processing animal dung Mujkuva) and Ethiopia (Mulu Senessa Farm Biogas), whereas all the observed business cases showed a considerably lower operation and maintenance costs for biodigestion technique annually (Figure 17).

As for soil nutrients and organic matter recovery, Bio-Prom Organic Manure production by BAIF India exhibited higher financial feasibility with increased revenue compared to Agri-Flora Organic Solutions of Kenya due to strong financial support from international organizations and development agencies.

As for feed recovery, Tanzania showed higher preference for livestock based – integrated farming systems (IFS) with higher revenue and lower capital cost compared to IFS from Assam, India (Figure 17).

As discussed earlier, livestock waste management business cases focus more on recouping expenditures through resource recovery. For example, cases recovering energy and biofertilizer from animal manure and abattoir waste achieve cost recovery via i) replacing expensive fossil fuels with biogas; ii) reducing grid electricity costs through electricity production; and iii) sale of surplus biogas and biofertilizer produced for additional revenue generation.

The soil nutrient recovery business cases recover costs via commercialization of granulated organic fertilizer produced from animal manure or biogas slurry.

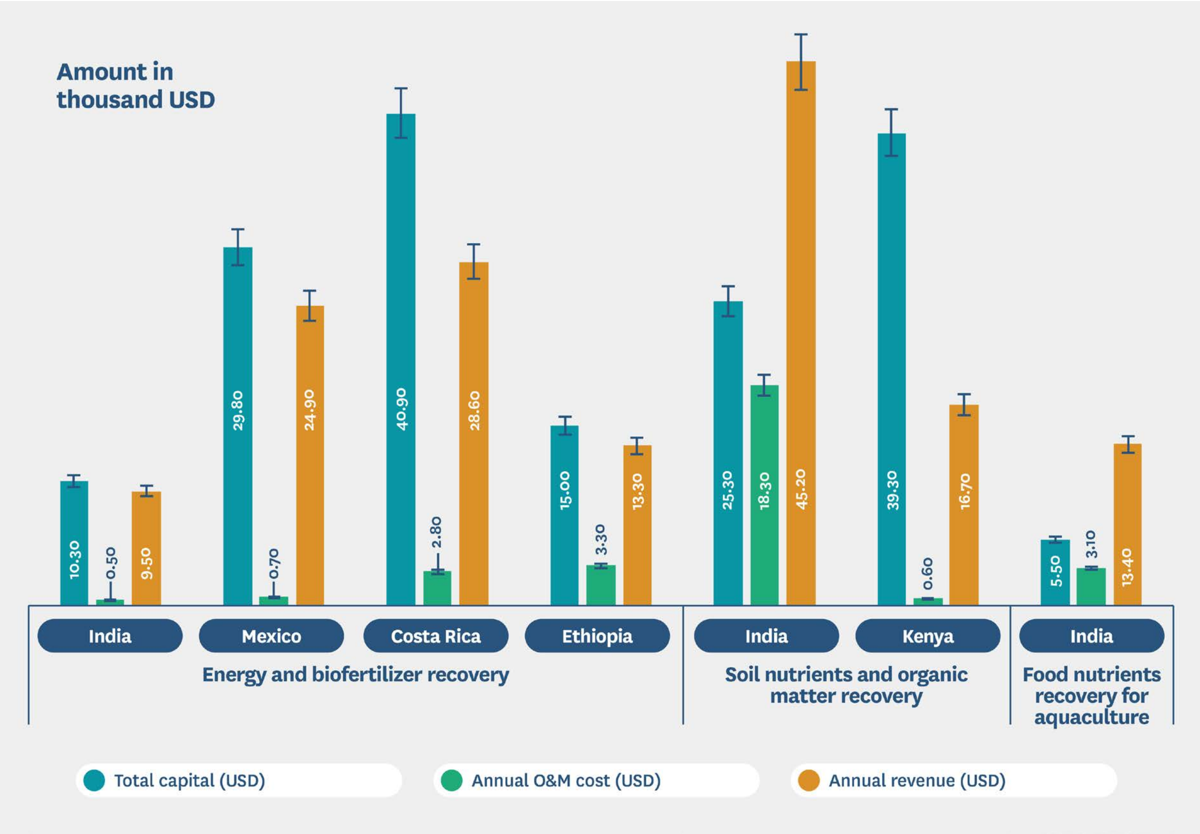

Figure 17. Financials of resource recovery business cases from different countries

Source: Authors' creation

Note: Total capital, O&M costs, and Revenue are unit costs of waste handled

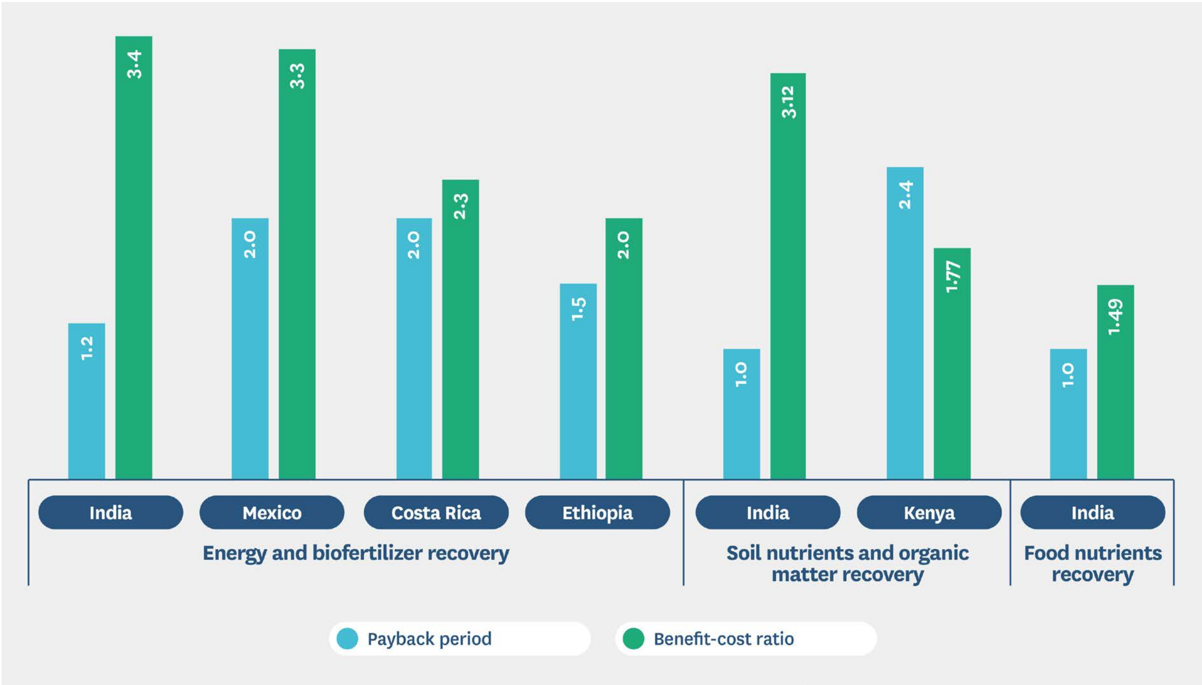

Figure 18. Payback periods and benefit-cost ratios of resource recovery business cases from different countries

Source: Authors' creation

The estimated payback period for cost recovery is longer for biogas and biofertilizer production at El Arreo Slaughterhouse of Costa Rica and LA MONTAÑA dairy farm of Mexico due to higher capital cost requirement, while the women's cooperative of Mujkuva, India was estimated to have a shorter payback period as it receives 40% of the cost as subsidy from the Union Ministry of New and Renewable Energy under the National Biogas and Manure Management Programme (NBMMP) (Figure 18).

As for soil nutrients recovery, the business cases from India and Kenya estimated to have a similar payback period for cost recovery. However, it should be noted that the results of financial analysis are only suitable for the selected business cases and the findings cannot be generalized.

Description of business models and case examples

Model for recovering energy and biofertilizer from animal manure and abattoir waste

Business model description

The business model has been developed from case studies which involves collection and treatment of animal manure and slaughterhouse waste, while offering three fundamental value prepositions: a) reduction of environmental pollution, b) biogas/CBG production and c) bio-slurry production as a residue from biodigestion process. The characteristics of these business cases serve as a basis to understand the key features of the business model.

The financial objective of the business cases is to achieve cost recovery through self-processing of livestock waste and reuse of value-added products, and to create an additional source of revenue for the rural community, livestock farms or abattoirs. The business model also includes cases which involve processing of waste from external farms or slaughterhouses for commercial production. Biogas energy applications include electricity generation and the substitution of traditional fuels such as LPG and diesel, while the bio-slurry turned into biofertilizer is used by farmers and communities to replace synthetic fertilizers.

During the treatment process, animal manure is collected using a central dung collector and pumped into the bio digestor, while abattoir waste is separated into solid and liquid fraction using a centrifugal separator before feeding into the biodigester for processing at an optimum temperature of 37°C. In the digester, manure is degraded to produce raw biogas in the presence of anaerobic bacteria which is then purified and compressed to a high pressure of around 200 Bar. Compressed biogas (CBG) is primarily used for self-consumption (for cooking, heating, lighting and electricity production) as a substitute for LPG and traditional biomass while surplus is sold to the local markets or supplied to national power grid. The digestate obtained from the biodigestion process is separated into solid and liquid fraction where liquid part is used for fertilizing their own farms while the solid is converted to biofertilizers and used in their own farms or commercialized in few cases.

The business model involves government-initiated household or community level projects as well as medium- to large-scale industrial business cases under private sector or PPPs (Figure 19). The government departments and ministries are major stakeholders of the business model. For instance, government-initiated projects and PPPs receive strong financial support from the government ministries which serves as an advantage for overcoming the burden of higher installation cost. Moreover, the business cases under private sector also rely on government support in terms of subsidies and incentives for successful operation and sustainability. The business cases also involve collaboration with international organizations and NGOs to facilitate technology transfer and provide training and capacity-building programs to enable the use of biogas technology (Figure 19).

The key drivers behind the success and higher replicability potential (Figure 20) of the business model are a) support from the local communities, as well as with local governments and local authorities; b) partnership with private organizations, NGOs and other development agencies; c) low cost (O&M costs) technology; d) effective governance system; and e) transparency in operation.

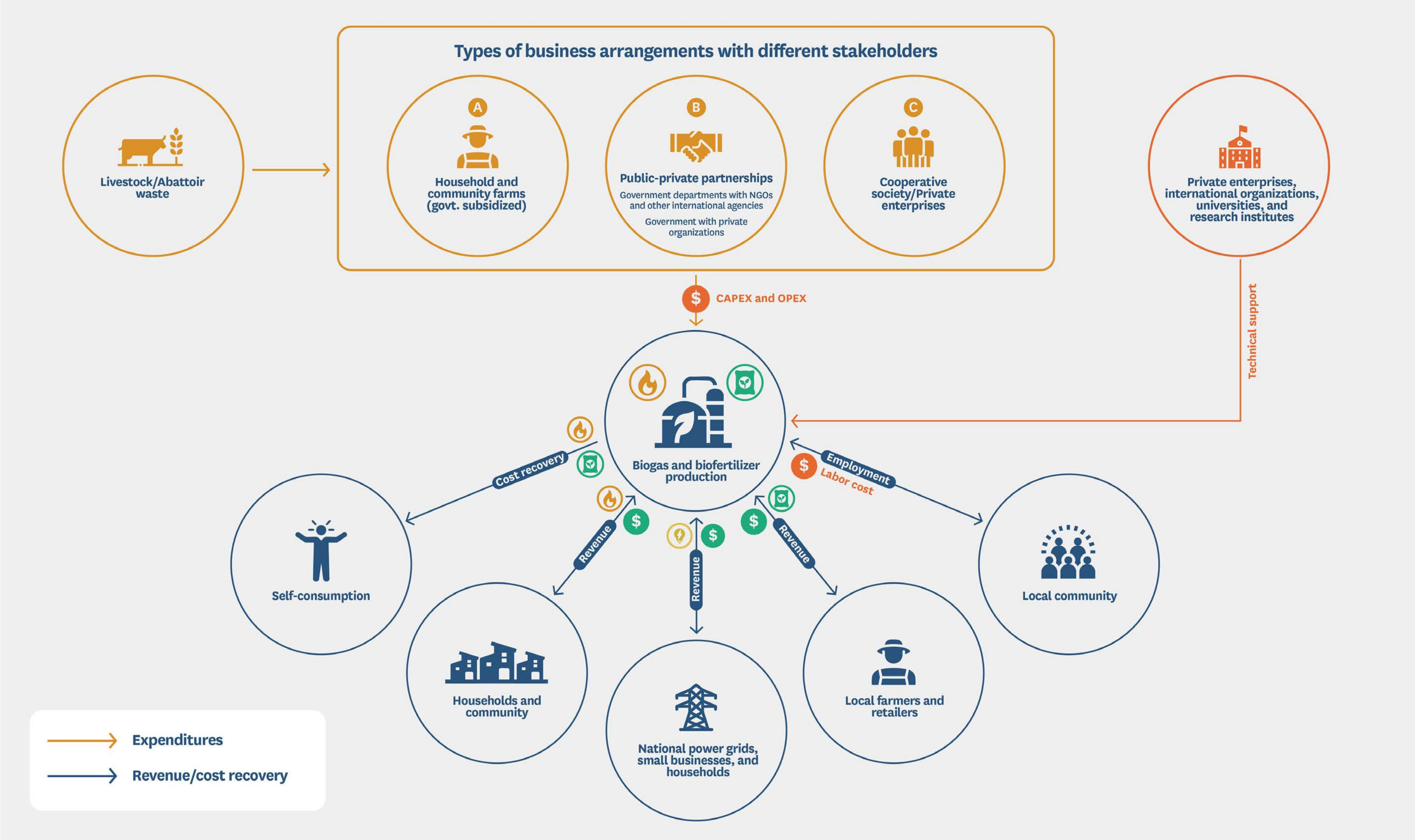

Figure 19. Value chain of energy and biofertilizer recovery business model

Source: Authors' creation

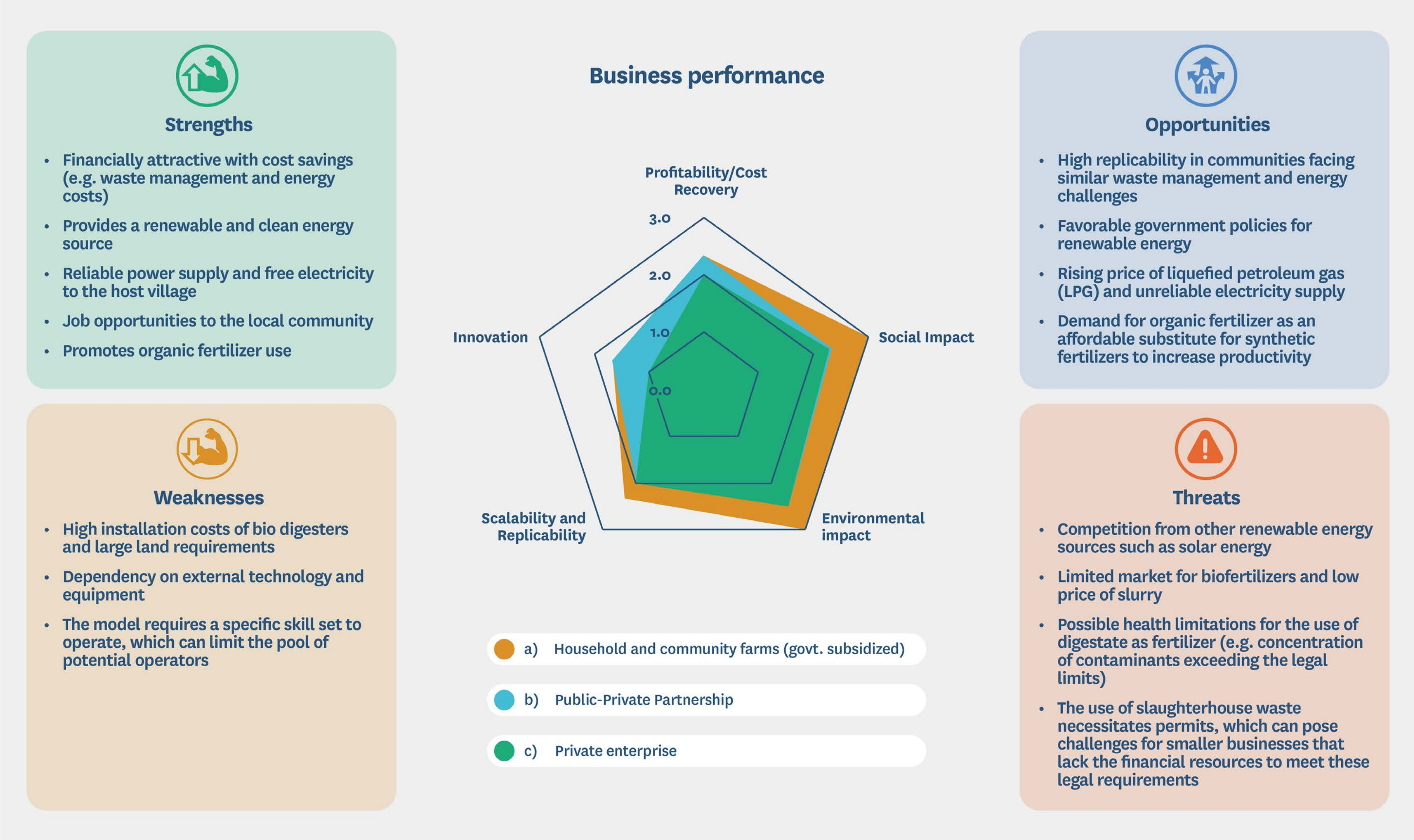

Figure 20. Business performance and SWOT analysis of energy and biofertilizer recovery business model

Source: Authors' creation

a) Case examples for energy and biofertilizer recovery household and community farms (government subisidized)

Zakariyapura cluster model, India

The Zakariyapura biogas model is a community-based project where 368 households out of 461 have installed flexi biogas units (Rath and Joshi 2020). The project is funded and supported by the Government of India through the National Biogas and Manure Management Programme (NBMMP) and is implemented by local government agencies such as the Gujarat Energy Development Agency (GEDA) and the Gujarat State Biotechnology Mission (GSBTM). The investment cost for a plant ranges from USD 358.80 to 382.72. Half of the cost is contributed by the National Dairy Development Board (NDDB) while the rest is managed by households (Jain 2024).

