Circular Economy for Sustainable Animal Feed: Harnessing Sargassum Fluitans for Food Security and Coastal Restoration in Lagos State, Nigeria

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ABSTRACT

In response to growing global concerns over feed scarcity, rising production costs, and coastal degradation, this study explores the transformative potential of Sargassum fluitans within a circular economy framework. The research assessed the sustainability of using this nutrient-rich yet environmentally problematic seaweed as an alternative animal feed ingredient for chickens, fish, pigs, and rabbits in Lagos State, Nigeria. Despite its abundance, Sargassum remains underutilized due to the absence of effective Monitoring and Evaluation (M&E) frameworks that ensure project efficiency, economic feasibility, and long-term sustainability. Guided by Implementation Theory and Theory of Change, this study employed a mixed-methods approach. A 12-week randomized controlled trial was conducted to evaluate the nutritional performance, growth metrics, and survival rates of animals fed Sargassum-based diets. Feed safety was ensured through Hazard Analysis and Critical Control Points (HACCP), while Linear Programming Optimization (LPO) developed cost-effective feed formulations. Quantitative data were analyzed using ANOVA and t-tests; qualitative insights were supported by stakeholder engagement and Logical Framework Analysis (LFA). Findings revealed that Sargassum-based feed is nutritionally comparable to conventional feeds and significantly reduced feeding costs by 55.5%. It enhanced animal growth, improved food security, generated green jobs, and contributed to coastal restoration by reducing Sargassum waste buildup. By closing material loops and repurposing marine biomass, the study offers a replicable model for integrating marine resources into sustainable agriculture. The result-based M&E framework ensured accountability, informed decision-making, and scalability, aligning the project with SDGs 2 (Zero Hunger), 8 (Decent Work and Economic Growth), 12 (Responsible Consumption and Production), 13 (Climate Action), and 14 (Life Below Water). This research repositions Sargassum from an ecological burden to a blue economy asset, offering a novel, data-driven, and locally adaptable solution for sustainable livestock production in sub-Saharan Africa.

Keywords*:* Sargassum fluitans; Circular economy; Sustainable animal feed; Monitoring and evaluation; Blue economy; SDGs; Cost optimization.

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INTRODUCTION

Background to the Study

Project management is increasingly recognized as a crucial factor in promoting project sustainability globally, including in Africa (Orieno, Ndubuisi, Eyo-Udo, Ilojianya, & Biu, 2024). Its application extends to agriculture and related industries, where circular economy principles are gaining prominence in enhancing sustainability and resource efficiency. Project management facilitates the integration of economic, social, and environmental

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considerations throughout the project life cycle, ensuring a balanced approach to sustainable development (Dubois & Silvius, 2020; Orieno et al., 2024). Sustainable project management requires continuous monitoring and evaluation to keep projects on track, generate critical insights, and support organizational learning, particularly in the agricultural sector (Akinradewo, Aigbavboa, Ogunbayo, Thwala, Tanga, & Akinradewo, 2022).

Pehu (2023) and Maddock (2023) highlight that the absence of monitoring and evaluation (M&E) in agricultural development projects can have significant negative consequences. One major issue is inefficiency, as the lack of systematic assessment makes it difficult to determine whether project objectives are being met effectively. Without data-driven feedback on what works and what does not, resources may be misallocated, resulting in waste and suboptimal outcomes. Furthermore, the absence of M&E weakens accountability, which is essential for ensuring that stakeholders fulfill their roles and responsibilities. Without proper evaluation mechanisms, transparency diminishes, making it difficult to assign responsibility for failures, ultimately eroding trust in project outcomes.

Moreover, M&E facilitates continuous learning and improvement by identifying lessons learned and best practices. Without these processes, opportunities for refinement throughout the project lifecycle are lost, increasing the risk of project failure. Finally, without systematic monitoring, it becomes challenging to assess the actual impact of the project on beneficiaries and the broader community. This ambiguity can weaken credibility and hinder efforts to secure funding for future initiatives, as stakeholders may hesitate to invest in projects with uncertain outcomes (International Fund for Agricultural Development [IFAD], 2023).

Agriculture is described as the art and science of planting of crops and rearing of animals. It can also be referred to as the backbone of many economies, a nexus where innovation, technology, and community engagement converge to shape the future. The World Bank (2024), states that agriculture has the potential to alleviate poverty for 75% of the world's population, especially in developing countries, where it can contribute over 25% of Gross Domestic Product (GDP). This projection is significant considering the anticipated global population of 9 billion by 2050 (United Nation, Department of Economic and Social Affairs [UNDESA], 2022). Animal farming specifically plays a crucial role in food security, contributing 40% to Africa's agricultural GDP (Mamphogoro, Mpanza, & Mani, 2024). Building on this, Nigeria's animal sector contributed 22.35% to the total GDP in the first quarter of 2021 (National Bureau of Statistics, 2023), with a significant portion of the population dependent on animal farming, including chicken, fish, pig, and rabbit farming.

Sustainable agricultural projects contribute to economic resilience and environmental conservation with animal feed ensuring a stable and sustainable food production system (SAP Integrated Report, 2024). Sustainable agricultural development is critical to ensuring food security and economic stability, particularly in developing nations such as Nigeria. Some of the challenges facing Nigeria's animal production sector include climate change, which disrupts food production, leading to food scarcity and creating urgency and potential for mismanagement (Abu, Azor & Ohioze, 2021). Resource depletion and population growth also threaten agricultural productivity, but most importantly, agricultural mismanagement further worsens both climate change and food scarcity (Akpotu & Chukwuka, 2023).

Animal feeds play a significant role in the food chain, with their safety recognized as a shared responsibility (Food and Agriculture Organization [FAO], 2020). Despite Nigeria's animal sector being vital for protein supply, Anosike, Rekwot, Owoshagba, Ahmed, and Atiku (2018) report that 80% of animal production costs are allocated to feeding. Nigeria's animal production industry is burdened by the high cost and scarcity of conventional animal feed, primarily driven by the increasing demand for feed ingredients. The country heavily relies on imported feed components such as maize, making the sector vulnerable to global supply chain disruptions, exchange rate fluctuations, and rising production costs, thereby creating economic challenges for local farmers (Angbulu, 2023).

For instance, the rising cost of conventional poultry feed in 2023 led to the closure of over half of Nigeria's poultry farms, causing significant economic hardships, poverty, and food insecurity (Poultry Association of Nigeria [PAN], 2024). As of June 2024, PAN reported that poultry farm closures contributed to a 15% increase

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in egg prices. During this period, the price of maize surged from ₦550,000 in May 2024 to ₦820,000 per tonne, marking nearly a 50% rise in just one month.

Globally, 56% of maize production is used for animal feed, while only 13% is directly consumed by humans (FAO, 2021). The cultivation of maize requires extensive land use, substantial freshwater resources, and significant time investment, leading to competition between animal feed and human food sources (Erenstein, Jaleta, Sonder, Mottaleb, & Prasanna, 2022). These challenges highlight the need to explore alternative, cost-effective, and sustainable feed sources, such as Sargassum-based animal feeds.

Each year, Sargassum, a marine seaweed biomass, is transported by ocean currents to beaches along the Atlantic coastlines, including Africa, between March and August (Araújo, Vázquez, Sánchez, Azevedo, Bruhn, Fluch, Garcia, Ghaderiardakani, Ilmjärv & Laurans, 2021). Sargassum thrives due to a combination of natural and human factors, such as changes in ocean currents, climate change, deforestation, industrial activities, and the inflow of pollutants like nitrogen, phosphorus, and iron into rivers (Adet, Nsofor, Ogunjobi, & Camara, 2017). In Nigeria, Sargassum fluitans was observed in large quantities as recently as 2011. The accumulation of this seaweed along Nigeria’s 960 km coastline has become a concern for coastal residents and businesses. Its excessive buildup negatively impacts marine ecosystems, tourism, fishing, transportation, and local economies, as it makes beaches less attractive and produces a strong, pungent odor (Adet et al., 2017). Despite the environmental, social, and economic challenges Sargassum poses to coastal communities, it is globally recognized for its rich content of carbohydrates, essential amino acids, minerals, antioxidants, and bioactive compounds (Anetekhai, Olateju, Nwatulegwu, Fagbohun, Elegbede, & Idowu, 2022; Desrochers, Cox, Oxenford, & Van-Tussenbroek, 2020; Gomez-Zavaglia, Prieto Lage, Jimenez-Lopez, Mejuto, & Simal-Gandara, 2019; Pardilhó, Cotas, Pereira, Oliveira, & Dias, 2022; Saratale, Kumar, Banu, Xia, Periyasamy, & Saratale, 2018).

The sustainable utilization of Sargassum seaweed aligns with the marine and blue economy by promoting sustainable marine resource management, fostering economic growth, and ensuring environmental sustainability. In recent years, excessive Sargassum blooms have posed significant environmental and economic challenges in coastal regions, including Nigeria. Left unmanaged, these blooms can disrupt marine biodiversity, affect tourism, and threaten local fisheries. However, through a circular economy approach, Sargassum can be repurposed into valuable products, including biofertilizers, bioplastics, and, notably, animal feed. By converting this abundant seaweed into livestock feed, resource efficiency is enhanced, and waste-to-wealth initiatives are supported (Anetekhai, Olateju, Nwatulegwu, Fagbohun, Elegbede, & Idowu, 2022).

The application of Sargassum in animal feed development contributes to marine industry diversification, reducing reliance on traditional sectors such as oil and gas. Additionally, Sargassum-based feed offers a climate-resilient, cost-effective alternative to conventional feed, which is often affected by price volatility and supply chain disruptions (Pardilhó, Cotas, Pereira, Oliveira, & Dias, 2022; Anetekhai et al., 2024). Despite its potential benefits, the adoption of Sargassum-based feeds in Nigeria remains limited, even with growing support from the Lagos State Government for alternative feed solutions (Ibitomi, 2024). This limited adoption is partly due to the absence of comprehensive monitoring and evaluation (M&E) frameworks to assess the performance, economic viability, and sustainability of Sargassum-based animal feed projects.

A structured M&E framework is essential for assessing the economic feasibility, environmental impact, and adoption rates of Sargassum-based feed initiatives. Effective M&E would provide critical insights into how farmers perceive and integrate Sargassum into their livestock production systems, helping to determine whether such initiatives can be scaled up for widespread use. Moreover, utilizing Sargassum as feed helps manage harmful seaweed blooms, protecting marine biodiversity and supporting key blue economy activities such as tourism and fisheries (Pardilhó et al., 2022). This aligns with agroecological principles, balancing food security with environmental conservation while advancing Sustainable Development Goal (SDG) 14, Life Below Water.

Despite its environmental and economic potential, Sargassum valorization faces critical challenges related to policy integration, farmer awareness, and scientific validation of its nutritional value. The United Nations’ 2030 Sustainable Development Goals (SDGs) can only be achieved if project management principles, particularly robust monitoring and evaluation of adaptive projects, are incorporated into Sargassum-related activities. Understanding the human, economic, and ecological significance of this seaweed as both a floating ecosystem and an economic resource is essential. Addressing the challenges of alternative animal feed development sustainably requires a comprehensive M&E framework that integrates management strategies and multisectoral collaboration efforts (Anetekhai, 2023; Nzeka & Beillard, 2019).

This study seeks to facilitate substantial progress towards achieving the United Nations’ 2030 Sustainable Development Goals (SDGs) by developing and implementing a comprehensive Monitoring and Evaluation (M&E) framework. The research underscores the need for enhanced collaboration between animal farmers and researchers to apply agile project management methods in evaluating the sustainability, adoption, and economic viability of Sargassum-based animal feed projects for chickens, fish, pigs, and rabbits in Lagos State. By incorporating multidisciplinary research, the study seeks to integrate sustainability principles, value chain analysis, and Hazard Analysis Critical Control Point (HACCP) standards into the M&E framework. Ultimately, this research will provide critical insights into the role of Sargassum-based animal feed in advancing sustainable blue economy initiatives, enhancing livelihoods, and promoting environmental conservation in Nigeria.

1.2 Statement of the Problem

The success of projects depends on well-structured monitoring and evaluation (M&E) systems that optimize decision-making, resource allocation, and long-term sustainability. However, many projects in Africa, particularly in Nigeria fail and suffer setbacks due to mismanagement lack of project management capacity, corruption, poor policy planning and weak M&E frameworks, leading to high failure rates (Okereke, 2017, 2020). Over 56,000 abandoned or cancelled projects in Nigeria have cost the country an estimated ₦12 trillion (Zawya, 2022). These issues have led to inefficiencies and poor outcomes, with Nigeria’s agricultural project failure rate reaching 70%–80%, significantly exceeding the global average of 40% (Gavrilova, 2020). Despite initiatives such as the Agriculture Promotion Policy (APP) to boost agricultural productivity, feed scarcity, rising production costs, and inadequate project monitoring and evaluation continue to undermine sustainability in animal production (FAO, 2023). Nigeria’s heavy reliance on agricultural imports has weakened the agricultural sector’s contribution to the economy. For instance, Nigeria's agricultural imports in the first quarter of 2024 totalled ₦920 billion, representing a 29.45% increase from Q4 2023 and a 95% increase from Q1 2023 (National Bureau of Statistics, 2024). This rise has hindered productivity, highlighting the urgent need for sustainable, locally sourced feed alternatives.

Sargassum-based feed has the potential to enhance feed availability and reduce costs, making it an emerging solution. However, the absence of a robust monitoring and evaluation (M&E) framework for its long-term sustainability in Nigeria raises concerns about its economic feasibility, environmental impact and social acceptance. Without an effective system to track its performance, its viability remains uncertain, necessitating a comprehensive assessment of its implementation. Despite increasing interest in sargassum as an alternative feed ingredient in developed countries, there has been limited research on the nutritional potential of Sargassum-based feeds compared to conventional feeds (Abed El-Fatah, Abousekken, Zaid, El-Tabaa, & Gazalla, 2024; Desrochers *et al.*, 2020; Gomez-Zavaglia *et al.*, 2019; Pardilhó *et al.*, 2022; Saratale *et al.*, 2018). Existing studies focused on sustainable livestock systems (Rodríguez-Hernández, Arango, Moreno-Conn, Arguello, Bernal-Riobo, & Pérez-López, 2023; Raba, Gurt, Vila & Farres, 2020), but they did not use optimization techniques used in project management such as Linear Programming Model. Although a preliminary study by Anetekhai (2023) explored the suitability of adopting Sargassum seaweed in the Nigerian animal sector, there was a lack of detailed investigations into the effect of managing the introduction of Sargassum as an intervention on animal performance.

Despite advancements in monitoring technologies like Walk Over Weighing systems (Wicha Noinan, Yamsa-Ard, Kamhangwong, Chaisricharoen & Sureephong, 2023) and IoT frameworks (Isaac, 2021), the impact of alternative feeds like Sargassum on animal growth remains largely unexamined. Existing studies such as Tobin, Bailey, Stephenson, Trotter, Knight and Faist (2022) and Sarnighausen, de Souza Silva, and Moraes (2021) have focused on cattle and pigs, neglecting poultry, fish, and rabbits—key species in Nigeria’s diversified

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farming. Additionally, limited analytical tools such as ANOVA and t-tests hinder a comprehensive evaluation of growth and behavioural outcomes. The lack of efficient monitoring and effective assessment of Sargassum-based feed projects results in poor data availability, limiting informed decision-making on feed sustainability, economic feasibility, and livestock performance. In Lagos State, where feed scarcity threatens food security, this gap undermines efforts to optimize alternative feeding strategies. Therefore, a systematic study is essential to assess the nutritional impact of Sargassum-based feeds and establish a robust monitoring and evaluation framework for sustainable livestock production.

The economic viability of Sargassum-based feed remains largely unexamined due to inadequate monitoring and evaluation frameworks. While studies have focused on system efficiency and operational optimization (Mendeja, Dulce, Martinez, Tuazon, Gaspado and Magnaye (2023) and Tholhappiyan, Sankar, Selvakumar, and Robert (2023) or broader economic evaluations in other sectors (Jankovic & Faria, 2022; Nesamvuni, Tshikolomo, Lekalakala, Petja and Van-Niekerk, 2022), they fail to assess its cost-effectiveness and market potential in livestock management (Domaćinović, Solić and Prakatur (2023) and Hammer (2017). Without comprehensive monitoring mechanisms to assess cost-effectiveness, market readiness, and long-term sustainability, stakeholders lack the necessary data to make informed investment and policy decisions. Consequently, there is an urgent need for a structured evaluation approach to determine the financial viability of Sargassum-based feed and support its integration into livestock production systems.

As demands for transparency and accountability grow, an effective M&E framework is needed to assess the performance of Sargassum-based feeds, which address feed scarcity in Lagos State, Nigeria. Existing frameworks, such as PMBoK, ISO 21500, and Prince-2, fail to integrate environmental, social, and economic principles or address climate change and resource constraints in alternative feed projects (Dubois & Silvius, 2020; Jaikaeo *et al.*, 2022; Taye, Bendapudi, Swaans, Hendrickx & Boogaard, 2018; Almadani, Ramos, Abuhussein & Robinson 2024). While innovations like GPS tracking and biometric identification have advanced livestock management, their application in evaluating novel feeds is limited (Tobin *et al.*, 2022; Shojaeipour, Falzon, Kwan, Hadavi, Cowley, & Paul, 2021). Current M&E systems also overlook key aspects like environmental sustainability, socio-economic impacts, and animal welfare (Tun, Onizuka, Tin, Aikawa, Kobayashi, & Zin, 2024). A tailored, result-based logical framework is thus required to ensure comprehensive, sustainable evaluation of Sargassum-based feed projects. Majorly, previous studies on M&E were restricted to survey research design focussing on the distribution of copies of questionnaire to respondents, however, this study utilised mixed methodologies in assessing the performance of sargassum-fed animals by applying the principle of randomization in selecting animals, evaluated the impact of sargassum-based feed compared to conventional feeds, and developed a logical, result-based monitoring and evaluation framework to promote sustainable animal management practices.

Objectives of the Study

The main objective of this study is to explore the potential of *Sargassum fluitans* within a circular economy framework for sustainable animal feed production, food security enhancement, and coastal restoration in Lagos State, Nigeria. The specific objectives are:

1. To evaluate the nutritional composition and quality of Sargassum fluitans-based animal feeds compared to conventional feed sources.
2. To assess the growth performance, weight gain, and survival rate of animals fed with Sargassum fluitans-based feeds relative to those fed with conventional feeds.
3. To analyze the economic viability and market potential of developing Sargassum fluitans-based animal feed as part of a circular bioeconomy.
4. To propose a sustainability and monitoring framework for integrating Sargassum fluitans utilization into coastal ecosystem restoration and food security strategies in Lagos State.

1.4.1 Research Questions

The study seeks to answer the following specific research questions:

a. What are the differences in the nutritional composition of Sargassum fluitans-based animal feeds compared to conventional animal feeds?

b. How does the growth performance, weight gain, and survival rate of animals fed with Sargassum fluitans-based feeds compare with those fed with conventional feeds?

c. To what extent is the production of Sargassum fluitans-based animal feed economically viable within a circular economy framework for sustainable feed development in Lagos State?

d. How can a sustainability and monitoring framework be designed to evaluate the integration of Sargassum fluitans utilization into food security and coastal restoration initiatives in Lagos State?

Research Hypotheses

The hypotheses tested were:

Hypothesis one (H_1)

Null Hypothesis (H_{01}): There is no significant difference between the nutritional contents of Sargassum-based animal feeds and conventional animal feeds.

Hypothesis two

Main Hypothesis (H_2) – Overall Performance

Null Hypothesis (H_{02}): There is no significant difference in the performance (weight, length, and survival rate) of animals fed Sargassum-based feeds and those fed conventional feed.

To further investigate the specific components of performance, three sub-hypotheses are formulated:

- Sub-Hypothesis 2.1 (Weight Analysis)
  H_{021}: There is no significant difference in the weight of animals fed Sargassum-based feeds and those fed conventional feed.

- Sub-Hypothesis 2.2 (Length Analysis)
  H_{022}: There is no significant difference in the length of animals fed Sargassum-based feeds and those fed conventional feed.

- Sub-Hypothesis 2.3 (Survival Rate Analysis)
  H_{023}: There is no significant difference in the survival rate of animals fed Sargassum-based feeds and those fed conventional feed.

By testing these sub-hypotheses, the study provides statistical evidence on the impact of *Sargassum fluitans* on weight, length, and survival rate.

Qualitative data were utilized to address research questions three and four. Consequently, descriptive statistical tools were employed for analysis, and no hypotheses were formulated for these research questions.

1.6 Scope of the Study

The research area was limited to Suntan Beach in Badagry Local Government, Lagos State, Nigeria. Studies by Anetekhai *et al.* (2023) found that *Sargassum fluitans* collected from Badagry Local Government are

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pollutant-free and safe for animal and human consumption. In addition, the preliminary examinations (trace metal and nutrition analyses) Anetekhai *et al.* conducted revealed the absence of lead, cadmium, and mercury, highlighting the seaweed's nutritional benefits for animal diets. This contrasts with the results of heavy metal analysis for samples Anetekhai *et al.* collected from other divisions of Lagos State - Ikorodu, Ikeja, Lagos Island, and Epe (IBILE) - which were found to contain pollutants due to heavy economic activities and the presence of oil-based industries in these areas.

The study focused on monitoring and evaluating the performance of chickens, fish, pigs, and rabbits fed with conventional feed and experimental feed, where 50% of the total feed composition consisted of Sargassum, over 12 weeks. The decision to use a 50% inclusion rate was based on a study by Anetekhai *et al.* (2023), which explored the potential of *Sargassum fluitans* for entrepreneurship development in coastal fishing communities. Although Anetekhai *et al.* had replaced 25%, 50% and 75% of maize (an energy source) with *Sargassum fluitans*, this study adopted a 50% inclusion rate for the entire feed composition to evaluate its impact on animal performance

Key performance Indicators were limited to weight gain, length gain, survival rate, and economic benefits. To achieve this, a logical, results-based M&E framework was implemented, incorporating both quantitative and qualitative data collection and analyses. Throughout the study, ethical standards regarding animal welfare and environmental sustainability were strictly adhered to.

1.7 Significance of the Study

This study aims to significantly contribute to several Sustainable Development Goals (SDGs) by promoting sustainable agriculture, enhancing food security, conserving natural resources, mitigating climate change impacts, and fostering partnerships for sustainable development, thus driving a more sustainable and equitable future globally. It will specifically contribute the following stakeholders:

Policymakers: It will inform government policies that enhance socio-economic development by boosting agricultural productivity, improving waste management, and promoting sustainable practices, particularly in Lagos State, Nigeria.

Agricultural industry: The research emphasizes sustainability and interdisciplinary collaboration for the industry to improve food security, environmental conservation, and economic development in Nigeria's animal sector.

Local Farmers and Practitioners: will benefit from insights into animal feed development, leading to improved productivity and sustainability in farming.

Academics: The study will contribute to the academic literature on agricultural project development by offering valuable insights for future research in sustainable project management and environmental conservation.

1.8 Operational Definition of Terms

Activities: Tasks carried out to implement the project and deliver identified outputs. These are largely under project management’s control.

Feed: Any substance or mixture of substances, whether processed, semi-processed, or raw, that is intended for consumption by livestock, poultry, or aquaculture species to provide essential nutrients for their growth, maintenance, reproduction, and overall health.

Goal or impact: The reason for undertaking the project is its ultimate aim, which aligns with the broader program's goals. It is the sustainable development outcome expected at the project's end. All outcomes contribute to this ultimate aim.

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Inputs: Inputs are resources needed for activities, which produce tangible outputs. This includes the financial, managerial and technical resources required to carry out activities. These are directly under project management control.

Outcome, Effect or purposes: What the project aims to achieve in development terms once completed within the allocated time. They are the motivation behind producing the outputs and are the expected results of those outputs. The project hypothesis is that the combined effect of achieving these outcomes will lead to the realization of the overall goal.

Output: Outputs are the immediate, specific results produced by the management of inputs. They lead to sustainable changes known as outcomes (mid-term results). These direct, measurable results (goods and services) of carrying out planned activities are partly under the control of project management.

Project evaluation: A periodic and comprehensive assessment aimed at measuring the broader impacts and sustainability of the project outcomes, including the long-term effects of Sargassum feed on animal health and performance.

Project monitoring: Systematic and ongoing process of collecting and analysing data related to the daily activities, inputs, and outputs of the Sargassum-fed animal project. It focuses on ensuring that project activities are progressing as planned, with continuous tracking from the project's inception.

Sargassum: A genus of brown seaweed commonly found in tropical and subtropical waters.

Sargassum-based animal feed: A feed which is being explored as a sustainable and cost-effective option in response to challenges like high feed costs, scarcity, and competition with human food supply.

Sustainability: The practice of maintaining processes or systems over time which involves the preservation and management of natural resources, ecosystems, and biodiversity to ensure their availability for future generations.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It focuses on balancing different, and often competing, needs against an awareness of the environmental, social, and economic limitations faced as a society.

REVIEW OF LITERATURE

2.0 Preamble

This section considered conceptual, theoretical, and empirical reviews. The conceptual review contains definitions, features and relevance of several concepts related to the study. The theoretical review captured a review of theories underpinning the study. Lastly, the empirical review explored the methodologies and findings of previous studies on monitoring and evaluating adaptive projects using diverse methodologies.

2.1 Conceptual Review

2.1.1 Sargassum Seaweed

Sargassum seaweed is a type of macroalgae that is commonly found in the Sargasso Sea and other tropical regions of the world (Desrochers *et al.*, 2020). Seaweeds, according to Pari, Uju, Hardiningtyas, Ramadhan, Wakabayashi, Goto and Kamiya (2025) are classified into three groups on the basis of their pigments: red (Rhodophyta), green (Chlorophyta), and brown (Phaeophyta). Red and brown seaweed accounted for 52% and 47%, respectively, while green seaweed only contributed to 0.04% of the overall production (Wang, Lu, Wang *et al.* 2019).

In 2019, 34.5 million tons of seaweed (brown, green, and red) were produced worldwide according to data published by the United Nations Food and Agriculture Organization (FAO, 2022). Brown Sargassum collected

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in Nigeria is identified as Sargassum fluitans otherwise referred to as Sargassum hystrix var. fluitans (Børgesen, 1914 cited in Solarin, 2018). Sargassum fluitans is a brown alga (Class = Cyclosporeae; Order = Fucales; Family = Fucaceae; Genus = Sargassum) adapted to a pelagic existence (Parr, 1939).

Sargassum Fluitans seaweed is characterized by a brushy, highly branched stem (thallus) with numerous leaf-like blades and berrylike floats (pneumatocysts). Linguistically, sargassum is called Agbon-mi in Yoruba, Ruwan-teku in Hausa and Okpuru-mmiri in Igbo language. Plate 2.1 presents the morphology of a typical Sargassum seaweed.

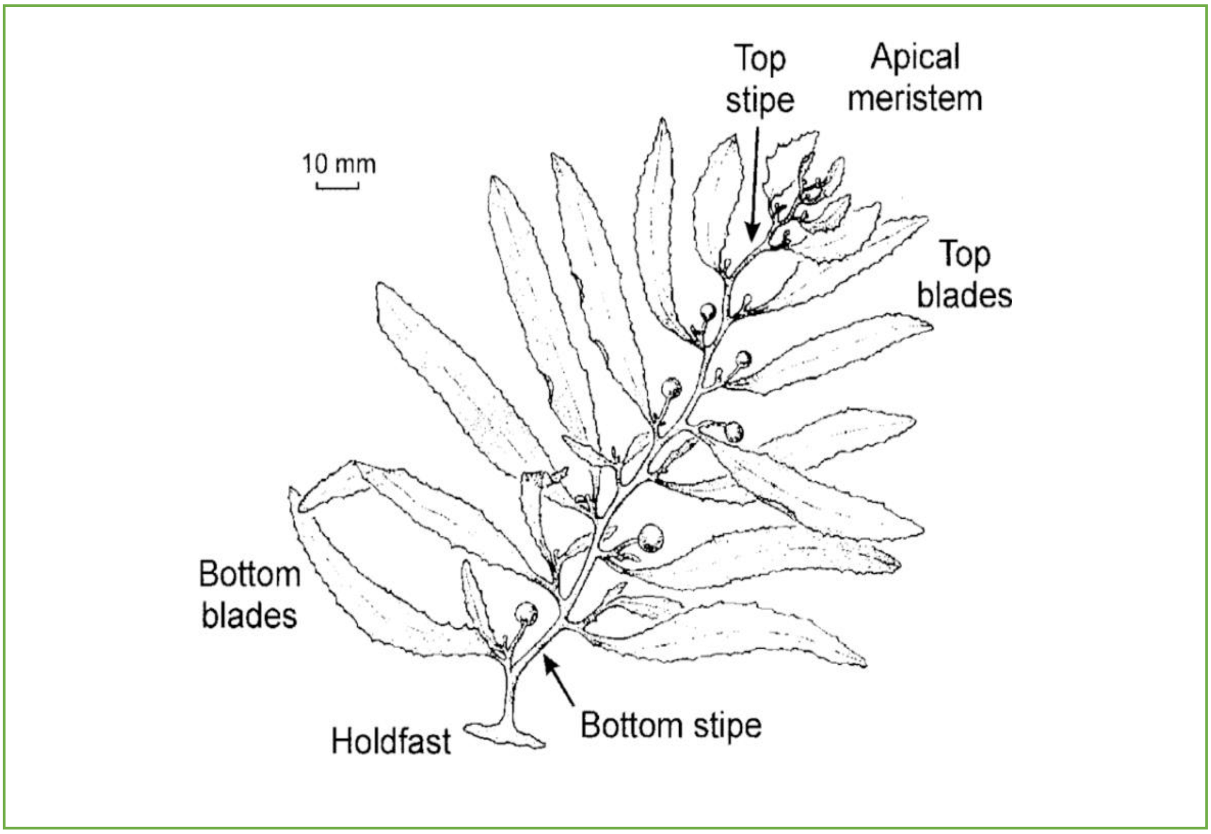

Plate 2.1: Morphology of *Sargassum* Fluitans seaweed

Source: Taylor, Sotka and Hay (2002), p.69.

2.1.1.1 Origin, Distribution, and Impact of Sargassum Seaweed

The origin of the Sargassum seaweed can be traced to the Sargasso Sea located entirely within the Atlantic Ocean. The Sargasso Sea is a region in the gyre in the middle of the North Atlantic Ocean bounded on the west by the Gulf Stream, on the north by the North Atlantic Current, on the east by the Canary Current, and on the south by the North Atlantic Equatorial Current (National Oceanic and Atmospheric Administration, NOAA, 2023; Smith & Brown, 2022). This system of ocean currents forms the North Atlantic Gyre. The coordinates for the Sargasso Sea are as follows: The latitude of Sargasso Sea is 34.307144, and the longitude is -66.269531 with the GPS coordinates of 34° 18' 25.7184" N and 66° 16' 10.3116" W. An extremely negative NAO index, that is shift in wind patterns, during winter 2009-2010 allowed Sargassum populations to escape the Sargasso Sea and head east. In 2011, the Great Atlantic Sargassum Belt began to form in the North Atlantic Ocean (NAO) located between 28°20’08” N and 66°10’30” (Wang, *et al.*, 2019). Ocean currents carried it south along the coast of Africa. These masses were further transported by currents toward the east of the Atlantic Ocean, rising along Brazil's coast until they arrived in the Caribbean region.

The West Africa sub-region is influenced by the Guinea Current, which is a slow, warm water current that flows eastward along the Guinea coast of West Africa (Bakun, 1978). This current is derived from the North Equatorial Counter Current (NECC) and the Canary Current, contributing to the region’s oceanography and

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climate. The Guinea Current's influence extends to various West African climate and ecosystem aspects. It affects weather patterns, marine life distribution, and even has implications for the region's economic activities, particularly in the fisheries sector. Additionally, the current plays a role in the transportation of sediments and nutrients along the coast, which can impact coastal erosion and the health of marine ecosystems. Understanding the dynamics of the Guinea Current is crucial for the region, especially in the context of climate change, as it can help in predicting weather patterns and planning for sustainable development along the coastal areas. The fluorescence spread along the Western coasts impacting the livelihood of the population.

In 2011, the phenomenon of nuisance Sargassum was observed on West African beaches, including the Nigerian coast (Jun, Yingqing, Ruru, Longhai, & Ruihao, 2024). Nigeria's coastline stretches 853 kilometres along the Gulf of Guinea, from the Benin Republic in the west to Cameroon in the east (Nigeria Coastline – Geography, 2023). The country claims a territorial sea of 12 nautical miles, an exclusive economic zone of 200 nautical miles, and a continental shelf up to 200 meters deep or to the depth of exploitation. This coastal region is crucial for trade, fishing, and tourism. The presence of Sargassum has significantly impacted marine life, coastal ecosystems, and local economies, threatening fisheries, tourism activities, and food security (Anetekhai *et al.*, 2022).

Several physical factors and external nutrient inputs influenced the occurrence of Sargassum and contributed to increased growth rates. These factors include climate change; changes in regional winds and ocean current patterns; increased sea surface temperature; increased supply of iron due the atmospheric deposition of Saharan dust linked to climate change and desertification; and nutrients from river sewage and nitrogen-based fertilizers (Wang *et al.*, 2019). Sargassum thrives in harsh circumstances, absorbing nutrients around them; they are key in de-acidifying oceans and improving water quality as they grow by drawing down excessive human products including carbon dioxide, nitrogen, and phosphorus (Carbonwave, 2021).

2.1.1.2 Chemical and Nutrition Contents of *Sargassum Fluitans*

Sargassum fluitans is renowned for its potential health benefits making it a potential for development and commercialization as animal feed (Anetekhai *et al.*, 2023; Desrochers *et al.*, 2020). It is a high-energy food due to its rich carbohydrate content and low in fat, making it a low-calorie option with cholesterol-lowering effects in liver cells. Studies have shown that *Sargassum fluitans* is rich in carbohydrates, beta-carotene, vitamins, and some essential amino acids displaying equivalent quality to forages, such as sorghum and barley that are commonly used as high-quality animal feed (Carrillo-Domínguez, Rodríguez-Martínez, Díaz-Martínez, Magaña-Gallegos, & Cuchillo-Hilario, 2023). According to Lomartire and Gonçalves (2023), sargassum contains vitamins (A, B1, B2, B9, B12, C, D, E, and K), minerals (calcium, iron, iodine, magnesium, phosphorus, potassium, zinc, copper, manganese, selenium, and fluoride), carbohydrate, protein, and essential amino acids like arginine, tryptophane and phenylalanine. They contain various bioactive compounds including antioxidants, flavonoids, phenolic compounds, and alkaloids that may support human health and help reduce the risk of various diseases (Choudhary, Khandwal, Gupta, Patel, & Mishra, 2023).

Table 2.1: Showing the Proximate Analysis of Dry *Sargassum fluitans* and Maize

Proximate/Mineral composition	Sargassum	Maize
Moisture (%)	8.45±0.38	13.00±0.06
Crude Protein (%)	10.68±0.11	8.70±0.21
Crude Fat (%)	5.96±0.07	0.50±0.04
Crude Fibre (%)	19.23±0.82	8.00±1.32
Ash (%)	14.08±0.09	0.50±0.03
Carbohydrates (%)	41.60±0.38	69.25±1.42
Nitrogen (%)	0.20±0.05	-

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Vitamin A (µg/100g)	1331.4±210.3	-
Vitamin C (µg/100g)	4411.29±106.8	-
Vitamin B2 (µg/100g)	47.23±5.68	-
Vitamin B 12(µg/100g)	12.0±3.60	-
Sodium(mg/100g)	32.0±1.30	-
Potassium(mg/100g)	408.0±1.50	-
Magnesium(mg/100g)	102.0±1.20	-
Calcium(mg/100g)	223.0 ±1.60	-

Source: Anetekhai *et al.* (2024), p.23

Sargassum fluitans can also provide nutrients that are lacking in terrestrial crops grown in micro-organism and mineral-depleted soils (Pari, *et al.* 2025). Regarding its chemical composition, *Sargassum fluitans* contains polysaccharides such as alginate and fucoidan (Anetekhai, 2023). The Blue Food Assessment (BFA), an international joint initiative of the Stockholm Resilience Center, Stanford University, underscored the relevance of *Sargassum fluitans* for reducing B12 and omega-3 deficiencies, especially for Africa (BFA, 2023). Rocha (2021) stated that sargassum is one of the best natural sources of iodine available.

The usage of sargassum seaweed in feeding animals will ensure a balanced intake of essential nutrients for the health and productivity of animals. The six basic components of animal ration which are protein, energy, fibre, minerals, and vitamins are contained in *Sargassum fluitans* (Anetekhai *et al.*, 2024). Protein is essential for forming muscles, skin, hair, and organs and is composed of amino acids, including eight essential ones that must be included in the diet. Fibre found in plant structures, is important for digestive health, providing energy through microbial action, and ensuring proper food passage. Minerals are divided into macro minerals (needed in large amounts) and micro minerals (needed in smaller amounts), both vital for structural, metabolic, and immune functions. Vitamins, required for metabolic functions and as antioxidants that help protect the body from oxidative stress, are categorized into fat-soluble and water-soluble groups. Many vitamins are synthesized by digestive microbes or derived from sunlight and forage (Rajauria, 2015).

2.1.2 Sustainable Development; The Pathway to Sustainability

The concept Sustainable Development was popularized by the 1987 Brundtland Report, which defined it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". According to Khalifeh, Farrell, & Al-Edenat, (2020), World Commission on Environment and Development defined sustainable development as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. Sustainable Development is a process that balances economic growth, social equity, and environmental protection to meet present needs without compromising the ability of future generations to meet theirs.

The 17 Sustainable Development Goals (SDGs), adopted by all United Nations Member States in September 2015, officially came into force on January 1, 2016. The 2015 Sustainable Development Goals (SDGs) build upon the foundation laid by the Millennium Development Goals (2000-2015), providing the United Nations with a comprehensive roadmap for global development through 2030. The 17 SDGoals form a comprehensive blueprint aimed at addressing global challenges to ensuring a better, sustainable and equitable future for all (UNSDG, 2023). The goals align with five (5) principles which provide a holistic framework for sustainable development, ensuring that no one is left behind. The principles are People (society), Prosperity (economic), Planet (environment), Peace, and Partnership.

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In the principle of People, the goals focus on social aspects, including ending poverty (Goal 1) and hunger (Goal 2), ensuring good health and well-being (Goal 3), providing quality education (Goal 4), and achieving gender equality (Goal 5), These goals aim to improve the quality of life and ensure that all individuals can live with dignity and access to basic necessities. The Prosperity principle covers economic aspects and includes goals such as ensuring access to affordable and clean energy (Goal 7), promoting decent work and economic growth (Goal 8), building resilient infrastructure and fostering innovation (Goal 9), and reducing inequalities (Goal 10) and creating sustainable cities and communities (Goal 11). These goals are designed to promote inclusive and sustainable economic growth, ensuring that all people can prosper and thrive.

In the Planet principle, environmental sustainability is emphasized through goals such as securing clean water and sanitation (Goal 6), promoting responsible consumption and production (Goal 12), taking urgent action on climate change (Goal 13), conserving life below water (Goal 14), and protecting life on land (Goal 15). These goals aim to safeguard the planet's resources and ecosystems for future generations. The Peace principle focuses on ensuring peaceful, just, and inclusive societies, encapsulated in Goal 16, which promotes peace, justice, and strong institutions. This goal highlights the need for effective governance and the protection of human rights to foster peaceful societies. Finally, the Partnership principle emphasizes the importance of global collaboration, encapsulated in Goal 17, which calls for strengthening the means of implementation and revitalizing the Global Partnership for Sustainable Development. This goal underscores the necessity of cooperation and partnerships at all levels to achieve the SDGs.

The term sustainability, derived from the concept of sustainable development, is linked to any human activity on the decisive consideration of human and environmental aspects in decision-making concerning any developed economic activity (Marcelino-Sadaba, Gonzalez-Jaen & Perez-Ezcurdia, 2015). Willard (2005) illustrated how organisations can evolve from mere compliance to a profound dedication to sustainability principles (See figure 2.1). He claimed that, in stage 1, Pre-compliance companies are labelled as "Outlaws" because they disobey social and environmental regulations, focusing solely on short-term profits, and showing no engagement with sustainability. Compliance companies (Stage 2) adopt a minimalist approach, adhering only to legal requirements for environmental and social regulations, thus showing a reactive stance.

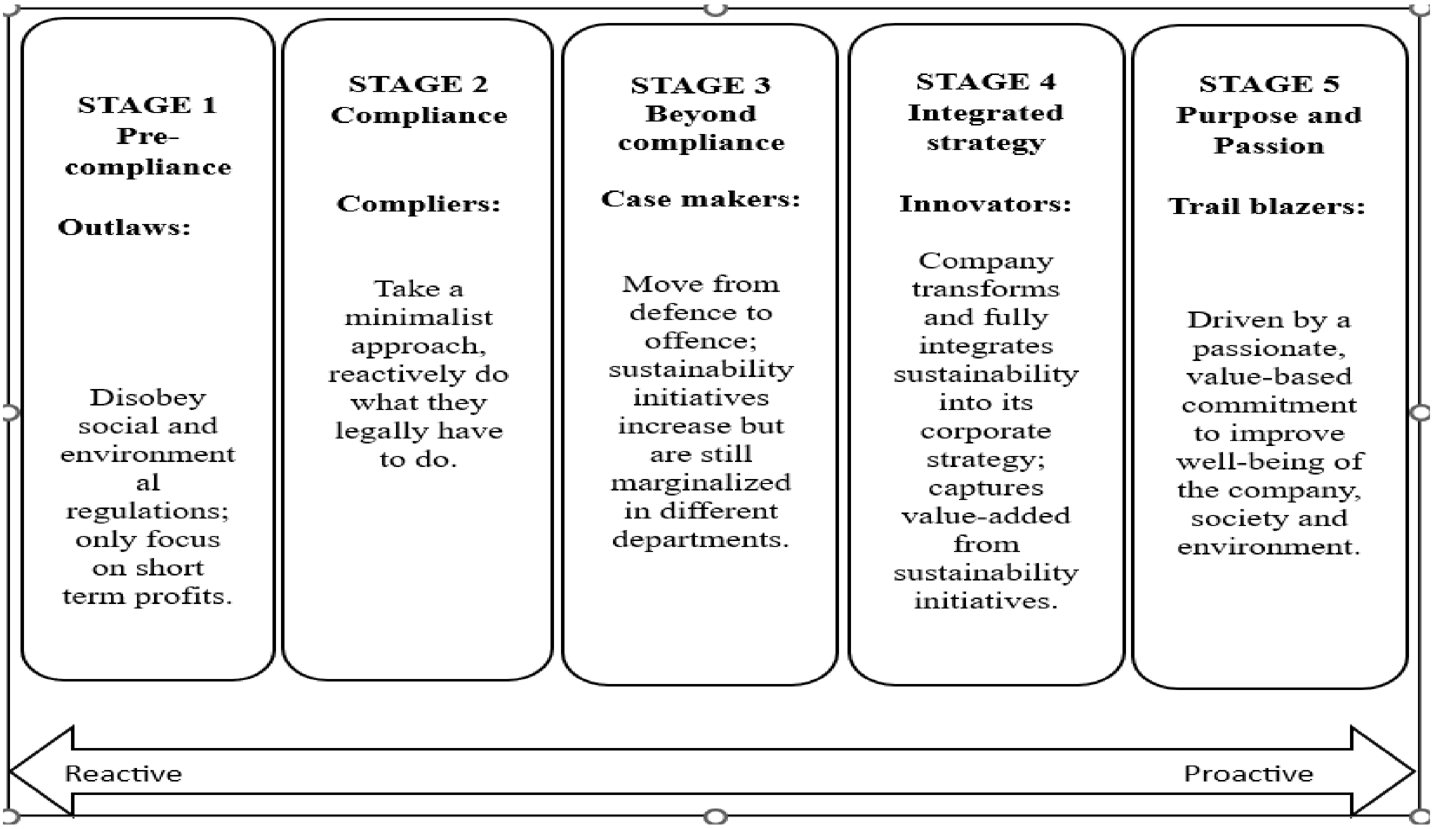

Figure 2.1: Stages of Sustainability

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Source: Adopted from Willard (2005), p. 4

In stage 3 Beyond Compliance companies also known as "Case-makers" begin to implement more sustainability initiatives, transitioning from defene to offense. However, these initiatives remain marginalized within different departments and are not fully strategic. As companies advance to Integrated Strategy (stage 4), they become "Innovators," fully integrating sustainability into their corporate strategies. This transformation allows them to capture added value from sustainability initiatives, indicating a proactive integration of sustainability into their business core. Finally, Purpose & Passion (stage 5) companies become "Trailblazers," driven by a passionate, value-based commitment to improve the well-being of the company, society, and the environment. At this stage, sustainability strategies are deeply embedded in the company's operations and culture, showing a complete commitment.

The shift from a reactive to a proactive approach in Willard's (2005) sustainability model occurs between Stage 3 (Beyond Compliance – "Case-makers") and Stage 4 (Integrated Strategy – "Innovators"). In the reactive stages (1-3), organisations either ignore sustainability (Stage 1), comply only with legal requirements (Stage 2), or implement isolated initiatives without full integration (Stage 3). The transition to proactivity begins in Stage 4, where organisations embed sustainability into their core strategy, recognizing it as a competitive advantage. By Stage 5 (Purpose & Passion – "Trailblazers"), sustainability becomes a fundamental value, fully integrated into the company's culture and operations. The key turning point is between Stage 3 and Stage 4, where sustainability shifts from being a response to external pressures to a strategic, value-driven commitment.

2.1.3 Project Management

A project is a temporary effort aimed at producing a unique product, service, or result (PMI, 2021). It involves a series of planned activities designed to achieve specific goals using allocated resources within a defined time frame. Gido, Clements, & Baker (2018) describe a project as a temporary endeavour intended to create a unique product, service, or result through a distinct set of interrelated activities, effectively utilizing resources within established specifications. The definition by Gido *et al.* and World Bank's definitions offers broader perspective, emphasizing not only the time frame and uniqueness of the outcome but also the uniqueness of the process, compared to the definition provided by PMI (2021). Projects operate within environments that can influence them; enterprise environmental factors (EEFs) and organizational process assets (OPAs). EEFs stem from the external environment and can impact at the organizational, portfolio, program, or project level. OPAs, in contrast, are internal to the organization and may originate from the organization itself, a portfolio, a program, another project, or a combination (PMI, 2017).

Project management is the application of processes, methods, skills, knowledge, tools, technique and experience to achieve specific project objectives according to the project acceptance criteria within agreed parameters (PMI, 2021). Association of Project Management defined project management as the entire system of processes, methods, skills, knowledge, and experiences for achieving specific project objectives according to the project acceptance criteria within agreed parameters (Murray-Webster & Dalcher, 2019). These definitions stressed the need for insight from knowledge across a wide spectrum with methods and the use of tangible tools in attaining results. While projects can be managed in terms of time, budget, and resources, their primary focus is on driving change rather than maintaining and operating an existing capacity (PMI, 2017). A project may be planned, implemented, and managed in three scenarios: as a stand-alone project, within a programme, or within a portfolio.

Project management expertise encompasses the art of identifying project requirements, addressing the diverse needs, concerns, and expectations of stakeholders, maintaining active communication with them, allocating and managing resources, and balancing competing project constraints—namely Scope, Schedule, Cost and Quality (Murray-Webster & Dalcher, 2019; PMI, 2019). Successful project management requires an integrated approach, where various knowledge areas are applied collectively and harmoniously to achieve project success. Project management is guided by principles such as value creation, stakeholder engagement, teamwork, stewardship, systems thinking, leadership, environmental tailoring, quality, complexity

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management, risk management, adaptability and resiliency, and change management (PMI, 2021). These principles ensure global standards are upheld throughout all project phases.

2.1.3.1 Project Management Methodologies

Project management life cycle methodologies include the predictive development approach and adaptive development approach (PMI, 2021).

2.1.3.1.1Predictive Life Cycle

Figure 2.2 shows the feasibility phase which determines if a business case is valid and if an organization can deliver the intended outcome. This is followed by the Design phase where Planning and analysis lead to the design of the project deliverable that will be developed. In the Build phase, the construction of the deliverable with integrated quality assurance activities is conducted, while the test phase involves conducting final quality review and inspection of deliverables before transition or acceptance by the customer. At the Deploy phase, project deliverables are put into use and transitional activities required for sustainment, benefits realization, and organizational change management are completed. Finally, in the closing phase project knowledge and artifacts are archived, project team members are released, and contracts are closed.

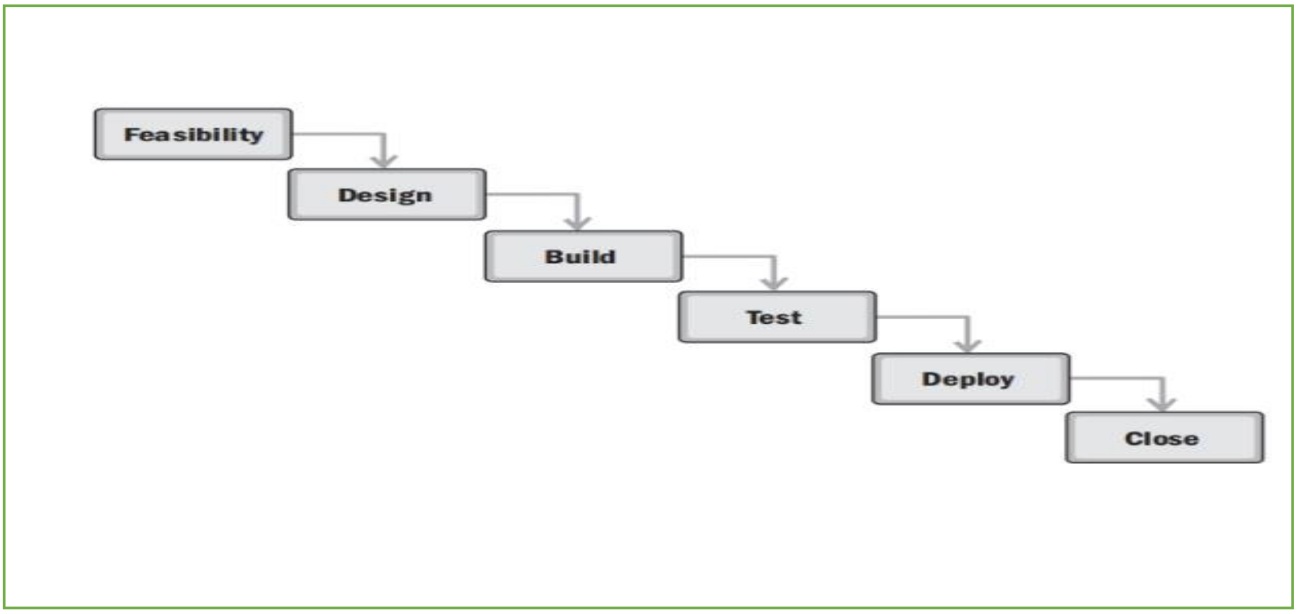

Figure 2.2: Predictive Life Cycle

Source: PMI (2021), p. 138

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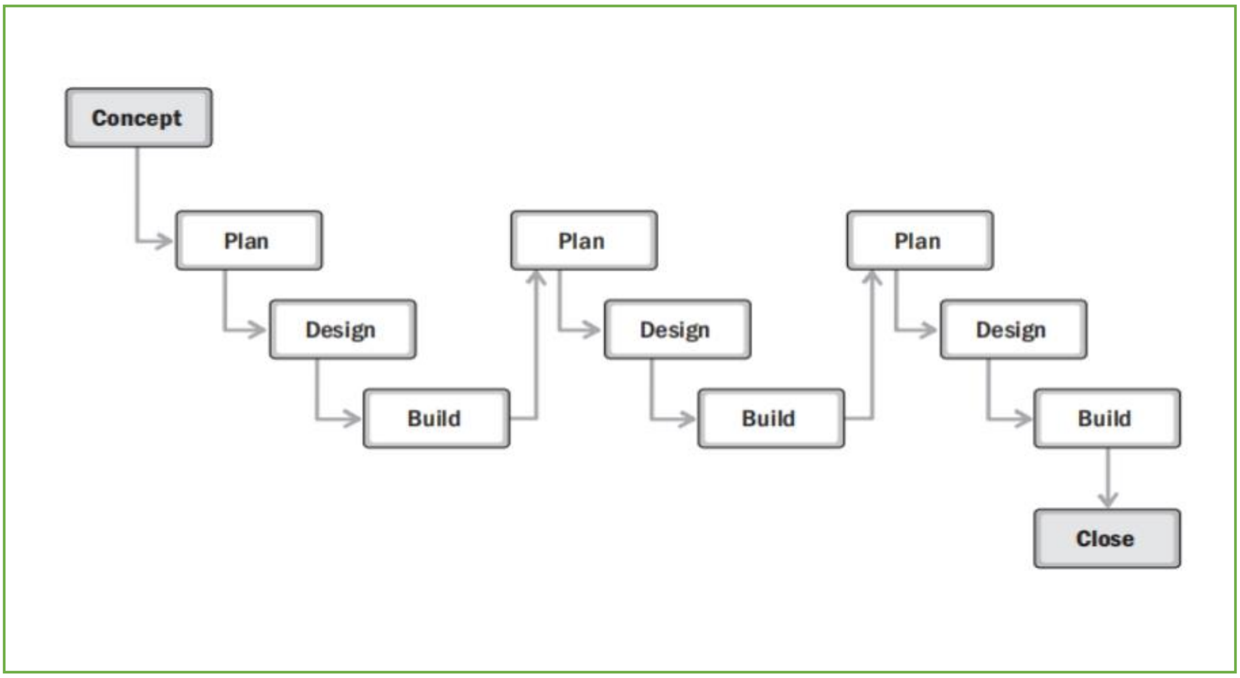

Figure 2.3: Life cycle with an incremental development approach

Source: PMI (2021), p. 139

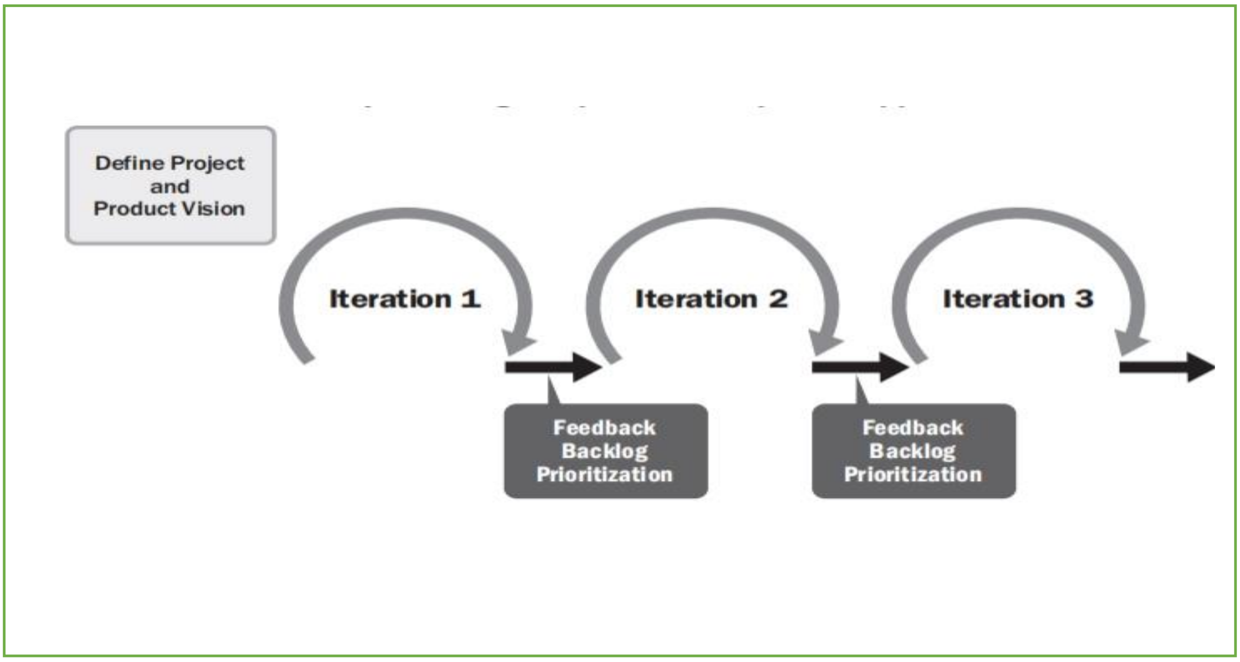

Figure 2.4: Project life cycle with adaptive development approach

Source: PMI (2021), p. 140

2.1.3.1.2 Adaptive Life Cycle

The adaptive development approach is a project life cycle used where the project team conducts iterations planning upfront to establish release plans and further planning occurs at the beginning of each iteration (PMI, 2021). The project scope is determined early but duration and cost estimates are routinely modified as understanding of the project change. Examples of adaptive methodologies are incremental and agile methodologies.

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2.1.3.1.2.1 Incremental Methodology

The incremental methodology focuses on dividing a project into smaller, sequential increments, each representing a portion of the final product's functionality (PMI, 2021). Figure 2.3 shows that incremental approach follows a predefined sequence, with detailed planning and limited flexibility within each increment. Customer feedback is typically gathered at the end of each increment, and risk management involves early delivery of high-priority components.

2.1.3.1.2.2 Agile Methodology

In contrast, to incremental methodology, agile methodology prioritizes flexibility, responsiveness, and iterative development. Agile projects utilize iterative planning, breaking down work into smaller iterations or sprints where teams focus on specific tasks, deliver incremental value, and receive feedback (PMI, 2021).

According to figure 2.4, adaptive projects process allows for continuous adjustments and refinements. Agile core principles emphasize the importance of individuals and interactions, promote customer collaboration over contract negotiation, and value responding to change over strictly following a plan (PMI, 2021).

The project team updates project backlog of features and functions to prioritize for the next iteration. Common practices include Scrum, which organises work into time-boxed sprints and involves specific roles, artifacts, and ceremonies; Kanban, which visualizes work to manage flow and limit work in progress; user stories, which describe features from the user's perspective; and burndown charts, which track progress by showing remaining work over time. The benefits of Agile include its flexibility to adapt to changing requirements, early value delivery through frequent iterations, and increased stakeholder engagement through regular feedback, ensuring alignment with their expectations throughout the project lifecycle (Wisitpongphan & Khampachua, 2016). Risk management in Agile involves active mitigation through iterative improvements and frequent testing.

Table 2.2: Differences between Incremental and Agile Project Methodology

Aspect	Incremental Methodology	Agile Methodology
Focus	Dividing the project into smaller, sequential increments	Flexibility, responsiveness, and iterative development
Approach	Predefined sequence of development phases	Iterative and adaptive with continuous feedback
Customer Collaboration	Periodic reviews at the end of each increment	Regular involvement and collaboration throughout
Flexibility	Limited flexibility within each increment	High flexibility and responsiveness to changes
Risk Management	Early risk mitigation through incremental delivery	Active risk management with frequent testing
Planning	Detailed planning upfront for each increment	Adaptive planning with evolving requirements
Delivery	Sequential delivery of functionality	Frequent delivery of working outputs
Feedback	Feedback mainly at the end of increments	Continuous stakeholder feedback
Frameworks	Often associated with traditional models like Waterfall	Includes Scrum, Kanban, XP, etc.

Source: Adapted from PMI (2021)

2.1.3.1 Sustainable Project Management

The growing complexity and changing environment have given rise to new fields directly related to projects and programs such as sustainability (Abbasi & Jaafari, 2018). Sustainable practices are introduced into management processes through a wide range of projects, including infrastructure creation and product innovation (Murray-Webster & Dalcher, 2019). Therefore, sustainable development provides the framework for sustainable project management to work. Sustainable project management integrates sustainability principles into development projects to minimize negative impacts on the environment, society, and the economy (Dubois & Silvius, 2020). It adopts a holistic approach from project conception to closure, promoting environmental cleanliness and improving quality of life (Mark & Lurie, 2018). Environmental sustainability aims to preserve and protect the natural environment by reducing energy consumption, recycling waste, using green materials, minimizing carbon footprint, preserving biodiversity, and minimizing pollution (Dubois & Silvius, 2020).

Social sustainability focuses on the project's social impacts and enhances social capital by fostering positive relationships between individuals and groups (Khalifeh *et al.*, 2020). It promotes community development through local employment and aims to improve stakeholders' quality of life. It also upholds human rights, ensuring fair wages, safe working conditions, and no use of child or forced labour. Economic sustainability seeks steady economic growth within environmental limits (Dubois & Silvius, 2020). It balances the long-term interests of stakeholders with short-term profitability for investors, emphasizing cost-effectiveness, affordability, job creation, and functionality throughout the project's lifespan. Table 2.3 shows the differences between the traditional project management approach and Sustainable project management.

Table 2.3: Differences between Traditional Project Management and Sustainable Project Management.

Category	**Traditional Project Management**	**Sustainable Project Management**
Timing	Short term oriented	Long-term orientation
Interest	In the interest of sponsor/stakeholders	Interest of the present and future generations
Orientation	Deliverable/result oriented	Life cycle oriented
Constraints	Scope, time, budget	People, planet, profit, peace and partnership
Scope	Reduced complexity	Increasing complexity

Source: Silvius & Brink (2014).

Table 2.3 shows that traditional project management focuses on scope, deadlines, and budget, while sustainable project management integrates sustainability principles. It considers long-term environmental, social, and economic impacts, aiming to balance present needs without compromising future generations. This approach promotes social equity, economic viability, and stakeholder engagement in an iterative process with local participation (Miller, 2021). This approach can be adopted for use in continuous delivery situations, such as the monitoring and evaluation of sargassum based animals.

Table 2.4: Leveraging Sargassum-based Projects to Achieve Sustainable Development Goals

Principle (Sector)	**Sustainable Development Goals (SDG)**	**Significance of Sargassum Seaweed as Animal Feed**	**References**
	SDG 1: No Poverty	By providing a low-cost feed alternative, Sargassum seaweed can reduce the expenses for animal farmers, increasing their profitability and potentially lifting	Weber and Matthews 2008).

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PEOPLE (Social)		them out of poverty.	
	SDG 2: Zero Hunger	Enhancing animal nutrition with Sargassum can improve animal health and productivity, leading to higher yields of meat and dairy products, thereby contributing to food security.	Rajauria (2015).
	SDG 3: Good Health and Well-being	Sargassum contains nutrients and bioactive compounds that can enhance the nutritional quality of animal products, indirectly benefiting human health.	Nandithachandraprakash. (2024)
	SDG 4: Quality Education	Implementing educational programs on the benefits and use of Sargassum as animal feed can enhance agricultural education and training.	Sultana *et al.* (2023).
	SDG 5: Gender Equality	Women farmers and entrepreneurs can benefit from the cost savings and increased income opportunities presented by utilizing Sargassum, promoting gender equality in agriculture.	Feedback Madagascar (2021)
PROSPERITY (Economic)	SDG 7: Affordable and Clean Energy	Processing Sargassum can potentially be integrated with bioenergy production, contributing to renewable energy solutions.	Owusu, Marfo, and Osei (2024); Farghali, Mohamed, Osman, and Rooney (2023).
	SDG 8: Decent Work and Economic Growth	The development of a Sargassum-based feed industry can create jobs and stimulate economic growth, especially in coastal communities.	Sowah, Jayson-Quashigah, Atiglo and Addo (2022).
	SDG 9: Industry, Innovation, and Infrastructure	Encouraging innovation in feed technology and infrastructure development for processing Sargassum can boost industrial advancement.	Anetekhai (2023)
	SDG 10: Reduced Inequality	Providing low-cost feed solutions can support small-scale and marginalized farmers, helping to reduce economic inequalities.	United Nation (2024).
	SDG 11: Sustainable Cities and Communities	Utilizing Sargassum can help manage coastal waste, contributing to cleaner and more sustainable urban and rural communities.	Oyesiku and Egunyomi (2014).
PLANET (Environment)	SDG 6: Clean Water and Sanitation	By utilizing seaweed that otherwise might decompose and pollute water bodies, the practice helps maintain cleaner coastal environments and water quality. Therefore, seaweed farming contributes to improved water quality	Spillias, Kelly, Cottrell, O'Brien, Im and Kim (2023).
	SDG 12: Responsible	Promoting the use of a naturally occurring resource like Sargassum	Farghali, Mohamed, Osman and Rooney,

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	Consumption and Production	encourages sustainable agricultural practices and reduces reliance on conventional feedstocks.	(2023).
	SDG 13: Climate Action	Sargassum, as a renewable resource, can help mitigate climate change by reducing the need for environmentally intensive feed production practices.	Salma *et al.* (2014)
	SDG 14: Life Below Water	Harvesting Sargassum can help control its overgrowth, which can otherwise harm marine ecosystems, thus supporting marine life conservation.	Doyle and Franks (2015).
	SDG 15; Life on Land	Using Sargassum as feed reduces the pressure on terrestrial ecosystems by decreasing the demand for land-based feed crops.	N'Yeurt and Iese (2014); Kumar *et al.* (2012),
PEACE	SDG 16: Peace, Justice, and Strong Institutions	Strengthening local economies and food security through innovative feed solutions can contribute to social stability and stronger institutions.	Feedback Madagascar (2021)
PARTNERSHIP	SDG 17: Partnerships for the Goals	Collaboration between governments, researchers, NGOs, and the private sector to develop and promote Sargassum-based feed aligns with fostering partnerships for sustainable development	FAO (2022)

Source: Modified from 17 United Nation's Sustainable Development Goals; Sustainable Development (2023).

Table 2.4 illustrates how Sargassum seaweed-based projects can contribute to achieving the United Nations Sustainable Development Goals (SDGs) across different principles or sectors. For the social sector, Sargassum as animal feed can reduce poverty (SDG 1), enhance food security (SDG 2), and improve health (SDG 3). Educational programs and gender equality (SDGs 4 and 5) benefit from the cost savings and opportunities created. Economically, Sargassum supports clean energy (SDG 7), economic growth (SDG 8), innovation (SDG 9), reduced inequality (SDG 10), and sustainable communities (SDG 11). Environmentally, it promotes clean water (SDG 6), responsible consumption (SDG 12), climate action (SDG 13), and biodiversity (SDGs 14 and 15). Finally, it contributes to peace (SDG 16) and global partnerships (SDG 17).

2.1.4 Project Monitoring and Evaluation

The project cycle comprises a structured approach that guides a project from inception to completion, illustrating the dynamic interaction and varying levels of effort required at different stages (PMI, 2017). A typical project cycle consists of five distinct phases: initiation, planning, execution, monitoring and controlling, and closing (See figure 2.5). These phases ensure the successful management and implementation of the project throughout its life (Good, 2024). Effort levels for different phases vary over time—the initiating phase peaks early, with planning also requiring significant initial effort. Execution reaches the highest peak, as most project work occurs during this phase. Monitoring and controlling maintain steady effort throughout the project, while the closing phase, requiring the least effort, inclines toward the end (PMI, 2017; Callistus & Clinton, 2018).

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Monitoring and Evaluation (M&E) is the process of assessing the progress, performance, and results of projects and programs (Nimco & Kaumbulu, 2024). While closely related, monitoring and evaluation serve distinct purposes, processes, and functions. EvalCommunity (2024) emphasizes the importance of distinguishing between these activities to enhance clarity and effectiveness. The differences between monitoring and evaluation are given in table 2.5.