The biogas plants are owned and operated by individual farmers, who contribute their cow dung (40–50 kg per household) as the primary feedstock. A cooperative manages the slurry collection from women milk producers and a 10-metric tonne capacity plant processes the bio-slurry into solid and liquid forms. The milk society takes charge of manufacturing and packaging the slurry under the brand name Sudhan and each household can save USD 41.86 per month through biogas and bio slurry production (total of 0.8–0.9 kg per household) (IDF 2022). The model aligns with India's national biogas promotion policies and programs. Moreover, the simple, low-cost (O&M cost) technology is easily scalable to other rural communities.

Banas biogas plant, Gujarat, India

In an effective "waste to wealth" initiative, the Banas Dairy from Banaskantha District of Gujarat is converting cow dung into biogas and slurry. While the biogas is then purified into Bio CBG (compressed biogas) and Bio CNG (compressed natural gas) for use as fuel in vehicles whereas the slurry is converted into organic manure for use in agricultural fields, thereby safeguarding the environment and the same time, promoting waste management. The feedstock for biodigester (cow dung) is procured from 254 local dairy farmers at the rate of Rs.1 per kilogram. The biogas plant has the capacity to treat 40 tons of cow dung and potato waste each day (SBM Grameen 2020).

The plant required a USD 962,388 investment and has an annual O&M cost of USD 560,328. USD 0.72 per kg of total revenue is generated from biogas, solid fertilizer and liquid fertilizer sales. The payback period is estimated at 5.4 years (SCRIBD 2020). The plant has strong government partnerships and improves local sanitation and hygiene. Risks include potential gas leakage, health hazards and market competition. Given the increasing demand for clean fuels, there is high potential for scaling up and replicating this model across India.

Women's cooperative for processing animal dung, Mujkuva village, Gujarat, India

Mujkuva is a village located in Anklav Taluka of Anand district in Gujarat, India. In 2017, NDDB organized 40 women dairy farmers from Mujkuva to form a self-help group (SHG) called "Jai Ambe." Each member received a domestic biogas plant with a prefabricated digester (two cubic meter capacity) installed at home to process cow dung. The plants were set up with the support of the NBMMP and implemented by the Union Ministry of New and Renewable Energy by offering a 40% subsidy on the project cost (IRMA 2020). Biogas generated is used as a clean cooking fuel for replacing LPG and firewood. The nutrient-rich slurry by-products obtained from the plant are collected and transported to a facility managed by the women's cooperative Mujkuva Sakhi Khad Sahakari Mandli. Here, the slurry is processed into organic fertilizers and sold under the Sudhan brand in partnership with NDDB (NDDB 2020).

Each household contributes 50–60 kg of dung daily to produce 0.8–0.9 kg of biogas and slurry, which generates a revenue of USD 39.73 per household/month. The model not only mitigates environmental impact, but also empowers women by providing economic opportunities. There is also high potential for scaling up and replication in other villages with supportive government policies. Risks relate to safety, environment and health impacts but can be mitigated with proper design, operation and maintenance.

Climate resilient waste management and energy capture technologies of Ecuador

The project involves designing and scaling up climate resilient waste management and energy capture technologies coordinated by CIMNE with its local partners INIAP and Instituto de Investigación Geológico y Energético (IIGE), in collaboration with the Ministerio del Ambiente and the Universidad Regional Amazónica Ikiam. It is also funded by UNIDO in the context of Climate Technology Centre & Network (CTCN) (UNFCCC 2020).

Biodigesters with volumes between 5 to 42 m^3 have set up in the provinces of Ecuador, namely, Santo Domingo de los Tsáchilas, Pichincha, Tungurahua, Imbabura and El Oro. With the installation of these biodigesters, around 43 m^3/day of biogas and 3,570 L/day of digestate are generated using 50–200 kg of livestock manure.

The biogas produced has various uses, such as cooking and heating, while the digestate allows the recycling of nutrients when used as an agricultural input. The proper use of biogas and digestate allows savings of USD 5,447 per year for small producers and a saving for the state through gas subsidy of USD 4,280 per year. Furthermore, these systems can prevent emissions of 387,313 kg of CO_2/year (CTCN 2019).

Biogas production from pig waste in Vietnam

Since 2003, Vietnam has initiated a nationwide initiative known as the Biogas Programme for the Animal Husbandry Sector (BPAHS). This program is implemented by the Biogas Project Division of the Ministry of Agriculture and Rural Development, in collaboration with the Dutch development organization SNV. Over the years, more than 100,000 household biogas plants have been constructed through this program. Notably, in the Thua Thien Hue province in central Vietnam, 2,900 family biogas plants have been installed.

The initiative has provided comprehensive training for builders, facilitators, and financial and technical support to ensure the quality and sustainability of biogas plants. Provincial and district-level authorities are often involved in the program's implementation (Roubik et al. 2016). The initial investment cost and O&M cost for a biogas plant with a capacity ranging from 6 m^3 to 8 m^3 are estimated as USD 352.62 and USD 105.94, respectively, which generates an annual revenue ranging from USD 199.76 to 275.87 (Verner et al. 2023).

The primary biogas plant types in the specified area are KT1 and KT2, which consist of components including a mixing inlet tank, a digester, a compensation tank with an overflow outlet, and a gas pipe. The digester and compensation tank have brick exteriors and can be dome-shaped or rectangular. Inlet and outlet pipes connect these tanks. The KT1 is suitable for easily excavated areas with good soil structure, while the KT2 is used in areas with challenging soil conditions or a high-water table, featuring a shallower design.

The operational principle of the biogas plants involves directing pig manure, often mixed with water, into the biogas inlet, allowing gravity to move it into the digester. Additionally, household toilets connected to the digester are flushed with water. Within anaerobic processes, bacteria break down organic matter to generate biogas, which collects under the dome and pushes digested material into the outlet tank. The biogas is then transported via a pipeline to end-users (Roubik et al. 2016).

Ghana Kumasi Abattoir Biogas

Kumasi Abattoir Company Ltd. is one of Ghana's largest abattoirs and a publicly owned company established in 1993 but started operations in 1998. Its core business is slaughtering cattle, small ruminants (mainly goats and sheep) and pigs. The abattoir has an area of about 7 hectares of which about half is occupied by the production area. The two main waste streams at the abattoir are solid and liquid waste. The solid wastes produced at the abattoir are comprised mainly (about 75%) of the solid rumen content of the slaughtered animals. The wastewater mainly consists of flushing water, blood and liquid rumen content, with a total quantity of 170 tons per day.

The Government of Ghana implemented a biogas as a pilot industrial biogas plant at the abattoir with the support of UNIDO and the Government of Korea and was completed in 2020.

The EUR 1.28 million biogas plant investment was the first UNIDO biogas project in Ghana to generate gas and electricity from animal waste. Total biogas potential of the combined waste components is about 846 m³ per day. There are basically three applications that are considered for using biogas at the abattoir: electricity production, LPG substitution and diesel substitution (Awafo and Amenorfe 2021).

Total annual production of biogas is about 152,000 m³, and the production costs per m³ of biogas is USD 0.48. The annual net electricity production of the company is 85,750 kWh (245 kWh/d) and annual LPG substitution is 32,309 kg (92 kg/d). In addition to biogas, the project also produces 175 tons (dry matter basis) of fertilizer annually using slurry generated during biogas production. Thereby, it generates a total revenue of USD 289,612,800 per year (Cudjoe et al. 2021). This is public property, and the biogas implementation had multiple benefits, but not just financial.

Indonesia Household Biogas Development Programme

Indonesia's National Energy Policy aims to increase the share of renewable energy in the country's energy mix. The government has set targets for renewable energy capacity, including biogas, to reduce dependence on fossil fuels. The government has introduced feed-in tariffs (FITs) for renewable energy sources, including biogas. FITs guarantee a fixed price for electricity generated from renewable sources, making it financially viable for investors to develop biogas projects. Moreover, the government has collaborated with international organizations and NGOs to facilitate technology transfer and provide training and capacity-building programs to promote the use of biogas technology among local communities.

The initial investment cost for a 6 m³ digester is estimated to be USD 271.29 and the O&M cost is USD 0.36. The project is estimated to provide monthly savings of USD 5.30 per household through fuel cost reduction and generates a revenue of USD 0.062 per kg/month through biofertilizer sales.

The technology and processes of this biogas production are centered around the sustainable conversion of pig manure into valuable resources. Key activities include the collection of cow manure and the generation of raw biogas and biofertilizer through anaerobic digestion. The biogas generated serves as an affordable and clean energy source for the community, reducing its reliance on traditional biomass and fossil fuels.

The aim of the project is to create a closed-loop system, contributing to reduced local pollution and greenhouse gas emissions, as organic waste is effectively managed (Bedi et al. 2017). However, it's vital to carefully manage potential health risks associated with the project, particularly for households living nearby, to ensure this eco-friendly initiative's overall success and sustainability.

First Quezon Biogas Corporation (FQBC), Candelaria, Philippines

First Quezon Biogas Corporation (FQBC), an association of local poultry farmers, developed a waste-to-energy pioneering project in partnership with the Singaporean co-investor Yamato Technologies Pte. Ltd. and EnviTec to address the annually accumulating tons of poultry manure from the local farms. The project received a subsidy under the Renewable Energy Act (the RE Act) of 2008, which focuses on promoting the development of renewable energy projects and reducing reliance on fossil fuels. The corporation, with a capital investment of USD 6.7 million, use 14,000 tons of chicken manure, 7,000 tons of rice straw and 8,000 tons of corn stove to generate 1.2 MW of electricity from biogas and biofertilizer (as a byproduct) which is used as organic compost (Bioenergy International 2017; Moisture Meter 2017).

The project generates an annual revenue of USD 9.7 million through biogas production and electricity generation (Estacio 2020). The bio digester not only generates low-carbon energy and electricity, but also reduces harmful methane emissions from farming wastes, increases energy security, and improves waste management and sanitation.

The host village, 22 families residing near the plant, is provided with free electricity of 50 kilowatts per month (Estacio 2020), as well as jobs, livelihood and other business opportunities. The biogas plant is also capable of supplying reliable power supply to around 6,000 households in the rural areas of Candelaria.

b) Case examples for energy and biofertilizer recovery under public-private partnerships

Nyongara Slaughterhouse Biogas, Kenya

The Nyongara Slaughterhouse is located in Dagorretti on the outskirts of Nairobi. Dagorretti has an abundance of slaughterhouses, which supply meat to Nairobi and its environs. Waste generated by the slaughterhouse was polluting the Nairobi River, so the National Environmental Management Authority (NEMA) initiated to close down slaughter-house units that were not meeting the regulatory norms of treating their waste. This catalyzed a public-private partnership between Nyongara Slaughterhouse and UNEP, UNIDO and KIRDI through the Ministry of Environment to develop a solution, to not only treat the waste to produce biogas but also provide monetary benefits to the slaughterhouse units (Kabeyi and Olanrewaju 2020).

The project was started in 2011, with a 15-kW biodigester, which is treating 300 kg of waste and generating 9 kWh of electricity per day. The biogas produced is used for heating and the electricity generated is used primarily for refrigeration and lighting purpose. The slurry output from the plant is high in nutrients and is used in cultivation of tomatoes within the slaughterhouse (Energypedia 2014).

The biogas production and electricity supply generate a revenue of USD 5,300 and the organic fertilizer production earns a revenue of USD 3,000 with a total O&M cost of USD 3,000 per year. This project is highly effective for slaughterhouses across Africa for reducing pollution and resource recovery. The enterprise has plans to scale up the biogas plant to process waste from other slaughterhouse units. Scientists and engineers from the KIRDI were involved in the implementation from the very beginning of the activity, which enabled UNIDO to transfer the know-how and skills to local technicians, making the maintenance, replication and up-scaling process easier (Rao and Gebrezgabher 2018).

FasoBiogaz SARL, Ouagadougou, Burkina Faso

FasoBiogaz SARL was founded in 2012 by two Dutch entrepreneurs. The enterprise is located in the industrial zone of Kossodo in Ouagadougou, Burkina Faso, and operates the first industrial biogas plant connected to the SONABEL power grid. The plant, with an installed electrical capacity of 275 kW, is transforming slaughterhouse waste and other available organic substrates into biogas and biofertilizer. The biodigesters receive organic waste from a slaughterhouse and a brewery nearby and use the biogas to produce electricity, which is sold to SONABEL, while biofertilizer is commercialized under the brand name “Nourrisol.”

The project is financed by the Dutch private investor company Van Kersbergen Invest B.V. In the framework of the Private Investor Program (PSI), the Netherlands Enterprise Agency has agreed to reimburse up to USD 813,825 based on a results-based milestones agreement. The initial investment amounts to USD 1,627,650 for implementing a plant with an installed capacity of 500 kW. Operating revenue ranging from USD 0.08–0.11 per kWh is generated through the sale of electricity. In 2015, FasoBiogaz negotiated a Power Purchase Agreement (PPA) with SONABEL for a desirable tariff for three years. With a currently installed power of 275 kW, the plant can daily inject between 4,200 and 4,300 kWh into the grid. With the planned extension, the income could be doubled (ECREEE 2020).

c) Case examples for energy and biofertilizer recovery by private enterprises

Bio-CNG plant at Krishnayan Gaushala, Haridwar, India

This Bio-CNG project located in Haridwar, Uttarakhand is being managed by Shree Krishnayan Desi Gauraksha Evam Gaulok Dham Seva Samiti Gaushala, the largest cow shelter in Uttarakhand, which cares for more than 2,200 non-milking cows.

Oil and Natural Gas Corporation Ltd (ONGC) undertook an initiative to convert cow manure into useful fuel and value-added products by setting up a Bio-CNG cum fertilizer and bottling plant at Haridwar. The plant covers an area of 0.28 ha. Feedstock for the plant is collected from three cow shelters.

The raw biogas generated is stored and compressed to produce compressed biogas (CBG). The purified CBG is stored in cascades and supplied to the Ayurveda factory in Sidcul, Haridwar. The slurry is separated into solid and liquid parts. The solid part is fortified and converted to biofertilizers, while the liquid part is used by the samiti on their own farm. Biofertilizers are packed in bags of 5 kg, 10 kg and 50 kg capacities and sold under the brand name Surabhi Sudha. Thirty-six products have been developed after enriching biofertilizer with microbes into bio-pesticide, growth promoter, PROM, fungicide, etc. The primary sources of funding for this project are (1) ONGC and (2) MNRE. The ONGC invested USD 212,668 through their CSR funds and MNRE is expected to give USD 24,305. The project generates a revenue of USD 0.68 per kg with annual O&M cost of USD 87,498. The project facilitates the availability of a clean environment to the local population of Haridwar and helps in protecting the fauna, i.e. 2,200 cows, by making the cow shelter self-sustaining from the revenue generated from biogas and biofertilizer production (SBM Grameen 2021; IBA 2020).