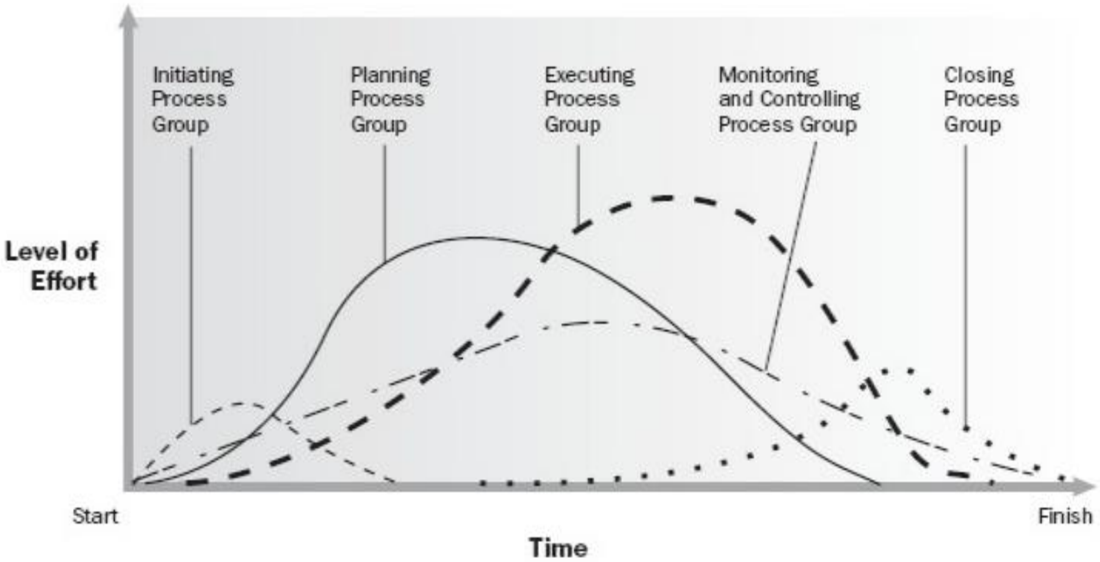

Figure 2.5: Process group interactions within a project

Source: Adapted from Callistus and Clinton (2018), p. 573

Table 2.5: Differences between Monitoring and Evaluation

S/N	Basis of Comparison	Project Monitoring	Project Evaluation
1	Definition	Systematic and routine collection of information about project activities	Periodic assessment of project activities
2	Frequency	Ongoing process to track progress	Periodic process to measure success against objectives
3	Timing	Starts from the initial stage of the project	Conducted at specific points, usually mid-project, end, or during stage transitions
4	Responsibility	Usually done by internal team members	Mainly done by external members, internal or combined
5	Purpose	Provides information for immediate remedial actions	Provides recommendations for long-term planning and organizational growth
6	Focus	Inputs, activities, and outputs	Outcomes, impacts, and overall goals
7	Data Collection	Regular meetings, interviews, reviews; usually quantitative data	Intense data collection, both qualitative and quantitative
8	Data Points	Multiple points of data collection	Data collected at intervals only
9	Perspective	Aims to improve efficiency.	Aims to improve overall effectiveness
10	Duration	Short-term	Long-term.
11	Scope	Checks if the project did what it	Checks the impact of what the project did

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		planned	
12	Improvement Focus	Improves current project design and functioning	Improves design of future projects
13	Detail Level	Focuses on details of activities	Looks at the bigger picture
14	Progress Comparison	Compares current progress with planned progress	Assesses positive/negative, intended/unintended effects
15	Utility of Information	More useful to the implementation/management team	Useful to all stakeholders
16	Result Utilization	Used for informed actions and decisions	Used for planning new programs and interventions
17	Efficiency Question	Answers "Are we doing things, right?"	Answers "Are we doing the right thing?"
18	Deliverables	Regular reports and updates	Reports with recommendations and lessons
19	Dependency	Effective monitoring does not rely on evaluation results	Effective evaluation relies on good monitoring to some extent
20	Quality Checks	Few quality checks	Many quality checks
21	Informative Role	Provides information for evaluation	Provides information for proper planning
22	Model	Management tool with a focus on day-to-day project operations	Used to assess the extent to which project objectives have been met

Source: Author’s Computation, November (2024).

2.1.4.1 Project Monitoring

Monitoring is an essential aspect of project management, involving the systematic collection of information about a project's activities to measure progress toward its objectives (Kabeyi, 2019). It provides ongoing feedback, facilitating better decision-making and future planning. Effective monitoring ensures that activities are carried out as planned, identifies deviations from the plan, and assesses the efficient use of resources. The project monitoring process starts with a baseline survey conducted before the intervention begins (PMI, 2021). This initial survey establishes a reference point against which future progress and impacts can be measured. Continuous monitoring throughout the project's duration evaluates inputs, activities, and outputs against established baselines or performance standards.

Project monitoring data comes from various sources, including logbooks, site visits, reports, meeting minutes, and financial documents. These data are typically entered into a management information system (MIS), which simplifies the tracking of project activities, budgets, and personnel. Systematic data collection and analysis allow project managers to track performance over time, verify tangible outputs, and ensure alignment with the project plan and assumptions (Calvani, & Chinnanon, 2003). There are four types of monitoring: process, technical, assumption, and financial monitoring. These types contribute to the overall project management framework, providing critical insights into project progress, strategy effectiveness, external influences, and financial health (Landau, 2024). Table 2.6 shows the types of monitoring and the activities involved in a typical project.

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Table 2.6: Types and Functions of Project Monitoring

Types of Monitoring	**Functions**
Process Monitoring	Collects and analyses data regularly to track if tasks and activities are on track to achieve outcomes, addressing what has been accomplished, and where and when activities took place.
Technical Monitoring	Evaluates the effectiveness of strategies and technical aspects during implementation to ensure they align with project goals.
Assumption Monitoring	Monitors external factors and assumptions made during planning to identify changes or influences that could affect project outcomes.
Financial Monitoring	Tracks expenditures against the budget to ensure financial accountability and identify any deviations requiring adjustments.

Source: Calvani and Chinnanon (2003).

2.1.4.2 Project Evaluation

Project evaluation is a systematic assessment of an ongoing or completed project's, effectiveness, efficiency, and outputs against set goals and standards (Kabeyi, 2019). It is also an act of examining project design, implementation, and results to provide insights into project success and goal fulfilment. According to Calvani and Chinnanon (2003) evaluation is a field of applied science that seeks to understand how successful projects are and to what extent they fullfill the objectives. Evaluations quantify changes against project goals, document project strategies' effectiveness, and evaluate short-term and long-term outcomes (Coali, Gambardella & Novelli, 2024). The flow of information in a evaluation process ensures transparency (availability and access to information), accountability (use and application of information) and inclusion where communities are given control over decision on appropriate criteria and indicators to assess project performance (Smith, & Benavot, 2019). According to Dolin, Black, Harlen and Tiberghien (2018) there are two methods of evaluation; formative evaluation and summative evaluation.

According to Durdikuliyevna, Anvarovna, and Zulayho (2019), formative evaluation is conducted before starting a project (Pre-Project evaluation) to assess the proposed project's feasibility and viability and while the project is ongoing (process evaluation). This evaluation occurs during implementation. Regular status reports, performance metrics, and quality assurance audits offer real-time insights, enabling project managers and stakeholders to promptly identify and address issues. Data are collected through interviews and focus groups to gauge participant satisfaction and stakeholder perceptions of project delivery. Process evaluation assesses how well a project is implemented, and examines the conditions under which it operates. The results obtained will inform decision-makers on whether to proceed, modify, or abandon the project. Summative evaluation also referred to as impact or ex-post evaluation is conducted after project completion to assess its overall success and outcomes (Durdikuliyevna *et al.*, 2019). It examines both intended and unintended effects over time, providing insights for future projects. This evaluation measures intervention quality and results, assesses design activities, and tracks changes in beneficiary behaviour to ensure accountability and cost-effectiveness. Data for summative evaluation is collected through various methods, including surveys, interviews, focus groups, document review, observations, case studies, and secondary data analysis Dolin *et al.*, 2018). These approaches help comprehensively assess project outcomes and ensure accountability and cost-effectiveness. Project monitoring with respect to the study is defined as the systematic and ongoing process of collecting and analysing data related to the daily activities, inputs, and outputs of the Sargassum-fed animal project. It focuses on ensuring that project activities are progressing as planned, with continuous tracking from the project's inception. Primarily conducted by internal team members, monitoring provides timely information for corrective actions to improve the project's efficiency and alignment with set objectives.

Project evaluation, on the other hand, is a periodic and comprehensive assessment aimed at measuring the broader impacts and sustainability of the project outcomes, including the long-term effects of Sargassum feed

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on animal health and performance. Conducted at key stages or upon project completion, evaluation leverages both qualitative and quantitative data to provide insights into the project's effectiveness, with a focus on whether the project achieved its intended goals. It offers valuable recommendations for future project designs, guiding strategic planning and decision-making for similar initiatives.

2.1.4.2.1Project Evaluation Criteria

The Organisation for Economic Co-operation and Development (OECD) Network on Development Evaluation according to Citaristi (2022) defined six evaluation criteria alongside evaluation principles in 1991 to achieve project success and sustainable development goals. the criteria are efficiency, cost-effectiveness, relevance, cohesiveness impact, and sustainability. These criteria provide a normative framework used to determine the worthiness of an intervention and serve as the basis upon which evaluative judgments are made. Table 2.7 presents the definitions and evaluation criteria questions raised by OECD DAC Network on Development Evaluation.

Table 2.7: Project Evaluation Criteria Definitions and Questions

Criteria	Definition	Question
Relevance	The extent to which the objectives of an operation are consistent with beneficiaries' needs, country needs, organisational priorities, and partners' and donors' policies.	Is the intervention doing the right things? Does the project address our needs?
Coherence	The degree to which the different components of a project or program work together harmoniously to achieve the intended objectives. It examines how well the various activities, interventions, and stakeholders are integrated	How well does the intervention fit?
Effectiveness	The extent to which the operation's objectives were achieved, or expected to be achieved, taking into account their relative importance.	Is the intervention achieving its objectives? Are the desired results achieved?
Efficiency	A measure of how economically inputs (funds, expertise, time, etc.) are converted to outputs.	How well are resources being used? Are we using resources wisely?
Impact	Positive and negative, intended or unintended long-term results produced either directly or indirectly. The goal level effects attributable to an operation.	What difference does the intervention make? To what extent have project activities affect changes for communities?
Sustainability	The continuation of benefits from an operation after major assistance has been completed.	Will the benefits last?

Source: Adapted from Organisation for Economic Co-operation and Development (2022).

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Table 2.8: Role of Monitoring and Evaluation in a Project Cycle

Description	**Project Phase**			
	Project Initiation Phase	**Planning and Re-design Phase** **(M&E)**	**Implementation Phase** **(Monitoring)**	**Post Project Phase** **(Evaluation)**
Focus and Activities	Conduct needs analysis to understand the needs and challenges of the target population through surveys and Interviews. Analyse existing data and research related to the population group to identify common issues and areas needing improvement. Involve community leaders and stakeholders to gain deeper insights and build trust. Define Objectives and SMART Goals.	The design of the project and how it will improve the lives of particular population group who are involved with the increase of income generation, social and environmental dimensions Identify external factors and assumptions i. Develop a comprehensive M&E plan detailing how the project will be implemented. ii. Define activities, funding, personnel, and materials. iii. Create a realistic timeline; milestones and deadlines. iv. Identify potential risks and develop mitigation strategies.	Project coverage, delivery, costs, intermediate out comes and other management concerns . Objective: Ensure effective and efficient execution of the project. i. Pilot Testing: Start with a pilot phase to test the project on a smaller scale and gather feedback. ii. Training and Capacity Building: Provide necessary training to staff and community members involved in the project. ii. Partnerships: Collaborate with local organizations, government bodies, and other stakeholders to enhance project reach and effectiveness.	Determining the intermediate outcomes and more substantial impacts of the project on beneficiaries
M&E Questions		Are the goals, objectives and activities appropriate in light of the project's context?	Are the specific inputs and services reaching the	Are the outcomes and/or impacts of the project on the targeted

		Are the project inputs and activities likely to achieve these objectives? Will the project's monitoring and evaluation system produces the information needed for critical decision making? Are the criteria used for targeting appropriately	targeted population and on time? Are inputs the desired quality? Are inputs being well, used by the population? Do actual project activities correspond with those spelled out in project design or implementation plan?	populations? Have the originally started objectives and goals been met by the project? What other effects (intended or unintended) did the project have on local communities, project staff, or government policies?

Source: Adapted from Calvani and Chinnanon (2003), p. 46-47.

Project evaluation in agriculture ensures objectives, efficiency, and sustainability through systematic M&E across project lifecycles. M&E agricultural project design allows for continuous feedback and timely management decisions through the establishment of metrics early (PMI, 2017). Comparing baseline data against outcomes enhances final evaluation credibility. Throughout the project, continuous monitoring ensures alignment with the established plan managing risks, maintaining quality, and implementing necessary changes as needed. Therefore, designing a project monitoring and evaluation plan at early stage is imperative. Table 2.8 shows the role of M&E throughout the life cycle of a project.

2.1.5 Monitoring and Evaluation System (M&ES)

A M&E system encompasses all monitoring and evaluation activities, ensuring effective oversight, performance assessment, and impact measurement (Okafor, 2021). The system tracks project progress against goals, identifying deviations for corrective action. The design of M&E system begins by designing the M&E plan, which involves collecting baseline data before project implementation begins; the planning phase precedes on-field activities and is vital for effective monitoring, evaluation, and project success (El-Khatib, Alhosani, Alhosani, Al-Matrooshi, & Salami, 2022). Sustainable Project monitoring and evaluation planning involves measuring, tracking, and reporting sustainability performance to stakeholders (Abdullah, Inan, & AI, 2021), hence, collaborative tools are essential for managing and visualizing project plans. An M&E plan's key components include real-time monitoring, evaluating outcomes against criteria, effective data management, and transparent reporting. These elements ensure accountability and support informed decision-making throughout the project.

Results-Based Monitoring and Evaluation (RBM&E) is a systematic approach employed to assess the efficiency of program activities, outputs, and outcomes. By analysing these factors, RBM&E identifies areas for improvement and informs strategic decisions (EvalCommunity, 2024). According to Kogen (2018), the

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prominence of RBM as a framework for assessing the efficiency and effectiveness of nonprofit organizations significantly increased due to its endorsement by the OECD. This approach ensures that programs meet their goals in terms of quality, cost-effectiveness, and timely delivery, serving as a robust accountability tool for project funders and stakeholders. Moreover, RBM&E supports intervention strategies by enabling stakeholders to assess their contributions and adjust actions to optimize outcomes during implementation. Van-Mierlo (2011) suggested that the logical framework is a suitable planning method for M&E in developmental projects.

2.1.5.1 Logical Framework Approach (LFA)

The Logical Framework Approach (LFA) is a methodology developed by Practical Concepts Incorporated (PCI) for USAID in 1969 (PCI, 1979). It aids in designing, monitoring, and evaluating international development projects by applying principles of 'management by objectives' (MBO) and 'management by planning' (MBP), popularized by Peter Drucker in the 1960s and rooted in ancient Greek military strategy (Crawford & Bryce, 2003).

LFA provides a structured framework for project design, implementation, and evaluation, helping to define monitoring and evaluation (M&E) systems and ensuring clarity in project objectives, activities, outputs, and outcomes. It supports project managers and evaluators in establishing logical linkages between means and ends, setting performance indicators, assigning responsibilities, and improving communication (Crawford & Bryce, 2003).

Table 2.9: A Typical Logframe Planning Format with Explanatory Notes

Goal/Impact (1)	Impact Indicators (11)	Data source/Means of verification (MOV) (12)	Assumption / Necessary conditions (10)
The sustainable development outcome expected at the end of the project. All outcomes	Measures the extent to which a contribution to the goal has been made. A function of evaluation	How data on goal achievement is to be collected	
Outcomes / Effects/Objectives (2)	Effective indicators (13)	(14)	EEF (9)
The expected result of producing the planned outputs. The project hypothesis being that the combined effect of producing the outcomes will be the realization of the goal	Measures the extent of which outcomes have been met. A function of evaluation	How data on objective achievement is to be achieved	Assumption concerning the outcomes-goal linkage (i.e pre-conditions for the goal)
Output (3)	Output/progress indicators (15)	(16)	OPA (8)
The direct measurable results (goods and services) of carrying out planned activities. These are partly under project	Milestones throughout life of project against which progress of project can be monitored	How data on progress is to be collected	Assumptions concerning the outputs-outcomes linkage (i.e. pre conditions for

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management's control			outcomes)
Activities (4)	(17)	(18)	OPA (7)
Tasks carried out to implement the project and deliver identified outputs. These are largely under project management's control	Activity schedule to monitor project progress (actual vs planned)	How activity implementation is to be reported	Assumptions concerning the activity-output linkage (i.e. pre-conditions for outputs)
Inputs (5)	Inputs indicators (19)	(20)	OPA (6)
The financial, managerial, and technical resources required to carry out activities. These are directly under project management control.	Budget to monitor the deployment of resources throughout the life of project	How inputs are to be accounted for and reported.	Assumptions concerning input-activity linkage (i.e. pre-conditions for activities)

Note: The numbers indicate the usual order of completion of the cells in designing a project strategy

Source: Adapted from Crawford and Bryce (2003), p. 365.

LFA employs a 5x4 log frame matrix or similar matrix for structured planning and evaluation. According to table 2.9, the rows of the matrix represent project objectives and the means to achieve them (vertical logic), while the columns indicate how these objectives can be verified (horizontal logic). This framework establishes a "cause-effect" or "means-ends" chain, known as the result chain. This tool is most effective when used throughout the entire project cycle. By aligning interventions with desired results and clarifying causality and linearity, the logical framework enhances understanding and management of project goals. Related models include Goal Oriented Project Planning (GOPP) and Objectives Oriented Project Planning (OOPP), which also enable sequential task management. The LFA does not prescribe a unified set of procedures or specific guidelines for evaluating projects but serves as a framework to delineate activity components and identify logical connections, aiding in logical thinking and analytical project structuring (Crawford & Bryce, 2003).

2.1.5.1.1 Vertical Logic

Vertical logic refers to the hierarchical structure of project objectives and their causal relationships, typically presented in a matrix format. It clarifies the hierarchy of project objectives, Causal linkages within this hierarchy, and assumptions. These elements collectively help define project intentions, outline the relationship between means and ends, and address uncertainties within the project and its environment. The key concepts integral to explaining vertical logic include:

Hierarchy of Project Objectives

The hierarchy of objectives is sequentially identified and structured as inputs, activities, outputs, outcomes, and impacts objectives. Monitoring focuses on inputs, activities, and outputs, while evaluation assesses outcomes and impacts (Coleman, 1987). The initial four levels—inputs, activities, outputs, and outcomes (objectives or purpose or effect)—are focused on the project itself. In contrast, the highest level, the goal (impact), connects the project to the broader program it belongs to. Achieving a project's outcome does not guarantee the achievement of its goal if other related projects aimed at the same goal do not meet their objectives.

Causal linkages

Results can occur in a simple linear fashion, following a clear "If-Then" pattern (Crawford & Bryce, 2003; Gladshtein, Pîrlea, & Sergey, 2024*).* Causal linkages use "If-Then" statements to outline logical relationships between goals, outcomes (objectives), outputs, activities, and inputs. This statement helps to see if the basic assumptions of the results chain hold. A project description, according to Crawford and Bryce (2003) can be derived from the matrix by breaking down the chain of conditional causality as follows and in figure 2.6:

a. IF inputs are provided, AND the input-activity assumptions hold, THEN the activities can be undertaken.

b. IF the activities are undertaken, AND the activity-output assumptions hold, THEN the project outputs will be produced.

c. IF the project outputs are produced, AND the output-outcome assumptions hold, THEN the outcomes should be realised.

d. IF the outcomes are realised, AND the outcome goal assumptions hold, THEN the goal is likely to be achieved.

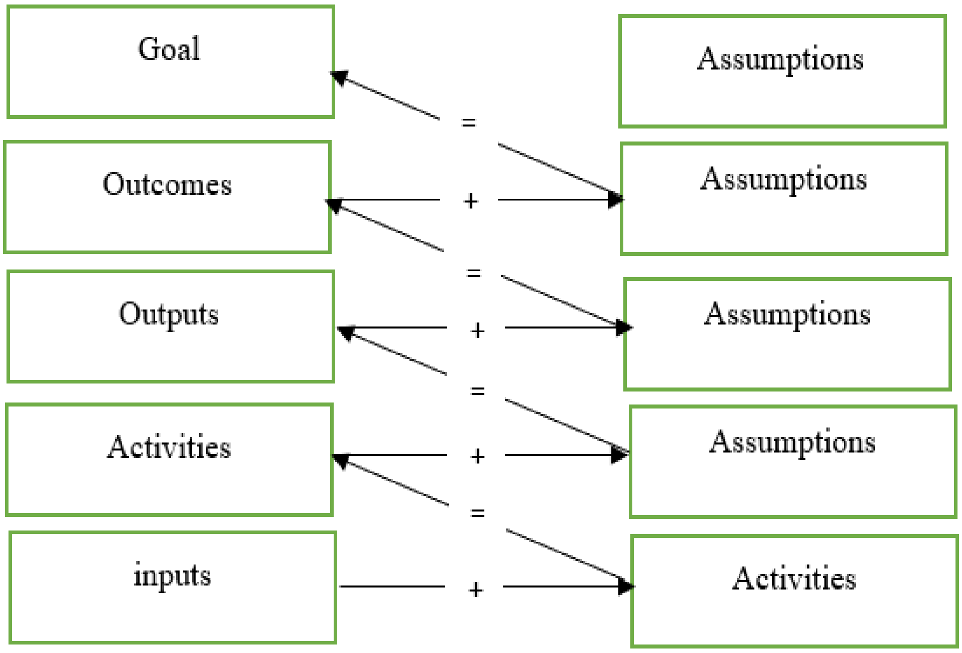

Figure 2.6: Hierarchy of objectives showing the logical relation IF-AND-THEN supporting the vertical logic of the log frame

Source: Adapted by AusAid (2000), p. 18

Assumptions

Project assumptions are factors that is EEFs and OPAs influencing project success beyond direct control critical assumptions of the project are identified, the potential internal risks (OPAs) and external risks (EEFs) that could prevent the project from achieving its expected results. Project assumptions can include events, conditions, or decisions essential for the project's success but are mostly or entirely outside the control of project management (Calvani, & Chinnanon, 2003). They are critical because they represent forces essential for the success of each level but may not be fully within the project's control. EEFs affect the project's goal level while OPAs affect the input, activities and output (PMI, 2017). When studying living subjects in agriculture and rural development projects, natural changes, known as the maturation effect, and environmental influences can affect assessments, even if the groups are initially similar. Monitoring these assumptions within the project's logical framework is crucial to evaluate their impact on achieving the defined

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outputs and objectives. A risk management and monitoring matrix is developed, to assess the indicators that can be collected at the same time by the same person and ideally using the same tools.

Moreover, the log frame indicates the degree of control managers will have over projects; project managers have direct control over inputs, considerable control over activities and partial control over outputs (Crawford & Bryce, 2003). Although at the outcome level, project management exert slight influence, however goal achievement requires an interaction of efficient project management, effective project design and the accommodation of externalities. This aligns with the notion of necessary and sufficient conditions.

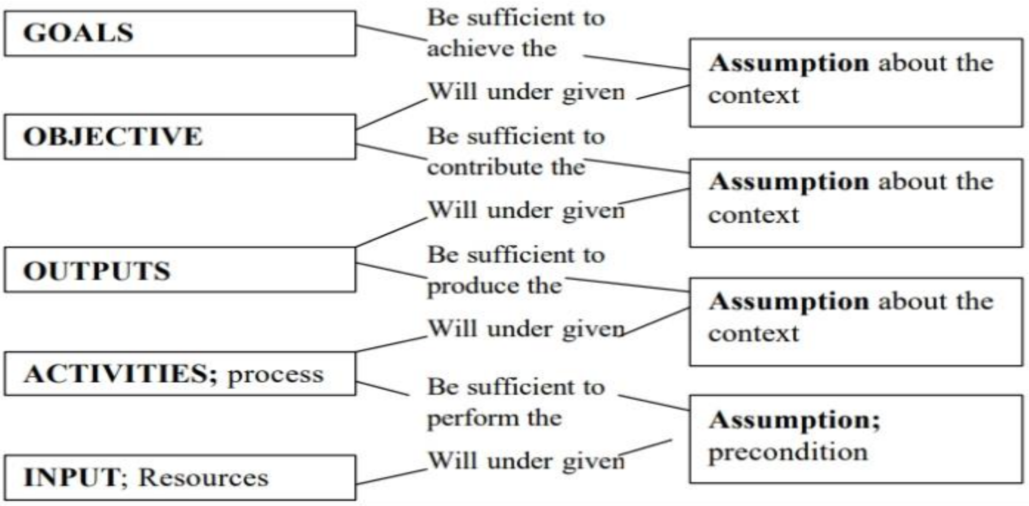

Figure 2.7: Necessary and sufficient conditions for Monitoring and evaluating projects and their assumptions

Source: Calvani and Chinnanon (2003), p. 37

Figure 2.7 shows that meeting project outcomes is necessary but insufficient to attain a project goal since the project is but one of several initiatives that may be required to address complex development issues. Producing outputs is necessary but may not be sufficient to achieve the outcomes since other factors beyond the project's control are likely to have an influence. Carrying out activities is necessary and should be sufficient to produce the required outputs, although some risks always exist.

The vertical logic of a strategy is tested at the M&E planning stage by starting at the top of the log frame matrix and asking the question ''how is each level in the hierarchy to be achieved?'' or by starting at the bottom and asking the question ''why is this objective/action being undertaken?'' (Calvani Calvani & Chinnanon, 2003).

2.1.5.1.2Horizontal Logic

The middle portion of the logframe matrix comprise the horizontal logic which complements vertical logic by defining how project progress is verified at each level of the hierarchy (Crawford & Bryce, 2003). While vertical logic focuses on the hierarchical structure of project objectives and their causal, horizontal logic ensures coherence and clarity in how project progress is verified at each level and how assumptions play into the achievement of objectives. In the second column of the matrix, the project manager is expected to identify objectively verifiable indicators (OVI) for each objective level to assess progress towards the goal. This involves selecting indicators for inputs, activities, outputs, outcomes, and impacts. The third column on the other hand, identifies the means of verification (MOV) or the source of indicator data for each of the OVIs. This implies that horizontal logic is the foundation of monitoring and evaluation information system (MEIS). Logic model, derived from LFA, guides Monitoring and Evaluation (M&E) plans by selecting indicators to assess inputs, processes or activities, outputs, outcomes, and impacts, outlining project objectives.

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2.1.5.2. Project Performance Indicators

Project performance indicators are quantifiable measures used to evaluate the success of a project (PMI, 2021). They provide a way to track progress and determine if the project is on the right path to achieving its goals. KPIs serve as signals that show whether or not progress is being made, allowing project managers and stakeholders to make informed decisions and take timely actions to ensure the project's success. Indicators are used as means to measure results at each objective level of the results chain. It is a balance between what needs to be known and what is desired to be known (Calvani & Chinnanon, 2003).

Table 2.10: Criteria for Selection of Indicators

Criteria	What to measure	Questions to ask
Validity	Measures the result	Is the indicator valid? Does the indicator measure the result?
Reliable	Consistent over time, measures trends, sensitive to change	Is the indicator a consistent measure over time? Can we use the indicator to measure trends over time? And is the indicator sensitive to change over time?
Simplicity	Easy to collect	Will the data be easy to collect?
Utility	Useful to generate information for decision-making and learning	Will the indicator be able to generate useful information for decision-making and learning?
Affordability	Resources to collect	Can the programme afford to collect the data with the resources it has? Is the data collected worth the effort and expense?

Source: Author's Computation, November (2024).

Indicators are selected for each result statement in the results framework. The indicators for inputs, activities and outputs allow for the measurement of project efficiency (i.e. the conversion of inputs to outputs), whereas indicators assigned to the outcome and goal rows, measure the effectiveness of the strategy in fostering the desired changes in beneficiary circumstances (Nichols, 1999; Crawford & Bryce, 2003).

2.1.5.3. Sources of Information and Method of Data Collection

Sources of information refers to where, from what or from who the information will come (Saunders, Lewis, & Thornhill, 2023). It involves the collection of data to inform indicators through primary (targeted communities, individuals, groups, staff, government officials) or secondary sources (existing documents such as census, district health surveys, reports). Methods of data collection is how information about indicators will be collected from diverse sources (Oyeniyi, Abiodun, Moses, Obamiro & Osibanjo, 2016). Selecting methods is dependent on what is being measured, the nature of information needed (quantitative or qualitative); information or data points needed to calculate the indicator; the level of statistical precision for generalization of data; resources and time required to use this method; available information from other reliable sources that can be used; the complexity of information to be collected; and the frequency of data collection among others (Cohen, Manion & Morrison, 2018).

A qualitative method is used when there is need for narrative or in-depth information (why and how questions). It is also used when quantifying results is not necessary. Quantitative methods, on the other hand, are used when there is need to conduct statistical analysis of the collected data, be precise, cover a large group or population and answers the "what" question (Calvani, & Chinnanon, 2003). A quantitative indicator necessitates a quantitative method for data collection, while a qualitative indicator requires a qualitative method to gather information qualitatively. For complex indicators at higher levels, it is crucial to employ a combination of methods (triangulation) to achieve a more comprehensive understanding (Hirose, & Creswell,

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2023; Takona, 2024). This approach involves using multiple methods to collect the same information, often resulting in the richest insights.

2.1.6 Implementation of the Monitoring and Evaluation System

Adapting the M&E guidelines from organizations such as the United Nations Development Programme (UNDP), World Bank, International Organization for Migration (IOM), United States Agency for International Development (USAID), this study identifies activities in the M&E developmental and implementation processes.

1. Conduct needs analysis and establish cause/effect relationships through problem tree analysis.

2. Design the M&E plan.

3. Identify stakeholders and conduct stakeholder mapping

4. Define project objectives.

1. Identify outputs and outcomes to understand program achievements and support theory of change.

2. Define logic and map indicators.

3. Establish SMART indicators (Specific, Measurable, Achievable, Relevant, Timely).

4. Identify milestones.

5. Develop a data collection plan, design instruments, and select tools primarily for output monitoring;

a. Primary sources: Surveys, Key informant interviews, Focused Group Interviews.

b. Secondary sources: Reports, administrative data.

1. Determine frequency and responsibility for data collection.

2. Plan data analysis methods

3. Develop reporting plan for communicating M&E results effectively.

4. Create feedback and learning plan to apply M&E findings for program improvement.

5. Implement plan and monitor activities

6. Analyse data.

1. Data Collection
2. Data Cleaning and Validation
3. Apply statistical or qualitative methods to investigate the data
    a. Identify trends, patterns, and relationships.
4. Performance Assessment

7. Report findings.

Overall, an M&E System defines roles, data collection methods, quality assurance, and reporting. They establish key indicators, data analysis techniques, and feedback loops, utilizing quantitative and qualitative methods

like surveys and interviews. Regular reviews optimize relevance and decision-making (PMI, 2021).

2.1.7 Sustainable Animal Production

Animal has been integral to human civilization for millennia, providing food, clothing, and livelihoods. Sustainable animal management is essential for balancing the demand for animal-based products with the need for ecological sustainability. According to the Food and Agriculture Organization animal contributes 40% of the global value of agricultural output and supports the livelihoods and food security of nearly 1.3 billion people (Kennady, Chakraborty, Biswal, & Rahman, 2023). Animal management is a vital part of agriculture, focusing on animal breeding, care, and use for food, fibre, and labour. It involves a blend of animal husbandry, nutrition, health care, breeding, and environmental sustainability. Traditionally significant for rural economies and food security, modern animal management now also addresses global challenges like population growth and ecological impact. Appropriate husbandry conditions according to Farm Animal Welfare Council (2009) involve conditions that follow the guiding principles of the "Five Freedoms", which recognize the important states of animal welfare for domesticated species:

1. freedom from hunger, malnutrition and thirst
2. freedom from heat stress or physical discomfort
3. freedom from pain, injury or disease
4. freedom from fear and distress and
5. freedom to express normal patterns of behaviour.

According to FAO (2017), adequate nutrition, the oral intake by animals of adequate levels of nutrients, substances, microorganisms, and other feed constituents, considering their combination and presentation, necessary to fulfill functions related to their physiological states, including the expression of most normal behaviour, and their resilience capabilities to cope with stressors of various type encountered in appropriate husbandry conditions. Adequate nutrition is achieved through the optimization of feed composition, manufacturing, presentation, and delivery to animals, minimization of the exposure of the animals to stressors in feeds, coverage of the animal's requirements for maintenance, activity, growth, production, and reproduction, support of digestion and physiological functions, body systems, and behavioural expression.

Sustainable practices in animal management aim to reduce environmental harm, such as greenhouse gas emissions and resource depletion, while enhancing productivity through advanced technologies and data-driven methods. Sustainable animal farming involves managing animals in a way that meets current demands without compromising the ability of future generations to meet their needs (Drury, Fuller, & Hoeks, 2023). This approach emphasizes sustainable practices, animal welfare, and economic viability. It addresses food security, minimizes resource depletion, reduces greenhouse gas emissions, and promotes ethical treatment of animals, all of which are vital for a healthy planet and balanced ecosystems. Effective management of sustainable agricultural projects, particularly in animal management, necessitates robust Monitoring and Evaluation (M&E) practices. By consistently monitoring activities, M&E evaluates the project's environmental and community impact, assessing aspects like greenhouse gas emissions reduction and improvements in local livelihoods. By implementing new models for nutrient management, environmental stewardship, and stakeholder engagement (farmers, local communities, government agencies), Sustainable Agile Project Management facilitates iterative project phases that allow flexibility and adaptability as the project evolves (Hasan & Laszlo, 2023). This adaptability is crucial for animal management projects that must respond to dynamic environmental conditions and shifting stakeholder needs. Combining M&E with Sustainable Agile Project Management leads to improved project performance, better future planning, and alignment with sustainability goals, thus ensuring the project's long-term success.

2.1.7.1 Standards and Guidelines for Animal Feed Production

United Nations Environment Programme (2023) stated that sustainable agriculture meets the needs of the present population while preserving the planet's future capacity. While sustainable animal practices prioritize space for health, productivity, and air quality, ensuring safer products through hygiene standards, a significant aspect involves developing nutritious, high-quality feed with minimal environmental impact. Proper animal nutrition is essential for achieving SDGs by promoting food security, economic growth, and environmental sustainability (Herbert, Hashemi, Chickering-Sears, Weis, Miller, Carlevale, Campbell-Nelson & Zenk, 2017).

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International standards for animal feed production, guided by organizations (External Enterprise Environmental Factors) like the International Feed Industry Federation (IFIF), Food and Agriculture Organization of the United Nations (FAO), and the International Organization for Standardization (ISO), ensure safety, quality, and sustainability. International Feed Industry Federation & Food and Agriculture Organization, IFIF/FAO (2021) offers comprehensive guidelines for stakeholders across the feed value chain, covering sourcing high-quality raw materials, maintaining hygiene standards during production, and proper storage and transportation practices. Emphasis is placed on quality control, regular testing, and traceability to prevent contamination and ensure feed safety. In Nigeria, the Federal Ministry of Health, through NAFDAC, aligns international standards with local requirements to safeguard animal feed quality and public health.

Evaluating sargassum as animal feed within a monitoring and evaluation (M&E) framework requires consideration of both external factors such as NAFDAC, market dynamics, technological advancements, and environmental impacts. These factors influence legal compliance, market demand, technological feasibility, and ecological sustainability of sargassum as feed. Internal factors include organizational culture, infrastructure, and workforce skills, impacting the readiness and capacity to implement and sustain the project. Organizational Process Assets (OPAs) encompass internal resources supporting project success, including established processes, policies, procedures, quality assurance for feed safety and nutritional standards, and risk management protocols. The corporate knowledge base, including historical data, lessons learned, and best practices, guides project decisions.