Gandaki Urja Pvt. Ltd., Nepal

The Gandaki Urja compressed biogas plant is located in Pokhara, Nepal, in the foothills of the Annapurna range. The plant uses 45,000 kgs of organic waste (livestock manure and municipal solid waste) to produce 528,000 kg of CNG per year and 11,000 tons of organic fertilizer per year. The initial investment of the project was USD 1,937,390 and generated a revenue of USD 176,836 per year. It has also received a partial subsidy (40%) from the Government of Nepal's Alternative Energy Promotion Center under the Ministry of Energy, Water Resources and Irrigation (MoEWRI). The project is estimated to reduce 14,000 tons of methane emissions annually. It provides an annual supply of 11,000 tons of organic fertilizer and 528,000 kg of compressed biogas substituting around 37,183 LPG cylinders. The project is expected to save 15,000 tons of organic waste going to landfills annually. It has created new employment opportunities with 20 full-time employees offering a total of USD 23,155 per year (Gadgil 2021; UIAA 2019).

Mulu Senessa Farm, Ethiopia

Mulu Senessa Farm in Ethiopia converts livestock manure to biogas and organic fertilizer. It was established in 2020 with SNV support to meet the dairy farm's energy needs. With 250 kg/day of manure input, it produces 10 m^3/day of biogas and 150 kg/day of organic fertilizer. Biogas powers farm equipment and facilities. Organic fertilizer is sold to local farmers. The biodigester system required a USD 4,500 investment. Annual O&M costs are USD 1,000, while generating a revenue of USD 4,000/year from fertilizer sales. The simple payback period is four years.

The system improves the local environment, provides renewable energy, creates jobs and supports organic farming. Given local demand, there is potential to scale up for commercial biogas production. Risks include the need for awareness of the business opportunity and benefits. The model has good replication potential with low investment costs and high local demand. It aligns with Ethiopia's strategy for a climate-resilient green economy and organic agriculture[5].

S&S Farm, Ethiopia

S&S farm is a dairy and slaughterhouse farm located in Modjo town of East Shoa Zone, Oromia region. The business was established in 2021. It was implemented with the technical support from SNV, the Dutch Development Organization. The waste used in the business is cow manure that comes from its own farm, so no further transportation of waste is required. The biodigester is an underground 60 m^3 digester to which the cow manure slurry is channeled for anaerobic decomposition. The outputs are biogas and organic soil nutrient. Nearly 500 kg of manure is fed to the digester every day. The biogas produced (about 20 m^3 per day) is used for dairy processing units, cooking and lighting. The organic matter is recovered from the basin downstream on a

[5] Data for the case study were obtained from the business entity through personal discussions.

regular basis (on average about 2 m^3 organic matter per day). Organic matter is used for gardening purposes within the farm compound.

The biodigester system requires a USD 10,000 investment and annual O&M cost of USD 1,500 and generates a revenue of USD 2,500/year from energy cost savings. The development of the biogas system has had significant impacts in reducing pollution and protecting the health of humans and the environment. The business was developed mainly to cover the energy needs of the dairy farm. Therefore, it is not yet fully commercialized. However, there is a potential and interest from the farm owners to expand this to commercialize both the gas and organic soil nutrient production. Currently, the business runs well and produces both biogas and soil nutrients.[6]

Melkam Endale Dairy Farm PLC, Ethiopia

Melkam Endale Dairy Farm Bio-digester System is located within the dairy farm found in Oromia region, Sheger Ketema, Sululta town. This business is a pioneer model in Ethiopia generating electricity from biogas using a biogas generator. It was developed in 2020 under the Biogas Dissemination Scale-Up Programme (NBPE+) managed by SNV. It is a 80 m^3 biodigester system using cow manure from its own dairy farm. A 16-Kilowatt (KW) biogas generator and a 30 m^3 biogas storage balloon (SNV 2021) are installed at the biodigester which produces around 32 m^3 of biogas and about 2 m^3 of bio-slurry per day. Currently, 8 kilowatts of electricity is produced from biogas, which is used in the cold chain and incubation room of the dairy farm.

Through the project, the farm has obtained a more reliable source of energy, which has not only reduced its electricity costs, but also avoided loss of dairy products from outage. The bio-slurry from the biogas produces organic soil nutrients, however, it is not fully commercialized yet. The soil nutrient is partly provided to local farmers and as the dairy farm has no crop farming activities, it is not used by the farm except in gardening. The business has an O&M cost of USD 2,200 while generating a revenue of USD 6,700 and is a reliable design for supply of off-grid clean electricity for a business.[7] The business is in line with the Ethiopia's climate resilient green economy strategy of 2012, thus, strong supports would be provided from the government.

Uilenkraal Dairy Farm, South Africa

Uilenkraal is a large dairy farm in South Africa that installed a biogas plant in 2015. It processes 200 m^3/day of cattle manure in a 7,000 m^3 anaerobic digester and produces 400 kWh/day of electricity from two biogas generators. The biogas system was designed locally by Cape Advanced Engineering at a lower cost than European imports. It reduces the farm's monthly electricity costs from USD 6,800 to USD 7,500 and the surplus biogas is flared. The digester also produces biofertilizers which are used onsite.

The model has strong potential for scaling up and replication at other large farms. The main barriers are high CAPEX and the inability to sell power to the national grid. Benefits of the project include energy cost savings, reduced pollution and GHG emissions, and job creation. Besides, onsite waste collection and local partners are crucial for affordable customized design. The project aligns with South Africa's goals to boost biogas and support decentralized clean Energy (NIRAS-LTS 2021; Claassen 2015).

LA MONTAÑA dairy farm, Mexico

LA MONTAÑA, a dairy farm with 82 cows, is located in Tizimín, Yucatán Península region in the south of Mexico, which is the lowest milk production area in the country. The farm was facing enormous challenges with floods and damaged feeding crops, interrupted milking process and regular electricity supply shortages. Therefore, the dairy farm, with the help of the Secretariat of Agriculture, Livestock, Rural Development, Fishing, and Food, initiated a biogas plant to address the annually accumulating tons of cow manure through this waste-to-energy project. It aims to solve various problems ranging from local power shortages and energy security to addressing the major concern of global climate change.

[6] Data for the case study were obtained from the business entity through personal discussions.

In the process, the system provides two value propositions: a) biogas/CBG production to replace fossil fuels, and b) bio-slurry, both solid and liquid, from biogas plants which are used as organic compost.

It uses 10 tons/day of animal manure to produce 650 m^3 /day of biogas, 7 tons/day of liquid biofertilizer and 2 tons/day of solid biofertilizer. The capital investment and O&M cost of the project are estimated as USD 298,000 and USD 7,000, respectively. It generates an annual revenue of USD 52,000 and the payback period was estimated at 5.7 years (Koldisevs 2014). The project can be replicated in various regions of Mexico due to higher availability of feedstock for biogas and biofertilizer production resulting from the significance of livestock production all over the country's territory.

Agropecuaria Aliar S.A., La Fazenda, Colombia

At Agropecuaria Aliar S.A.[7], the productive chain begins with agriculture, which provides the main raw material for animal feed production. It also involves a pig production cycle, followed by animal processing and the production of meat products for marketing. From these processes, liquid and solid organic waste, pig waste and meat by-products (blood, bones and hair, handled in an animal meal processing plant) are obtained. These wastes are treated through anaerobic digestion plants, where it is transformed into fertilizer and biogas in one of the main pig centers, Machijure, Aliar.

The investment cost of the plant is USD 667,743 and O&M cost is estimated as USD 146,903. The biogas to energy generation plant has a capacity to supply up to 80% of the center's energy demand (800 kWh). In 2022, of the total biogas produced, 2,614,048 m^3, 56.3% was used as fuel for electricity generation and the remaining 43.7% was piped to a flare for the transformation of methane into carbon dioxide, where it is finally released into the atmosphere. It also transformed 88.5% of the wastewater into liquid (1,032,734 m^3) and solid fertilizers (6,063 tons), which are used as inputs for the irrigation of pastures and forages for cattle, where they feed about 5,000 animals, preventing the use of synthetic fertilizers.

Centro Internacional de Inversiones S.A (CIISA), Costa Rica

The main activity of the Centro Internacional de Inversiones S.A (CIISA)[8], in the El Arreo slaughterhouse, is the slaughter of pigs and cattle, as well as the sale of meat, value-added food products and other products. The activity generates 59 tons/day of waste such as blood, animal fatty tissues, fats trapped in separation traps, pig manure, manure from livestock, rumen content, primary sludge generated in the plant wastewater treatment and food waste. The waste is treated through anaerobic digestion to produce biogas (2,973 m^3/day) for internal consumption and obtain dehydrated biosolid (9.5 tons/day) delivered to an external party for the production of fertilizer.

The project plays a significant role in mitigating the environmental impacts associated with waste disposal and generating economic, environmental and social benefits. The project receives an annual saving for transportation, disposal and treatment of organic waste (manure, blood and food waste) of USD 372,934 per year through biogas and biofertilizer recovery. Waste management reduces CO_2 emissions by 299 tons/year. The substitution of fossil fuel to avoid CO_2 emissions of 1,650 tons/year, and also constitutes a saving of USD 364,704 per year. In addition, the utilization system generates new jobs and improves the relationship with neighbors by mitigating bad odors coming from the plant.

Model for recovering soil nutrients and organic matter for agriculture from animal manure and abattoir waste

Business model description

The business model has been developed from cases that are committed to promoting organic farming practices and allow deviation from agrochemical fertilizers through the production of organic or organically blended fertilizers using decomposed animal manure collected from livestock farms or using slurry generated as a residue from biogas plants.

[7] Data for the case study were obtained from the business entity through personal discussions.

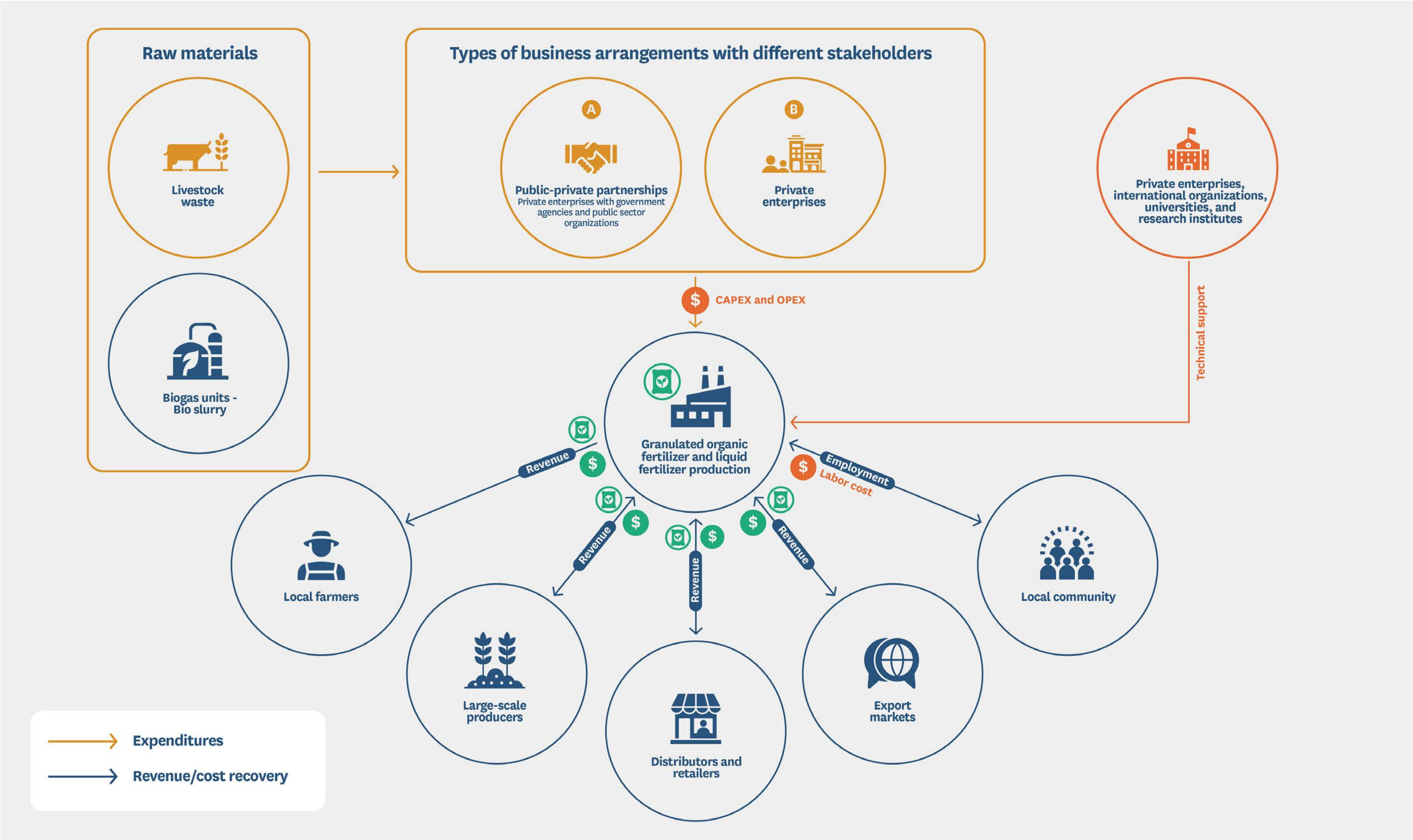

Figure 21. Value chain of soil nutrients and organic matter recovery business model

Source: Authors' creation

The business cases involve commercial organic fertilizer production under private sector or PPPs which remain as the main sources of investment for the business model while obtaining financial and technical support from development agencies and other partners (Figure 21). However, as the business is still in its infancy, financial support from the government in terms of subsidies and incentives will play a crucial role, especially in attracting more investors.

The process of production begins with sourcing organic materials that can be transformed into high-quality fertilizers. The organic fertilizers can be manufactured from decomposed manure and biogas slurry by adding gypsum, carbon and other products based on the fertilizer requirement. The decomposition process of manure can take three to six months. The process of decomposition at high temperatures ensures that any weeds or diseases are killed. The composted manure is then brought to the factory for processing. The process in general includes raw material sourcing, composting, mixing and blending, granulation, drying, quality control, packaging and marketing. The business model can produce special recipes of organic fertilizers based on soil test results. Following production, commercial links and technical support to farmers are established so that the products can be used as soil regenerators.

Organic fertilizer not only reduces dependence on expensive synthetic fertilizers and hence costs, but also contributes to soil health and sustainable production systems in developing nations. Moreover, the product has a diverse customer base from smallholder farmers to large-scale producers, as well as retailers and export markets which elevates the profitability and sustainability of the business.

The model has a high replicability potential in developing economies, as attitudes and demand for organic fertilizers is steadily increasing among farmers with the excelling demand for organic agricultural products (Figure 22). While organic soil nutrients from manure have overall superior benefits, there may also be potential risks associated with it, including: (i) market risks due to demand fluctuations; (ii) operational risks related to sourcing raw materials and distribution of the products; (iii) financial risks related to costs of scaling up production and market expansion; and (iv) social risks such as reception by the public of organic fertilizers, employee satisfaction, etc. However, these risks are minor and could be avoided by proper planning and devising strategies for mitigating the risks.

a) Case examples for soil nutrient and organic matter recovery under PPPs

Grupo Terra Zan S.A.S. E.S.P., Colombia

Grupo Terra Zan[8] bases its business model on circular economy, applying innovative technologies to create products that contribute to soil regeneration, which reduces the carbon footprint and improves the quality of crops that guarantee human and animal health. It recovers the soil with the application of organic fertilizers, transferring the necessary technical knowledge to farmers, for the progressive transition from chemical to regenerative agriculture. The approach is not only limited to composting, but extends to other technologies, such as the revalorization of livestock wastewater into value-added products, such as fertilizers and industrial services. Terra Zan has its own microorganism plant and a technical team dedicated to the continuous optimization of these processes.

The company uses 50 m^3/day of organic waste including animal manure, poultry waste, slaughterhouse waste, crop residues and industrial food waste to produce 46 m^3 of organic fertilizer per day. It generates an annual revenue of USD 1,022,453 and has an O&M cost of USD 633,359 per year. The key partners of the company include government agencies and public sector organizations such as AGROSAVIA and Tecnoparques SENA, financial entities such as Bancolombia, Leasing Bancolombia and Renting Bancolombia, universities such as Universidad de La Salle, Universidad Central and UNICAFAM, private sector collaborators such as Corporación 9R Sostenible and multilateral organizations.

[8] Data for the case study were obtained from the business entity through personal discussions.