2.1.7.2 Value Chain in Feed Production

The value chain, originally formulated by Porter (1985), is a representation of a firm as a chain of linked activities that work together to create value for customers. It serves as a framework to analyse how a firm's activities generate value for its customers. Value chain management is the action taken by a firm to optimize its value chain. Value chain, widely applied in business and management, defines the sequence of processes that enhance products or services from inception to consumption. In the context of sargassum-based feed production, the value chain spans from raw sargassum harvesting to final product delivery to the market (Anetekhai, 2022). Adopting a value chain and collaborative approach enables continuous adaptation to new data, prompt delivery of valuable insights, and heightened stakeholder engagement. Sargassum-based feed value chain according to Anetekhai (2022) begins at the up-stream (input) stage with the harvesting and washing of sargassum. This stage involves collecting sargassum from coastal areas and thoroughly washing it to remove impurities such as salt and sand, preparing it for further processing (See figure 2.8).

At the mid-stream (transformation) stage, the cleaned sargassum undergoes a series of processing steps. First, it is dried to reduce moisture content, which is essential for further handling and storage. Following drying, the sargassum is milled into smaller particles and ground to achieve the desired particle size. The ground sargassum is then mixed with other ingredients to create a nutritionally balanced livestock feed. This mixture is pelleted to form uniform feed pellets, which are more convenient for handling and feeding. Project quality control measures such as the application of HACCP principles ensure that the processed feed meets safety and nutritional standards (IFIF/FAO, 2021). The image of a typical a chicken feed production chain in figure 2.9 illustrate its flow (Amin & Sobhi (2023).

In the down-stream (output) stage, the focus is on sargassum-based livestock feed as the final product. The packaged feed undergoes storage to ensure it remains in good condition until it is distributed to various markets or directly to livestock farms. Supporting primary activities (up-stream, mid-stream and down-stream) are the secondary activities (Internal Enterprise Environmental Factors), which enhance the efficiency and quality of the entire process. Firm infrastructure provides the necessary physical and organizational structures, including factories and warehouses, to support production. Human resource management focuses on recruiting, training, and managing the workforce involved in the value chain. Technological advancement plays a crucial role in improving the methods used in harvesting, processing, and distribution, such as advanced drying techniques and automated packaging systems. Lastly, procurement ensures that all necessary resources and materials, such as machinery, packaging supplies, and additional feed ingredients, are acquired to maintain smooth production operations.

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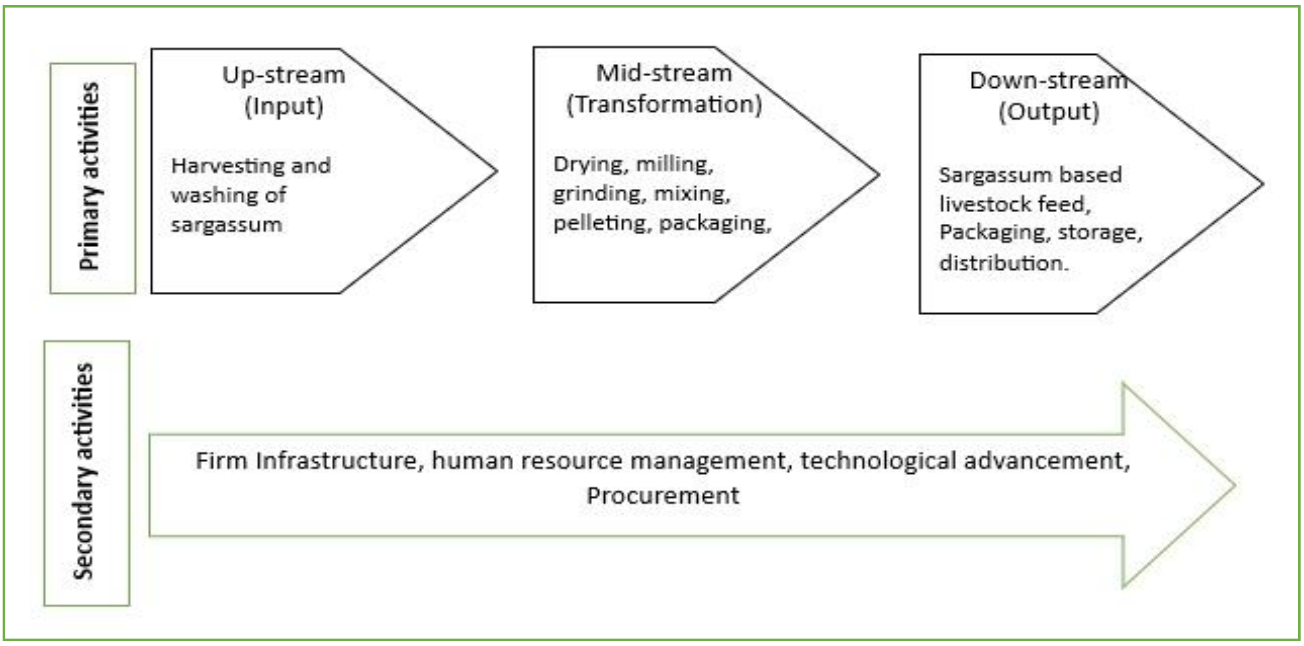

Figure 2.8: Sargassum-Based Feed Value Chain

Source: Adapted from Anetekhai (2022).

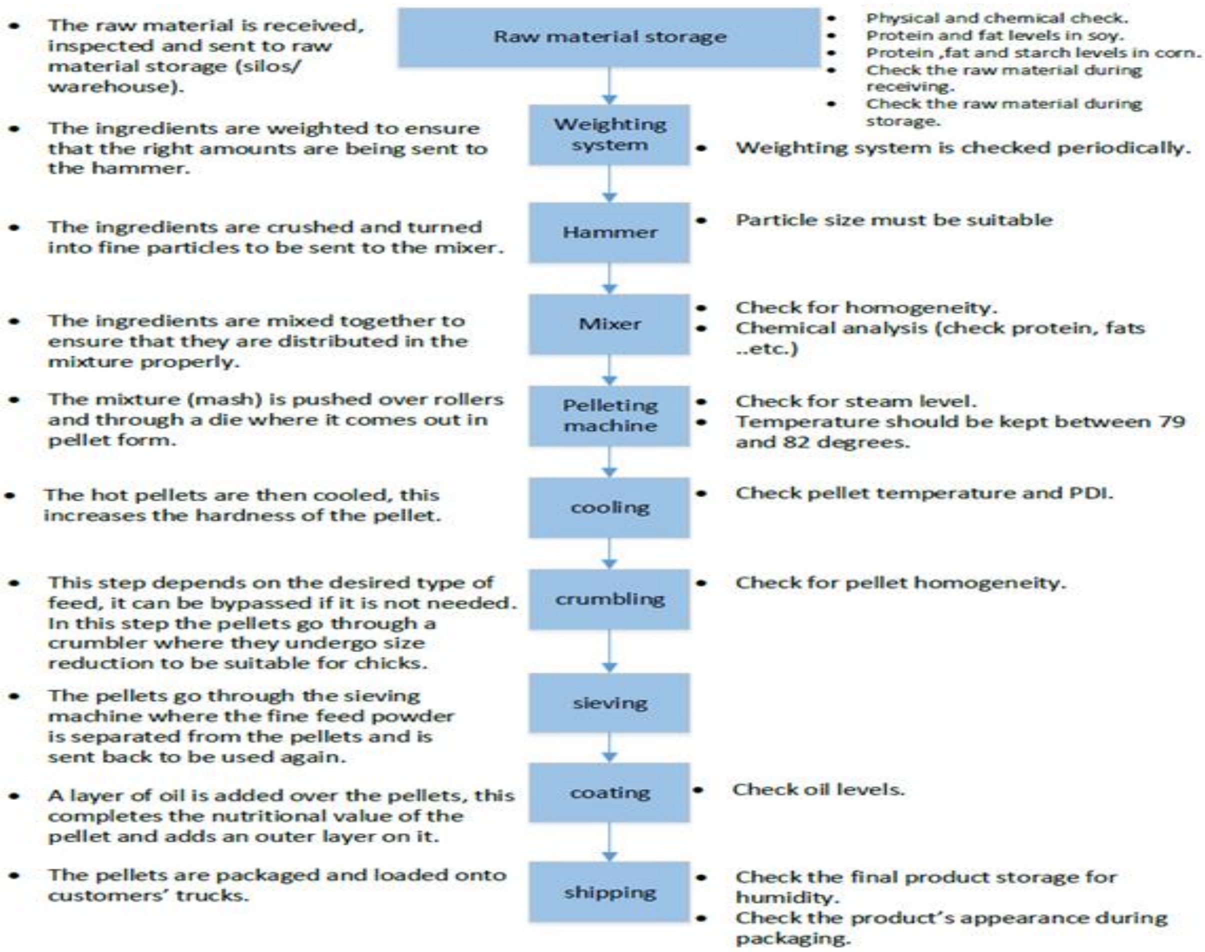

Figure 2.9: Livestock feed production chain

Source: Amin and Sobhi (2023), p. 14

2.1.7.2.1 Animal Feed Quality Management: Developing a HACCP Plan

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Hazard Analysis and Critical Control Points (HACCP), is a systematic approach to food safety designed to identify, evaluate, and control hazards significant to food safety (Dlamini, & Adetunji, 2023). These processes are utilized in the food industry to ensure that food products are safe for consumption and meet the necessary quality standards for animal health and nutrition, as well as efficiency and cost savings through preventive measures. HACCP is based on seven principles: conducting a hazard analysis (biological, chemical, and physical), determining critical control points (CCPs), establishing critical limits, setting up monitoring procedures, defining corrective actions, verifying the system, and maintaining documentation (Wilmcow, 2012).

In developing a HACCP plan, OPAs involve assembling a knowledgeable team, describing the product and its processing methods, identifying the intended use and consumers, and constructing and verifying a detailed flow diagram of the process. Implementing an M&E plan will help ensure that sargassum-based feed supports the health, growth, productivity, and welfare of livestock. The HACCP team includes the Quality Assurance Manager, Production Manager, R&D Specialist, Operations Supervisor, and a Regulatory Expert. The image of Critical Control Point Decision Tree in figure 2.10 illustrate its flow.

2.1.7.2.2 Project Audit: Verification Procedures for HACCP Plan in Sargassum-Based Animal Feed Production

Verification procedures are crucial for ensuring the effectiveness of the HACCP plan in sargassum-based animal feed production. These procedures include regular audits of the HACCP plan implementation, which provide an overall assessment of compliance and identify areas for improvement. Additionally, microbial testing (Pathogenic bacteria, molds, and fungi) and chemical testing (Heavy metals, pesticide residues, and marine toxins) of the final product ensures that the feeds meet safety and quality standards (FAO, 2020). A thorough review of monitoring and corrective action logs is also essential, as it ensures all control measures are effectively managed. This review process will identify any deviations and assess the adequacy of corrective actions taken. By maintaining detailed documentation and conducting systematic verifications, the HACCP plan ensures ongoing food safety and quality control in the production of sargassum-based livestock feeds.

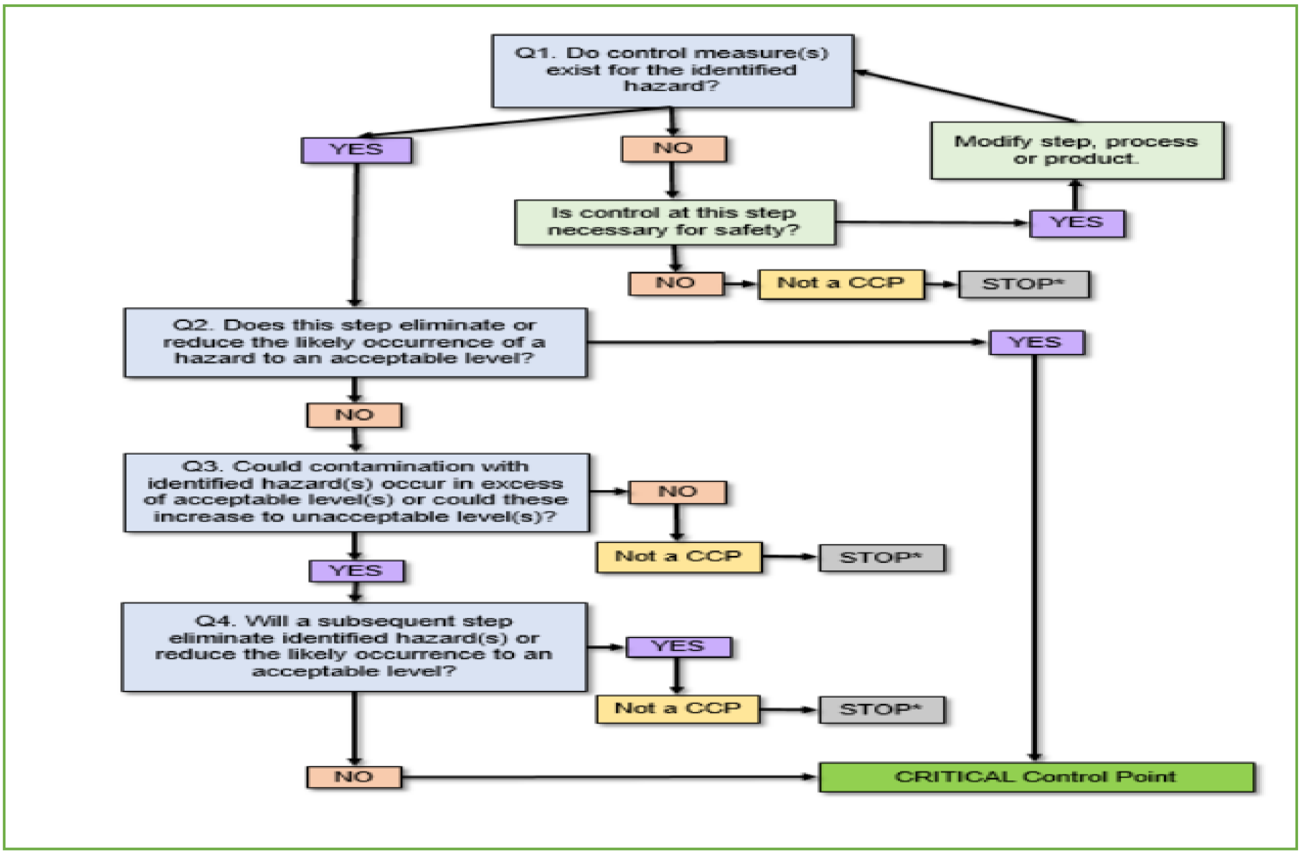

Figure 2.10: Critical Control Point Decision Tree

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Source: National Advisory Committee on Microbiological Criteria for Foods (1992), https://www.fda.gov/food/hazard-analysis-critical-control-point-haccp/haccp-principles-application-guidelines

2.1.7.3 Project Feedback and Accountability Mechanism

Monitoring and Evaluation (M&E) is integral to project management, focusing on feedback, structured learning, and promoting development through transparency and accountability. Feedback in M&E disseminates information and assesses progress, communicating findings, conclusions, recommendations, and lessons learned from programs (Kabeyi, 2019). Structured learning involves monitoring and evaluating the management process, using insights to inform decision-making and adapt actions based on evidence (Jacobson, Carter, Thomsen, & Smith, 2014). According to Edmunds and Marchant (2008), the integration of monitoring and assessment information is crucial for revealing best practices and areas needing improvement. M&E facilitates learning from experiences and sharing knowledge, enhancing practices by understanding successful approaches and integrating new information and teachings. Moreover, M&E reports and findings promote transparency and accountability by disseminating insights to stakeholders, civil society, and the broader community (Edmunds & Marchant, 2008). This ensures widespread access to information, supporting democracy and good governance. By involving stakeholders in the evaluation process, M&E enhances the internalization of lessons learned and supports evidence-based analyses for effective decision-making and sustainable development initiatives.

2.1.8 Economic Evaluation and Value Determination of Intervention Projects

Economic evaluation is a valuable tool for assessing the cost-effectiveness of interventions, encompassing various methods to assess value for money by comparing the costs and outcomes of different options. The economic value of alternative feedstuffs in animal diets can be determined by their ability to provide essential nutrients such as energy, protein, and phosphorus, which are the primary cost drivers (Rajauria, 2015). To achieve this, price must be established for the alternative feed and a nutritional composition of the alternative feed known. Using tools and techniques such as linear programming.

There is a growing use of Cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA) to evaluate the costs and health effects of new interventions compared to current practice (Raba, *et al.*, 2020; Hammer, 2017), each serving different purposes. In the context of monitoring and evaluating the performance of animals fed with sargassum-based feed, understanding the distinctions between CEA and CBA becomes crucial for a comprehensive evaluation.

2.1.8.1 Cost-Effectiveness Analysis (CEA)

Cost-Effectiveness Analysis (CEA) focuses on determining the most efficient way to achieve specific outcomes, typically measured in non-monetary units such as life years gained or cases prevented (Kim & Basu, 2021; Levin & Belfield, 2015). It is widely used in sectors like healthcare and education to assess interventions' productive efficiency by comparing costs to outcomes. In livestock management, CEA can evaluate the efficiency of alternative feeds, such as sargassum-based feed, by measuring performance outcomes like cost per unit of weight gain, reduced disease incidence, or improved reproductive rates. This method helps determine whether sargassum-based feed is a cost-effective alternative to conventional feed, supporting informed resource allocation decisions. The outcome of CEA is expressed as the cost per unit of effect, such as cost per improvement in health metrics, with lower costs indicating higher cost-effectiveness. According to Myer and Maddock (n.d.), the Cost-Effectiveness Ratio is calculated by dividing total cost by the outcome (see Equation 1).

Cost-Effectiveness Ratio = Total Cost / Outcome…………. Eqn (i)

2.1.8.2 Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) evaluates whether a project's benefits outweigh its costs by assigning monetary values to both. Commonly used in areas like infrastructure and environmental policies, CBA results are

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expressed as a net present value (NPV) or benefit-cost ratio (BCR), with a BCR greater than one (1) or a positive NPV indicating that benefits exceed costs. Applied to sargassum-based feed, CBA would quantify direct costs and benefits, such as feed price and financial gains from improved livestock performance, alongside indirect factors like environmental impacts, potential veterinary cost savings, and long-term animal health benefits. The analysis would determine economic viability, with a BCR greater than one (1) or a positive NPV signifying that the feed is a financially advantageous alternative.

Net Present Value (NPV)

CBA considers the time value of money. Future costs and benefits are discounted to their present value using an appropriate discount rate. The NPV is calculated as the sum of discounted benefits minus the sum of discounted costs. A positive NPV indicates that the benefits outweigh the costs. For one cash flow from a project payable within a year from now, then the calculation for the NPV is given as;

$$NPV = \frac{\text{Cash flow}}{(1+i)^t} - \text{initial investment}$$ … Eqn (ii)

where:

i is the required return or discount rate

t is the number of time periods

When analysing a longer-term project with multiple cash flows, NPV is given as:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

Where**:**

Rt = Net cash inflow outflows during a single period

i = Discount rate or return that could be earned in alternative investments

t = Number of time periods

Decision Rule: for NPV are;

If NPV > 0, the project is considered economically viable.

If NPV < 0, the costs exceed the benefits, and the project may not be recommended.

Benefit-Cost Ratio (BCR)

The benefit-cost ratio (BCR) is a key metric in Cost-Benefit Analysis (CBA). It quantifies the relationship between the total benefits and total costs of a project or intervention. The formula for calculating the BCR is as follows:

BCR=Total Costs/Total Benefits

Decision rules for BCR are;

If BCR > 1: The benefits exceed the costs. A BCR greater than 1 indicates that the project is economically favourable.

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If BCR = 1: The benefits equal the costs. In this case, the project breaks even.

If BCR < 1: The costs exceed the benefits. A BCR less than 1 suggests that the project may not be economically viable.

Decision-makers often use the BCR to prioritize projects and allocate resources effectively.

Overall, while CEA aims to find the most efficient way to achieve a specific outcome, BCR evaluates the overall economic value of a project by comparing its costs and benefits in monetary terms.

2.2 Theoretical Review

This study is anchored on Theory of Change implementation theory which provided detailed understanding of how change happen. The theories are discussed in a logical order, considering the proponents, assumptions, and main issues each theory addresses. The discussion also identifies supporters and critics of each theory and highlights their relevance to the study.

2.2.1 Theory of Change

Theory of Change (ToC) emerged in the mid-1990s from program theory and program evaluation, particularly highlighted by the Center for Theory of Change Inc (2019). Its historical roots can be traced back to Peter Drucker's "*Management by Objectives*" from his 1954 book "*The Practice of Management*," and evaluation theorists like Huey Chen, Peter Rossi, and Michael Quinn Patton (James, 2011). Key contributions were made by Carol Weiss, who emphasized in 1995 the importance of clearly articulating assumptions behind complex programs to enhance evaluation, associated with the Aspen Institute's Roundtable on Community Change (Weiss, 1995).

ToC assumes that the interconnected steps in the change process can improve evaluation planning and claims for predicted outcomes (Theory of Change Community (2023). It links program activities to outcomes, illustrating how this lead to desired long-term goals through multiple feedback loops, thus enhancing understanding in complex domains like governance. The steps involved in ToC include identifying long-term goals, mapping conditions (outcomes) necessary for these goals, linking activities/interventions to outcomes, and improving planning and evaluation through clear linkage between activities and goals. Theory of change starts with program outputs focusing on policies, attitudes, practices, and knowledge. These outputs are informed by evidence from methods and tools, tested innovations, and strategies for scaling up. Partnerships and capacity building play a critical role in influencing practices. The improved uptake of innovations leads to enhanced capacity and coordination along value chains. Key outcomes (IDOs) include increased productivity, quality, employment, and environmental sustainability. Ultimately, these outcomes contribute to higher-level impacts such as food security, nutrition, reduced poverty, and sustainable natural resources.

The widespread adoption of ToC can be seen among philanthropic organizations, government agencies, international NGOs, and the UN, integrating systems thinking to promote social change. It provides a framework to articulate relationships between a project's components, including inputs, activities, outputs, and outcomes, leading to long-term goals. However, ToC has faced challenges and criticisms, such as early programs often lacking specificity in assumptions, difficulties in evaluating complex initiatives due to unclear change processes, and the need for well-defined theories to claim credit for outcomes (The Georgia Basin Inter-Agency Theory of Change Project, 2017). Despite these challenges, ToC remains relevant for studying initiatives like sargassum-based livestock feed, as it maps out assumptions and connections between activities and outcomes. This enhances planning and evaluation, ensuring that the study meets its research objectives and contributes to evidence-based decision-making in the development of sargassum-based feed. Figure 2.11 shows a Livestock and Fish Theory of Change framework developed by Child (2013) for value chain interventions to achieve specific outcomes and impacts (SLOs).

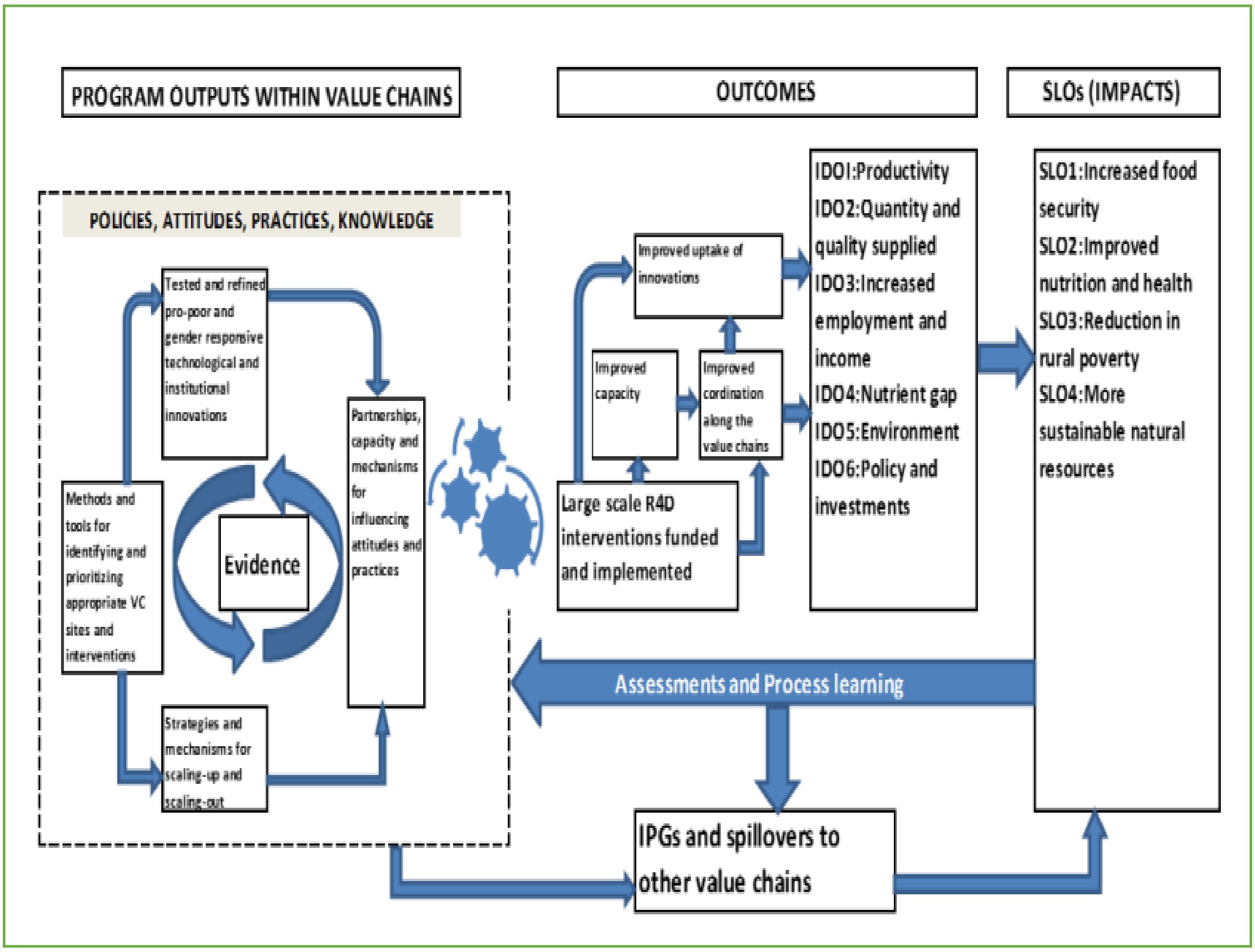

Figure 2.11: Livestock and Fish Theory of Change

Source: Adapted from Child (2013), p. 4

2.2.2 Implementation Theory

Implementation theory has evolved through contributions from diverse fields such as public administration, organizational behaviour, and policy studies. At its core, the theory posits that successful implementation of interventions hinges on navigating complex social processes within real-world settings. This involves dynamic interactions among stakeholders, organizational contexts, and external factors, acknowledging the non-linear nature of implementation.

Numerous researchers and practitioners have endorsed implementation theory (Ashcraft *et al.*, 2024; Lewis *et al.*, 2020; Nilsen, 2020), employing it to translate research into practice effectively. For instance, Ashcraft *et al.* (2024) highlighted the theory's role in rigorously assessing effectiveness and implementation outcomes, using strategies like distributing educational materials, conducting meetings, providing audit and feedback, and facilitating external support. These efforts have shown improvements across various contexts, aligning with the theory's emphasis on multifaceted approaches for successful implementation. However, while implementation theory has gained prominence in guiding interventions, it has also faced criticism.

Critics argue that theory may not always outperform common sense in guiding practical implementation. For example, Barwick, Dubrowski, and Damschroder (2020) contended that implementation theory is not necessarily superior to common sense for guiding implementation. Additionally, inconsistencies in terminology can make it challenging to compare and assess different frameworks.

Implementation theory is relevant to introducing sargassum-based livestock feed to animals, offering a process-oriented framework that aligns with the project management life cycle: planning, execution, and

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evaluation stages. Its insights help navigate the complexities of adaptive projects, ensuring a comprehensive understanding and strategic deployment.

Theory of Change and Implementation Theory are essential theories for this study. Inline with Nilsen (2020) who stated that practical challenges require pragmatic approaches beyond theoretical constructs. They provide structured approaches to design interventions, understand the causal pathways, monitor progress, and evaluate outcomes effectively. This dual approach ensures that the study not only meets its research objectives but also contributes to evidence-based decision-making in sargassum-based animal feeds development.

2.3 Empirical Review

This subsection deals with both methodologies and findings review of prior empirical works on monitoring and evaluation system and how the study compares in terms of methodologies and findings.

2.3.1 Assessment of the Nutritional Contents of Alternative Animal Feeds

Rodríguez-Hernández *et al.* (2023) evaluated sustainable intensive systems for cattle production in Colombia, focusing on maintaining environmental services while improving productive and reproductive indexes between 2011 and 2015. The study monitored environmental and animal production variables by measuring weight gain and calving interval in animals while pasture/crop productive variables included yield and forage quality. Soil ecosystem services (ES) were evaluated through macrofauna biodiversity, biogeochemical cycles, and soil physical and chemical variables. Principal components analysis was used to estimate indicators for these variables. For climate regulation of ES, soil organic carbon (SOC) storage at a depth of 20 cm and annual accumulated greenhouse gas (GHG) emissions were measured. The result revealed that Agroforestry schemes improved ecosystem services; lime and fertilizers increased productivity; water regulation unchanged; macrofauna biodiversity and SOC higher in forests.it further revealed that the proposed strategy demonstrated improvements in specific ecosystem services, indicating their potential for sustainable cattle farming in the region.

Tobin *et al.* (2022) explored advances in precision livestock management aimed at improving sustainable meat production and animal welfare in extensive rangeland systems. The study examined technologies like GPS and accelerometers fitted to ear tags or collars for real-time tracking and monitoring. The result of the study showed that GPS improved animal location monitoring in adverse weather and throughout the grazing season, while accelerometers identified behavioural changes due to grazing, disease, parturition, or stress. The study recommended widespread implementation of these technologies, development of better detection algorithms, and using the Five Freedoms framework to evaluate animal welfare impacts.

Sarnighausen *et al.* (2021) conducted a meta-synthesis on greenhouse gas emission in cattle livestock system. The study employed a qualitative approach, reviewing and synthesizing findings from 53 scientific experimental papers. It focused on methodologies used for quantifying greenhouse gas emissions from cattle. The findings revealed that the dominance of methane emissions from enteric fermentation and bovine waste in overall agricultural emissions, contributing substantially to global greenhouse gas totals. The study recommended standardized methodologies and consistent data in cattle greenhouse gas emission research. It recommended on-site quantification, anaerobic digestion for waste reduction, and innovative dietary approaches to reduce enteric methane emissions.

Shojaeipour *et al.* (2021) investigated the key limitations in the autonomous biometric identification of cattle to enhance livestock welfare and management, replacing invasive methods like branding or ear tagging. The research involved the creation of a large dataset of cattle face images, the development of a two-stage YOLOv3-ResNet50 algorithm for biometric identification, evaluation of the model across different cattle breeds, and the use of few-shot learning to minimize data collection and training time. The study provided a publicly available dataset of 300 individual cattle, developed an effective algorithm for biometric identification with 99.13% accuracy in muzzle detection and 99.11% in testing accuracy, and demonstrated the algorithm's applicability across various breeds. The study recommended adopting the two-stage YOLOv3-ResNet50 algorithm for automated cattle biometric identification to improve livestock management and welfare.

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Raba *et al.* (2020) examined inefficiencies in the animal feed supply chain, focusing on challenges such as inaccurate timing and quantity assessments when restocking feed bins, impacting cost and labor efficiency. The study highlighted the critical need for accurate and cost-effective sensors to measure stock levels of solid materials stored in containers and open piles across various sectors. It discovered that traditional technologies fail due to accuracy-cost trade-offs, hence, an integrated feedstock management system utilizing an RGB-D sensor for precise depth measurements was proposed. This system included a data processing pipeline to calculate daily consumption rates per feed bin, aiming to optimize supply chain operations and enhance efficiency.

2.3.2 Monitoring and Evaluation of Animals' Performance

Wicha *et al.* (2023) conducted a study on the implementation and evaluation of the Walk Over Weighing (WoW) system for monitoring the weight of beef cattle to enhance efficiency in weight management and decision-making processes. The WoW system enabled farmers to remotely weigh, track, and process weight data for their cattle. The system provided insights into stable growth performance, readiness for market sale, high growth rate performance, and low growth rate performance, accounting for differences in cattle age. The study demonstrated that the WoW system significantly improved the efficiency of the beef cattle weight monitoring process. The correlation of cattle growth with health status was high ($r > 0.900$) for healthy cattle, whereas poorly healthy cattle showed a lower correlation coefficient.

D'Urso, Arcidiacono, Pastell and Cascone (2023) evaluated the performance of the SEWIO ultrawide-band (UWB) real-time location system for identifying and localizing cows in dairy barns through preliminary laboratory analyses. The study focused on quantifying the errors of the SEWIO system in laboratory conditions and assessing its suitability for real-time monitoring of cows. The position of static and dynamic points was monitored in different experimental set-ups using six anchors. Errors related to specific movements were computed, and statistical analyses, including one-way ANOVA and Tukey's honestly significant difference, were conducted to assess the equality of errors based on point positions and typology (static or dynamic). Specific information was provided for installing the SEWIO system in dairy barns and monitoring animal behaviour in resting and feeding areas. The study recommended SEWIO system for herd management and analysing animal behavioural activities.

Isaac (2021) established a livestock monitoring and management system platform using an IoT framework to enhance farming, livestock, and agricultural operations. The study utilised IoT technology with relevant sensors for dairy monitoring, focusing on real-time and operational scenarios. The study described the technical use-case in terms of entity/informational model, deployment view, functional view, and business process hierarchy. It also details the flow of data and its interactions within the IoT stack. The study demonstrated that IoT technology with appropriate sensors effectively determines geographical boundaries, asset tracking, interoperability, re-usability, and functionality in livestock monitoring. The detailed analysis of data flow and interactions supported the system's feasibility and efficiency in real-time scenarios. The study recommended implementing the IoT-based livestock monitoring system to improve management and operational efficiency in farming and agriculture.

Arellano, Cabacas, Balontong and Ra (2020) developed a system that captures pig images using a camera, evaluates, and estimates the weight based on the captured images. Experimental research design was conducted to compare actual weights with weights computed from image pixels. The result revealed an average margin of error of ±0.041% between actual weights and computed image weights, indicating the system's effectiveness and reliability as an alternative to traditional weighing methods, which can cause stress to the livestock. The study recommended adopting image-based swine management system to improve efficiency and reduce stress in weight monitoring for both small and large livestock operations.

Brown-Brandl *et al.* (2019) conducted a review of passive radio frequency identification systems for animal monitoring in livestock facilities. The study compared Low Frequency (LF), High Frequency (HF), and Ultra-High Frequency (UHF) RFID systems in large livestock and poultry research facilities. It evaluated hardware characteristics, system design, and data processing for automated illness detection and behaviour monitoring. It examined the differences in tag construction, reader and antenna functionality, communication physics, speed

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of detection, anti-collision procedures, and the impact of materials like water and metal on system performance. Data processing methods and feeder visits are also compared across the three systems. The study discovered that LF, HF, and UHF RFID systems showed varied strengths and consideration (distinct range, environmental resilience, and data processing methods) for improving livestock and poultry facility operations. The study recommended developing RFID systems for predictive models to enhance animal welfare and management.