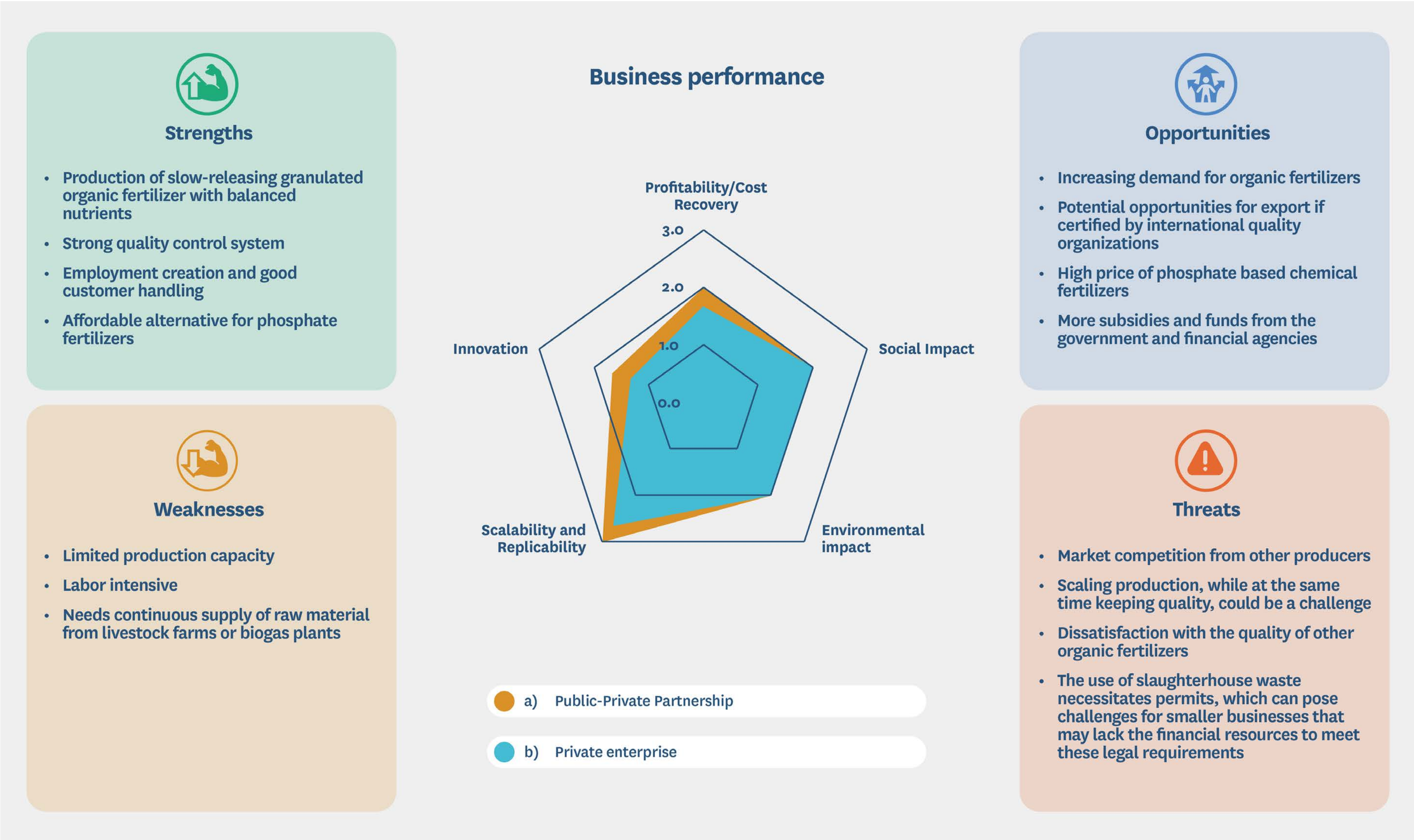

Figure 22. Business performance and SWOT analysis of soil nutrients and organic matter recovery business model

Source: Authors' creation

Terra Zan has been a pioneer and innovator of the industrial composting process in the region. It has been an example to other companies as it recognizes the market potential of organic fertilizers and contributes to the overall drive for more sustainable practices in the region. Terra Zan uses locally accessible equipment and technology, ensuring efficient operation and reducing dependence on external supplies.

b) Case examples for soil nutrient and organic matter recovery by private enterprises

Agri-Flora Organic Solutions, Kenya

Agri-Flora Organic Solutions Limited is located at Just Kali, Nyahururu, Kenya. The company was incorporated in 2017 and is committed to organic farming and sustainable food security (KCV 2021). The company produces a flagship product called, Asili granulated fertilizer, which is a slow-release fortified organic fertilizer with carbon-based compounds and enriched with essential nutrients such as calcium, zinc, manganese, magnesium and iron. The fertilizer is produced from fully decomposed animal and plant waste (total of 15 tons of waste per day) as well as liquid organic fertilizer. The product has no fillers and is blended to have balanced nutrient contents (KCIC 2021). The company makes special recipes for fertilizers based on the soil tests it conducts for farmers and the product undergoes a quality test before being packaged and distributed.

The company reaches its customers via the following channels: (i) direct sell to farmers, (ii) collaborations with local agro-input retailers to make their fertilizers accessible to farmers; and (iii) online platforms to reach a wider audience. Both small-scale and large-scale farmers use the products. The product generates an annual revenue of USD 250,000 with an O&M cost of USD 10,000.[9] To address the increase in demand for organic fertilizers, the company has partnered with Kenya Climate Innovation Center (KCIC) and Kenya Climate Ventures (KCV), who provide business advisory services, financial support and guidance (KCIC 2021; KCV 2021). The demand for the products is increasing as Agri-Flora actively engages in awareness campaigns, workshops and farmer training programs to educate the community about the benefits of organic farming and use of their fertilizers.

Organic Fertilizer Manufacturers Botswana

Organic Fertilizer Manufacturers Botswana (OFMB) produces organic blended fertilizer from manure (110 tons per day). The company has a state-of-the art plant for production of granulated fertilizer with a capacity of about 30,000 tons per year. It operates under a wide-ranging value chain that includes: (i) raw material sourcing; (ii) manufacturing and blending – they blend and process the raw materials to create Ecocert certified organic fertilizers; (iii) granulation and packaging; (iv) distribution of granulated organic fertilizers for the export market as well as for the local market; (v) sales and marketing to reach their target customers; and (vi) customer engagement with farmers, providing agronomic services such as soil testing, offer advice on fertilizer application, crop-specific needs, and sustainable practices.

The company supplies its products to local farmers, processors, distributors and retailers within Botswana. The Ecocert certified organic fertilizer can be exported to the European Union and United States through the African Growth and Opportunity Act (AGOA).[10]

The product generates an annual revenue of USD 2.6 million with an O&M cost of USD 100,000 annually. The organic fertilizer serves as a soil treatment and because of Botswana's strategic geographic position, is ideally placed to penetrate the regional agricultural input requirement market mainly South Africa, Zambia, Namibia, Zimbabwe, Angola and the D.R.C. The organic fertilizer generally has few risks, but some of the associated risks may include demand fluctuations, sustainability of sourcing raw materials and distribution channels, costs of scaling up production and expanding to new markets, and public perception of organic fertilizers.

[9] Data for the case study were obtained from the business entity through personal discussions.

[10] https://www.organicfmb.com/

Bio-Prom Organic Manure by BAIF, India

The Soil Protection and Rehabilitation of Degraded Soil for Food Security in India (ProSoil) is an Indo-German development cooperation project implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) in partnership with the National Bank for Agriculture and Rural Development. Under this project, GIZ India, in collaboration with BAIF Development Research Foundation (IRESA model), is supporting an initiative to produce Bio-PROM, an organic fertilizer produced using residue from biogas plants which aligns with the government strategy on promoting organic farming. This project is based on the Integrated Sustainable Energy and Sustainable Agriculture (IRESA) model of BAIF Development Research Foundation through which it has supported several farmers to set up biogas plants within the region.

The farmer households having a pre-installed biogas plant serve as suppliers of dry cake (biogas residue) and the Farmer Producer Organization (FPO) is involved in purchasing dry cakes from the farmers at USD 0.084 per kg. The dry cake is transported to the manufacturing unit, where it is mixed with 22% rock phosphate and liquid organic fertilizer to produce powdered Bio-PROM, which can be further converted to pellets (GIZ 2023).

Six Bio-PROM manufacturing units have been successfully inaugurated in districts, namely Sindhudurg, Nashik and Nandurbar of Maharashtra, Navsari of South Gujarat.[11] Three new Bio-PROM units will be commenced shortly (Gadgil 2021). A Bio-RPOM unit has the capacity to manufacture 462 MT of Bio-PROM annually with 277 MT of dry cakes prepared from biogas residue, which generates a revenue of USD 0.17 per kg. The Government of India through its National Biogas and Manure Management Programme has promoted the installation of around 5 million household size biogas plants from 2017 to 2018. The notable increase in biogas production and growing demand for biofertilizers act as key drivers for promoting Bio-PROM initiatives in the country (GIZ 2023).

[11] https://baif.org.in/what-we-do/Bio-recycling

Model for recovering feed for aquaculture from animal manure and abattoir waste

Business model description

Livestock-based integrated farming systems (IFS), connect three agricultural components, namely livestock farming, aquaculture and crop cultivation to create a sustainable and synergistic system based on circular economy principles. IFS forms the core of the business model (Figure 23).

Livestock farming is central to this integrated system and contributes high-quality protein and valuable manure. Fishponds are stocked with fish species that thrive on livestock manure, which is directly applied to the ponds without the involvement of any treatment technologies, creating a natural cycle of nutrient exchange. Brans and vegetable residues from crop cultivation are used as fish feed. Through their waste (fish manure and manure-fertilized pond water), the fish provide essential nutrients for the vegetable crops, enhancing overall productivity.

The integrated farming systems use several types of manure including cow dung manure, goat manure, pig manure, chicken manure, duck manure and a combination of manure for fertilization of fishponds. Fish species widely used in integrated aquaculture systems of South Asia include catla, rohu, mrigal, grass carp and silver carp. Tilapia and catfish are prominently cultivated in Africa.

Small-scale rural farmers (under individual ownership) dominate IFS (Figure 24). The value chain of IFS encompasses multiple stages and activities and generates various income streams for farmers that contribute to the creation of a holistic and sustainable livelihood for farmers, while reducing GHG emissions, soil degradation and water pollution. As for increasing the replicability potential of IFS (Figure 24), efficient government programs and frameworks focusing on developing sustainable agriculture and involvement of public-private partnership are beneficial.

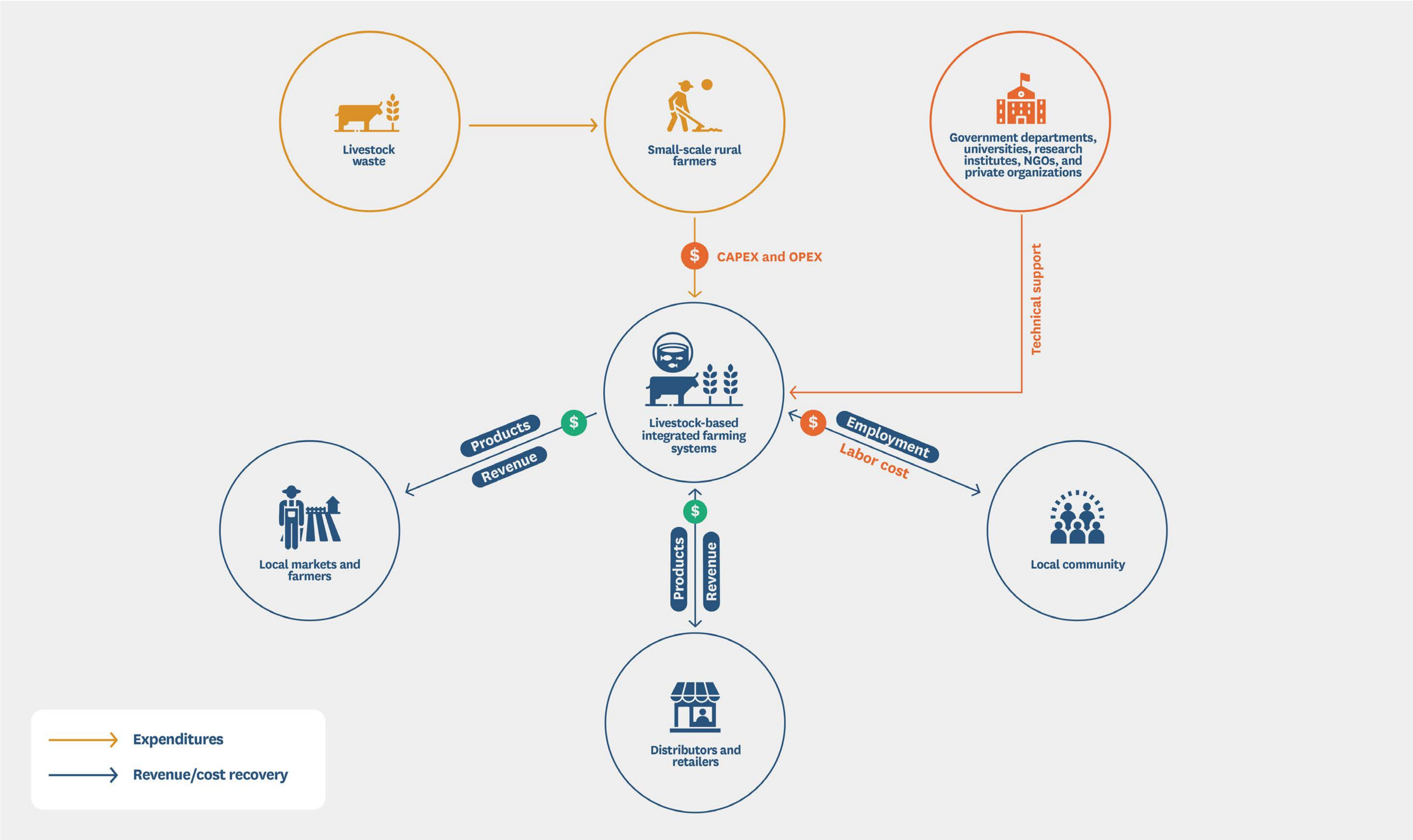

Figure 23. Value chain of feed recovery for aquaculture business model

Source: Authors' creation

In addition to livestock manure, slaughterhouse waste and by-products are also considered as significant resources obtained from livestock production.[12] It has a high potential for conversion into nutrient-rich fish feed, which is highly effective in reducing the dependency on expensive fish feed and overcoming the shortage. Fish feed from slaughterhouse waste is mainly produced by private organizations with an aim of promoting sustainable treatment and management of slaughterhouse waste, while earning profits. However, it involves potential risk of disease transmission, which can be prevented by carrying out sterilization procedures to remove harmful pathogens from waste before converting it into fish feed.

Case examples for feed recovery for aquaculture by small scale farmers

Integrated farming system in Assam, India

Assam is home to many smallholder farmers who practice subsistence farming. Integrating pig, fish and vegetable production helps to improve their livelihoods. The operational ratio of the business is two female indigenous breed pigs, one male exotic (Hampshire) breed pig and a homestead pond. Two-month-old piglets are raised for six months, resulting in two batches of pigs being reared in conjunction with one batch of fish per year. The fish species released into the pond include catla, rohu, mrigal, grass carp and silver carp. The fertilized pond water, enriched with blue-green algae due to the addition of pigsty sludge, is used to irrigate horticultural crops such as okra in the Kharif season and cabbage in Rabi season. A control mechanism is installed in the drain to regulate the flow of pig sludge and prevent water quality degradation in the fishpond. While pigs receive intensive care regarding feed and health, fish are not fed and the fishpond does not receive any external fertilizers. Pig sludge is recycled to meet the fish's feed requirements.

According to a study done by Assam Agriculture University between 2008 and 2014, The IFS of pig-fish-vegetable, consisting of one male Hampshire and two female local pigs, a fishpond of 450 m, and vegetable cultivation of cabbage and okra on 1000 m of land, resulted in an income of USD 1,598.96 and a benefit-cost ratio of 3.5:1, which was remarkably higher compared to the traditional practice of piggery using local pig breeds, which resulted in an income of USD 230.78 and a benefit-cost ratio of 1.4:1. Given the productivity and profitability of integrated farming systems, there is great potential for the business model to replicate across Assam and other parts of India (ICAR 2014).

Integrated farming system in Ri Bhoi, Meghalaya, India

Like the case reported in Assam, livestock rearing initiates the value chain of IFS, which integrates aquaculture and crop cultivation. Manure from 34 pigs serve as valuable organic fertilizer rich in crop nutrients which is used to cultivate vegetables in an integrated manner. It also involves the cultivation of aquatic plants or the creation of a symbiotic environment with fishponds. The IFS in Ri Bhoi fulfils the multiple objectives of making farmers self-sufficient by ensuring the family members have a balanced diet, improving the standard of living through maximizing the total income. The IFS systems in Ri Bhoi were reported to provide an additional income of USD 597.54/ha with 84% employment enhancement rate within the community (Roy et al. 2014).

Meghalaya has a rich diversity of livestock, poultry, crops and horticulture. The efficient utilization of the locally available national resources is very important for sustainable development. Therefore, IFS is very promising for improving overall farm productivity and profitability, generating new employment opportunities, conserving natural resources, and maintaining the sustainability of the agroecosystem by effectively recycling the farm by-products and efficiently using available resources.

[12] Data for recovering feed for aquaculture from slaughterhouse byproducts is not available and there are environmental, and health (nutritional) concerns associated with producing fish feed from slaughterhouse waste.

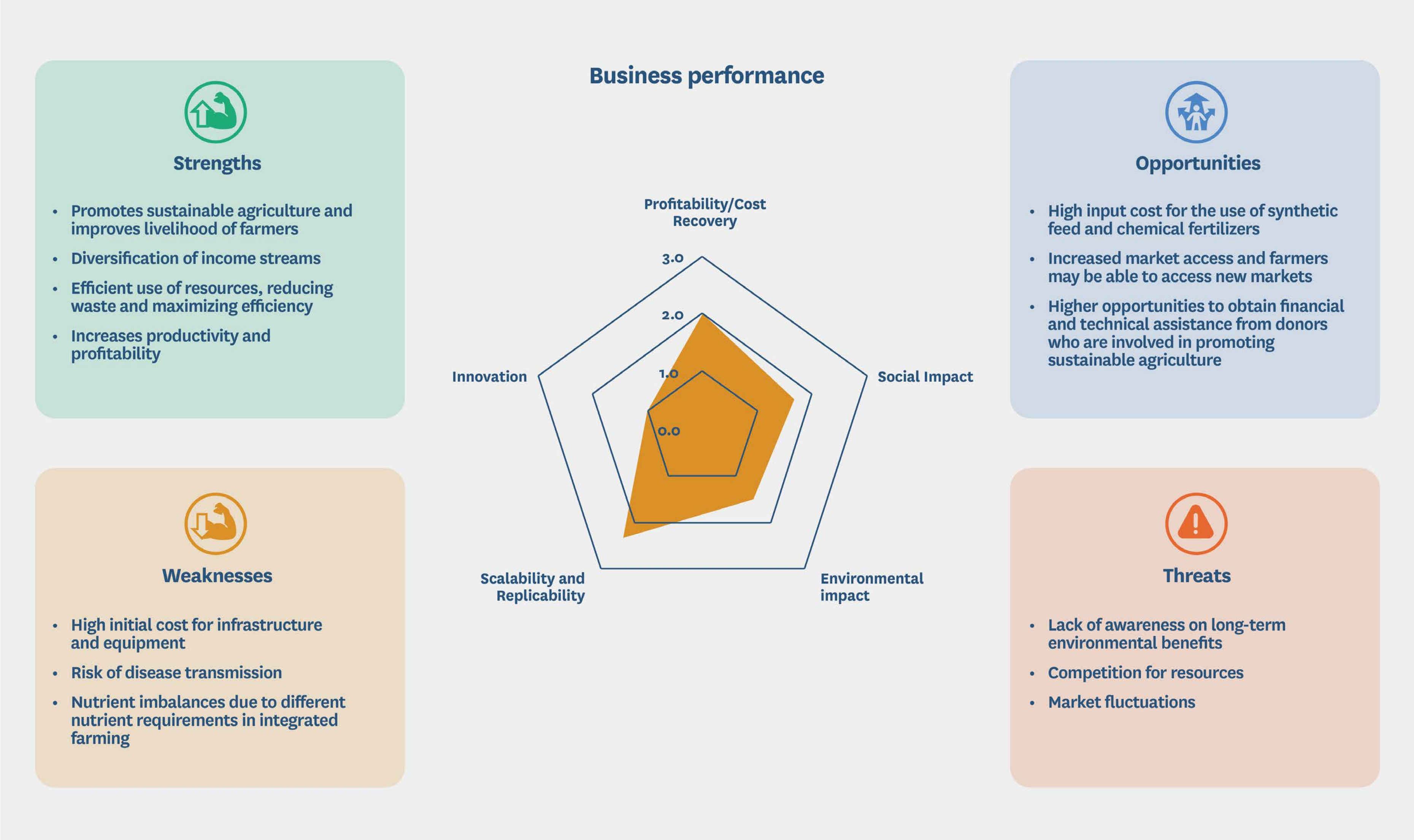

Figure 24. Business performance and SWOT analysis of feed recovery for aquaculture business model

Source: Authors' creation

Integrated agriculture and aquaculture system (IAA) of Tanzania

In Tanzania, IAA systems involving livestock farming and crop cultivation are being conducted intensively in six districts, namely, Kilombero, Igunga, Mvomero, Songea rural, Songea urban and Mbarali. Across the six districts, 65 integrated aquaculture systems were observed. The most common fish species cultivated in IAA ponds include tilapia and catfish or a combination of both. The most widely used fish feed includes a combination of brans and vegetable residues from crop cultivation.

The average amount of feed provided to the ponds is around 7.6 tons/ha/year with feeding frequency ranging from once a day to once per week. There is no reporting for the use of commercial feeds. Manure (2.1 tons/ha/year) from livestock farming is used for pond fertilization, with cow dung (71%) being the most prominent type of manure used, which is followed by chicken manure (11%) and a combination of various manures (6%). Pond fertilization using manure stimulates the growth of natural food sources such as zooplankton, phytoplankton and periphyton growth, thereby decreasing the requirement of fish feed. There is no reporting on the use of chemical fertilizers, antibiotics or hormones in fishponds. The products harvested from livestock farming, aquaculture and crop cultivation are sold to local markets and neighbors.

IAA systems are significant in reducing expenditure on costly feed and fertilizers, which form more than 60% of the total input cost. IAA ponds can earn 1.54 times higher total revenue and three times higher net income compared to non-IAA ponds in Tanzania. 38% of IAA farmers are planning to expand their farming activities due to higher productivity and profitability (Mulokozia et al. 2021).

Indiscriminate use of manure on fishponds, may have an impact on the dissolved CO_2 level of the fishponds and negatively affect water quality due to an accumulation of toxic metabolites. Animal manure is also rich in pathogens and antibiotics, which can cause several health risks in fishes and humans (after consumption). Therefore, it is necessary for fish farmers to learn about the permissible limit of manure input to maintain the physio-chemical parameters of the pond at a range suitable for fish growth and survival without affecting the natural ecosystem of the pond.

Conclusion

Developing and implementing business models for livestock waste management are pivotal in addressing multifaceted challenges linked to livestock production. These models, categorized into recovering energy and biofertilizer, soil nutrients and feed for aquaculture, not only transform waste into valuable resources but also foster sustainable agriculture, enhance economic prospects and bolster environmental and public health safeguards.

The diversity in organizational approaches and regulatory approaches (like financial subsidies, availing investments, and market development mechanisms) underscores varying performance levels and scalability potentials, highlighting the importance of tailored strategies to maximize economic feasibility and replicability across diverse contexts. For example, government-initiated households- and community-based energy recovery projects (in Southeast Asia and South Asia, respectively) from animal farms exhibit higher economic feasibility and replicability. Privately operated models are suitable for large-scale operations, enabling the commercialization of products to increase revenue. These types of businesses are observed in Latin America. However, these models depend on financial support from the government and technical support from other private players.

Models related to soil-nutrient recovery (in Sub-Saharan Africa) and food nutrient recovery for aquaculture (in South Asia) also show higher replicability in low- and medium-income countries due to fewer technical and skill requirements. Emphasizing these models in low- and medium-income countries can catalyze a resilient and sustainable agricultural sector, offering a pathway towards lasting environmental stewardship and economic resilience.

Implementing circularity in livestock waste management – Guidance for entrepreneurs

Key findings

- The implementation of a circular bioeconomy business commences with a feasibility assessment that analyzes the technical, legal, financial and environmental strengths and weaknesses. For example, the feasibility study for small and medium enterprises typically involves a baseline survey, while large enterprises necessitate a multicriteria assessment employing various indicators to better understand the business conditions.
- The second most critical step involves the development of a comprehensive business plan that delineates financial objectives, evaluates market conditions, formulates business strategies, defines organizational structure, identifies potential risks and establishes financial mechanisms.
- A strengths, weaknesses, opportunities and threats (SWOT) analysis pertaining to a resource recovery business can assist entrepreneurs in evaluating the business environment and achieving a competitive advantage.
- Among the available financial resources, government subsidies play a critical role in facilitating the successful implementation and sustainability of resource recovery businesses. However, in developing countries, these subsidies are predominantly allocated to energy recovery with limited focus towards nutrient recovery, which serves as a significant factor in attracting further private investment in biogas production.

Entrepreneurs and livestock farmers, cooperatives/trusts in social business interested in circular bioeconomy products from livestock waste need to adapt to market environments by understanding the key drivers of the business and making appropriate plans for the business. Adopting circular bioeconomy (CBE) principles aids entrepreneurs to attract stakeholders who focus on environmental, social and governance (ESG) criteria and offers financial viability to the businesses. In return, entrepreneurs also have a catalytic role in facilitating the transition towards CBE by increasing awareness and acceptance at a local level and creating ripple effects within the value chain in which they are key players (UN 2023).

The development of CBE initiatives in the livestock waste management sector of emerging economies is still at its infancy with various factors including resource management, risk mitigation and market growth playing a significant role in accelerating the development process. Figure 25 shows the main drivers and challenges to this sector.

Livestock waste availability, the low cost of treatment and subsidies provided by governments are the main drivers of the businesses. However, the lack of valorization of the waste and commercialization, competition from other bio-products provides a steep challenge to scale the business. This chapter aims to provide guidelines on constructing a sequential plan to assess and enhance the implementation potential of CBE business models utilizing livestock waste in developing nations. The detailed implementation plan unfolds the essential steps required for initiating a successful CBE business model, which includes feasibility assessment, market positioning, strategic and action planning, risk assessment and mitigation plan, stakeholder management and financial planning (Details in Annex 3).

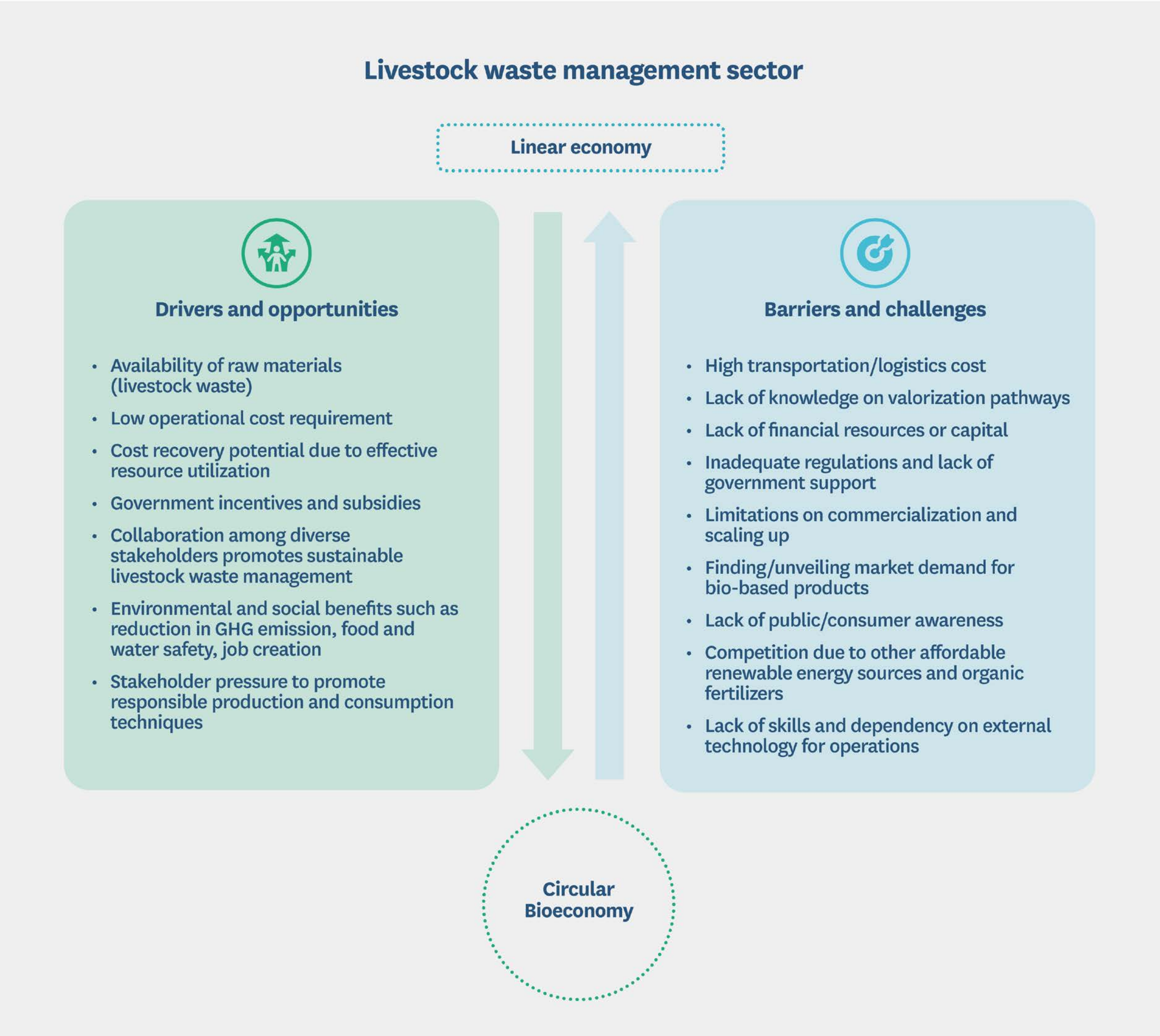

Figure 25. Key drivers and barriers of circular bioeconomy business models utilizing livestock waste in developing countries

Source: Adapted from Salvador et al. 2022

Feasibility analysis for determining the implementation potential of livestock waste management business

A feasibility study is the first and most crucial step in implementing a business model which investigates the viability of a business venture. The study should evaluate the model's technical, financial, legal and environmental strengths and drawbacks. Feasibility analysis for small- and medium-sized enterprises (SMEs), farmers, trusts/cooperatives involve a baseline survey, while for large scale businesses a multicriteria assessment based on different indicators is necessary to determine the sustainability of the business.

Baseline survey

SMEs could exploit a baseline survey to analyze the past and ongoing livestock related CBE businesses, their operational landscape and limitations for a specific geographic location through primary and secondary data collection which involve expert interviews, data mining, as well as workshops with local experts and key stakeholders (if resource permits).

As SMEs play a significant role in the progress of CBE, especially in developing nations, the baseline survey could be an effective tool for entrepreneurs to narrow down suitable business models that aligns with a) the current priorities of the local stakeholders; b) the local institutional landscape including public and private players in the livestock waste management sector; c) the existing policy framework and investment climate; and d) the resource availability of the targeted area. Considering the various factors, the past CBE activities and stakeholder perspectives are crucial for decision-making of the analysis.

Methodology

Initially, the survey uses a set of basic questions (Otoo et al. 2016) to understand the economic, environmental and social conditions of a specific geographic location, such as:

- Is the required livestock waste sufficiently available in the location?
- Are there appropriate technologies available and accessible for the business?
- Is there any indication of demand for the livestock waste-derived product?
- Are there any legislations/regulations which could prevent the business?
- Are there any institutions (public, private) which could qualify as business owners and partners and be interested?
- What is the financial viability of the model based on the costs and revenue?

As livestock waste management businesses can be implemented in different locations such as rural, per-urban and urban areas, the output from a baseline survey can be used to select the most suitable location with a conducive environment for the specific resource to be recovered. The survey output can also be used to assess the financial viability of the proposed CBE business model and its sustainable impact on society. A diverse data on existing livestock waste related CBE businesses and their locations, obtained from the survey, is beneficial to analyze and mitigate potential risks associated with establishing a business model within the area.

In case of any ***non-supportive answers*** (e.g. resource limitations, market competitions or regulatory barriers) or ***challenges in data access***, the entrepreneurs would have to target a different location or consider replacing the business model accordingly. However, some limitations can be addressed which can pave the way for implementation of the business within the selected area, e.g. low institutional capacity through training workshops or market limitations through expansion to new market segments.

Multicriteria assessment (MCA)

The feasibility analysis for large-scale CBE interventions related to livestock waste management initially involves a baseline survey for selecting the most appropriate geographic location and suitable CBE business models that align with the current priorities and business conditions of the targeted location. The survey is followed by a multicriteria assessment, which is an unbiased approach to provide future investors/stakeholders (the public and private sectors, financial institutions and donors) with sufficient information to evaluate the potential of the proposed CBE business models with respect to their return on investments (ROI) in both monetary and non-monetary (social or environmental) terms. Conducting a multicriteria assessment for assessing the sustainability, replication and scaling-up potential of the CBE businesses demands an in-depth knowledge on several factors, such as efficiency of institutional environment, functioning of input and output markets, supportive economic, regulatory and financial conditions (investment climate).