2.3.3 Economic Viability and Sustainability of Alternative Feeds

Mendeja *et al.* (2023) evaluated the peTrace system, designed to support the poultry supply business in the province of Oriental Mindoro, focusing on its functionality, usability, and effectiveness. Rapid Application Development (RAD) methodology was used for software development, emphasizing rapid prototyping and iterative design and Alpha testing conducted by Information Technology Practitioners to address design and functionality issues. Purposive sampling technique was used to identify 50 respondents, including IT practitioners, store owners, staff, and clients, to evaluate the system. The evaluation questionnaire was based on ISO 25010 software quality criteria. An assessment of the peTrace system yielded high scores in functional appropriateness (4.90), performance efficiency (4.85), usability (4.83), security (4.83), and maintainability (4.82). The system was found to be broad in design, easy to maintain, and adaptable to any portable device regardless of the operating system, making it suitable for any local feed store. The study recommended implementing real-time analysis for future growth to provide continuous monitoring with minimal delays. This enhancement would further improve the system's functionality and usability.

Tholhappiyan *et al.* (2023) developed an IoT-based agriculture monitoring system to improve resource management and maximize agricultural output. The system used wireless sensors to collect real-time data on various factors and employed cloud-based tools for processing and predictive analytics. A smartphone interface allowed farmers to monitor and manage operations remotely. Renewable energy technologies powered the system, enabling automation. The study found that the system provided real-time data and insights, supporting sustainable agriculture by optimizing resource use. It recommended implementing such systems to enhance resource management, increase output, and support sustainable farming.

Domaćinović *et al.* (2023) monitored animal behaviour and microclimate conditions in dairy production facilities using Precision Livestock Farming (PLF) systems. The study employed a range of modern electronic measuring devices, including sensors, biosensors, pedometers, computers, 2D and 3D surveillance cameras, thermal cameras, microphones, laser detectors, and automatic scales to monitor and collect data. computerized algorithms were used for data processing to inform decision-making. The result discovered that PLF systems positively impact early detection of diseases and stress in dairy cows, leading to more efficient use of production resources, increased production efficiency, and improved animal welfare. While PLF systems offered significant opportunities for enhancing dairy farm management, there were also potential risks. The study recommended that future commercialization of these systems be guided by professional evaluations based on multidisciplinary research to objectively assess their benefits and address any challenges.

Jankovic and Faria (2022) conducted a study on economic evaluation methods, principles, and approaches in healthcare. The research aimed to identify treatments and services offering the best value for money, specifically focusing on cost-effectiveness. The study explored various types of economic evaluations, methods for determining cost-effectiveness, the design and implementation of economic evaluations within clinical trials and model-based studies, and techniques for addressing uncertainty. Assessments of drugs, diagnostic tests, surgical procedures, and pharmaceutical interventions were used as data collection instruments. The analysis reviewed how economic evaluation methods were applied in different case studies, emphasizing their execution and impact on policy decisions. The study concluded that economic evaluations are crucial for determining cost-effective healthcare solutions and recommended that healthcare policymakers adopt economic evaluation frameworks to guide funding decisions.

Nesamvuni *et al.* (2022) assessed the vulnerability of smallholder livestock farmers to climate change in Limpopo and Mpumalanga provinces, focusing on Vhembe and Gert Sibanda District Municipalities. The study developed a M&E framework with SMARTT indicators to guide the assessment across design, planning, implementation, and evaluation phases. Data was collected through structured questionnaires, observations,

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and interviews from 469 smallholder farmers. Key areas assessed included demographic and economic household characteristics, livestock and crop production, access to services, credit, hazard occurrences, adaptation and coping strategies, and resilience levels. The framework categorized vulnerability into exposure, sensitivity, and adaptive capacity, each with specific indicators related to climate stimuli, system disturbances, and socio-ecological resilience. The study proposed mainstreaming the framework to enhance impacts and outcomes in supporting smallholder livestock farmers facing climate variability.

Burlamaqui, Poccard-Chapuis, De Medeiros, De Lucena Costa and Tourrand (2018) explore the management implications for cattle farms adopting crop-livestock-forestry systems (CLFIS) in Roraima, Brazilian Amazonia. Using a mixed-methods approach, the study collected secondary government data, conducted interviews, and monitored farms. The findings revealed labour and management difficulties, compounded by increased activity differentiation, knowledge diversification, and complex management requirements were significant barriers to CLFIS adoption. Hammer (2017) evaluated the development of a UHF RFID system for detecting pigs and cattle in German livestock farming, emphasizing the need for sustainable management systems. Over a three-year project, nine transponder types were developed and tested through laboratory and field experiments. Dynamic test bench assessments and driving experiments showed that the system had a reading rate of 99% for cattle and 98% for pigs. Cost-benefit analysis indicated that the current system is not yet viable for practical use, particularly in fattening pig and dairy cattle husbandry due to high costs per animal.

2.3.4 Monitoring and Evaluation Framework for Assessing the Performance of Alternative Feed Development Projects

Almadani *et al.* (2024) developed an image segmentation model using computer vision to automate the detection of estrus in sows, thereby improving breeding efficiency and addressing health and welfare issues in group-housed animal settings. The study proposed using an image segmentation model to localize the vulva in pigs through infrared imagery. The process involved isolating the vulva region with a red rectangle and generating vulva masks by applying a threshold to the red area. The system was trained using U-Net semantic segmentation with grayscale images and corresponding masks as input. The U-Net model was chosen for its simplicity, robustness, and suitability for processing multiple images. The performance of the model was evaluated using the intersection over union (IOU) metric. The model achieved an IOU score of 0.58, surpassing alternative methods like the SVM with Gabor (0.515) and YOLOv3 (0.52). This indicated that the U-Net semantic segmentation model was effective in accurately detecting the vulva region, thus automating the detection of estrus in sows.

Tun *et al.* (2024) conducted a study on innovate livestock health management by using a top-view depth camera integrated with a 3D depth camera and deep learning for accurate cow lameness detection and classification. The Detectron2 Framework and IOU techniques were employed for precise cow detection and tracking, achieving an average detection accuracy of 99.94% and tracking accuracy of 99.92% over a three-day period. Feature extraction from the cow's backbone area was used for classification, evaluating Random Forest, K-Nearest Neighbor, and Decision Tree classifiers. The study highlighted the potential of this technology for early lameness detection, recommending its adoption and further optimization.

Janocha, Milczarek, Gajownik-Mucka and Matusevicius (2023) analyzed welfare and motor activity indicators in Polish Holstein-Friesian black-and-white cows to support farmers in breeding management decisions. The survey involved 236 cows during a 305-day lactation period, housed in an open-sided free stall barn, before and after implementing the DeLaval DelPro complete computer management system. The study evaluated the motor activity and breeding parameters of cows categorized into three groups based on daily milk production. The study demonstrated that the highest-yielding cows spent more time (12.5 vs. 10.5 hours/day) lying down and resting than the lowest-yielding cows. The highest motor activity (29.66% of the herd) was observed in the morning between 3:00 AM and 6:00 AM, while the lowest (6.78%) occurred between 9:00 PM and midnight. The study established that monitoring significantly improved all evaluated breeding parameters (insemination index, inter-pregnancy interval, and calving interval) in the highest-yielding group of cows ($P \leq 0.05$). The study therefore recommended using livestock management software to improve the welfare and breeding indicators of Polish Holstein-Friesian black-and-white cows.

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Jaikaeo *et al.* (2022) presents a GPS livestock tracking method using LoRa communication to improve management of extensive livestock grazing systems. The research implemented a GPS tracking system utilizing LoRa technology with a novel medium access control mechanism. Field trials were conducted across three locations in Thailand and Vietnam to assess the system's performance under real on-farm conditions. Position accuracy, timeliness of data collection, and the system's effectiveness in varying landscapes were evaluated. The result showed that the system enhances range land management, livestock monitoring, disease control, and product traceability. Recommendations include optimizing communication in varied landscapes, reducing device costs, and customizing functionalities for regional needs to promote adoption. Based on the findings, the study recommends further refinement of the medium access control mechanism to optimize communication reliability in diverse landscape conditions. It suggests ongoing efforts to reduce device costs and increase lifespan to enhance the system's affordability and sustainability for adoption by farmers and certification groups. Additionally, integrating feedback from end-users to tailor the system's functionalities to specific regional needs could further enhance its practical utility in extensive livestock management.

Chinh, Anh, Hieu, and Radhakrishnan (2021) developed a monitoring system for biogas-based power generation systems using Internet-of-Things (IoT) devices, aimed at diagnosing or predicting faults in advance to plan timely maintenance. The research design involved acquiring generator operation information through field devices. Data were collected and managed by the Lambda architecture and the Apache Kafka software platform. Historical data analyses of various operation scenarios were provided to evaluate system performance and discuss fault diagnosis. The study recommended the widespread adoption of such monitoring systems to enhance the reliability and efficiency of biogas-based power generation, particularly in rural areas.

Mwangi and Moronge (2020) examined the role of logical framework on monitoring and evaluation of public-private partnerships projects in Nairobi County, Kenya using the System Approach Model, Structural Functional Approach, and Project Scheduling Theory. Employing a descriptive research design, the study focused on PPP infrastructure projects in sectors like Transport/Roads, Energy and Petroleum, and Health. Census data collection method was used, using questionnaires. Correlation analysis was used for the study using SPSS. The study revealed strong positive correlations ($p < 0.05$) between independent variables (Project Purpose, Verifiable Indicators, Means of Verification, Assumptions) and the dependent variable (Monitoring and Evaluation). The study recommended the integrating Project Purpose, Verifiable Indicators, Means of Verification, Assumptions into the logical framework approach for enhanced project monitoring and evaluation.

Warinda (2019) conducted a study on evaluating operationalisation of integrated monitoring and evaluation system in Kisumu County. The study assessed the extent of operationalisation of NIMES through utilisation of the electronic project management information system (e-ProMIS). the study adopted mixed methods approach through single-point face-to-face interviews using semi-structured questionnaires. primary and secondary data were collected from 10 key indicators to assess the level of operationalisation of NIMES using Likert scale. Both random and purposive sampling was used. The study discovered that the operationalisation of NIMES is unsatisfactory, and data collected are incorrectly formatted.it concluded that dysfunctional monitoring and evaluation (M&E) systems, limited human capacity on M&E, lack of NIMES champions, limited availability of data, unclear information flow to decision makers and inadequate integration of NIMES in planning and budgeting were some of the factors hindering operationalisation of NIMES.

Çelikyürek, Karakuş and Kara (2019) conducted a study on storing and evaluation of the records of livestock enterprises in database. The primary objective of the study was to provide detailed information on the use of database software in livestock enterprises, focusing on how these systems can enhance productivity in animal production. The study utilised a comprehensive review of existing literature, industry regulations, and practical applications of Database Management Systems (DBMs) in livestock enterprises. It examined the technical data requirements as stipulated by Turkish regulation number 27137, which aligns with European Union standards for the identification, registration, and monitoring of sheep and goat-type animals. The study found that compliance with Turkish regulation number 27137 and European Union standards for sheep and goat-type animals is integral, ensuring data accuracy and regulatory adherence.

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Taye *et al.* (2018) evaluated Outcome Mapping (OM) as a monitoring and evaluation tool for the imGoats project in India and Mozambique, aimed at enhancing small ruminant value chains to boost income and food security. Using an action research design, the study collected data through document reviews, interviews, focus groups, participant observations, and workshop feedback. The results indicated that OM effectively supports value chain and innovation systems interventions by promoting strategic thinking and learning. The study recommended OM for its adaptability to various contexts and methodologies but noted the need for longer project durations to measure behavioural changes effectively.

2.4 Gaps in Literature

Despite the numerous studies reviewed, there remain gaps in understanding how project monitoring and evaluation can effectively be used to assess sargassum-based feed interventions in the Nigerian agricultural sector.

2.4.1 Gap 1: Limited studies on the comparison between the nutritional content of Sargassum-based animal feeds with that of conventional animal feeds.

The reviewed literature highlights significant contributions to sustainable livestock management, feed optimization, and technological innovations but reveals critical gaps that align with the objective of this study. While studies like Rodríguez-Hernández *et al.* (2023) focused on sustainable cattle production and ecosystem services, the studies did not explore alternative feed ingredients such as Sargassum, leaving a gap in understanding its potential in animal nutrition. Similarly, research by Raba *et al.* (2020) emphasized inefficiencies in feed supply chains and the need for optimization technologies but lacked a comparative analysis of alternative and conventional feeds in terms of nutritional content and animal performance.

Another critical gap is the absence of nutritional profiling for novel feed types. While studies like Sarnighausen *et al.* (2021) addressed dietary approaches for reducing greenhouse gas emissions, they did not provide specific insights into the nutritional and performance impacts of innovative feed ingredients. Although advancements in livestock monitoring technologies, such as GPS and accelerometers, were explored by Tobin *et al.* (2022) and biometric identification by Shojaeipour *et al.* (2021), these innovations primarily targeted animal management rather than assessing the nutritional contents of feeds like Sargassum. Furthermore, while Rodríguez-Hernández *et al.* (2023) integrated environmental metrics, such as soil organic carbon and greenhouse gas emissions, with livestock productivity, these metrics were not linked to feed nutritional content or performance outcomes. Lastly, the geographical focus of most studies, including those by Rodríguez-Hernández *et al.* (2023) and Tobin *et al.* (2022), is outside Nigeria, leaving a gap in research specific to this region, where the socio-economic and environmental contexts differ significantly. This gap is critical given the pressing need for sustainable livestock production solutions tailored to Lagos state, Nigeria. Addressing these gaps through this study will contribute to a deeper understanding of the nutritional value and practical application of Sargassum-based feeds for diverse animal species, enhancing sustainable livestock production in Nigeria.

2.4.2 Gap 2: Limited empirical studies on the evaluation of the significant differences in the performance of animals fed with Sargassum and those fed without Sargassum.

Despite advancements in livestock monitoring and management systems, significant gaps remain in understanding the effects of Sargassum-based feeds on animal growth. Existing studies primarily focus on implementing advanced technologies like the Walk Over Weighing (WoW) system for cattle (Wicha, 2023), IoT frameworks for dairy monitoring (Isaac, 2021), and RFID systems for large livestock facilities (Brown-Brandl *et al.*, 2019). These studies improve weight and behaviour monitoring but do not address how specific feed types, such as Sargassum, influence growth metrics like weight and length.

Additionally, technologies such as image-based weight estimation (Arellano *et al.*, 2020) and real-time location systems (D'Urso *et al.*, 2023) enhance operational efficiency but fail to incorporate dietary interventions in their assessments. There is no exploration of how alternative feeds impact the growth performance of animals being monitored. Furthermore, the focus of these studies is predominantly on cattle

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and pigs, with limited attention to other species like poultry, fish and rabbits, which are vital for diversified farming systems, particularly in Lagos State, Nigeria. Moreover, most research centred on operational and management efficiencies rather than linking technological advancements to nutritional or growth outcomes. For instance, Arellano *et al.* (2020) highlighted the stress-reducing benefits of image-based weight monitoring but did not explore how these tools can be used to assess the impact of alternative feeds. Importantly, none of the reviewed studies compared the weight and length outcomes of animals fed Sargassum-based feeds with those fed conventional diets using Analysis of Variance (ANOVA) to determine significant differences.

These gaps highlight the need for research that evaluates the impact of Sargassum-based feeds on growth performance across various animal species, comparing outcomes with conventional feeds to establish their potential for sustainable livestock production.

2.4.3 Gap 3: Limited studies on the assessment of the economic viability of developing Sargassum-based feed to sustain its market readiness.

While several studies explored innovative technologies and systems in agriculture and livestock management, there is a noticeable gap in literature regarding the economic viability of alternative feeds, particularly Sargassum-based feed, in sustaining market readiness. Research such as Mendeja *et al.* (2023) and Tholhappiyan *et al.* (2023) highlighted advancements in system efficiency for monitoring and optimizing agricultural and livestock operations, but these studies primarily focused on operational and technological improvements excluding the economic aspects of feed development. Additionally, studies like Domaćinović *et al.* (2023) and Hammer (2017) examined livestock management technologies, but they do not address the cost-effectiveness or market potential of alternative feed sources like Sargassum.

Moreover, the studies conducted by Jankovic and Faria (2022) on economic evaluations in healthcare and Nesamvuni *et al.* (2022) on climate change vulnerability focused on broader economic frameworks but failed to provide specific insights into the economic viability of Sargassum-based feed within the animal production sector. While there is literature on the use of innovative systems for resource optimization and farm management, the economic feasibility of developing Sargassum as a sustainable feed resource, including its cost structure, profitability, and potential market adoption, remains unexplored. This gap underscores the need for a comprehensive economic assessment to evaluate the potential of Sargassum-based feed in supporting sustainable and scalable livestock production.

2.4.4. Gap 4: Absence of Studies on the Development of a Monitoring and Evaluation Framework for assessing the Performance of Sargassum-Based Feed Development Project

While there is a wealth of research on M&E frameworks in livestock management systems, such as those using Outcome Mapping (Taye *et al.*, 2018) and various technological systems for health management (Almadani *et al.*, 2024; Janocha *et al.*, 2023), few studies focused on the specific context of alternative feed sources like Sargassum. Most existing M&E frameworks are primarily designed for traditional livestock production systems or biogas-based projects (Chinh *et al.*, 2021), leaving a gap in literature for frameworks tailored to alternative feed ingredients like Sargassum. Furthermore, although M&E frameworks in livestock systems sometimes use structural-functional models (Mwangi & Moronge, 2020), there is a lack of result-based frameworks that specifically measure the nutritional impact, economic feasibility, and effectiveness of Sargassum-based feeds.

Another significant gap lies in the lack of context-specific frameworks, particularly for developing regions like Nigeria. Much of the existing M&E research focuses on developed countries or generalized agricultural systems (Almadani *et al.*, 2024; Warinda, 2019), while the Sargassum feed project requires frameworks that account for regional challenges, including resource constraints, infrastructure issues, and climate factors.

Lastly, many studies evaluate M&E from a single-dimensional perspective, focusing on efficiency, health outcomes, or operational effectiveness (Janocha *et al.*, 2023), but there is a need for a more comprehensive, multi-dimensional approach. This approach should include environmental sustainability, socio-economic impacts, and animal welfare, alongside production performance, to fully assess the potential of Sargassum-

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based feed. This broader, holistic framework is not sufficiently represented in the literature. Therefore, a significant gap exists in the development of a result-based logical M&E framework that is context-specific, multi-dimensional, and integrates modern technologies to assess the performance of Sargassum-based feed development projects.

2.5 Conceptual Framework for the Study

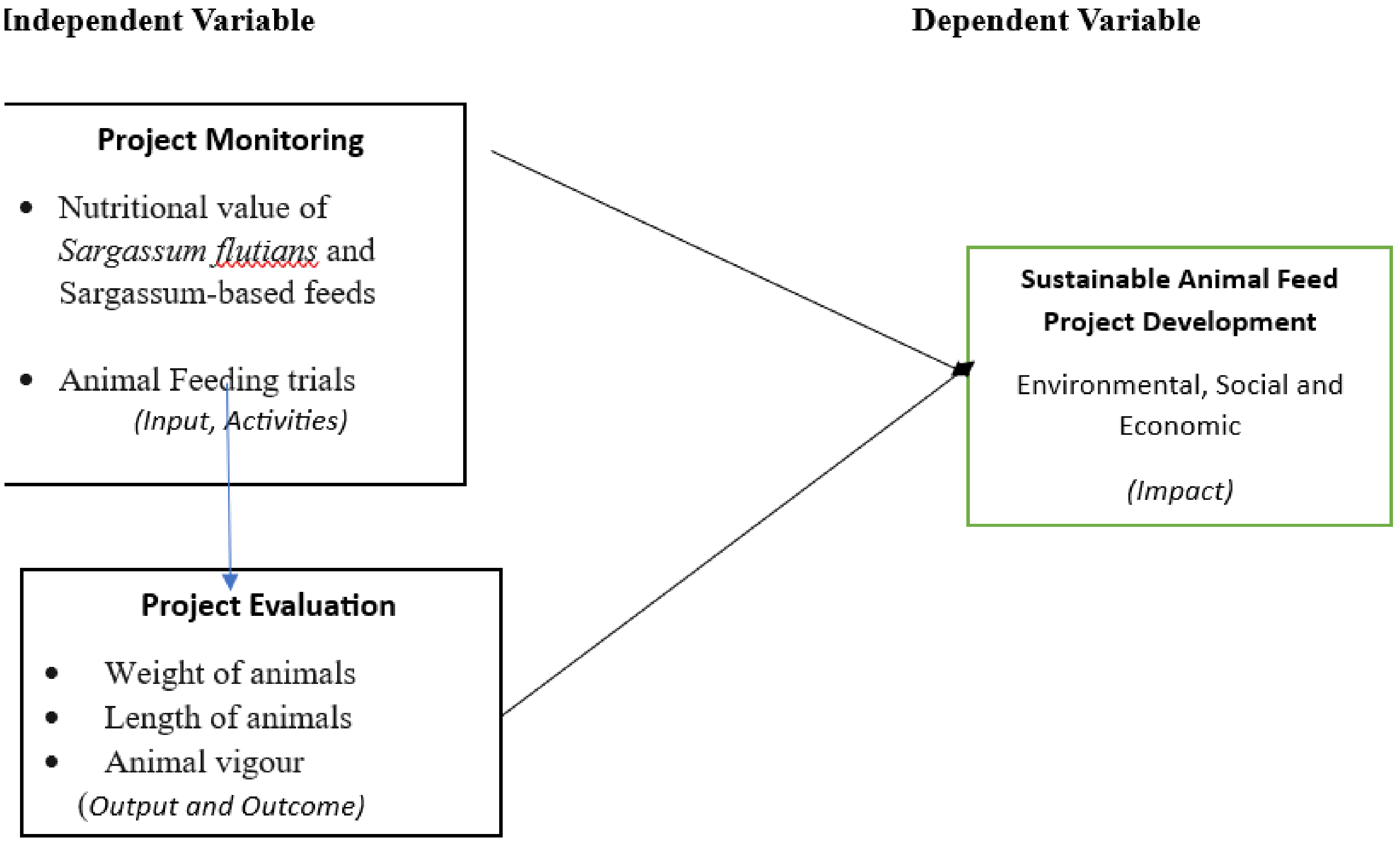

Figure 2.12: Conceptual Framework for the Study

Source: Framework Developed by the Researcher (2024).

The conceptual framework for this study explores the relationship between project monitoring, project evaluation, and their impact on the sustainability of Sargassum-based animal feed development in Lagos State, Nigeria. In this framework (see figure 2.12), project monitoring serves as the independent variable, comprising three key components: input, activities, and output. Monitoring ensures that allocated resources (input) are effectively utilized through well-structured processes and actions (activities), leading to measurable results (output). It provides real-time data for tracking progress and making necessary adjustments during project implementation.

Project evaluation acts as a mediating variable, assessing both output and outcome. While monitoring focuses on immediate project activities, evaluation measures their effectiveness by analysing the quality and quantity of Sargassum-fed animals produced (output) and the overall success of the feed in improving animal growth, health, and sustainability (outcome). Evaluation serves as a feedback mechanism, helping to identify areas for improvement and ensuring that the project remains aligned with its objectives.

The dependent variable, sustainable animal production, represents the long-term impact of using Sargassum-based feed. Sustainability is assessed through key indicators such as animal health and growth performance, which determine the nutritional adequacy of the feed; cost-effectiveness, which evaluates its economic feasibility for farmers; and environmental sustainability, which considers the reduction in reliance on conventional feed and its contribution to waste management.

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This framework highlights that effective project monitoring enhances project evaluation, which in turn strengthens sustainability outcomes. When monitoring ensures that inputs and activities align with project goals, and evaluation provides feedback on effectiveness, the project is more likely to achieve long-term sustainability in animal feed production. Ultimately, the success of Sargassum-based feed development depends on a well-integrated monitoring and evaluation system, ensuring that the project remains cost-effective, environmentally sustainable, and beneficial to livestock farmers. This study provides valuable insights into how Sargassum-based feed can contribute to sustainable agriculture and food security by establishing a systematic approach to assessing project performance.

METHODOLOGY

3.0Preamble

This chapter presents the methodology adopted for the research. It outlined the mix of methods used for the study, including research philosophy, research design, population, sample and sampling techniques, mathematical models for each experimental diet formulation, sources of data, instruments for data collection, procedures for data gathering, methods of data analysis, and ethical considerations. The methodology aligned with established project management principles, ensuring a structured and systematic approach throughout the study.

3.1 Research Philosophy

The study was guided by the research questions, objectives, and the theoretical framework underpinning the study. A pragmatic philosophical disposition was adopted, integrating both positivist (quantitative) and interpretivist (qualitative) methods, as recommended by Saunders *et al.* (2023) and Pasian (2015). Pragmatism allowed for flexibility in methodology, enabling the study to provide practical insights relevant and applicable to real-world settings. The study emphasized the practical application of research findings, aligned with the interdisciplinary nature of project management. This was achieved by integrating knowledge from diverse academic disciplines, including management sciences, natural sciences, applied sciences, environmental studies, and agriculture. By adopting this approach, the research produced findings that are theoretically sound and practically applicable in various contexts.

At the project initiation phase, collaborative partnership, a key principle in pragmatic action research, was were established formed with the Centre of Excellence for Sargassum Research (CESAR), a leading research institution in Nigeria focused on sargassum seaweed situated in Lagos State university, Ojo, Lagos State, Nigeria. This collaboration facilitated knowledge sharing and increased the chances of successful implementation of sustainable practices. CESAR’s expertise provided a solid foundation for the study, as it was the only centre in Nigeria specializing in sargassum-related research and practices. The project charter developed in this phase served as a foundational document for the project management plan.

During the project planning phase, the population and sampling technique used for the study were determined and animal feeds formulated. The sargassum-based feeds formulated for the study were tailored to meet the specific nutritional requirements of the animals under study using linear programming. A comprehensive project management plan was developed at the end of this phase to guide the research process. The project implementation phase involved introducing the formulated sargassum-based feed into the animals' diet. This phase utilized a combination of pragmatic action research and agile project management approaches, which facilitated iterative development and continuous improvement. After each sprint (week), the data collected were reflected on, and research protocols adjusted based on the insights gained. Throughout the project, continuous feedback was gathered from stakeholders, which played a crucial role in refining the monitoring process and making ongoing adjustments to the research protocol. This iterative process ensured that challenges were addressed promptly and the research remained responsive to emerging data. The dynamic and adaptable nature of this approach led to more robust and actionable outcomes, enhancing the quality and relevance of the findings and ensuring the project met its objectives effectively.

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3.2 Study Area

The study focused on the invasion of sargassum seaweed at Suntan Beach, located in Badagry, Lagos State, Nigeria. Badagry Local Government Area, situated on the southwestern coast of Lagos State is bordered by the Gulf of Guinea to the south. The geographical coordinates of Badagry are approximately 6.4167° (6° 25' 0" N) latitude and 2.8846° (2° 53' 5" E) longitude (See figure 3.1).

Additionally, the performance evaluation of sargassum-fed animals was conducted on an existing farm located in the Ijotun community, within the Badagry Local Government Area. This dual-site approach provided comprehensive insights into both the ecological impact of the sargassum invasion and its potential use in enhancing livestock nutrition and productivity. The study was conducted in a section of the farm, utilizing existing facilities to ensure that each animal species was housed and managed under optimal conditions. The housing setup was optimized to meet international standards and environmental requirements specific to each species.

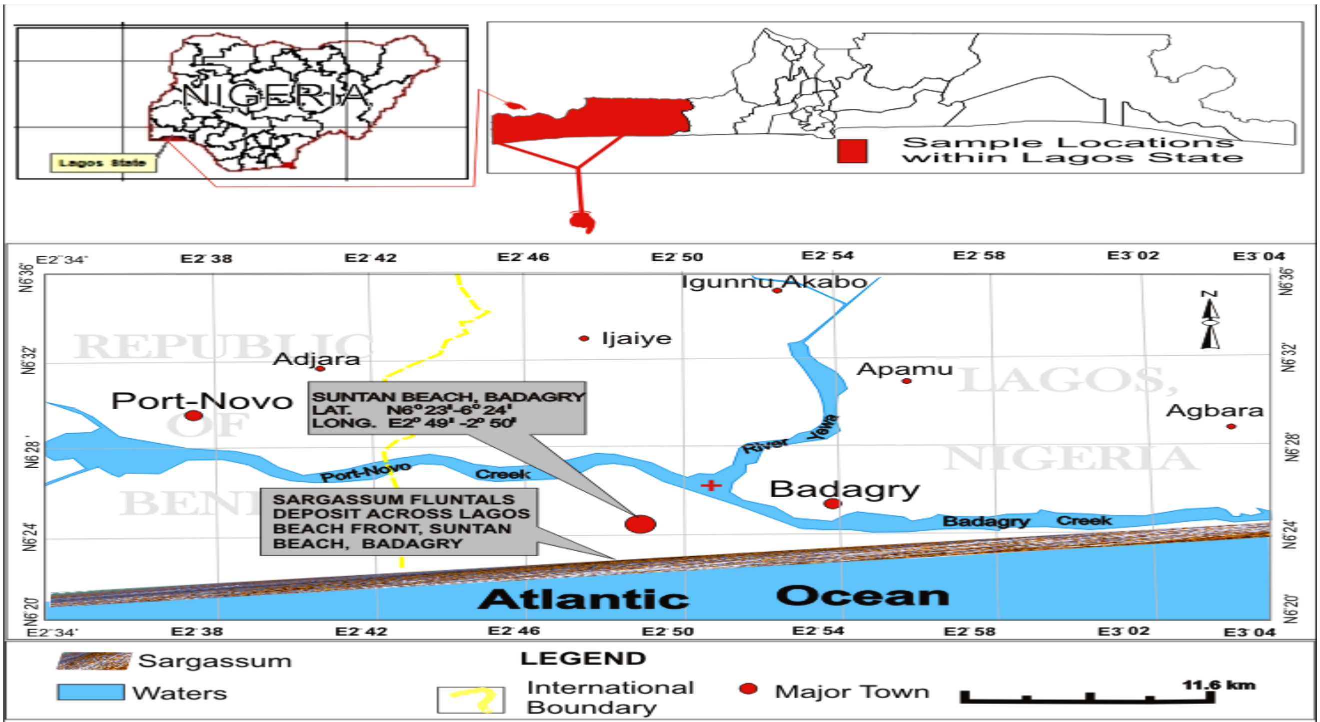

Figure 3.1: Map of Study Area Showing Deposited Sargassum Along Suntan Beach, Lagos.
Source: Designed by Olorunnimbe R., GIS Lab., School of Transport and Logistics, LASU (for WNATULEGWU, BLESSING, 2024)

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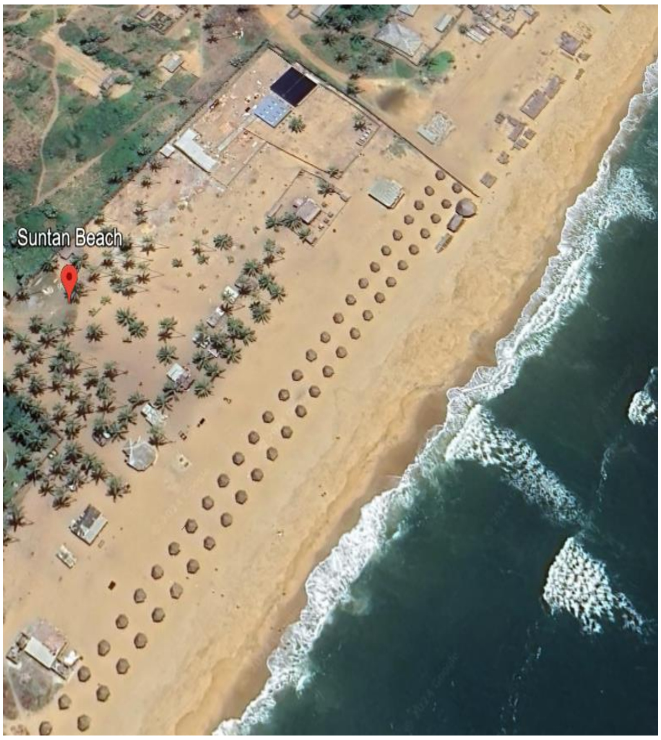

Figure 3.2: 3D Image showing Suntan Beach before Sargassum seaweed invaded the community
Source: Google Maps. (2024). Aerial view of Suntan Beach coastal area in Badagry, Lagos State, Nigeria

Figure 3.3: Sargassum seaweed on the shores of Suntan Beach
Source: Field Survey, August (2024).

Figure 3.4: Transportation of *Sargassum fluitans* from Suntan Beach in Badagry, Lagos State, Nigeria to Lagos State University for further analysis.
Source: Field Survey, August (2024).

3.3 Research Design

This study employed a mixed-methods approach, combining quantitative experimentation with qualitative action research to evaluate the impact of Sargassum-based feed on animal sustainability. The quantitative component involved controlled experiments, while the qualitative component integrated stakeholder collaboration and iterative problem-solving cycles of planning, action, observation, and reflection to assess the intervention’s impact. Action research fostered continuous improvement by designing interventions and

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evaluating outcomes through collaborative partnerships. The study adopted a longitudinal explanatory research design to assess the performance of animals (chickens, fish, pigs, and rabbits) fed with Sargassum-based feed. A longitudinal cohort study was conducted over 12 weeks, tracking animal growth, health, and behaviour to measure the impact of Sargassum-based feed on sustainability. The study also employed a Randomized Controlled Trial (RCT) strategy, a type of experimental research design, to compare the performance of various animal species fed Sargassum-based feed with those on conventional feed. Additionally, an explanatory research design was used to analyse variations in animal responses through repeated observations, facilitating a deeper understanding of trends and patterns in dietary effects. These combined approaches ensured that observed changes could be directly attributed to the dietary intervention.

3.4 Population of the Study

The reference (target) population for this study comprises all broiler chickens, catfish, pigs, and rabbits within Badagry Local Government Area, Lagos State. This broader population represents the group for which the study findings are intended to be generalized. The experimental (accessible) population is a carefully selected subset of the target population, chosen to ensure uniformity in breed, age, and health status. This selection ensures that the study findings remain valid, reliable, and generalizable.

Table 3.1: Population of the Study

Animal	Number of animals under study	Number of weeks	Total number of data points
Chicken	20	12	240
Fish	90	12	1080
Pig	6	12	72
Rabbits	20	12	240

Source: Author’s Computation, November (2024).