Methodology

Some conventional feasibility assessment approaches such as the technical, economic, legal, operational, and scheduling (TELOS) and the value chain approach (VCA) exhibit limitations in analyzing the different risks associated with the CBE business models. So, a MCA framework incorporating seven key criteria is recommended for assessing the feasibility of large-scale livestock waste related CBE business models (Otoo et al. 2016) (Figure 26).

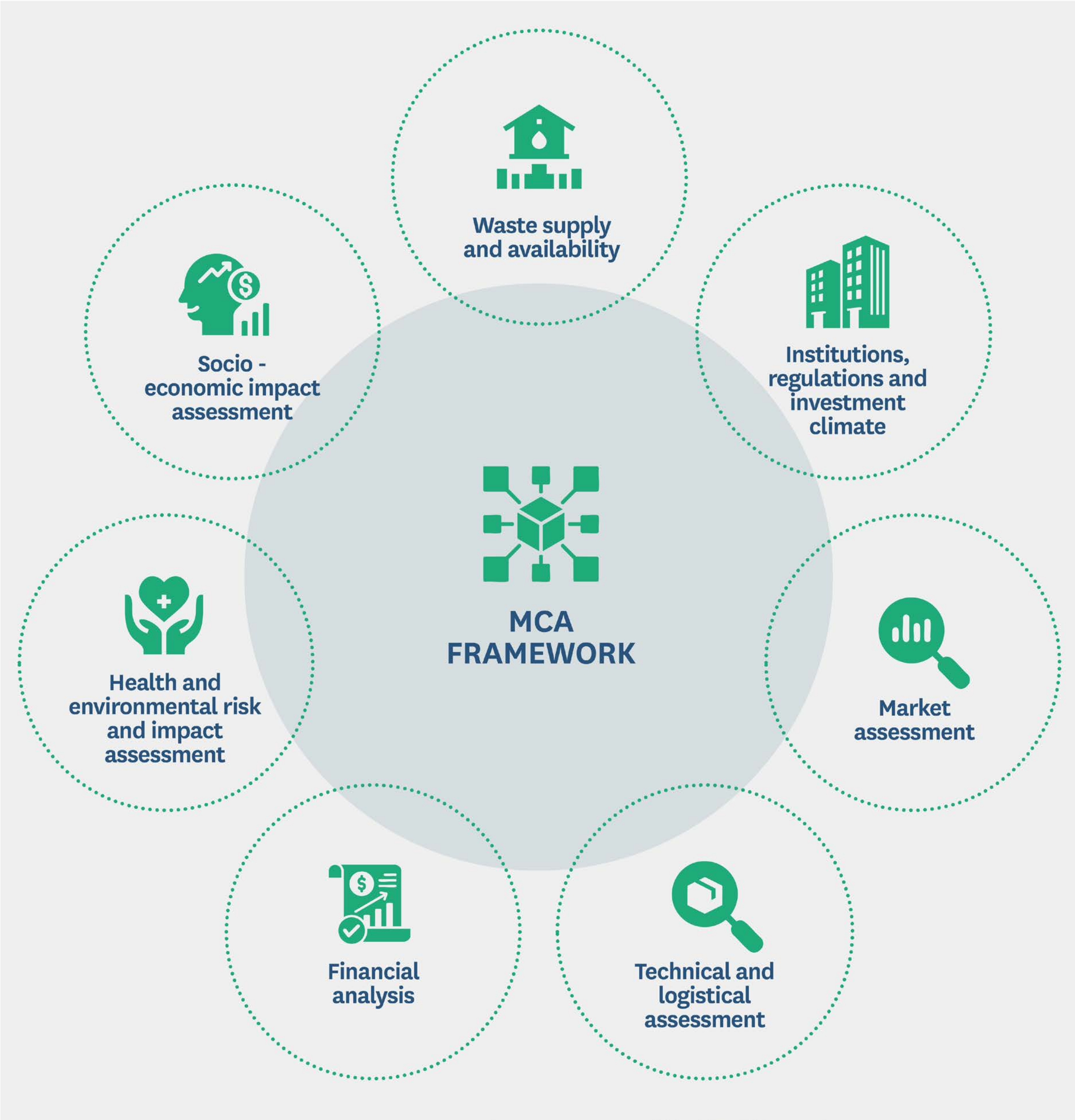

Figure 26. Criteria for the MCA framework

Source: Adapted from Otoo et al. 2016

Each criterion (outlined in Box 1) consists of a set of indicators evaluated based on the quantitative analysis (i.e. scoring, ranking and weighting) using a few research questions and sub-questions (presented in Annex 1) which are addressed through a specific methodology (Annex 2). The MCA framework provides an extensive range of criteria applicable for assessing the feasibility of a wide variety of CBE business models, thus, the list of criteria and indicators can be adapted by entrepreneurs based on the context or type of business model being analyzed.

Box 1. Assessment framework for the seven criteria of the MCA approach

Waste supply and availability

- Assessing the sustainability of the source (i.e. availability, quantity and quality of livestock waste), its supply and infrastructural support for effective collection and transportation of the livestock waste from origination points to the processing facility.
- Analyzing the prevailing range of market prices of livestock waste as well as costs associated with the procurement.

Institutions, regulations and investment climate

- Assessing the strengths and weaknesses of the institutional landscape (including laws, policies and incentive schemes).
- Analyzing the existing and forthcoming regulatory initiatives related to resource, recovery and reuse of livestock waste (including institutional/municipal/communal level support and inter/intra sectoral cooperations).
- Assessing the status of the investment climate for determining the probability of private sector participation in livestock waste management sector and the level of public acceptance in waste valorization and reuse.

Market assessment

- Assessing the market value of the recovered products (such as biogas and biofertilizer), the characteristics and dynamics of the market structure, long-term viability of recovered products in the market given existing or expected competition, pricing and marketing strategies for the CBE business model with respect to the targeted location.

Technical and logistical assessment

- Assessing the technical options available for the output production, accessibility to equipment, the level of resource requirements (including labor, land, transportation/storage space, continuous energy and water supply), the local institutional and human capacity to operate and maintain any suggested technology, related processes and production cycle.

Financial analysis

- Assessing the financial viability and cost recovery potential of the livestock waste related CBE business models utilizing few financial parameters including payback period, benefit-cost ratio (BCR), net present value (NPV) and internal rate of return (IRR).

Health and environmental risk impact assessment

- Assessing the potential hazards of the CBE business models to the society (including workers and public) and mitigation strategies to be compliant with national and international health and environmental standards
- Evaluating the potential health and environmental impacts (positive and negative) of the CBE model at the system boundary level.

Socio-economic impact assessment

- Assessing the social, health and environmental benefits and costs from the implementation of the livestock related CBE business model in the selected community or city including its effect on households, governments and other businesses.

Source: Adapted from Otoo et al. 2016

Development of a business plan for ensuring sustainability of the business

After determining the suitability of the CBE business model for the targeted location using an appropriate feasibility analysis method based on the objective of the entrepreneur and the proposed scale of operation, it is essential to develop a business plan as the next and crucial step for implementing the business and ensuring its sustainability. A business plan comprises of several key components that define the goals of a business and highlights the methods for attaining the goals (Figure 27). A successful business plan helps determine the financial needs of the proposed business model, to attract investors and secure additional funding, to form strategic alliances, to evaluate competitors and identify customer segments, and to set objectives for employees and managers.

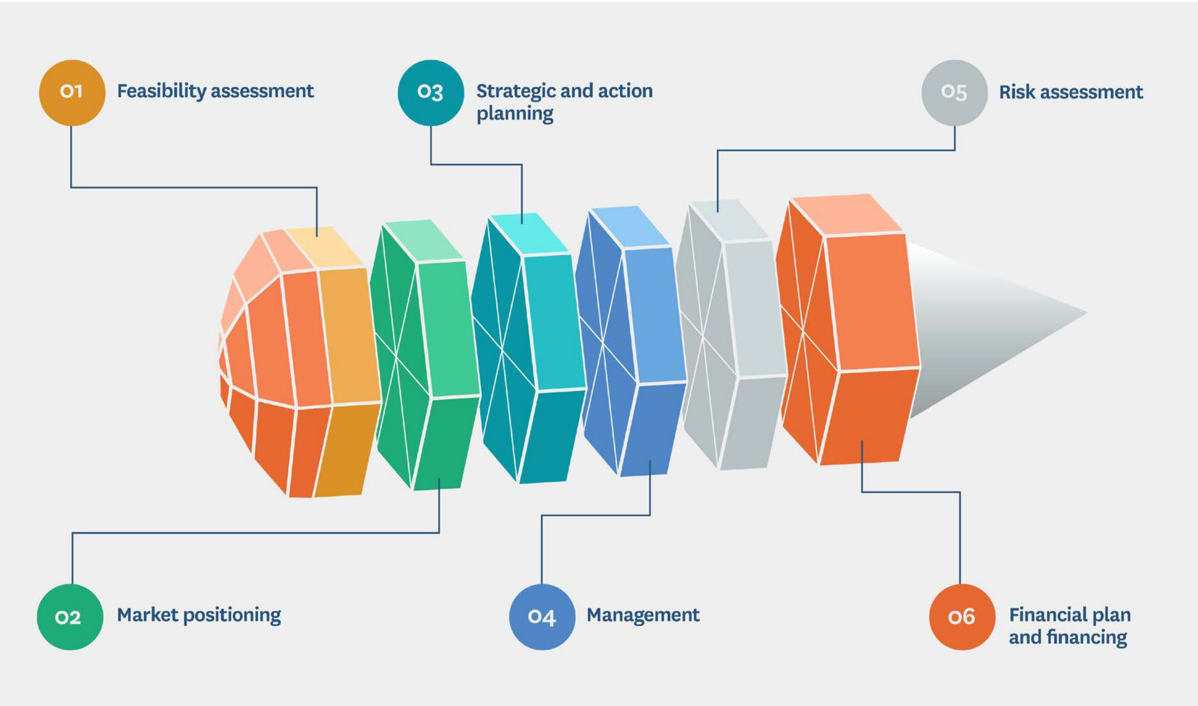

Figure 27. Key components of a business plan

Source: Authors' creation

Market positioning

The market positioning component of the business plan provides a description of the products and services offered by a business and highlights the values of the business relative to the competitors. This section describes the existing market gap where the entrepreneur will introduce the products as well as the customer segments to be targeted. The market mix is a tool used for defining the market position of a business which is a coherent combination of the four attributes (4 Ps) including product, price, place (distribution) and promotion (Figure 28), based on which the marketing strategy for a business is developed.

The **product** is the tangible aspect of products and services offered to the market (i.e. biogas, biofertilizer/organic manure and feed for aquaculture) with an aim to satisfy the needs of the targeted customers. Product can be categorized as core product, actual product or augmented product. In the case of livestock waste management products, the entrepreneurs need to clearly define the core and actual product on the basis of consumer need and quality, packaging and the design.

Price is the revenue generating element of the marketing mix. Revenue streams of a business model are made up of the price of the recovered product and the pricing model. The price of a product can be determined by adding a profit margin percentage to the costs (fixed and variable costs) associated with producing and distributing the product. The pricing approach should be logical and justified to produce adequate return on investment while leaving room for margin of error.

Place describes the channels of a business model, through which the business interacts with the customer to markets, sell and deliver their products. The includes a chain of distributors, wholesalers and retailers who shape the distributing channel of the business.

Promotion is the communication component of the marketing mix which describes the relationships the business establishes with the customer to promote the products/services offered and channels through which it promotes. Promotion strategies can include advertising, public relations and sponsorships, personal selling and sales promotion that play a crucial role in determining the positioning of the product in the target market.

Figure 28. The marketing mix

Source: Authors' creation

A few key questions (Figure 29) could be raised by entrepreneurs to determine the ideal pricing, place and promotion strategies for the proposed CBE business model, as follows:

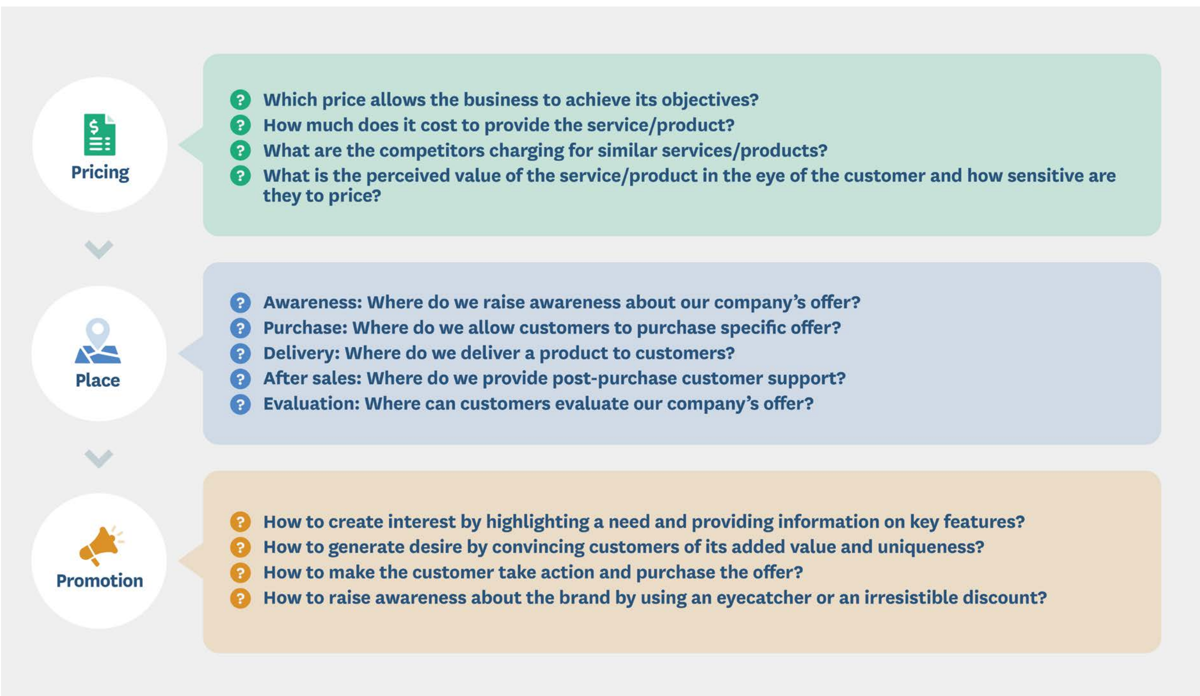

Figure 29. Key questions for determining the ideal pricing, place and promotion strategies

Source: Authors' creation

Strategic and action planning

Strategic and action planning involves identifying and implementing mission and vision statements of a business model by outlining production performance goals, defining pathways for accomplishing the objectives, setting-up timeline for activities and milestones, mapping out resource allocation techniques and developing evaluation processes for monitoring the progress.

A SWOT analysis is a significant tool for analyzing the strengths, weaknesses, opportunities and threats of a business model (Figure 30). It can aid the entrepreneurs to develop strategies and obtain competitive advantage, as follows:

- **S-O strategy**: How can you use your strengths to take advantage of the opportunities?
- **W-O strategy**: How can you use your opportunities to overcome the weaknesses?
- **S-T strategy**: How can you take advantage of your strengths to avoid real and potential threats?
- **W-T strategy**: How can you minimize your weaknesses and avoid threats?

Risk assessment and management

Businesses face a variety of risks including internal risks such as financial, market, technology and operational risks, and external risks such as legal and regulatory, environmental, economic and socio-cultural risks (Figure 31). Therefore, the identification, management and mitigation of risks are crucial for the success and sustainability of a business.

Figure 30. The components of SWOT analysis

Source: Authors' creation

Figure 31. Types of risks

Source: Authors' creation

The risk assessment and management process for a CBE business model consists of five essential steps (Figure 32). The process begins with describing the business environment and identifying the potential risks associated with the CBE business models to analyze the impacts of the risks on one another as well as on the business model. The identified risks should be evaluated individually to determine the probability, speed, vulnerability and repetitiveness. Following the evaluation, risks should be prioritized according to the level of impact, permeability and influence capacity. Finally, a suitable risk management plan should be developed and implemented along with continuous monitoring to ensure effectiveness. The execution of the overall process relies on a team of specialists with extensive knowledge in the field of risk management (Cervantes-Cabrera and Briano-Turrent 2018).

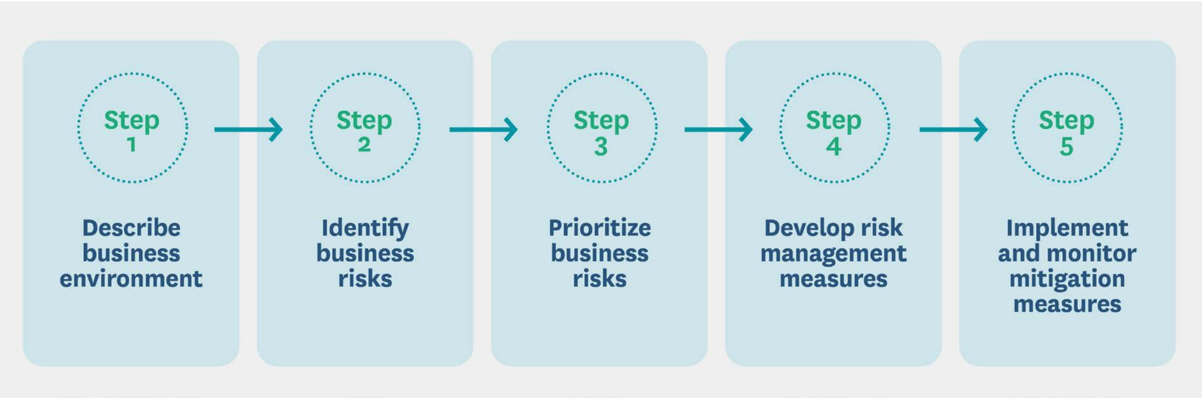

Figure 32. Steps of risk assessment and management process

Source: Authors' creation

Organization and management

Organization and management is a crucial component of the business plan as it introduces the management team responsible for day-to-day operations and outlines the organizational structure which are essential for smooth operation of the business leading to its success. Each CBE business model is distinctive in the type of employees needed depending on the products being recovered, yet, in general, the organization and management component of a CBE business model using livestock waste should highlight the following sections:

- The ownership structure, which could be a sole proprietorship, partnership or corporation.
- The internal management, which shows the department heads, including sales, marketing, administration and production.
- The external management, which includes an advisory board, consultants and R&D professionals to support the internal management.
- The human resources, which covers staffing requirements (part-time or full-time), skills needed for employees and the costs (proposed salaries, bonuses, profit sharing plans, etc.).

Financial plan and financing

The financial planning component of the business plan is essential for regulating the investment activities of a business and for ensuring proper utilization of available financial resources. This section outlines the start-up budget for the business model which depends on the waste-to-resource option, scale of operation, required technology, existing partnerships and use of public infrastructure. Besides, it covers the main financial statements in terms of profit and loss statements, balance sheet and cash flow statements (Figure 33). Furthermore, the key financing resources required for the functioning of the proposed CBE business model should also be discussed (Box 2).

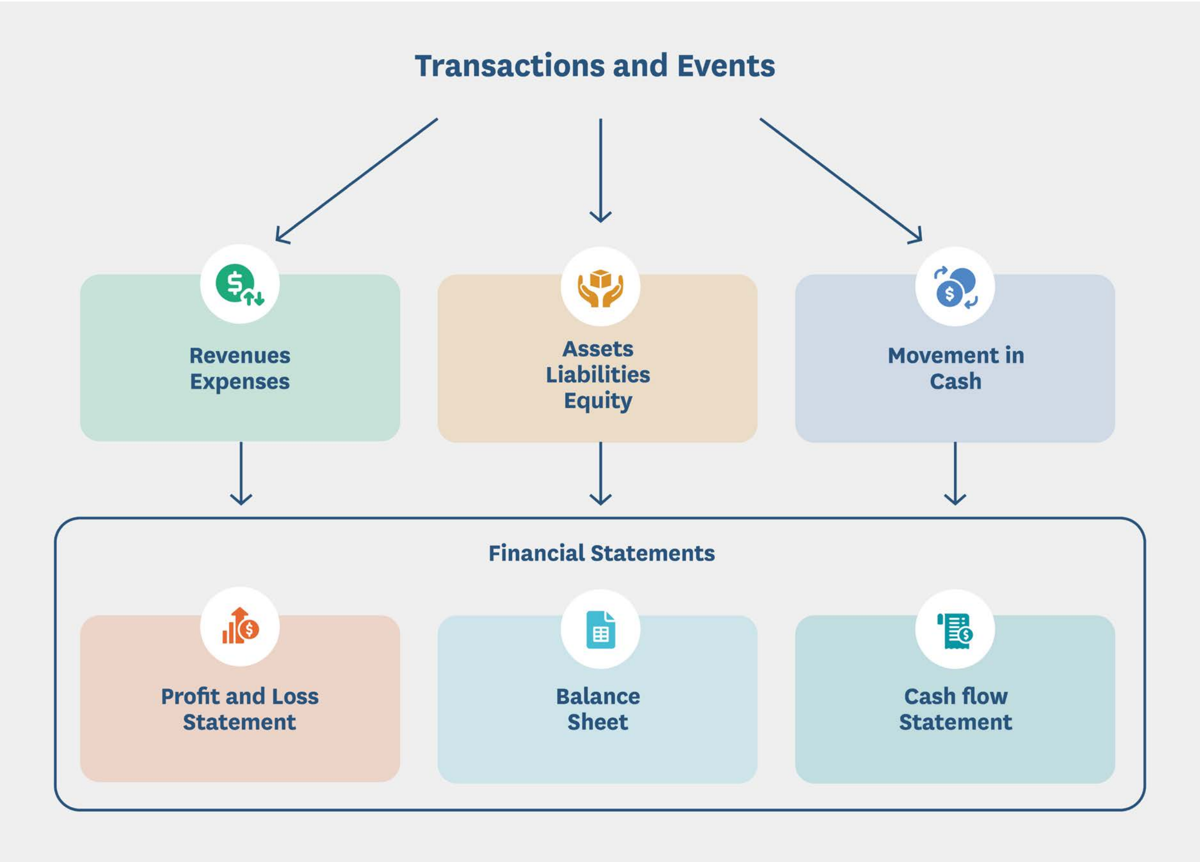

Figure 33. Main financial statements of a business model

Source: Authors' creation

Box 2. Key financial resources for a CBE business model utilizing livestock waste

Self-financing and informal financing

Self-financing refers to the use of personal savings or assets to cover the initial investments. Informal financing involves borrowing money from friends or family members, while it can offer several advantages such as accessibility, flexible terms and lower interest rates, it can also have several drawbacks such as lack of documentation and clarity and limited funding capacity.

Debt financing

Debt financing refers to selling debt instruments in the form of bank loans or bonds to individuals or institutions such as bank or other lending institutions for capital expenditures. Debt financing allows business to leverage a small amount of capital retaining all ownership control and are generally tax detectable. However, payments on debt should be made regardless of the revenue which could be risky for businesses with inconsistent cash flow.

Equity financing

Equity financing is the process of raising capital by selling the shares of ownership of the business to investors and stakeholders. Unlike debt financing, the payment need not be repaid in equity financing, furthermore, large investors can offer business expertise, guidance and resources for successful operation of the business. Yet it requires the entrepreneurs to share a part of the profit which could be a potential drawback.

Public funding

Public funding plays a significant role in promoting circular transitions among entrepreneurs. Governments of emerging economies are supporting sustainable livestock waste management businesses, especially in rural communities through cost sharing (of capital cost), as well as offering financial assistance to waste management systems recovering biogas, biofertilizer and organic manure through subsidies (Figure 34), tax exemptions, green bonds, loans, grants and public credit guarantees and public-private blended finance.

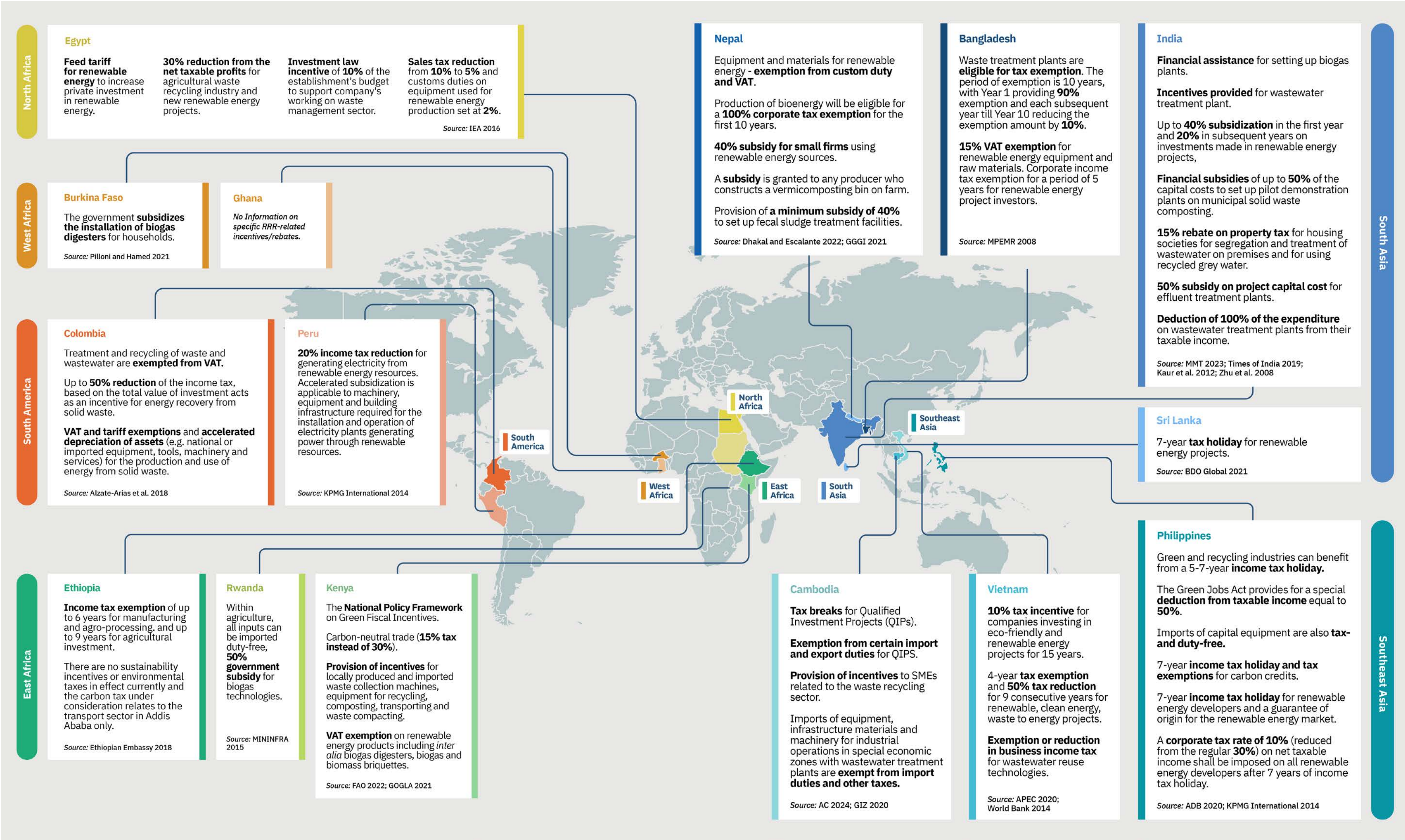

Figure 34. Overview of RRR-related incentives provided by selected countries
Source: Authors' creation

The national governments of several countries from South Asia, East Asia and Pacific, Africa and Latin America and the Caribbean regions provide part (16% to 85%) of the investment cost of biogas plant as subsidies to promote the adoption of biogas technology. A few South Asian countries such as India, Bangladesh and Nepal offer subsidies (30% to 50%) for implementing composting plants for processing livestock waste (Figure 34). Notably, while subsidies can be beneficial during the initial stages of business development and in achieving financial sustainability, complete reliance on them may pose financial risks once they are withdrawn.

To conclude, this chapter summarizes the different components of the business plan and their role in outlining the vision and mission statements, timeline for activities, financial performance goals, growth expectations, risk management strategies, structures and roles of different stakeholders, resource allocation techniques and marketing strategies for the implementation of selected CBE business models.

Conclusion

The main objective of this chapter is to develop guidelines for willing entrepreneurs, farmers, trusts, cooperatives and social enterprises to determine the feasibility of their business proposition. While a baseline survey is sufficient for small and medium businesses, large-scale businesses need to complete a multicriteria assessment. This is based on analyzing waste supply and availability, institutions, regulations, market assessment, technological assessment, financial analysis, health and environmental risk and impact, and socioeconomic assessment.

Following the feasibility analysis, a business plan needs to be prepared irrespective of the business size. The business plan highlights the market assessment, risks, financial requirements, strengths and weaknesses in the business operations. There are different sources of finances for such a business, and the enterprise needs to carefully plan based on the availability of its own sourced fund (equity). This includes debt financing, available subsidies, and collaborations with public organizations for loans and grants. Although this chapter discusses the feasibility analysis and contents of a business plan, conducting a feasibility analysis and a plan requires careful data accumulation to make an informed decision about sustainability. To convert the challenges into an enabling environment, developing strategic partnerships remains a key driver for business growth in most developing economies.

Countries such as India, Indonesia, China and Kenya are effectively establishing government-industry-academia partnerships to encourage the incubation of new businesses in various sectors, thereby promoting the overall economic growth. Establishing partnerships among diverse stakeholders beyond the value chain, for example the partnership between government, industry, and universities, can also be effective in enabling successful circular economy transformations in the livestock waste management sector, which can help to overcome crucial barriers including R&D and technical limitations and skilled labor requirements.

Public institutions are playing a key role in promoting sustainable start-ups. For example, PROCOMER in Costa Rica conducts knowledge exchange programs to strengthen entrepreneurial skills of green start-ups which can be supportive in assisting CBE businesses to accelerate their expansion to overcoming the existing market barriers.

The feasibility analysis and business plan process highlights ways and mechanisms to understand and estimate the challenges or input, costs, technologies and market for converting the challenges into driver of scaling the business.

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Annex 1. Business Model Canvas

<table>
<tr>
<td rowspan="2">Key partners

Who are your key partners?

Who are your suppliers?

Which key activities do partners perform?</td>
<td>Key activities

Which key activities do your value propositions require?
Your channels? Customer relationships? Revenue streams?</td>
<td rowspan="2">Value propositions

What benefits are they deriving from this bundle of products and services?

What added value do you deliver to the customer?

Which one of your customers’ problems are you helping to solve?

Which customer needs are you satisfying?</td>
<td>Customer Relationships

What type of relationships does each of your customer segments expect you to establish and maintain with them?

How are they integrated with the rest of your business model?</td>
<td rowspan="2">Customer segments

For whom are you creating value?

Which jobs do they really want to get done?

Who are your most important customers?</td>
</tr>
<tr>
<td>Key resources

Which key resources do your value propositions require? Your channels? Customer relationships? Revenue streams?</td>
<td>Channels

Through which channels do your customer segments want to be reached, buy your offer and receive after-sales support?

How are you integrating them with customer routines?</td>
</tr>
</table>

<table>
<tr>
<td>Cost structure

What are the most important costs inherent in your business model?
How much does each cost item contribute to overall costs?</td>
<td>Revenue streams

For what value are your customers really willing to pay?
How are they currently paying?
How much does each revenue stream contribute to overall revenues?</td>
</tr>
<tr>
<td>Social and environmental costs

What are the potential environmental risks of your business?
What are the potential health risks for workers and the wider society?</td>
<td>Social and environmental benefits

What potential benefits could your business model bring to the environment?
Can your business model improve health/reduce hazards?
Does it provide jobs?</td>
</tr>
</table>

Annex 2. Summary of indicators and research questions for each criterion (adapted from Otoo et al. 2016)

Criteria	Indicators	Research questions
Waste supply and availability	A1. Sources, quantity, quality of generated and available waste	• What are the waste sources, amount generated, quality thereof that are currently collected?
	A2. Reliability of resource supply	• Is the waste found all over town and available every month?
	A3. Competitors' index for waste resource	• What is the current use of the waste i.e., which potentially competing alternative destinations exist?
	A4. Status of legal, institutional and	• Is the waste supply legal and who are the actors along the sanitation service chain providing the resource?
Institutions, regulations and investment climate	B1. Structure and capacity of institutions	• What organizations and boundary partners involved in sanitation influence RRR in the locality under consideration and what are their responsibilities and interlinkages? • What are the processes and instruments for implementation, monitoring and enforcement? • Are there any gaps in the types of stakeholders that would make it difficult to establish • RRR initiatives/businesses?
	B2. Policy and legal framework support	• What policy and regulatory/ legal documents exist in support of or in opposition to RRR and sanitation? • Is legislation enforced? • What supportive legal incentives are there for existing and future RRR interventions? • How easy is land access? • Are there any stakeholders that will make the implementation of RRR initiatives particularly easy or difficult and how influential are they?
	B3. Level of budgetary and other incentives for engagement	• What is the level of budgetary or fiscal support for RRR initiatives, if any? • Are there investors, banks or donors in the city who are interested in funding sanitation and RRR businesses?
	B4. Community support	• What is communities' awareness of laws around waste, sanitation and RRR? • Are communities aware of the RRR objectives? • What kind of RRR options communities know, how do they perceive/support/reject them, and can we explore communities' perceptions about other RRR options?
	B5. Status of investment climate for RRR operations	• What is the status of the capital market as related to the willingness of financial institutions to invest in RRR initiatives, probable terms of financing available from banks and other investors, and the nature of financing mechanisms? • What are the local determinants of a supportive investment climate and implications for new business set up and development in the RRR sector?
Market assessment	C1. Theoretical market segments and size	• What are potential market segments and their sizes? • Are these segments already using a related product or could they be open to it? • How much of the product would these clients need over the year and when under different growth scenarios?