The experimental population was drawn from an existing farm where facilities were optimized to meet international animal welfare standards. Table 3.1 presents the experimental population size used in the study. A total of 20 broiler chickens, 90 catfish, 6 pigs, and 20 rabbits were observed over a 12-week period, with data points systematically collected for each species to assess the impact of Sargassum-based feed on growth performance and sustainability.

3.5 Sampling Technique

Random sampling was employed to minimize biases, ensuring that the findings are valid, reliable, and generalizable to the broader animal population. The subjects, or units of analysis, were randomly selected from the experimental population and divided into two groups: a control group (Group A) and an experimental group (Group B). The control group served as a baseline for comparison.

Table 3.2: Distribution of samples used for the study

Animal	Control group	Experimental Groups
	Group A	Group B
Chicken	10	10
Fish	45	45
Pig	3	3

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Rabbits	10	10
Treatments Administered	Conventional feed	Sargassum-based feed

Source: Designed by the Researcher (2024)

3.6 Sources of Data

Data for the study were obtained from both primary and secondary sources. Quantitative indicators (weight and length) are sources of numerical data on animal growth, while qualitative indicators (health status, behaviour) are sources of observational and descriptive data on animal well-being and conduct. The economic viability of the project was also ascertained by evaluating the costs of feed production and the market value of the animals under study.

3.7 Research Instruments

The study utilised a range of operational equipment, including cameras, pH meters, tape recorders, tape rules, digital scales, digital thermometers, tags, among others. Additionally, industry-based checklists were employed, encompassing protocols for monitoring and reporting observations such as vital signs, length, weight, and mortality rate; project charter template and Field notes. References were made to enterprise environment factors' guides such as NAFDAC regulations, IFIF/FAO, ISO/TS 22002-6 technical specifications and National Research Council specifications. A collaboration scale adapted from Frey, Lohmeier, Lee and Tollefson (2006) was used in measuring the level of collaboration among the public-private partners involved in the sargassum-based aminal feed development project (See appendix iii).

3.8 Experimental Procedures and Protocols

This section details the processes involved in preparing Sargassum-based feeds for feeding trials and describes how the animals under study were housed and managed during the feeding trials.

3.8.1 Preparation of Sargassum Seaweed for Feed Production

Sargassum seaweed was collected from Suntan Beach and thoroughly cleaned using clean running water to remove extraneous materials such as sand particles, pebbles, and shells. The biomass was then dried and grounded. To ensure that the Sargassum samples used in the study were free from pollutants and nutritionally suitable for animal consumption, trace metal analysis and proximate analysis were conducted at ISI Analytical Laboratory in Lagos State, Nigeria, which holds accreditation number ISO/IEC 17025, before feed formulation. Project monitoring activities were initiated during the preparation phase for the production of Sargassum-based feeds. Table 3.3 provides a detailed overview of the Critical Control Points (CCPs), the corresponding control measures, established monitoring procedures for each CCP, and the corrective actions taken to ensure adherence to HACCP (Hazard Analysis and Critical Control Points) principles. These measures were implemented to maintain feed safety and quality throughout the production process.

Table 3.3: Critical Control Points (CCPs) in Sargassum-Based Feed Production

Critical Control Points (CCPs)	Hazard	Control Measure	Monitoring Procedures	Critical Limits	Corrective Actions
Washing of Sargassum	Removal of physical contaminants and reducing microbial	Used clean, potable water; monitored water quality.	Conducted regular water testing.	Water quality parameters (absence of coliforms).	Sargassum rewashed when water quality was compromised.

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	load				
Drying	Prevention of microbial growth.	Ensured proper drying temperature and time.	Logged temperature and time.	Drying temperature and time (60°C for 6 hours).	Extended drying time and increased temperature when needed.
Grinding	Introduction of physical contaminants.	Used sieves to remove foreign objects.	Performed visual inspection and logged sieve use.	Mesh size for sieves (1 mm).	Re-ground and re-sieved when foreign objects were detected.
Mixing	Uniform distribution of ingredients.	Validated mixing times and processes.	Maintained a mixing log.	Mixing time (10 minutes).	Re-mixed when distribution was not uniform.
Pelleting	Ensuring feed stability and preventing microbial growth.	Monitored pelleting temperature and pressure.	Recorded temperature and pressure.	Pelleting temperature (80°C) and pressure.	Adjusted pelleting process when critical limits were not met

Source: Modified from Amin and Sobhi (2023)

3.8.2 Feed Formulation Process

Animal feeds were formulated in compliance with HACCP principles, following guidelines from IFIF/FAO (2021). Two types of feed were prepared for the experiment: Control and Experimental Feeds. The primary goal of the feed formulation was to replace expensive energy components in conventional feed with Sargassum. Ingredients for each feed type were thoroughly mixed, milled, and pelleted using local machines. The pelletized feeds were then dried and stored appropriately for use during the feeding trial phase.

Conventional Feed Formulation

Conventional feed formulations were adapted from previous studies: Chicken feed formulation (Cilev, 2020), Fish feed formulation (Anetekhai *et al.*, 2024), Pig feed formulation (Ikehi, 2022) and Rabbit feed formulation (Okon, 2023).

Experimental feed formulation

The experimental feeds for each animal category were formulated using linear programming, incorporating *Sargassum fluitans* at a 50% inclusion rate. This least-cost approach ensured that the feeds met the nutritional requirements (table 3.5) of the target animal species while optimizing cost efficiency. A summary of the feed ingredient prices and nutrient composition is presented in table 3.4.

Table 3.4: Feed Composition of Selected Feed Ingredients

Nutrients	Ingredient	Cost per kg (₦)	Energy (kcal/kg)	Crude Protein (%)	Crude Fat (%)	Crude Fibre (%)	Ash (%)	Source
Carbohydrates	Sargassum	500	2,400	10.05	0.64	19.38	9.72	Proximate analysis
	Maize	900	3,350	8.7	4	8	1.08	Markey survey

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	Rice bran	350	2,937	12.7	13.9	30	12	Markey survey
Protein	Soybean meal	1200	2,557	48.5	21.2	6	5	Markey survey
	Fish meal	7000	2,820	72	4.5	0.56	15.84	Markey survey
	GNC	950	3,500	58	10	5	5	Markey survey
	Meat and bone meal	300	2,680	50.4	10	2.5	20	Markey survey
Fibre	Wheat	400	3,100	20	5	15	6	Markey survey
	Wheat offal	350	3,120	15	5	13	5	Markey survey
	P.K.C	160	3,750	18	6	17.5	6	Markey survey

Source: Market Survey (2024)

Table 3.4 shows the selected ingredients, their prices, and nutrient compositions for energy, crude protein, crude fat, fibre and ash. The prevailing market prices of the feed ingredients were used to estimate the unit cost of the various diets. Feed cost and cost per weight gain were calculated at the time of the experiment, when $1 was equivalent to ₦1,600.

Table 3.5: Nutritional Composition Requirements for Target Animal Species Based on Age Categories

Nutrition composition	Animals			
	Broiler chicken (4 weeks old)	Rabbit (8 weeks old)	Pig (4 weeks old)	Fish (6 weeks old)
Energy (kcal/kg)	3000-3200	2200-2600	3300-3600	2800-3200
Crude Protein (%)	13% - 24%	14% - 16%	18% - 20%	35% - 40%
Crude Fat (%)	6% - 8%	2% - 4%	4% - 6%	10% - 15%
Crude Fibre (%)	2% - 3%	18% - 25%	2% - 4%	5% - 7%
Ash (%)	6% - 7%	8% - 10%	6% - 8%	10% - 12%

Source: National Research Council, NRC (2002)

Table 3.5 outlines the minimum and maximum nutrient requirements according to National Research Council (2002) for animal feeds tailored to specific animals and their respective ages before feeding trials. Energy needs vary, with pigs requiring the highest (3300-3600 kcal/kg) and rabbits the lowest (2200-2600 kcal/kg). Crude protein content is critical, ranging from 13%-24% for broiler chickens to 35%-40% for fish. Crude fat and fibre levels also differ, with fish needing higher fat (10%-15%) and rabbits requiring substantial fibre (18%-25%). Ash content, representing mineral levels, ranges from 6%-12%, with fish needing the highest. These values ensure animals meet growth and health requirements during feeding trials.

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3.8.3 Linear Programming Model Formulation for Sargassum-Based Animal Feeds

Linear programming, an optimization technique, was employed to address alternative feed ingredient mix challenges by developing model equations with objective functions, demand constraints, nutrient requirement constraints, and non-negativity constraints specific to each species under study. The model minimized feed costs while ensuring that the dietary requirements for protein, energy, fibre, and other nutrients were met. Key inputs for the least-cost formulation included data on the quality, availability, and prices of locally available feed ingredients, primarily sources of carbohydrates, protein, and fibre. These details, along with nutrient specifications for the livestock systems, were used to construct the linear programming model equations.

The formulation of the Linear Programming model involves the following steps:

Let: i = Feed nutrient components of feed ingredients, where i = 1, 2, …… m

j = Number of feed ingredients, where j =1, 2…n

X_j = Quantity of feed ingredient j in the feed mix (decision variable)

X_t = Total quantity (Kg) of feed to be produced

Z = Total cost of feed ingredients used in the feed formulation

C_j = Unit cost per kg of feed ingredient j (in naira)

a_{ij} = Amount (in fraction of X_j) of nutrient available in feed ingredient j

B_i = Dietary requirement (fraction of X_t) of nutrient i for animal category

Objective Function:

The Objective function is to minimise the cost of the feed formulation and it is in the form:

Minimize $Z = \sum C_j X_j$; $Z = C_1X_1 + C_2X_2 + \dots . C_{10}X_{10}$

That is, Minimize Z = 500 Sargassum + 900 Maize + 350 Rice bran + 1200 Soybean + 7000 Fish meal + 950 GNC + 300 MBM + 400 Wheat + 350 wheat offal + 160 PKC

Constraints:

The objective function is subjected to the following constraints;

Minimum Requirements: $a_{ij} \sum X_j \geq B_i$: $a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \dots ainX_j \geq B_i$
Maximum Requirements: $a_{ij} \sum X_j \leq b_i$: $a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \dots ainX_j \leq b_i$
Demand Requirements: $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} = X_t$

Sargassum Restriction Constraint:

A constraint was included to limit the inclusion of Sargassum to a maximum of 50% of the total composition:

That is: $X_1 \leq 0.5(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10})$

This ensured that Sargassum contributed no more than 50% of the total feed weight for the animals in the experimental groups. This restriction ensured that Sargassum's inclusion in the diet adhered to the predetermined nutrient requirements, maintaining the balance necessary for proper growth and health during feeding trials

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Non-Negativity Constraints

The non-negativity constraint ensured that all ingredient quantities used in the feed formulation are either zero or positive values. It also ensures that the formulation aligns with practical requirements, where ingredients are either excluded ($X_j = 0$) or included in positive amounts.

That is: $X_j > 0$

Table 3.6: Equations formulation for the Linear Programming Model

Nutrients	**Ingredient**	**Notation**	**Cost (₦) per kg (C)**	**Cost of optimal amount of ingredient**	**Energy (kcal/kg)**	**Crude Protein (%)**	**Crude Fat (%)**	**Crude Fibre (%)**	**Ash (%)**
Carbohydrates	Sargassum	X_1	500	$500X_1$	$2400X_1$	$10.05X_1$	$0.64X_1$	$19.38X_1$	$9.72X_1$
	Maize	X_2	900	$900X_2$	$3350X_2$	$8.7X_2$	$4X_2$	$8X_2$	$1.08X_2$
	Rice bran	X_3	350	$350X_3$	$2937X_3$	$12.7X_3$	$13.9X_3$	$30X_3$	$12X_3$
Protein	Soybean meal	X_4	1200	$1200X_4$	$2557X_4$	$48.5X_4$	$21.2X_4$	$6X_4$	$5X_4$
	Fish meal	X_5	7000	$7000X_5$	$2820X_5$	$72X_5$	$4.5X_5$	$0.56X_5$	$15.84X_5$
	GNC	X_6	950	$950X_6$	$3500X_6$	$58X_6$	$10X_6$	$5X_6$	$5X_6$
	Meat and bone meal (MBM)	X_7	300	$300X_7$	$2680X_7$	$50.4X_7$	$10X_7$	$2.5X_7$	$20X_7$
Fibre	Wheat	X_8	400	$400X_8$	$3100X_8$	$20X_8$	$5X_8$	$15X_8$	$6X_8$
	Wheat offal	X_9	350	$350X_9$	$3120X_9$	$15X_9$	$5X_9$	$13X_9$	$5X_9$
	P.K.C	X_{10}	160	$160X_{10}$	$3750X_{10}$	$18X_{10}$	$6X_{10}$	$17.5X_{10}$	X_{10}

Source: Author's Computation, November (2024).

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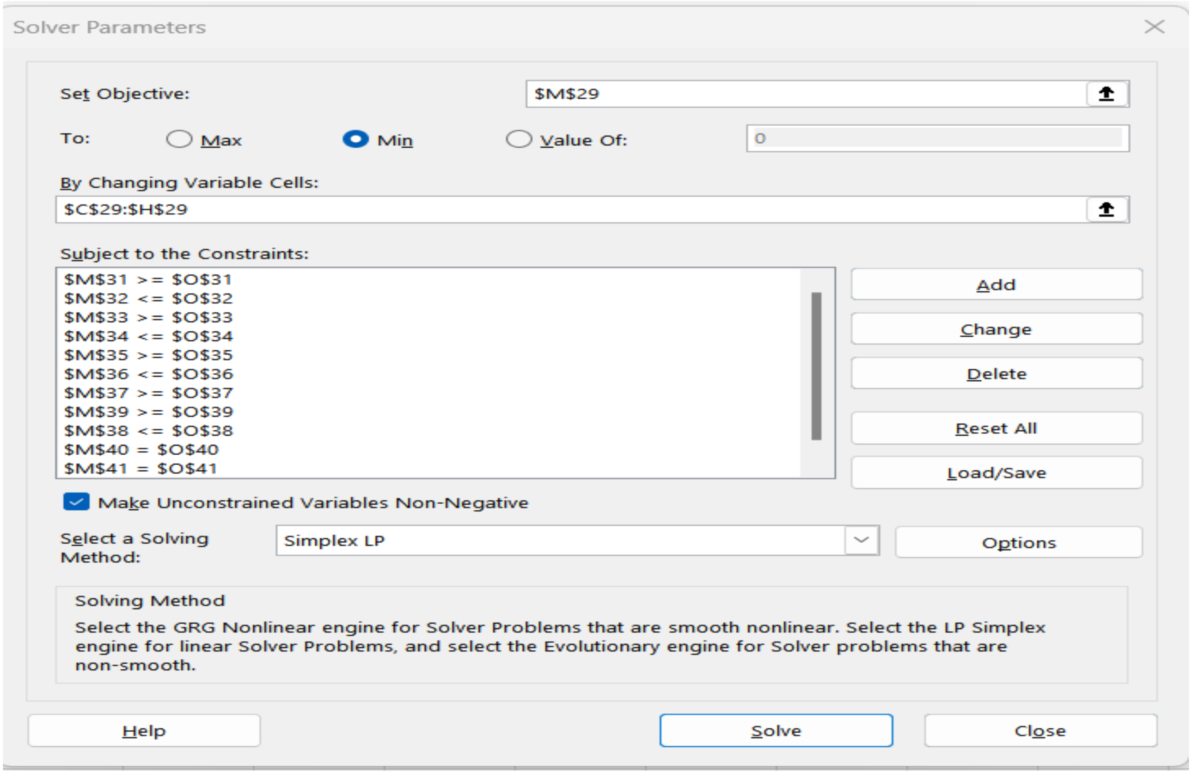

Figure 3.5: Microsoft Excel Solver Add-in Application Output

The equations formulation for the Linear Programming (LP) Model presented in Table 3.6 provides a structured approach to optimizing feed formulation by determining the most cost-effective combination of ingredients while meeting the required nutritional standards. The table categorizes feed ingredients based on their primary nutrient contributions—carbohydrates, protein, and fiber—and assigns each ingredient a decision variable (X_1 to X_{10}) to represent the amount utilized in the feed formulation. The cost per kilogram of each ingredient is specified, with the total cost of each ingredient's optimal amount expressed as the product of its unit cost and the quantity used in the formulation. Additionally, the table outlines the nutrient composition of each ingredient in terms of energy (kcal/kg), crude protein (%), crude fat (%), crude fiber (%), and ash (%), with each nutrient contribution expressed as a function of the ingredient quantity.

This LP model serves as the foundation for determining an optimal feed mix that minimizes cost while satisfying predefined nutritional constraints. The Microsoft Excel Solver Add-in Application Output (Figure 3.5) provides the computational results, identifying the optimal values for X_1 to X_{10} that yield the most cost-efficient and nutritionally balanced feed formulation. By applying this optimization model, the study ensures that the formulated feed meets the required nutrient thresholds while incorporating Sargassum as an alternative ingredient, which is of particular interest in evaluating its viability in animal feed. The model's implementation is crucial in assessing the economic and nutritional feasibility of Sargassum-based feed formulations, offering insights into sustainable and cost-effective livestock nutrition.

3.8.4 Animal Housing and Management

Proper housing and management are foundational to the success of the feeding trials. The study ensured that the animals were housed and managed under conditions aligned with recommended housing practices to promote their well-being and ensure the accuracy of the results.

3.8.4.1 Chickens

Two (2) groups of chickens were housed in well-ventilated coops equipped with perches and nesting boxes. Each group consisted 10 four-week-old broiler chicks. Sufficient spaces were provided to prevent

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overcrowding, and dry, absorbent litter, such as wood shavings or straw, was used to maintain cleanliness, as recommended by Honig *et al.* (2024). Proper lighting was also provided to regulate their overall health.

3.8.4.2 Fish

6 weeks old catfish were kept in two (2) 1000-litre 4 by 4 feet tanks with each containing 45 fingerlings. Efficient filtration systems were utilized to maintain good water quality, as recommended by Anetekhai, Clarke, Osodein, and Dairo (2018). Optimal water temperature was maintained, and adequate aeration was provided to ensure sufficient oxygen levels in the water. These measures supported the well-being of the fish and ensured the integrity of the feeding trials.

3.8.4.3 Pigs

For pigs, two (2) adequate spaces were also provided to allow free movement and rest. Proper ventilation and durable, non-slip flooring were ensured, as recommended by Gopakumar and Deka (2020). Group housing was implemented, with three (3) pigs per space, acknowledging that pigs are social animals and thrive in such environments.

3.8.4.4 Rabbits

Two (2) groups of 3-month-old rabbits were housed in spacious hutches with solid floors and good ventilation. Each group consisted ten (10) rabbits. Soft bedding materials such as hay and straw were provided to ensure comfort. Adequate space for movement and exercise was maintained, and a stable temperature was ensured to avoid stress, as recommended by Cano, Carulla, and Villagrá (2024). These practices promoted the well-being of the rabbits and contributed to the success of the feeding trials.

3.8.5 Feeding Trials

Before conducting the feeding trials, the initial weights and lengths of each animal were measured using tapes and digital scales, and the findings were recorded to establish baseline measurements and evaluate the initial health status of each animal. Additionally, an initial welfare assessment was conducted, documenting animal behaviour and physical condition to ensure that only healthy animals were included in the study. This structured approach established a foundation for accurately gauging the impact of Sargassum-based feed on the animals' health, growth, and overall welfare.

During the controlled feed trial phase, the control group (Group A) was fed with conventional feed, while the experimental groups (Group B) were fed with the planned intervention, which consisted of feed with a 50% Sargassum inclusion rate.

Treatments:

i. Sample A received conventional feed (control group).

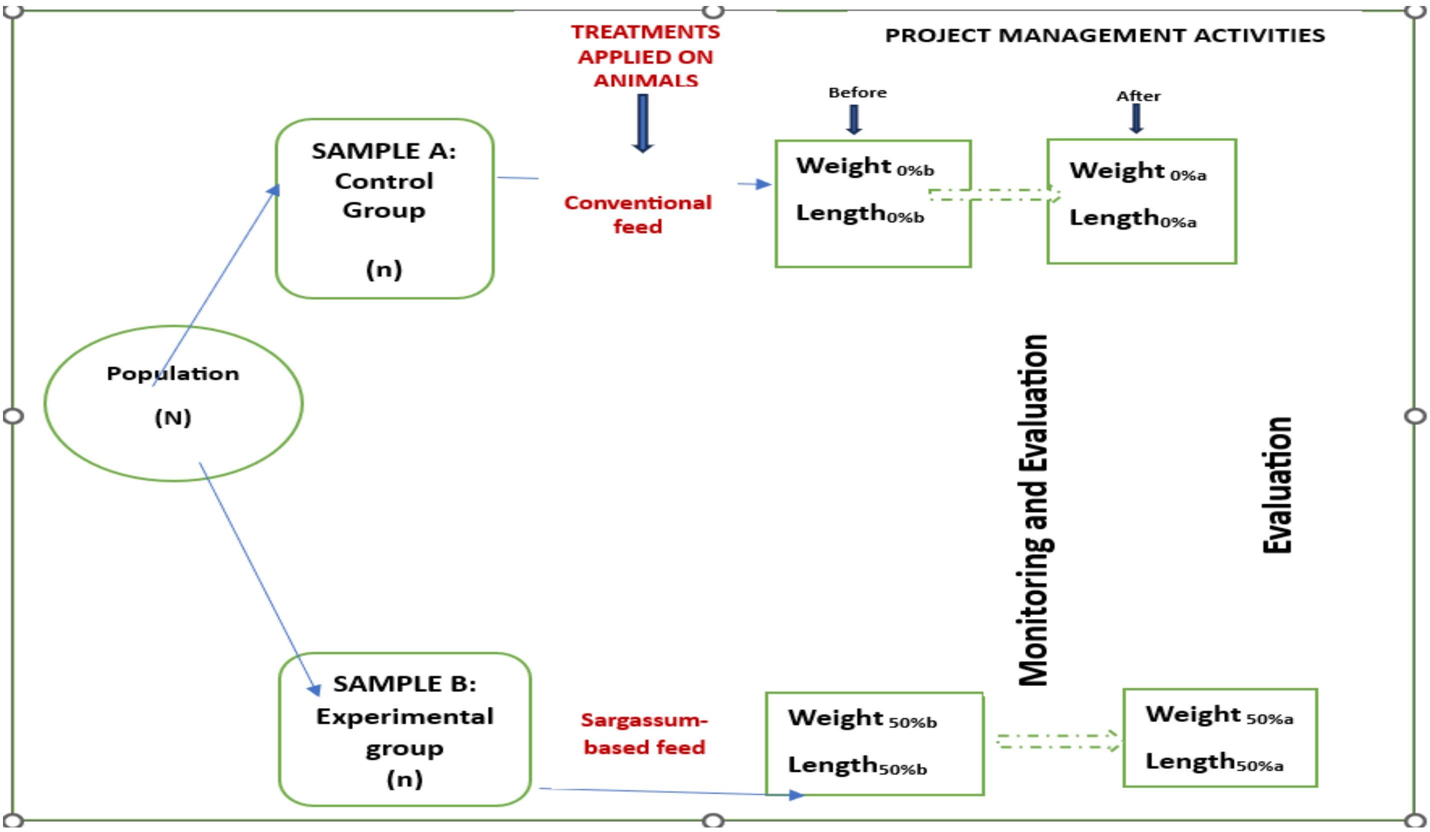
ii. Sample B received feed with 50% Sargassum (experimental group).

Measurement:
The weight and length of each sample were measured before and after the treatment. The measurements were structured as follows:

i. Sample A: Weight (0%) and Length (0%) before; Weight (0%) and Length (0%) after.

ii. Sample B: Weight (50%) and Length (50%) before; Weight (50%) and Length (50%) after.

The flowchart in Figure 3.6 depicts the feeding trial experiment, outlining the processes followed in applying different feed treatments to the samples and measuring the outcomes before and after the treatments.



Note: Population (N): Represents the experimental population from which samples are drawn.

Samples (A, B): Two sample groups taken from the experimental population (n).

Figure 3.6: Experimental trials for the study

Source: Modified after Casley and Lury (1982). Monitoring and evaluation in agriculture and rural development projects.

The flowchart in Figure 3.6 provides a structured visual representation of the feeding trial experiment, detailing the sequential processes involved in applying different feed treatments to selected animal samples and evaluating their responses over time. The experiment is designed to assess the effects of varying feed formulations, including Sargassum-based feed, on key performance indicators such as weight gain, length gain and overall health status.

At the initial stage, the population (N) represents the entire group of animals from which the samples were drawn. From the experimental population, two distinct sample groups (A and B) were selected, each with a specific sample size (n). These groups were subjected to different feeding treatments, one receiving conventional feed and the other Sargassum-based feed, to enable a comparative analysis of their nutritional impact.

Following the feed application phase, measurements are taken before and after the treatment period to monitor changes in critical parameters. These measurements provide quantitative data for assessing the effectiveness of Sargassum-based feed in comparison to conventional feed, thereby informing conclusions on its economic and nutritional viability. The flowchart systematically captures these experimental steps, ensuring clarity in the research methodology and facilitating reproducibility in future studies.

3.9 Data Collection and Monitoring Approach

To ensure transparency and replicability, the research employed a systematically planned approach, monitoring both quantitative indicators (weight and length) and qualitative indicators (health status and behaviour) over 12 weeks using the Agile Project Management method. The welfare of the livestock was continuously monitored,

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with observations conducted throughout the 12 weeks to detect any immediate effects or adverse reactions. When health issues were identified, corrective actions, such as the introduction of supplements, were taken following IFIF/FAO (2021) standards to address these concerns.

At the end of the feed trial, data were collected from both the experimental and control groups, focusing on key performance indicators (KPIs) such as weight gain, length gain, feed conversion ratio, and survival rate. Monitoring was conducted in line with IFIF/FAO (2021) standards to ensure consistency and reliability. The development of the project's monitoring and evaluation framework followed a structured approach based on assumptions influenced by Coleman (1987), Lindoso (2011), Mwangi and Moronge (2020), and Nesamvuni *et al.* (2022), which helped ensure consistency, rigor, and the overall effectiveness of the monitoring process.

3.10 Validity and Reliability of the Research Instruments

Reliability and validity, as recommended by Saunders et al. (2023), were applied to ensure the quality of the study. The validity and reliability of the study relied on the transparency and trustworthiness of the research and data presented.

3.10.1 Validity of the Research Instruments

Validity refers to the extent to which a study accurately measures or predicts what it is intended to measure and the degree to which conclusions drawn from the data are justified and appropriate (Saunders *et al.*, 2023). Content validity was ensured by ensuring that the research comprehensively covered all relevant aspects of Sargassum-fed livestock performance. A thorough approach to data collection and analysis was adopted, and the findings were subsequently reviewed by the researcher's project supervisors and other experts in the field. Their evaluations helped to confirm that the results were unbiased and that the methods and interpretations aligned with the intended constructs of the study. Construct validity was maintained by ensuring that the measures used in the study accurately represented the constructs of interest. Participants were approached carefully, and concurrent triangulation was employed to cross-verify the findings, ensuring that the study's results were credible, accurate, and applicable to the research questions. External validity was achieved by ensuring that the experimental population was an accurate representation of the reference population, which allowed the study's findings to be generalized to a larger population or broader context. Ecological validity was guaranteed by conducting the study within the animals' natural environment, ensuring that the research accurately reflected the dynamics of real-world settings. This approach ensured that the findings were not only scientifically sound but also relevant and applicable to actual conditions.

3.10.2 Reliability of the Research Instruments

Reliability in research is crucial for ensuring the consistency and reproducibility of findings, aiming to minimize errors and maintain unbiased information (Oyeniyi *et al.*, 2016). Animals of similar ages were randomly assigned to each group to ensure equivalence and reduce bias when evaluating responses to Sargassum seaweed. The materials and methods were thoroughly detailed to ensure consistent application across studies, facilitating comparable results. Standardized protocols, adapted from IFIF/FAO (2021), specified performance indicators tailored to each animal species, ensuring comprehensive documentation of findings. Additionally, various types of data—document reviews, observations, and surveys—were gathered to enhance reliability through a diverse approach. Consistency in survey methods and data collection processes was maintained to strengthen reliability and ensure the reproducibility of results over time. This methodological rigor guaranteed reliable findings, enabling a holistic assessment of the Sargassum-based feed's impact on animal health and behaviours over the 12-week study period. Conclusions were drawn from statistical analysis substantiated by observed evidence.

3.11 Methods of Data Analyses

Evidence-based insights were derived from quantitative and qualitative data collected simultaneously but analysed separately. The results were then compared and contrasted to validate or triangulate the findings.

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3.11.1 Quantitative Analysis

Quantitative analysis focused on statistical comparisons of performance metrics between control and experimental groups, using descriptive and inferential statistics. For descriptive statistics, animal growth performances and economic performance were evaluated

Animal Growth Performance Evaluation

1. Weight gain (kg) = Final body weight – Initial body weight
2. Length gain (kg) = Final body length – Initial body length
3. Percentage weight Gain = (Weight gain ÷ Initial weight) x 100
4. Percentage length Gain = (Length gain ÷ Initial length) x 100
5. Feed Conversion Ratio = Total feed intake ÷ Weight gain
6. Survival Rate (%) = (Ns/N_0) X 100

Where N_S = Number of animals surviving at the end of the study period

N_0 = Initial number of animals at the start of the experiment

The survival rate is a key indicator of animal vigour in this study and is assessed based on the number of animals remaining alive over 12 weeks.

In the case of inferential statistics, the study employed independent t-test, Analysis of Variance (ANOVA) and Chi-square to assess differences in group means at various scales

1. **I**ndependent t-test was used to compare the performances of control and experimental groups within each animal category providing insights into whether a statistically significant difference existed between them.
2. A Chi-square test was conducted to determine whether there was a statistically significant difference in survival rates between the experimental (Sargassum-fed) and control (conventional feed) groups.
3. ANOVA was further applied to extend the analysis across multiple groups, enabling the evaluation of differences among Chickens, fish, pigs and rabbits categories.

The inclusion of these methods allowed for a comprehensive examination of the data, ensuring a robust statistical assessment by addressing comparisons at both two-group and multi-group levels. This dual approach enhanced the reliability of the findings and provided additional understanding of the variations in the data.

Economic Performance Evaluation

Cost-effectiveness Analysis

Cost-Effectiveness Ratio = Total cost ÷ Weight gained

Benefit Cost Ratio = Market value of 1kg meat ÷ Cost of producing 1 kg meat

Profitability Analysis

Profit Per Kilogram of Meat = Market Price Per Kg − Cost of Producing Per Kg

Profit Margin (%) = (Profit per Kg meat ÷ Market price per kg meat) x 100

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Cost-saving potential of Sargassum-based feed (%) =

$$\frac{(\text{Cost}_{\text{Conventional}} - \text{Cost}_{\text{Sargassum}})}{(\text{Cost}_{\text{Conventional}})} \times 100$$

Return on Investment (ROI) = (Profit per Kg meat ÷ Cost per kg meat) x 100

3.11.2Qualitative analysis

Content Analysis

The qualitative analysis used content analysis to categorize observational data on animal performance, including health, vitality, feeding behaviour, and survival. This method identified patterns by comparing animals fed with Sargassum-based and conventional feed. By integrating qualitative and quantitative findings, the study ensured a systematic, measurable evaluation of Sargassum’s effects, enhancing result reliability and clarity.

Stakeholders Network Analysis

Data for this analysis were obtained from CESAR LASU's existing dataset. The nature of the partnerships among the entities involved in the Sargassum-based feeds development project was coded and subsequently transformed into a Partnership Relationship Matrix, utilizing a 4-point Likert scale (Appendix V).

Gantt Chart

Microsoft Project software was employed to streamline project management activities. Specifically, it was used to create project timelines, set milestones, allocate personnel, and document project costs. The integration of these tools ensured that project activities aligned with strategic objectives and adhered to the established schedule.

The study evaluated the convergence and divergence of findings from the quantitative and qualitative data sets. Any discrepancies between the findings would prompt further investigation to determine if differences in performance indicators were significant and attributable to the feed. This comprehensive approach ensured a thorough validation of the results.

3.12 Ethical Considerations

The research adhered to established ethical guidelines, prioritizing integrity, transparency, and respect for all stakeholders. Full disclosure of the researcher’s identity, qualifications, and affiliations was provided to foster trust and collaboration. A multi-perspective approach was employed, considering the diverse viewpoints of stakeholders to address the ethical implications comprehensively. Ethical standards were strictly followed throughout the research process, including obtaining informed consent from gatekeepers, ensuring data privacy and confidentiality, and securing approval from the Lagos State University (LASU) Ethical Committee.

Official permission to conduct the research in Badagry, Lagos Sate was first obtained from LASU’s Ethical Committee. Following this, the Director of CESAR and the farm owner were contacted, with informed consent obtained from them. Consent procedures adhered to key principles: competence, voluntarism, full information, and comprehension, ensuring participants’ privacy and protecting their rights throughout the study. Project communication and negotiation skills were employed to address sensitive or controversial findings, upholding integrity and respect for all involved. The study adhered to the ethical principles outlined by Cohen *et al.* (2018) and the American Psychological Association’s Ethical Principles and Code of Conduct (2016). These principles cover ten core areas, including resolving ethical issues, competence, human relations (avoiding harm, ensuring informed consent), privacy, confidentiality, and record-keeping. By rigorously applying these principles, the research upheld the highest standards of ethical soundness and scholarly rigor, ensuring the protection of all stakeholders' rights and dignity.

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RESULTS

4.1 Preamble

This chapter presents, analyses, and interprets the data collected on the impact of project monitoring and evaluation on the sustainability of sargassum-fed animals in Badagry, Lagos State, Nigeria. The data collected during the 12-week feeding trial were analysed to assess the impact of Sargassum-based feed on the growth, health, feed conversion ratio, and behaviour of the animals. The primary objective was to compare the performance of animals fed Sargassum-based feed (experimental groups) to those fed conventional feed (control group). To formulate the experimental feed, a linear programming model for ingredient mix optimization was employed through Excel Solver-Addin software, ensuring that the nutritional contents of the experimental feeds are in line with globally acceptable standards.

To analyse the data, both descriptive and inferential statistical methods were used. Descriptive statistics, including mean, standard deviation, range and percentage were calculated to summarize the data and provide an overview of the overall performance of the animals in each group. Control groups helped establish baseline values and trends related to growth and health providing clear views of how sargassum-based feeds influence animals' performances. In addition, economic analysis such as profitability and cost-effectiveness metrics were used to evaluate whether Sargassum-based feed can sustain its market readiness, ensuring that the feed is both cost-effective and financially viable for long-term use.

For inferential analysis, the stated hypothesis was tested using Independent T-Test, Chi-square test and Analysis of Variance (ANOVA) to evaluate whether there were significant differences between the experimental and control groups in terms of weight and length facilitated by Statistical Product for Solutions (SPSS). A five percent (5%) level of significance was used for data analysis. The decision rule states that if the p-value of the generated result is less than 0.05, the null hypothesis (H_0) will be rejected. Otherwise, the null hypothesis will not be rejected. Finally, a result-based logical monitoring and evaluation framework was developed for assessing the performance of the Sargassum-based feed development project.

4.2 Descriptive Statistics of Animals under Study

The data collected over 12 weeks of feed trials for both the experimental group (fed with Sargassum) and the control group (fed without Sargassum) shown in table 4.1 were analysed separately. Key parameters, including average weight gain, average daily weight gain, percentage change in weight, change in length, and percentage change in length, were used for the analysis.

Table 4.1: Comparison of Performance Parameters Between Control and Experimental Groups for Different Animal Species

Performance	**Chicken**		**Fish**		**Pig**		**Rabbit**	
Parameters	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Age of animal	4 weeks old	4 weeks old	6 weeks old	6 weeks old	4 weeks old	4 weeks old	3 months old	3 months old
Number of days for feed trial	84	84	84	84	84	84	84	84
Ave rage initial weight (Kg)	0.6	0.6	0.025	0.026	9.67	9.83	1	0.93
Average final weight	4.5	4.4	0.854	1	23.67	24.5	2.18	2.83

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(kg)								
Average weight gain (Kg)	3.9	3.8	0.829	0.974	14	14.67	1.18	1.9
Average daily weight gain (Kg)	0.046	0.045	0.01	0.012	0.17	0.17	0.014	0.023
Percentage (%) change in weight	650%	633%	3316%	3746%	145%	149%	118%	204%
Ave rage initial length (Cm)	16	16	15	15	31.7	32.67	53	42.5
Average final length (Cm)	26	27	50	51	37.86	41.54	63.5	61
Change in length (Cm)	10	11	35	36	6.16	8.87	10.5	18.5
Percentage (%) change in length	62.50 %	68.75 %	233.30%	240.00 %	19.40 %	27.20 %	19.80 %	43.50 %
Total feed intake (Kg)	80	80	39.6	52.36	281.82	290.01	75	75
Feed intake per animal (Kg)	9.06	8.9	1.13	1.31	93.94	96.67	7.5	7.5
Feed conversion Ratio	2.32	2.34	1.3	1.5	6.71	6.59	6.36	3.94
Number of animals at the beginning of the project	10	10	45	45	3	3	10	10
Number of animals at the end of the project	8	8	35	40	3	3	10	10
Heath status	Good	Good	Good	Good	Good	Good	Good	Good
Behaviour	Good	Good	Good	Good	Good	Good	Good	Good
Nature of faeces	Good	Good	Good	Good	Good	Good	Good	Good
Survival rate	80%	80%	78%	89%	100%	100%	100%	100%
Mortality rate	20%	20%	22%	11%	0%	0%	0%	0%

Source: Field Survey, November (2024)

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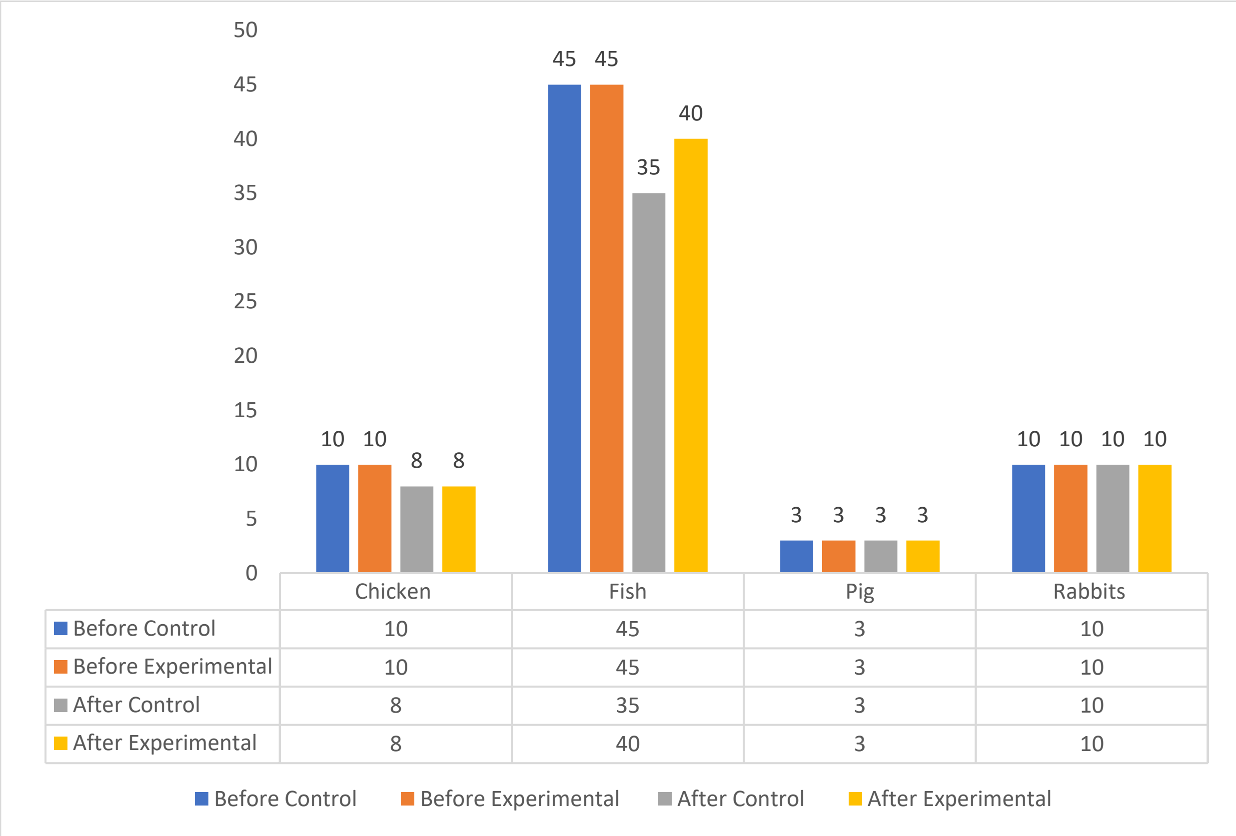

Figure 4.1: Distribution of used animals before and after the experiment

Table 4.1 shows the data on the comparison among the performance parameters of chickens, fish, pigs, and rabbits under these feeding conditions revealed varied outcomes across the species. The number of animals before and after the feeding trials for both the control group and the experimental group is presented in figure 4.1. The number of chickens used for the study decreased from 10 to 8 in both the control and experimental groups, resulting in a mortality of 20% and a survival rate of 80% in each case. In fish, the number decreased from 45 to 35 in the control group, while a smaller decline was observed in the experimental group, where the count reduced to 40.

The survival and mortality rates across the animal groups highlight the positive impact of Sargassum-based feed on animal health. For fish, the mortality rates were 22% and 11% for the control and experimental groups, respectively, corresponding to survival rates of 78% and 89%. This indicates an improvement in fish survival when fed the experimental diet. For pigs, the number of animals remained constant at three across all conditions, with no recorded mortality, resulting in a 100% survival rate. Similarly, rabbits maintained a consistent population of ten before and after the trials in both the control and experimental groups, also achieving a 100% survival rate. In the case of chickens, survival rates were identical at 80% for both the control and experimental groups.

Overall, pigs and rabbits exhibited 100% survival rates regardless of diet, indicating no adverse effects from the Sargassum-based feed. Fish demonstrated improved survival rates with the experimental diet, while chickens showed no difference between the two groups. These results emphasize the role of optimal nutrition, such as Sargassum-based feed, in enhancing immune function and reducing mortality rates.

4.2.1 Weight Gained Across Animal Species

Figure 4.2 revealed that for chicken, the average weight gain was slightly higher in the control group (3.9 kg) than in the experimental group (3.8 kg). The percentage change in weight (650% for the control group vs. 633% for the experimental group) showed minimal differences, suggesting that Sargassum-based feed supported similar growth efficiency. In fish, the experimental group outperformed the control group, with a higher average weight gain (0.974 kg vs. 0.829 kg) and a greater percentage change in weight (3746% vs.

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3316%). For pigs, the experimental group achieved higher weight gain (14.67 kg vs. 14 kg) and a slightly improved feed conversion ratio (FCR) (6.59 vs. 6.71), demonstrating better feed utilization with Sargassum-based feed. Rabbits fed the experimental diet showed the most notable improvements, with weight gain (1.9 kg vs. 1.18 kg) and percentage weight change (204% vs. 118%) being significantly higher compared to the control group as shown in figure 4.2.

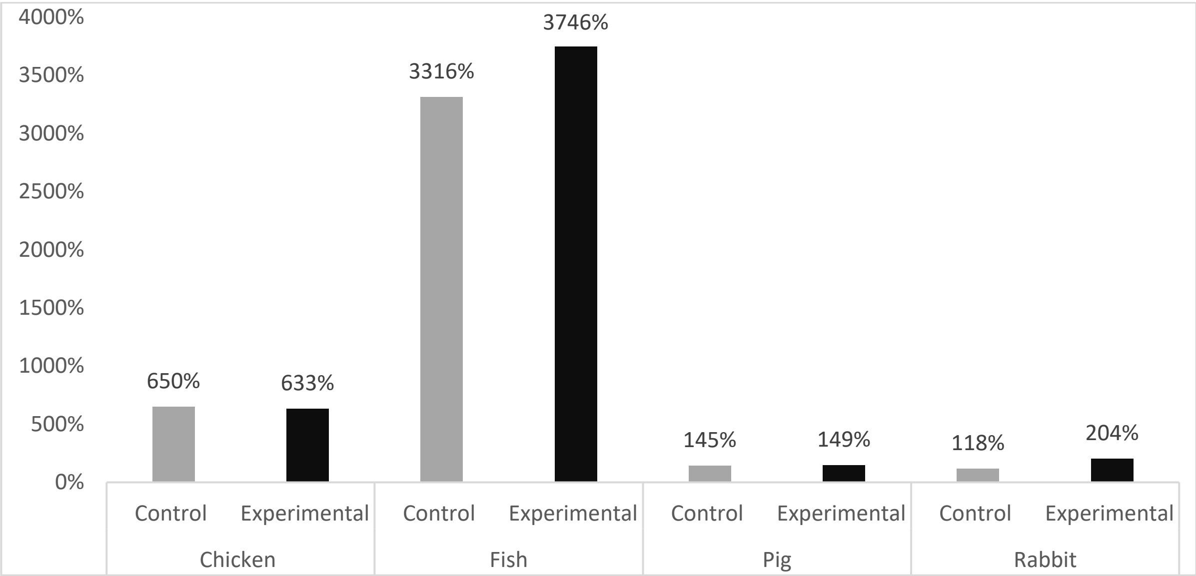

Figure 4.2: Comparative analysis of the percentage change in weight of animals in control and experimental groups

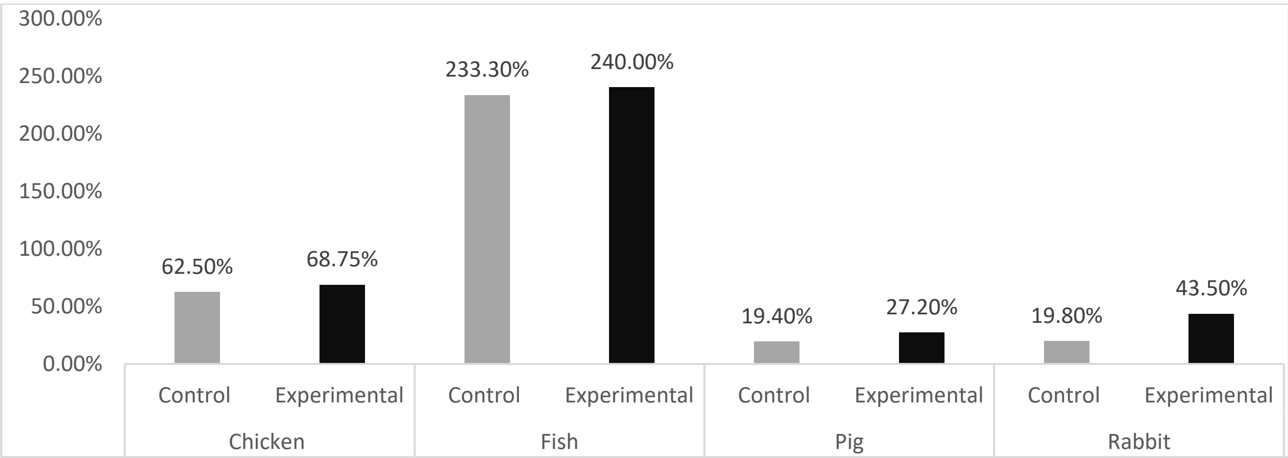

Figure 4.3: Comparative analysis of the length gained by animals in control and experimental groups

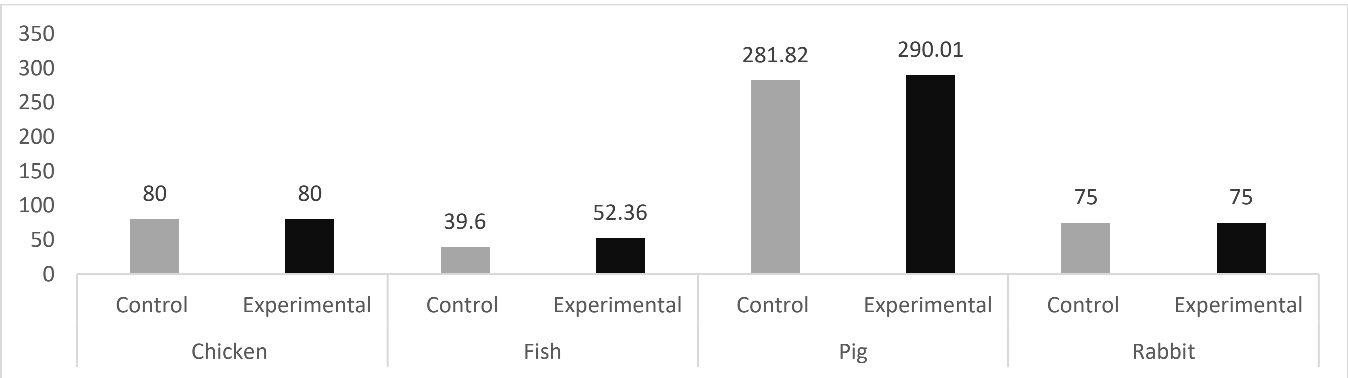

Figure 4.4: Comparative analysis of feed intake by Fish, Chickens, Rabbits, and pigs fed with sargassum-based and conventional feeds.

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4.2.2. Length Gained Across Animal Species

Figure 4.3 shows that across all species, the experimental feed supported better length gains, particularly for fish and rabbits. The percentage length changes were 240% (experimental) vs. 233.3% (control) for fish and 43.5% (experimental) vs. 19.8% (control) for rabbits, with the rabbit group exhibiting the most significant response to the Sargassum supplement.

4.2.3 Comparative Analysis of Feed Intake in Fish, Chickens, Rabbits, and Pigs Fed with Sargassum-Based and Conventional Feeds

The feed intake results in figure 4.4 revealed interesting patterns, with the fish group showing the highest feed intake among all four species. Chickens and rabbits had comparable feed intake across both groups, whereas fish and pigs fed with Sargassum consumed more feed. Specifically, the experimental group of fish had a total feed intake of 52.36 kg compared to 39.6 kg for the control group, while pigs consumed 290.01 kg compared to 281.82 kg in the control group.

4.2.4 Feed Conversion Ratios (FCR) Across Species

Feed conversion ratio (FCR), a measure of the efficiency with which animals convert feed into weight gain, varies significantly among the animals. The FCR for chickens (2.32 for the control group vs. 2.34 for the experimental group) showed minimal differences, suggesting that Sargassum-based feed supported similar growth efficiency. The lowest FCR values are observed in fish (1.3 for the control group vs. 1.5 for the experimental group), indicating that fish are highly efficient in converting feed into weight gain. Despite higher feed intake, pigs and rabbits utilized the experimental feed more efficiently. For pigs, the experimental group achieved higher weight gain (14.67 kg vs. 14 kg) and a slightly improved FCR (6.59 vs. 6.71), demonstrating better feed utilization with Sargassum-based feed. Rabbits in the experimental group had a significantly better FCR (3.94 vs. 6.36), reflecting greater efficiency of the Sargassum-based feed.

4.3 Analysis of the Objectives of the Study

4.3.1 Analysis of Objective One and Research Question One

Objective One: To compare the nutritional value of animal feeds made from sargassum to traditional animal feeds.

Research Question One: Is there a difference between the nutritional contents of sargassum-based animal feeds and conventional animal feeds?

The first objective of this study compared the nutritional value of animal feeds made from sargassum to traditional animal feeds. To achieve this, Linear Programming (LP) optimization models for ingredients mix problem were developed using Excel Solver to formulate Sargassum-based feeds. The models aimed to minimize feed costs while meeting the nutritional requirements of the animals under study. Constraints were applied to ensure the dietary requirements for protein, energy, fibre, and other nutrients were met. The findings for conventional feeds and sargassum-based feeds are as presented in table 4.2.

Table 4.2: Feed Composition for Conventional and Sargassum-Based Diets Across Target Animal Species

Type of feed	Chicken	Fish	Pig	Rabbit
Conventional Feeds	Maize 40% Rice bran 8% Wheat 15% Soybean 20% Fish meal 4%	Maize 17.06%, Soyabean 24.98% GNC 24.98% Fish meal 24.98%	Maize 67.30% Soybean 29.25% Bone meal 2%	Maize 43.86% Soyabean meal 23.23% Wheat offal 15% PKC 3%

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	GNC 5%			Fish meal 11.61% Meat and bone meal 2.6%
Sargassum - Based Feeds	Sargassum fluitans 50% Maize 20.7% Soybean 6.61% Meat and bone meal 23.01%.	Sargassum fluitans 50% Maize 30% Soybeans 23.8% Fish meal 15.5% GNC 12% Meat and bone meal 3% PKC 2%	Sargassum fluitans 50% Maize 14% Soybean meal 15% Meat and bone meal 5% Wheat 10% PKC 10%	Sargassum fluitans 50%, Rice bran 15.5% Fish meal 7% Wheat 24%

Source: Author's Computation, November (2024).

Table 4.2 presents the composition of conventional and Sargassum-based feeds for chickens, fish, pigs, and rabbits, highlighting key ingredient formulation differences and nutritional priorities. Conventional feeds rely heavily on energy-rich grains like maize, wheat, and rice bran, supplemented with protein sources such as fish meal, soybean, and groundnut cake to meet species-specific nutritional needs. In contrast, Sargassum-based feeds replace 50% of conventional feed ingredients with *Sargassum fluitans* reducing reliance on traditional grains and promoting sustainability.

Table 4.3: Nutritional value analysis of the feeds used for the study

Nutritional contents of the feeds	**Chicken**		**Fish**		**Pig**		**Rabbit**	
	Conventional	Sargassum based	Conventional	Sargassum based	Conventional	Sargassum based	Conventional	Sargassum based
ME (kcal/kg)	3,114.8	2,682	2,729	2,924	1,959	2,872	2,230	2,600
Crude Protein (%)	17.66	22	40.9	37	23.75	20	9.36	17
Crude Fat (%)	6.39	5	4.42	8	4	6	6.75	4
Crude Fibre (%)	4.16	12	3.56	12	10.8	15	20.12	18
Ash (%)	4.49	10	12.67	10	4	8	6.2	9

Source: Author's Computation, November (2024).

Table 4.3 revealed distinct nutritional variations between conventional and Sargassum-based feeds. While Sargassum-based feed demonstrates a competitive energy profile, its effects vary across species. Fish and rabbits benefit from higher metabolizable energy (ME) levels (2924 kcal/kg vs. 2729 kcal/kg for fish; 2600 kcal/kg vs. 2230 kcal/kg for rabbits), suggesting its viability as an energy source for these animals. However, for chickens and pigs, conventional feed provides slightly higher ME (3114.8 kcal/kg vs. 2682 kcal/kg for chickens; 2872 kcal/kg vs. 1959 kcal/kg for pigs).

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Protein content also varies by species. Sargassum-based feed offers higher crude protein for chickens (22% vs. 17.66%) and rabbits (17% vs. 9.36%), making it a strong protein source for these animals. Conversely, fish and pigs receive lower protein levels compared to conventional feed (37% vs. 40.9% for fish; 20% vs. 23.75% for pigs), which may limit its application in high-protein diets.

Crude fat levels show mixed results. Fish and pigs benefit from increased fat content in Sargassum-based feed (8% vs. 4.42% for fish; 6% vs. 4% for pigs), enhancing energy density. However, chickens and rabbits receive lower crude fat compared to conventional feed (5% vs. 6.39% for chickens; 4% vs. 6.75% for rabbits). Sargassum-based feed significantly increases crude fibre content across all species, particularly in chickens (12% vs. 4.16%). Rabbits and pigs also show higher fibre levels (20.12% vs. 18% for rabbits; 15% vs. 10.8% for pigs), potentially benefiting gut health and digestibility. Additionally, Sargassum-based feed enhances mineral content, as reflected in higher ash levels for chickens (10% vs. 4.49%), pigs (8% vs. 4%), and rabbits (9% vs. 6.2%), which may contribute to improved bone health and metabolic functions.

Restatement of Hypothesis One

Null Hypothesis (H_{01}): There is no significant difference between the nutritional contents of Sargassum-based animal feeds and conventional animal feeds.

To test the hypothesis, independent t-test was used. In the analysis, the nutritional values of conventional feeds were compared to sargassum-based feeds. The independent t-test results are presented in table 4.4.

Table 4.4: T-Test Result of the Nutritional value analysis of feeds used for the study

Nutritional Contents of the Feeds	**Chicken**		**Fish**		**Pig**		**Rabbit**	
	Conventional	Sargassum based	Conventional	Sargassum based	Conventional	Sargassum based	Conventional	Sargassum based
ME (kcal/kg)	3,114.8	2,682	2,729	2,924	1,959	2,872	2,230	2,600
Crude Protein (%)	17.66	22	40.9	37	23.75	20	9.36	17
Crude Fat (%)	6.39	5	4.42	8	4	6	6.75	4
Crude Fibre (%)	4.16	12	3.56	12	10.8	15	20.12	18
Ash (%)	4.49	10	12.67	10	4	8	6.2	9
t Stat	0.10		-0.05		-0.27		-0.11	
P-value at 0.05	0.92		0.96		0.80		0.91	

Source: Author’s Computation, November (2024).

Table 4.4 presents the nutritional composition of conventional and Sargassum-based feeds across different animal species. The t-statistics for chickens (0.10), fish (-0.05), pigs (-0.27), and rabbits (-0.11) resulted in p-values of 0.92, 0.97, 0.80, and 0.91, respectively. Since all p-values exceed the significance threshold (0.05), the study fails to reject the null hypothesis (**H_{01}**) indicating no statistically significant differences in nutritional contents between conventional and Sargassum-based feeds.

Decision

Null hypothesis (H_{01}) is not rejected, hence, there is no significant difference between the nutritional

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contents of Sargassum-based animal feeds and conventional animal feeds. Based on the ingredient composition analysis and statistical assessment, Sargassum-based feed formulations are nutritionally comparable to conventional feeds for chickens, fish, pigs, and rabbits. The t-test results indicate no statistically significant differences in nutritional contents, supporting the conclusion that Sargassum-based feed can serve as a viable alternative ingredient.

4.3.2 Analysis of Objective Two and Research Question Two

Objective Two: To evaluate the significant differences in the performance (weight, length and survival rate) of animals fed with sargassum-based feeds and those fed with conventional feeds.

Research Question Two: Is there a significant difference in the performance (weight, length and survival rate) of animals fed with sargassum-based feeds and those fed with conventional feeds?

To determine whether there is a significant difference in the performance (weight, length, and survival rate) of animals fed Sargassum-based feeds compared to those fed conventional feeds, the three (3) sub-hypotheses were formulated and tested using appropriate statistical analyses. By testing these hypotheses, the study provided statistical evidence on the impact of *Sargassum fluitans* on animal performance in terms of weight, length, and survival rate.

Restatement of Hypothesis 2 (Main Hypothesis on overall performance)

Null Hypothesis (H_{02}): There is no significant difference in the performance (weight, length, and survival rate) of animals fed with sargassum-based feeds and those fed with conventional feeds.

To test this, the hypothesis was broken down into three sub-hypotheses based on specific performance indicators:

4.3.2.1 Sub-Hypothesis 2.1 (Weight Analysis)

Null Hypothesis ($H_{02.1}$): There is no significant difference in the weight of animals fed *Sargassum fluitans* and those fed without *Sargassum fluitans*.

The Independent t-test was used to compare the weight of the animals in the control and experimental groups for each species at 0.05 level of significance.

Table 4.5: Comparative analysis of the weight of animals in the control and experimental groups

Weight Parameters	Chicken		Fish		Pig		Rabbit	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Average initial weight (Kg)	0.6	0.6	0.025	0.026	9.67	9.83	1.00	0.93
Average final weight (kg)	4.5	4.4	0.854	1.00	23.67	24.5	2.18	2.83
Average weight gained (Kg)	3.9	3.8	0.829	0.974	14.00	14.67	1.18	1.90
t Stat	0.04		-0.23		-0.09		-0.66	
P-value at 0.05	0.97		0.83		0.93		0.55	

Source: Author’s Computation, November (2024)

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The results for weight parameters in table 4.5 show no statistically significant differences between animals fed

with the control diet (conventional feed) and the experimental diet (Sargassum-based feed) across all species at a 0.05 level of significance. For chickens, the t-statistic was 0.044 with a p-value of 0.97, indicating no significant difference in weight. Similarly, for fish, pigs, and rabbits, the t-statistics were -0.23, -0.09 and -0.66 respectively, with corresponding p-values of 0.83, 0.93, and 0.55, all exceeding 0.05 significance level. Based on these results, null hypothesis was not rejected, suggesting that the weight outcomes between the two diets are statistically comparable

Decision

Null hypothesis ($H_{02.1}$) s not rejected, hence, there is no significant difference in the weight of animals fed Sargassum fluitans and those fed without Sargassum fluitans.

4.3.2.2 Sub-Hypothesis 2.2 (Length Analysis)

Null Hypothesis ($H_{02.2}$): There is no significant difference in the length of animals fed *Sargassum fluitans* and those fed conventional feed.

The Independent t-test was also used to compare the length of the animals in the control and experimental groups for each species at 0.05 level of significance.

Table 4.6: Comparative analysis of the length of animals in the control and experimental groups

Length Parameters	Chicken		Fish		Pig		Rabbit	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Average initial length (Cm)	16	16	15	15	31.7	32.67	53	42.5
Average final length (Cm)	26	27	50	51	37.86	41.54	63.5	61
Average length gained (Cm)	10	11	35	36	6.16	8.87	10.5	18.5
t Stat	-0.10		-0.05		-0.18		0.08	
P-value	0.92		0.97		0.87		0.94	

Source: Author's Computation, November (2024).

Table 4.6 shows that the t-statistics for chickens, fish, pig, and rabbit were -0.1, -0.05, -0.18, and 0.08, respectively, with p-values of 0.92, 0.97, 0.87, and 0.94, respectively. The p-value remained above the 0.05 level, indicating no statistical significance, further supporting the null hypothesis. The results indicate that the length parameters do not significantly differ between the control and experimental diets across all species.

Decision

Null hypothesis ($H_{02.2}$) is not rejected, hence, there is no significant difference in the length of animals fed Sargassum fluitans and those fed conventional feed.

4.3.2.3 Sub-Hypothesis 2.3 (Survival Rate Analysis)

Null Hypothesis ($H_{02.3}$): There is no significant difference in the survival rate of animals fed *Sargassum*

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fluitans and those fed conventional feed.

In this hypothesis, the survival rates of animals fed with Sargassum-based feed and those fed with conventional feed were as shown in table 4.7 compared across different species, including chickens, fish, pigs, and rabbits.

Table 4.7: Comparison of Survival Rate Parameters for Control and Experimental Groups

Performance Parameters	Chicken		Fish		Pig		Rabbit	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Age of animal	4 weeks old	4 weeks old	6 weeks old	6 weeks old	4 weeks old	4 weeks Old	3 months old	3 months old
Number of animals at the beginning of the project	10	10	45	45	3	3	10	10
Number of animals at the end of the project	8	8	35	40	3	3	10	10
Survival rate	80%	80%	78%	89%	100%	100%	100%	100%
Mortality rate	20%	20%	22%	11%	0%	0%	0%	0%

Source: Field Survey, November (2024)

Analysing survival and mortality patterns across species, pigs and rabbits exhibited 100% survival in both experimental and control groups, indicating that feed type did not affect their survival. Similarly, chickens had a survival rate of 80% in both groups, further reinforcing the lack of a feed-related impact. However, in fish, the Sargassum-fed group had a slightly higher survival rate (89%) compared to the control group (78%), though this difference was not statistically significant.

A Chi-square test was conducted to determine whether there was a statistically significant difference in survival rates between the experimental (Sargassum-fed) and control (conventional feed) groups.

Table 4.7: Chi-square test of the difference in the survival rate of animals fed *Sargassum fluitans* and those fed conventional feed.

Observed Values						Expected Values				
Animal	Group	Survived	Dead	Total		Animal	Group	Survived	Dead	Total
Chicken	Experimental	8	2	10		Chicken	Experimental	8.60	1.40	10
	Control	8	2	10			Control	8.60	1.40	10
Fish	Experimental	40	5	45		Fish	Experimental	38.71	6.29	45
	Control	35	10	45			Control	38.71	6.29	45
Pig	Experimental	3	0	3		Pig	Experimental	2.58	0.42	3
	Control	3	0	3			Control	2.58	0.42	3
Rabbit	Experimental	10	0	10		Rabbit	Experimental	8.60	1.40	10

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	Control	10	0	10			Control	8.60	1.40	10
Total		**117**	**19**	**136**		**Total**		**117**	**19**	**136**
X^2 = 0.36										
p-value = 0.99										

Source: Author’s Computation, November (2024).

The results of the Chi-square test in table 4.7 indicate that there is no statistically significant difference in the survival rates of animals fed with Sargassum-based feed and those fed with conventional feed. The computed Chi-square value (X^2) is 0.36, and the p-value is 0.99, which is much greater than the conventional significance levels of 0.05. This suggests that the observed differences in survival rates between the experimental and control groups are likely due to chance rather than the type of feed administered.

Decision

Null hypothesis ($H_{02.3}$) is not rejected, hence, there is no significant difference in the survival rate of animals fed *Sargassum fluitans* and those fed conventional feed. The findings imply that feeding animals with Sargassum-based feed does not significantly alter their survival probability compared to conventional feed.

4.3.2.4 One-Way Analysis of Variance (ANOVA)

A One-Way Analysis of Variance (ANOVA) was conducted to evaluate whether different feed types significantly affect the growth and development of various animal species. This method was chosen to compare the means across multiple groups and assess the impact of Sargassum-based feed on animal performance.

Table 4.8: One-Way Analysis of Variance (ANOVA)

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	999.14	7	142.73	0.40	0.899	2.25
Within Groups	14405.84	40	360.15			
Total	15404.97	47				

Source: Author’s Computation, November (2024)

The ANOVA results in table 4.8 revealed that the calculated F-statistic is 0.40 with a corresponding p-value of 0.899, which is significantly greater than the level of significance used for the study. This suggests that there is no statistically significant difference between the control and experimental groups. The F-statistic of 0.40 is also smaller than the critical F-value of 2.25, further reinforcing the conclusion that the feed types (Sargassum-based and conventional) do not differ significantly in their impact on the animals' performance across the four species.

Decision

Null hypothesis (H_{02}) is not rejected, indicating that Sargassum-based feed performs similarly to conventional feed in terms of performance parameters. This suggests that the ingredient composition of the formulated Sargassum-based feeds influences nutritional content and animal performance, making it a viable alternative for animal nutrition.

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4.3.2.5 Content Analysis: Qualitative Analysis of the Performance of the Animals

The evaluation of animal performance in response to dietary interventions is essential in assessing the viability of alternative feed sources. This study investigated the qualitative aspects of the animals' performance. Table 4.9 presents the results of the examination of the health status and behaviour with the aim of determining the impact of Sargassum inclusion on overall animal well-being.

Table 4.9: Comparison of Qualitative Performance Parameters between Control and Experimental Groups for Different Animal Species.

Performance Parameters	**Chicken**		**Fish**		**Pig**		**Rabbit**	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Initial number of animals	10	10	45	45	3	3	10	10
Final number of animals	8	8	35	40	3	3	10	10
Heath status	Good	Good	Good	Good	Good	Good	Good	Good
Behaviour	Good	Good	Good	Good	Good	Good	Good	Good
Nature of faeces	Good	Good	Good	Good	Good	Good	Good	Good
Colour of skin/feather	White	Light brown	Ash	Golden brown	Light pink	Light pink	Normal	Normal

Source: Field Survey, November (2024)

4.3.2.3.1Qualitative Analysis of the Health Status and Behaviour of Chickens

The study analysed the performance of two groups of birds, one fed with conventional feed (Group A) and the other with 50% Sargassum-based feed (Group B). Both groups exhibited similar outcomes in health, vitality, and digestion. Birds in Group A displayed full, white feathers, while those in Group B had full but light brown feathers, indicating a possible dietary effect on pigmentation without any apparent health issues. Both groups showed very good responsiveness to feed, with normal behaviour, no signs of stress or disease, and no digestive problems such as diarrhoea. Mortality rates were identical at 20%, with two birds lost in each group, though no specific causes of death were discovered. Survival rates were also consistent at 80% for both groups. These results suggest that the inclusion of Sargassum-based feed at 50% did not negatively impact the health, digestion, or survival of the birds compared to conventional feed.

4.3.2.3.2Qualitative Analysis of the Health Status and Behaviour of Fish

The performance of two groups of fish was analysed: Group A (control) was fed with conventional feed, and Group B was fed with 50% Sargassum-based feed. Group B demonstrated improved health and growth outcomes. The fish in Group A showed a standard coloration, while those in Group B exhibited golden brown colour, likely due to the Sargassum-based diet, without much signs of stress or health complications. Both groups displayed active swimming behaviour and good feed acceptance, indicating no adverse effects on behaviour or vitality. Mortality rates were higher in group A (22%) compared to group B (11%). Overall, the study discovered that fish in group B consumed more feed and had more weight than those in group A,

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suggesting that the Sargassum-based feed had no detrimental impact on fish health or survival compared to conventional feed.