	C2. Market value of recovered resource (via WTP) and possible market size	• What is the market value of the resource? • How much are consumers per market segment willing to pay [vs. their ability-to-pay] for the created RRR product? • What factors are likely to affect the demand for these products? • What is the possible market size?
	C3. Market structure – competitive advantage index	• What is the structure of the market for the recovered resource? • How do competitors set their prices?
	C4. Market outlook of recovered resource	• What is the market outlook, market trends/ growth? • To what extent will the RRR product be viable over time in a competitive market?
	C5. Pricing strategy	• What are the most effective pricing strategies (price markups by segment/ marginal profitability by market segments) for the RRR product?
	C6. Marketing interest, capacity and strategy	• What are the optimal market segments and marketing strategies for the business? • What strategies are available to maximize profits and minimize risks associated with the optimal market segment?
	C7. Optimal location of business	• Where is the optimal location to site an RRR business processing plant? • What are the optimal numbers and sizes of the RRR processing plant(s)? • What factors (like transportation) are likely to affect the implementation of the optimal plant in a given location?
	C8. Distribution strategies	• What are the distribution strategies (efficiency of distribution systems) of the business? • Which partner can help cutting distribution costs?
Technical and logistical assessment	D1. Availability of technologies	• What suitable technologies are available locally for the proposed RRR intervention?
	D2. Technology (resource) requirements index (spare parts, other production factors)	• Are there resource constraints related to labor, land, energy or other factors of production?
	D3. Performance and efficiency of technology	• What is the level of performance and efficiency of the proposed technology?
	D4. O&M requirements	• Are the required technologies, finance, regulations and incentive mechanisms available to support timely repair and maintenance?
Financial analysis	E1. Operating cost index production cost indicators	• Is the business financially viable and under what conditions? • Can the product be produced costeffectively with positive profits and under what conditions? • Is the firm operating at an optimal production capacity based on the choice of technical process, related costs, etc.?
	E2. Operational index (e.g. operating and financial self-sufficiency)	
	E3. Payback period; financial benefit-cost ratio	
	E4. Economies of scale and financial sustainability across core business partners	
	E5. Firm performance (percentage of cost recovery, profitability ratio, inventory turnover ratio, market growth rate)	

	E6. Firm's performance under risk	• What are the uncertainties associated with key performance indicators of the business model and how do they affect the overall financial viability of the business model? • What are the probabilities and implications/effects of 'adverse' events on the viability of the business model, given changes in market demand, supply chain, technology, capital markets, etc.?
Health risk and impact assessment	F1. Work-related risks (types, frequency and severity of potential accidents) at the resource recovery unit	**Occupational and consumer (user of recovered resource) health risk** • What are the potential critical exposure points along the value chain of the RRR intervention under consideration? • What are the known occupational health hazards associated with the implementation of the RRR intervention (from waste acquisition to transformation)? • What are the potential risks to the different exposure groups (e.g., workers, consumers, farmers)? • What are the potential health impacts (positive and negative) at the specific system boundary level?
	F2. Risk of exposure to pathogens and toxic substances from inputs, outputs and byproducts of the process (waste acquisition to transformation into final product)	
	F3. Health risk reduction strategies in place (e.g., safety equipment, training) for the waste to resource process	**Risk mitigation measures** • What are the relevant national standards to be observed and complied with for the proposed RRR intervention? • What (additional) risk mitigation processes/measures can be put in place along the value chain? • What institutional arrangements exist for health risk assessment, mitigation and monitoring, and how effective are they? • What is the most cost-effective combination of control measures to guarantee a safe end-product? • What operational and verification monitoring is needed (parameter and critical limit) as well as incentive systems for compliance to ensure that the controls are working as required?
	F4. Practicable strategies available for adherence of end-product to public health standards	
	F5. Potential health benefits of the proposed RRR intervention	• How do the RRR-induced risks compare at the community level with similar risks not related to the proposed RRR intervention?
	F6. Comparative risk assessment in the local context	• How do the RRR-induced risks compare at the community level with similar risks not related to the proposed RRR intervention?
Environmental risk and impact assessment	G1. Estimated atmospheric emissions (e.g., GHG emissions) from the resource recovery process	• What are the potential environmental risks and impacts of the proposed RRR intervention?
	G2. Estimated emissions (solids and fluids) to waterbodies and soil	
	G3. Existing affordable mitigation strategies available for mitigation of likely emissions	
	G4. Potential positive and negative environmental impacts of the proposed RRR intervention and use of recovered resources in the long run	

Socio-economic impact assessment	**Socio-economic benefit indicators**	**Socio-economic cost indicators**	• What are the expected (monetized) financial, social, health and environmental benefits and costs from the implementation of the proposed RRR intervention(s) within the selected system boundary?
	H1. Estimated number of direct and indirect jobs created H2. Estimated energy offsets (electricity, fuel, etc.) H3. Incremental gain in crop yield H4. Foreign currency saved from reduced import of substitute products (e.g. fertilizer, energy, etc.) H5. Cost savings (transport, labor) from averted waste disposal	K1. Estimated number of jobs lost due to RRR intervention K2. Estimated increase in energy demand from waste transformation K3. Increase in on-farm labor requirements through compost use	
	Environmental benefit indicators	**Environmental cost indicators**	
	I1. Cost savings from estimated averted atmospheric GHG emissions I2. Water conservation index based on averted direct emission of untreated waste into waterbodies I3. Land conservation index based on averted effect from waste reuse vs. baseline scenario I4. Cost savings – market value of land used for landfills (economic value of land made unusable by direct disposal of untreated waste)	L1. Costs of disamenity effects of intervention as measured by: • Costs of estimated atmospheric GHG emissions from the resource recovery process • Estimated emissions (solids and fluids) to waterbodies and soil	
	Health benefit indicators	**Health cost indicators**	
	J1. Cost savings from averted human exposure to untreated waste (reduced level of exposure to pathogens and toxic substances) J2. Improved health through more nutritious food or cleaner energy produced with waste derived fertilizer/fuel	M1. Level of exposure to pathogens and toxic substances from inputs, outputs, and byproducts of the process	

Annex 3. Methodology for feasibility ranking of the seven criteria of MCA framework (Otoo et al. 2016)

Annex 3A. Methodology for feasibility ranking of the waste supply and availability criterion

RANKING OF KEY INDICATORS				FEASIBILITY RANKING
1. AMOUNT OF AVAILABLE QUALITY WASTE (A1)	2. RELIABILITY OF RESOURCE SUPPLY (A2)	3. COMPETITORS' INDEX FOR THE WASTE RESOURCE (A3)	4. STATUS OF THE LEGAL, INSTITUTIONAL AND REGULATORY ENVIRONMENT (A4)	
Waste resource under consideration is inexistent and/or inaccessible	Significant variations in availability and accessibility in quantity and quality of the waste resource	High level of competition for the waste resource	Access and use of the waste resource under consideration is not permitted by law	NO FEASIBILITY
Waste resource is available but accessible in limited quantity and/or quality	Moderate variations in spatial or temporal availability of the waste resource, related mitigation measures come at a high cost	Moderate level of competition – mitigatable effects at high cost	Use of the waste resource is permissible but there are significant access constraints related to national legislature	LOW FEASIBILITY
Waste resource is readily available and accessible in required quantities and qualities	Minimal variations in availability and supply of the required waste resource – variations can be mitigated (e.g. storage of the resource)	Minimal existing use of the particular waste resource (moderately low number and scale of related entities)	Access and use of waste resource is permitted by law with considerations that can be addressed	MEDIUM FEASIBILITY
Waste resource is readily available and accessible in required quantities and qualities	The waste resource is available in proximity and when needed	Limited to no existing use of the waste resource under consideration	Access and use of the targeted waste resource is permitted by law	HIGH FEASIBILITY

Source: Otoo et al. 2016

Annex 3B. Methodology for feasibility ranking of the institutions and regulations criterion

RANKING OF KEY INDICATORS			FEASIBILITY RANKING
1. ENABLING ENVIRONMENT (B2, B3, B5) • **RRR legislation and policy** • **Financing RRR** • **Investment climate for private sector engagement**	**2. IMPLEMENTATION STRUCTURE AND CAPACITY (B1)** • **Implementing agencies and capacities** • **Company establishment**	**3. COMMUNITY ACCEPTANCE AND SUPPORT (B4)** • **Local values for waste and public RRR acceptance and engagement** • **Compliance with laws and regulations**	
1. No policy exists to support RRR and/or reuse is illegal 2. No budget support for funding RRR 3. Legislation restricts private sector participation in RRR	1. No dedicated sanitation department 2. No/low capacity of all institutions involved in sanitation/RRR resulting in poor waste collection, transformation, recovered resource marketing 3. No companies involved in RRR or waste management	1. No awareness about RRR and waste management 2. No acceptance by end users for RRR products because of culture and/or risk perceptions 3. No or very low compliance by citizens and private companies in following waste management and reuse rules/regulations	NO FEASIBILITY
1. Policy and legislation support for RRR 2. Low budget support for funding RRR 3. Legislations on PPP are weak and no incentives to encourage private sector participation	1. Dedicated sanitation department with focus on waste management only and no/limited knowledge of RRR 2. No/low capacity of the institutions involved in waste management resulting in poor functioning and need for costly outsourcing of functions 3. Time taken to legally register RRR and waste management companies is too long and a complicated process	1. Low awareness about RRR and waste management 2. Mixed response of end users on RRR products 3. Low compliance by citizens and private companies in following waste management and reuse rules and regulations	LOW FEASIBILITY
1. Policies and legislation support RRR 2. Budget support provided for co-funding RRR 3. Legislation supports PPP but incentives to encourage private sector participation are limited	1. Dedicated sanitation department with focus on RRR exists and functions well 2. Sufficient capacity exists in the institutions involved in RRR from waste transformation to the marketing of the generated products 3. RRR and waste management companies can be easily set up	1. Awareness about RRR and waste management exists but is not high enough 2. End users accept and value RRR product(s) 3. Compliance by citizens and private companies can realistically be improved	MEDIUM FEASIBILITY
1. Policies and legislation support RRR 2. Sufficient budget support provided for funding RRR by the public sector 3. Legislation supports PPP and encourages private sector participation	1. Dedicated sanitation department with focus on RRR exists and functions well 2. Sufficient capacity exists in the institutions involved in RRR from waste transformation to the marketing of the generated products 3. RRR and waste management companies can be easily set up	1. High awareness about RRR and waste management 2. End users accept and value targeted RRR product(s) 3. Most citizens and private companies follow waste management and reuse rules and regulations	HIGH FEASIBILITY

Annex 3C. Methodology for feasibility ranking of the market criterion

RANKING OF KEY INDICATORS				FEASIBILITY RANKING
1. MARKET SIZE (C1)	**2. WILLINGNESS TO PAY (C2)**	**3. MARKET STRUCTURE (C3)**	**4. MARKET OUTLOOK (C4)**	
Market too small or unreliable to cover expected costs	WTP < current market price of all competitive substitute products	1. Difficult market entry 2. High level of concentration (monopolistic/oligopolistic market) 3. High level of product differentiation of competitive products 4. Price taker 5. Potential negative profit margins (without subsidies) *[links to Financial criterion]*	10 years and beyond to reach growth stage	NO FEASIBILITY
Market small but reliable	WTP < current market price of the next best substitute product	1. Medium to difficult market entry 2. Medium to high level of concentration 3. Medium to high level of product differentiation of competitive products 4. Price taker 5. Potential negative profit margins (without subsidies)	10 years and beyond to reach growth stage	LOW FEASIBILITY
Market potentially large but also unreliable	WTP > current market price of the next best competitive substitute product	1. Medium level of ease for market entry 2. Low to medium levels of market concentration 3. Limited to no product differentiation 4. Oligopolistic fertilizer market but potential price setter 5. Potential that net profit margins are positive	5–9 years to reach growth stage in business life cycle	MEDIUM FEASIBILITY
Market appears large and reliable	WTP > current market price of all competitive substitute products	1. Easy market entry 2. Limited level of market concentration 3. Limited to no product differentiation 4. Price setting market 5. Potential that net profit margins are positive	<5 years to reach growth stage in business life cycle	HIGH FEASIBILITY

Annex 3D. Methodology for feasibility ranking of the technology criterion

RANKING OF KEY INDICATORS				FEASIBILITY RANKING
1. AVAILABILITY/ ACCESSIBILITY OF TECHNOLOGY AND SPARE PARTS (D1)	**2. TECHNOLOGY REQUIREMENTS INDEX (D2)**	**3. PERFORMANCE AND EFFICIENCY OF THE TECHNOLOGY (D3)**	**4. O&M REQUIREMENTS (D4)**	
Required technologies or spare parts not available	Limited to no access and availability of production factors	Low performance	High with low performance incentives	NO FEASIBILITY
Limited availability of technology (acquisition at relatively high cost)	Moderate access and availability to production factors but at exorbitantly high cost (above market price)	Low to medium performance	Low with low performance incentives	LOW FEASIBILITY
Moderate access and availability of technology at current market prices	Moderate access to production factors at current market prices	Medium performance	High but with good incentives and financial support	MEDIUM FEASIBILITY
Easy access and availability of required technology	Easy access and availability to production factors	High performance	Low with good incentives and support	HIGH FEASIBILITY

Annex 3E. Methodology for feasibility ranking of the financial criterion

RANKING OF KEY INDICATORS			FEASIBILITY RANKING
1. P (NEGATIVE NPV)*	**2. MEAN NPV**	**3. MEAN IRR**	
0-30%	Negative	Less than discount rate	NO FEASIBILITY
30-50%	Negative	Less than discount rate	
50% and above	Negative	Greater than discount rate	
50% and above	Negative	Less than discount rate	
30-50%	Negative	Greater than discount rate	LOW FEASIBILITY
50% and above	Positive	Less than discount rate	
0-30%	Negative	Greater than discount rate	LOW TO MEDIUM FEASIBILITY
30-50%	Positive	Less than discount rate	
0-30%	Positive	Less than discount rate	MEDIUM FEASIBILITY
50% and above	Positive	Greater than discount rate	
0-30%	Positive	Greater than discount rate	MEDIUM TO HIGH FEASIBILITY
30-50%	Positive	Greater than discount rate	HIGH FEASIBILITY

Annex 3F. Risk analysis matrix based on indicators f1 and f2, considering f3

RISK = L X S
Very high ≥
Risk 32
High risk 13-32
Medium risk 7-12
Low risk <6

LIKELIHOOD (L)		SEVERITY (S): Insignificant 1	Minor impact 2	Moderate impact 4	Major impact 8	Catastrophic impact 16
Very unlikely	1	1	2	4	8	16
Unlikely	2	2	4	8	16	32
Possible	3	3	6	12	24	48
Likely	4	4	8	16	32	64
Almost certain	5	5	10	20	40	80

Annex 3G. Methodology for feasibility ranking of the financial criterion

RANKING OF KEY INDICATORS: 1. P (NEGATIVE NPV)*	2. B:C ratio	3. MEAN IRR	FEASIBILITY RANKING
0–30%	< 1	Less than discount rate	NO FEASIBILITY
30–50%	< 1	Less than discount rate	
50% and above	< 1	Greater than discount rate	
50% and above	< 1	Less than discount rate	LOW FEASIBILITY
30–50%	< 1	Greater than discount rate	
50% and above	< 1	Less than discount rate	
0–30%	> 1	Greater than discount rate	
30–50%	> 1	Less than discount rate	
0–30%	> 1	Less than discount rate	
50% and above	> 1	Greater than discount rate	MEDIUM FEASIBILITY
0–30%	> 1	Greater than discount rate	
30–50%	> 1	Greater than discount rate	HIGH FEASIBILITY

Notes: Defined as the probability of the NPV to be negative.

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