4.3.2.3.3Qualitative Analysis of the Health Status and Behaviour of Rabbits

The study also evaluated the rabbits in two groups: Group A (control) was fed conventional feed, and Group B

received a 50% Sargassum-based diet. Both groups exhibited good fur quality. Rabbits in both groups were highly receptive to their respective feeds, displayed normal activity levels, and showed no indications of stress or illness. However, rabbits fed with sargassum-based feeds eat more feeds compared to others. No abnormal stool was observed in both groups, confirming proper digestion across both groups. Mortality rates were consistent at 0% in both groups, demonstrating that the Sargassum-based feed was a viable alternative for rabbits without compromising their health or vitality.

4.3.2.3.4Qualitative Analysis of the Health Status and Behaviour of Pigs

The pigs were divided into two groups: Group A (control) fed with conventional feed, and Group B fed with 50% Sargassum-based feed. Both groups showed good skin condition. The pigs in both groups exhibited normal feeding behaviour, high vitality, and no signs of stress or health issues. Stool consistency remained normal, with no instances of diarrhea observed. Mortality rates were 0% in each group suggesting that the Sargassum-based feed had no adverse effects on the pigs and was comparable to conventional feed in terms of health and survival outcomes.

4.3.2.4 Mixed Method Data Convergence and Divergence

A mixed-method approach was employed to integrate qualitative and quantitative assessments, ensuring a comprehensive understanding of the intervention's effects. Observations of animal responsiveness to feed, physical condition, and mortality trends were analysed alongside measurable performance metrics. While health and behaviour indicators remained consistent across both diet groups, minor variations such as pigmentation changes and feed consumption differences were noted. The results demonstrated that animals fed a 50% Sargassum-based diet exhibited similar health, vitality, and survival rates to those on conventional feed, reinforcing its potential as a sustainable alternative. Improvements in weight gain, survival rates, and feed conversion ratios aligned with qualitative indicators of good health, normal behaviour, and acceptable stool consistency. While the majority of findings converged, minor discrepancies were observed, such as slight differences in weight gain and feed conversion efficiency in chickens. However, these did not negatively impact overall well-being. This analysis provides valuable insights into the use of Sargassum as an environmentally friendly feed option, offering practical implications for animal farmers seeking sustainable nutrition solutions without compromising productivity.

4.3.3. Analysis of Objective three and Research Question three

Objective three: To examine the economic viability of developing Sargassum-based feed to sustain its market readiness.

Research Question three: Is the development of Sargassum-based feed economically viable to sustain its market readiness?

This section describes the achievement of objective three (3) which is to assess the economic viability of

developing Sargassum-based feed to sustain its market readiness. Table 4.10 presents optimized feed models for Sargassum-based animal feeds, detailing ingredient compositions and their minimum cost per kilogram for chickens, rabbits, pigs, and fish. The cost estimates are derived from financial data obtained from feed ingredient vendors and the researcher's field expenses related to Sargassum processing (see Appendix vi). These models were developed using linear programming to determine the most cost-effective feed formulations for each animal species.

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Table 4.10: Optimized Cost of Sargassum-Based Feeds for Target Animal Species

Sargassum-Based Feeds	**Feed Optimization Models**	**Minimum Cost per Kg (Z)**
Chicken Feed	500 (*0.5*) Sargassum + 900 (*0.21*) Maize + 1200 (*0.07*) Soybean + 300 (*0.23*) MBM	₦ 585.33
Rabbit Feed	500 (*0.5*) Sargassum + 350 (*0.16*) Rice bran + 7000 (*0.07*) Fish meal + 300 (*0.24*) Wheat	₦ 895.82
Pig Feed	500 (*0.5*) Sargassum + 900 (*0.14*) Maize + 1200 (*0.07*) Soybean + 300 (*0.05*) MBM + Wheat (*0.1*) +160 (*0.1*) PKC	₦ 627
Fish Feed	500 (*0.5*) Sargassum + 900 (*0.03*) Maize + 1200 (*0.24*) Soybean + 7000 (*0.16*) Fish meal + 950 (*0.12*) GNC + 300 (*0.03*) MBM +160 (*0.02*) PKC	₦ 1778.36

Source: Developed by the Researcher using Linear Programming Technique (2024)

Table 4.10 shows that each feed formulation incorporated 50% sargassum, with varying proportions of other conventional feed ingredients tailored to the nutritional needs of each species. For instance, the sargassum-based chicken feed consists of 50% sargassum, 20.7% maize, 6.61% soybean, and 23.01% meat and bone meal, with a minimum cost of ₦585.33 per kilogram. The sargassum-based rabbit feed contains 50% sargassum, 15.5% rice bran, 7% fish meal, and 24% wheat, and costs ₦895.82 per kilogram.

The sargassum-based pig feed is made up of 50% sargassum, 14% maize, 15% soybean meal, 5% meat and bone meal, 10% wheat, and 10% palm kernel cake, costing ₦627 per kilogram. Finally, the sargassum-based fish feed includes 50% sargassum, 3% maize, 24% soybean, 16% fish meal, 12% groundnut cake, 3% meat and bone meal, and 2% palm kernel cake, with a minimum cost of ₦1,778.36 per kilogram. The variation in cost per kilogram reflects the different nutritional needs of the animals, with fish feed being the most expensive due to its higher protein requirements.

Table 4.11 compared the cost of formulating a kilogram of conventional feed adapted from previous studies, and Sargassum-based diets developed for this study using linear programming.

Table 4.11: Cost of producing 1kg Feed Conventional and Sargassum-Based Diets Across Animal Species

Type of feed		**Chicken**	**Fish**	**Pig**	**Rabbit**
Conventional feeds	Feed Formulation	Maize 40% rice bran 8% Wheat 15% Soybean 20% Fish meal 4% GNC 5%	Maize 17.06%, soyabean 24.98% GNC 24.98% fish meal 24.98%	Maize 67.30% soybean 29.25% Bone meal 2%	Maize 43.86% Soyabean meal 23.23% Wheat offal 15% PKC 3% Fish meal 11.61% Meat and bone meal 2.6%
	Cost of feed (Per Kg)	₦ 1,015.50	₦ 2,439.21	₦ 962.70	₦ 1,551.30
Sargassum based feeds	Feed Formulation	Sargassum fluitans 50%	Sargassum fluitans 50%	Sargassum fluitans 50%	Sargassum fluitans 50%,

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		maize 20.7% Soybean 6.61% Meat and bone meal 23.01%.	Maize 30% Soybeans 23.8% Fish meal 15.5% GNC 12% Meat and bone meal 3% PKC 2%	Maize 14% Soybean meal 15% Meat and bone meal 5% Wheat 10% PKC 10%	Rice bran 15.5% Fish meal 7% Wheat 24%
	Cost of feed (Per Kg)	₦ 585.33	₦1,778.36	₦627.00	₦ 895.82

Source: Author's Computation, November (2024).

Table 4.11 and Figure 4.5 show that the analysis of the cost of producing 1 kg of feed across different animal species revealed notable differences between the conventional and Sargassum-based feed formulations. For chickens, the cost of 1 kg of conventional feed is ₦1,015.50, while the cost of 1 kg of Sargassum-based feed is significantly lower at ₦585.33, indicating a substantial cost reduction of 42.5%. Similarly, for fish, the conventional feed costs ₦2,439.21 per kg, while the Sargassum-based feed is more affordable at ₦1,778.36, resulting in a cost saving of 27%. In the case of pigs, the cost of conventional feed is ₦962.70 per kg, compared to ₦627.00 for the Sargassum-based feed, which represents a cost reduction of 34.8%. For rabbits, conventional feed costs ₦1,551.30 per kg, while the Sargassum-based feed costs ₦895.82, yielding a savings of 42.3%.

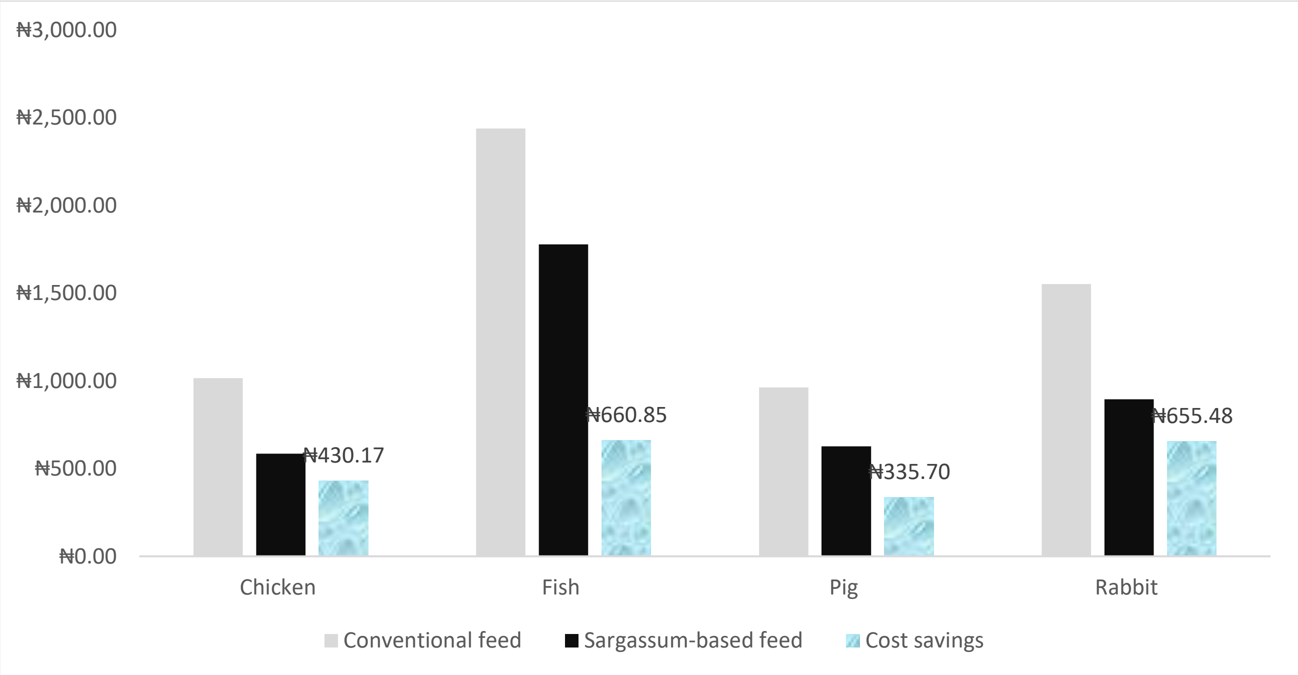

Figure 4.5: Cost saving in Producing One Kilogram (1Kg) of Sargassum-based versus conventional animal feeds

To evaluate the economic sustainability of Sargassum-based feed compared to conventional feed, profitability and cost-effectiveness analyses were conducted across the four animal species. Key economic indicators examined included total feed intake, feeding costs over 12 weeks, survival rates, cost per kilogram of meat produced, profit margins, and return on investment (ROI). The objective was to determine which feed option offers a more cost-effective conversion of feed costs into weight gain, informing its financial viability for large-scale adoption. Table 4.12 presents a comparative economic assessment of conventional and Sargassum-based feeds. By analysing the market value of weight gain relative to feeding costs, the study assessed the profitability and economic viability.

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Table 4.12: Economic Comparison of Conventional and Sargassum-Based Feeds across Animal Types

Economic Indicators	Chicken		Fish		Pig		Rabbit	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Cost of 1kg feed (₦)	1,015.50	585.33	2,439.21	1,778.36	962.70	627.00	1,551.30	895.82
Total feed intake (kg)	80.00	80.00	39.60	52.36	281.82	290.01	75.00	75.00
Cost of feeding all animals for 12 weeks (₦)	81,240.00	46,826.54	96,592.72	93,114.95	271,308.11	181,836.27	116,347.50	67,186.49
Number of surviving animals	8	8	35	40	3	3	10	10
Cost of feeding an animal (₦)	10,155.00	5,853.32	2,146.50	2,069.22	90,436.04	60,612.09	11,634.75	6,718.65
Average final weight (kg)	4.50	4.40	0.85	1.00	23.67	24.50	2.18	2.83
Average weight gain per animal (kg)	3.90	3.80	0.83	0.97	14.00	14.67	1.18	1.90
Cost of producing I kg meat (₦)	2,256.67	1,330.30	2,513.47	2,069.22	3,820.70	2,473.96	5,337.04	2,374.08
Market price per Kg Meat (₦)	4,700	4,700	3,000	3,000	5,000	5,000	6,000	6,000
Total benefits (Market price of the meat produced) (₦)	169,200.00	165,440.00	89,250	120,000	355,050	367,500	130,800	169,800
Cost Benefit Ratio	2.08	3.53	0.92	1.29	1.31	2.02	1.12	2.53
Profit Per Kg of Meat (₦)	2,443.33	3,369.70	486.53	930.78	1,179.30	2,526.04	662.96	3,625.92
Profit Margin (%)	52.00%	71.70%	16.20%	31.00%	23.60%	50.50%	11.00%	60.40%
Return on Investment (%)	108.30%	253.30%	19.40%	45.00%	30.90%	102.10%	12.40%	152.70%
Cost-Effectiveness Ratio (₦/Kg)	2,603.85	1,540.35	2,589.27	2,124.46	6,459.72	4,131.70	9,859.96	3,536.13
Cost-saving potential of	41.10%		17.70%		35.20%		55.50%	

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Sargassum-based feed (%)				

Source: Author’s Computation, November (2024)

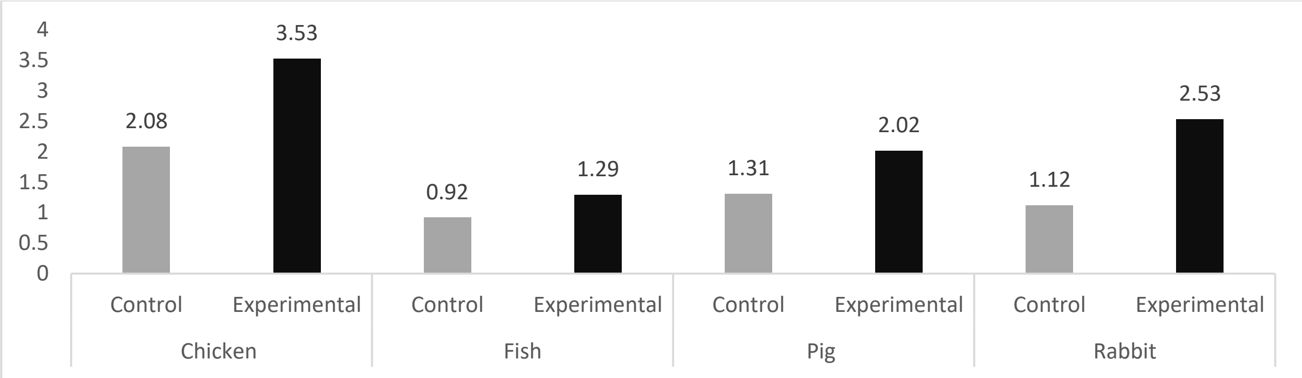

Figure 4.6: Comparative analysis of Cost-Benefit Ratio for using Sargassum-based feed versus conventional feed across animal types.

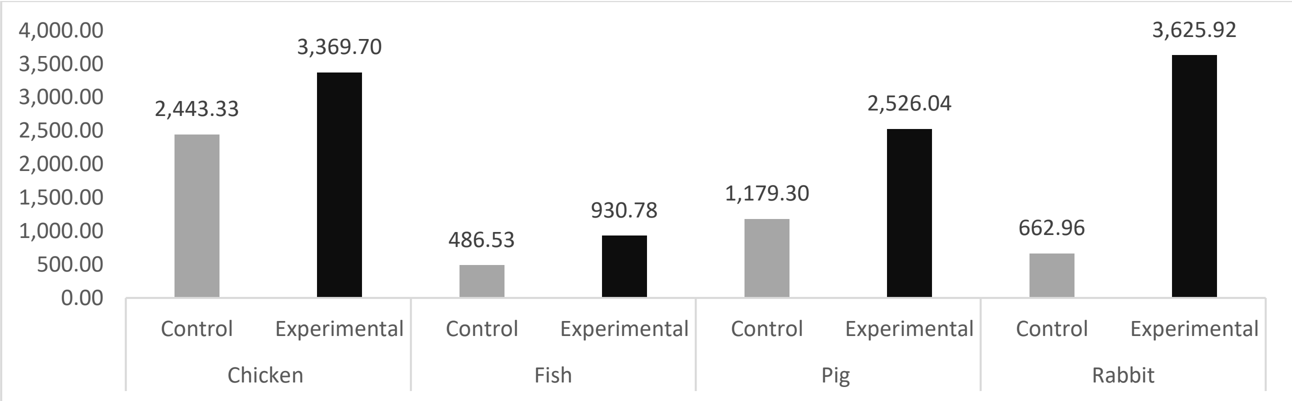

Figure 4.7: Comparative analysis of profit per kilogram of Meat obtained by using Sargassum-based feed versus conventional feed across animal types.

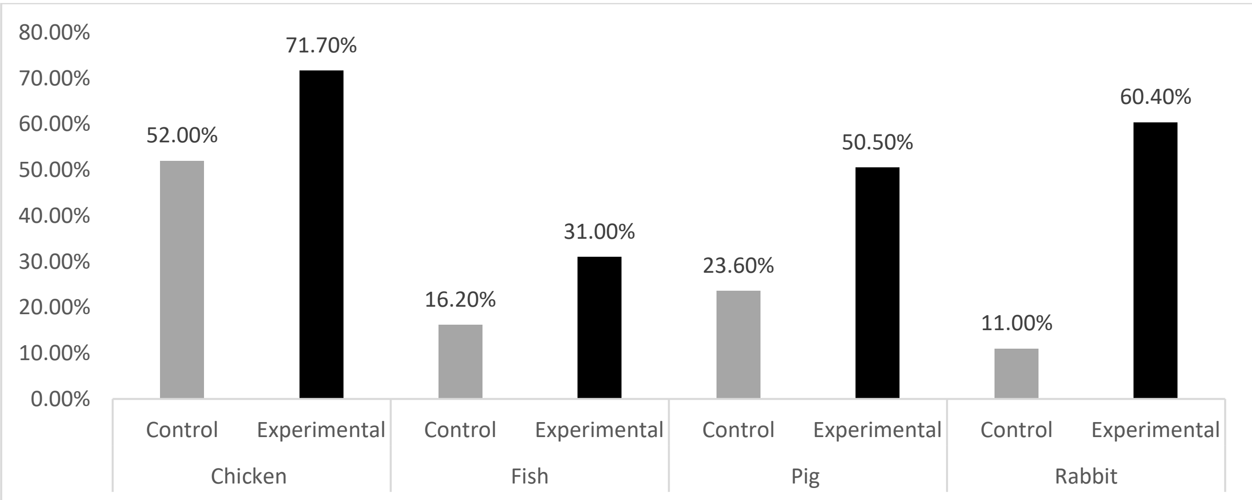

Figure 4.8: Comparative analysis of Profit Margin in percentage obtained by using Sargassum-based feed versus conventional feed across animal types.

Cost Benefit Ratio (CBR)

Figure 4.6 reveals significant economic advantages of using Sargassum-based feed across all animal types. For

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chickens, the experimental feed achieved a BCR of 3.53 compared to 2.08 for the control group, highlighting substantially higher cost efficiency. Similarly, for fish, the experimental BCR (1.29) surpassed the control BCR (0.92), though the improvement was moderate. Pigs also demonstrated marked gains, with the experimental group's BCR increasing to 2.02 compared to 1.31 in the control group. Notably, rabbits exhibited the most substantial improvement, with the experimental BCR rising to 2.53, more than double the control BCR of 1.12. These findings strongly reinforce the economic viability of Sargassum-based feed, particularly for chickens and rabbits, as it consistently enhanced cost efficiency and profitability.

Profit Per Kilogram of Meat

The Profit Per Kilogram of Meat in figure 4.7 indicates the profitability for each animal type, with Sargassum-based feed yielding higher profits. For chickens, the profit per kilogram increased from ₦2,443.33 in the control group to ₦3,369.70 in the experimental group, a notable increase of ₦926.37. The pigs also showed a higher profit per kilogram in the experimental group (₦2,526.04) compared to the control (₦1,179.30). Rabbits showed the most significant change, with profit per kilogram rising from ₦662.96 (control) to ₦3,625.92 (experimental), an impressive increase. The fish category also reflected enhanced profitability with Sargassum-based feed, rising from ₦486.53 to ₦930.78. This analysis underscored that Sargassum-based feed enhanced the profitability across all animal types, with the greatest gains observed in rabbits and chickens.

Profit Margin (%)

The Profit Margin in figure 4.8 assesses the percentage of profit generated relative to the cost of production. The experimental group consistently showed higher profit margins for all animals. For example, chickens showed an increase in profit margin from 52.00% (control) to 71.70% (experimental). Similarly, pigs and rabbits experienced notable increases, with pigs rising from 23.60% to 50.50% and rabbits from 11.00% to 60.40%. Fish also demonstrated an improvement, with the margin growing from 16.20% to 31.00%. These results indicated that Sargassum-based feed significantly enhanced profit margins across all animal species, particularly in chickens and rabbits.

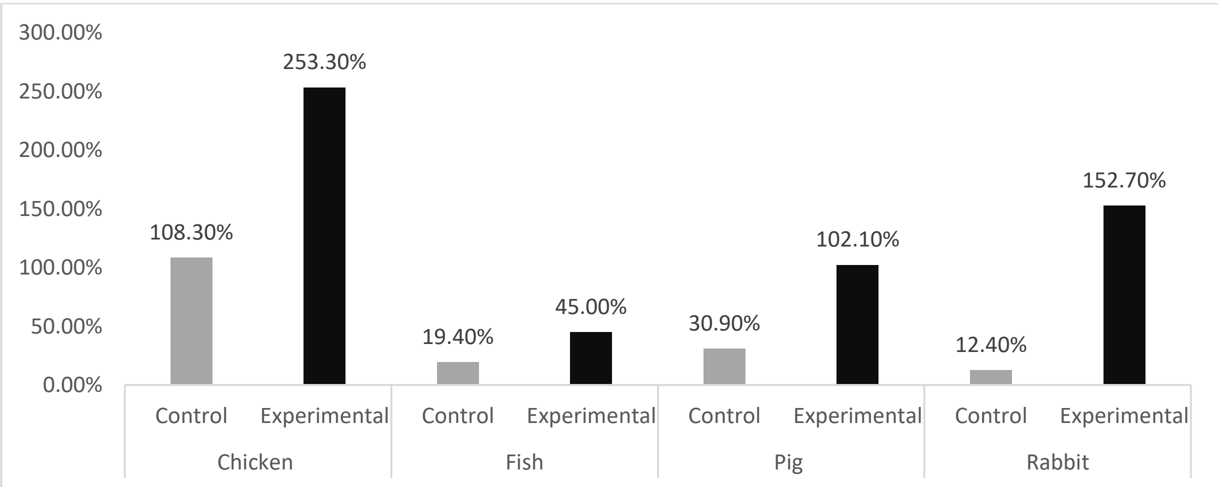

Figure 4.9: Comparative analysis of Return on Investment (ROI) obtained by using Sargassum-based feed versus conventional feed across animal types.

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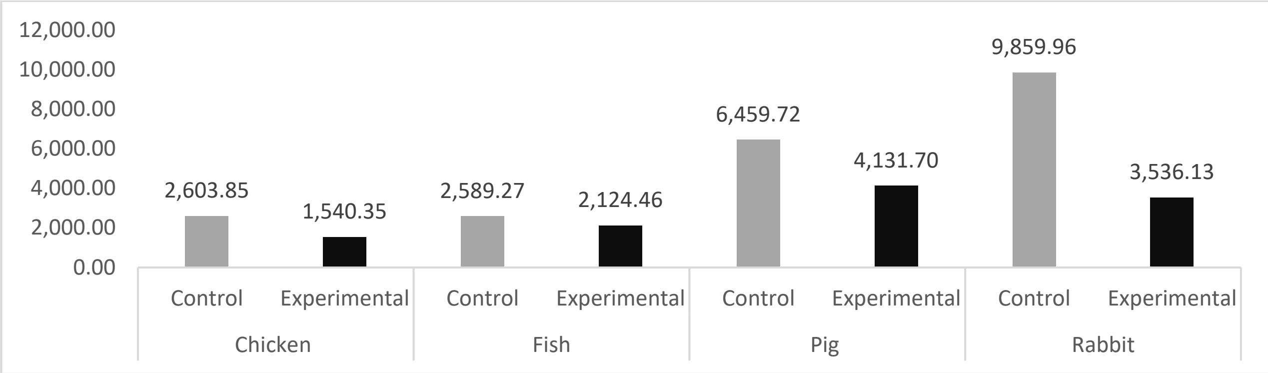

Figure 4.10: Comparative analysis of Cost-Effectiveness Ratio obtained by using Sargassum-based feed versus conventional feed across animal types.

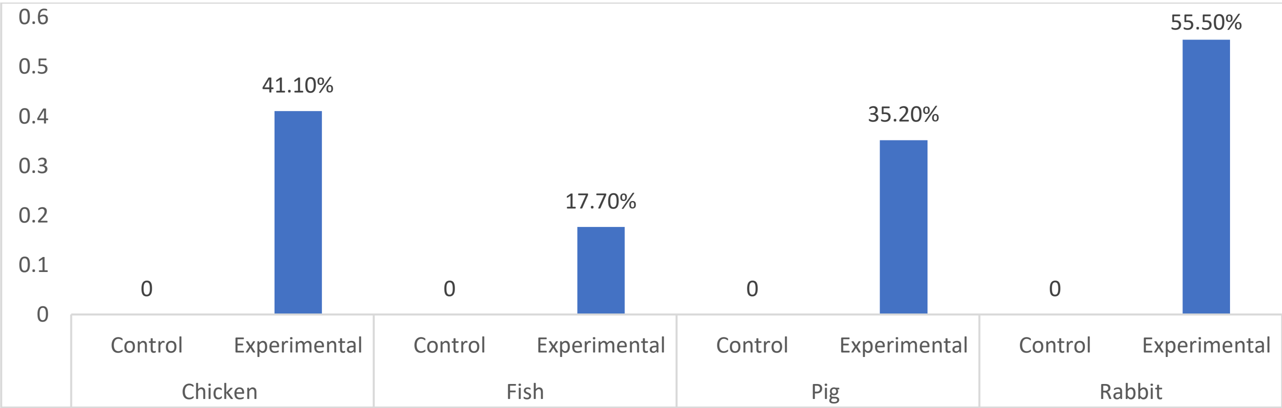

Figure 4.11: Cost-Saving Potential of feeding animals with of Sargassum-Based Feed over 12 weeks.

Return on Investment (ROI)

The Return on Investment (ROI) in figure 4.9 measures the profitability relative to the cost invested. The experimental group demonstrated higher ROI, particularly for chickens, with ROI rising from 108.30% (control) to 253.30% (experimental), showing that the return on investment for Sargassum-based feed was more than double compared to conventional feed. Pigs also showed improvement, with ROI increasing from 30.90% to 102.10%, and rabbits from 12.40% to 152.70%. Although the fish ROI improved from 19.40% to 45.00%, the increase was more modest compared to the other species. Overall, the ROI analysis confirmed that Sargassum-based feed provided a superior return on investment, especially for chickens and rabbits.

Cost-Effectiveness Ratio

The Cost-Effectiveness Ratio (CER) in figure 4.10 compares the cost of producing one kilogram of meat for both control and experimental groups. For all animal types, the experimental group that used Sargassum-based feed demonstrated more favourable cost efficiency. Notably, the CER for chickens in the experimental group was significantly reduced from ₦2,603.85/kg (control) to ₦1,540.35/kg (experimental), indicating a higher cost-efficiency in the use of Sargassum feed. Similarly, pigs and rabbits showed reductions in CER, with pigs decreasing from ₦6,459.72/kg to ₦4,131.70/kg and rabbits from ₦9,859.96/kg to ₦3,536.13/kg. The most significant reduction was observed in rabbits, reflecting a considerable improvement in cost-effectiveness when using Sargassum-based feed. These findings highlighted that Sargassum-based feed was a more cost-effective alternative compared to conventional feeds, particularly for pigs and rabbits.

Cost-Saving Potential of feeding animals with of Sargassum-Based Feed over 12-week.

The cost-saving potential illustrated the percentage reduction in feed costs when using Sargassum-based feed in figure 4.11. The experimental group showed significant savings across all animal types, with the most substantial savings in rabbits (55.50%), followed by chickens (41.10%). Pigs experienced a 35.20% cost-

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saving potential, while fish showed a reduction of 17.70%. These findings highlighted that Sargassum-based feed was particularly advantageous in reducing feed costs for rabbits and chickens, providing a substantial cost-saving opportunity for farmers adopting this alternative.

Decision

The objective of assessing the economic viability of developing Sargassum-based feed to sustain its market readiness has been achieved. The findings demonstrates that Sargassum-based feed not only improves cost-effectiveness but also significantly enhances profitability, profit margins, and ROI, while substantially reducing feed costs. By utilizing a readily available and cost-effective resource, farmers can reduce feed expenses. Furthermore, the sustainability benefits of Sargassum feed align with sustainable feed production practices, solidifying its potential as a viable and economically advantageous alternative to conventional feed ingredients.

4.3.4 Analysis of Objective four and Research Question four

Objective four: To design a monitoring and evaluation framework for assessing the performance of a Sargassum-based animal feed development project.

Question four: Can a monitoring and evaluation framework be designed to assess the performance of a sargassum-based animal feed development project?

To achieve objective four (4), the combined approach of Social Network Analysis, Gantt chart and IF-AND-THEN logic was used in emphasizing the monitoring and evaluation processes involved in the Sargassum-based feed development project.

4.3.4.1 Social Network Analysis

Social Network Analysis was used to map identified stakeholders involved in the project and to analyse how the relationships between these entities influence the project's sustainability. This approach helped to reveal how information sharing and collaboration contribute to sustainable project outcomes. Gephi, a SNA tool, was used to visualize and analyse the relationships (see figure 4.12 and table 13). Nodes represent stakeholders, and edges (lines) indicate connections such as information flow, collaboration and communication networks. The results of the document analysis were instrumental in identifying the key stakeholders associated with the project.

Table 4.13: SNA's Measure of Centrality among the Stakeholders of Sargassum-Based Animal Feed Project

Label	Eccentricity	Closeness centrality	Harmonic closeness centrality	Between centrality
CESAR LASU	1	1	1	80.37
Feed Manufacturers	2	0.71	0.79	10.00
Veterinarians/Nutritionists	2	0.63	0.71	3.53
Feed Ingredient Suppliers	2	0.6	0.67	2.17

Source: SNA's Measure of Centrality among the Stakeholders Computed using Gephi Application.

An assessment of the overall connectivity of the social network in figure 4.12 shows that the network is a high-density network indicating a strong collaboration with diverse entities. The measure of between centrality of each node shown in table 4.13 showed that CESAR LASU is the most influential and connected entity in the community (Centrality = 80.37) followed by Feed manufacturers (Centrality = 10.00).

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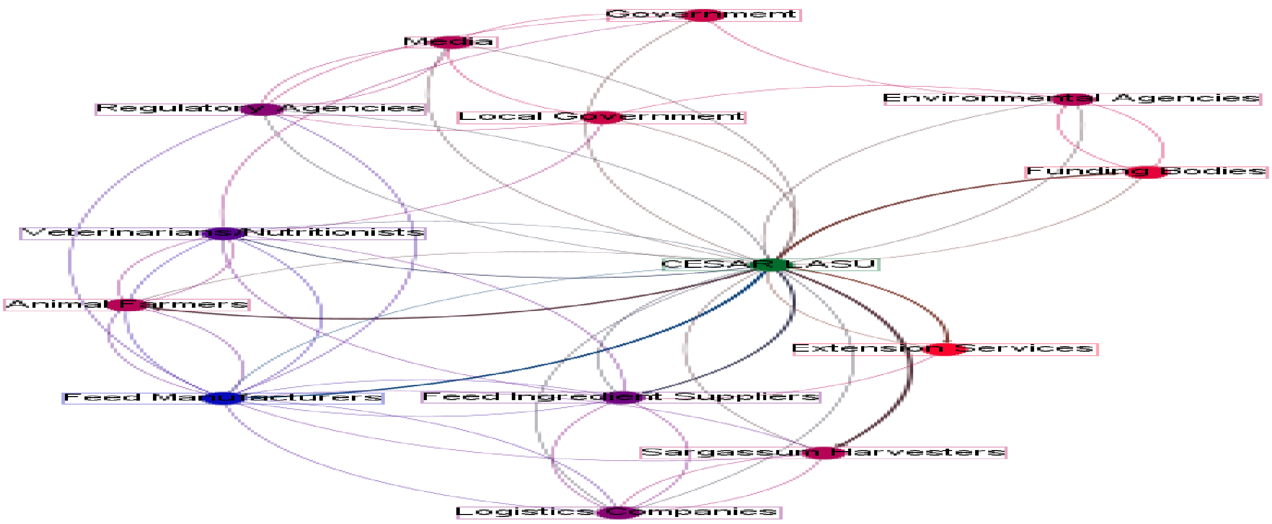

Figure 4.12: Social Network Analysis of Sargassum -Based Animal Feeds Project.

Source: Source: Social Network Analysis Developed by the Researcher (2024).

4.3.4.2 Gantt Chart Development

The Gantt chart effectively outlined the project’s key tasks, timelines, and responsible parties, ensuring a well-structured approach from start to finish. The list of project activities in figure 4.13 and Gantt chart in figure 4.14 provide detailed tasks involved in the development of Sargassum-based animal feed. The project life cycle is divided into four main phases: Initiation, Planning, Execution, and Project Closure.

Figure 4.13 shows that a project charter and stakeholders’ engagement strategy were developed at the initiation phase. The planning phase involved obtaining necessary permits, conducting market research and feasibility studies, and creating a project management plan. At the execution phase, proximate analysis of Sargassum seaweed, feed formulation and testing, feeding trials to assess nutritional value, and an evaluation of the project's sustainability were conducted, with the project manager, nutritionist, and feed manufacturer responsible for these tasks. Lastly, the project closure phase involves preparing the final project report, conducting a closure review, and implementing quality control measures, managed by the project manager.

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GANTT CHART

	WBS	Task Mode	Task Name	Duration
0	**0**		**Developement of Sargassum-based animal feed**	**84 days**
1	**1**		**Initiation**	**2 days**
2	**1.1**		**Project Charter Development**	**2 days**
3	1.1.1		Defined project objectives and scope.	1 day
4	1.1.2		Identified and developed a stakeholder engagement strategy.	1 day
5	1.1.3		Project charter emphasizing sustainability principles developed.	0 days
6	**2**		**Planning**	**4 days**
7	2.1		Obtain Required Permits and Regulations	4 days
8	**2.2**		**Market Research and Feasibility Study**	**4 days**
9	2.2.1		Identify necessary resources, including sargassum seaweed and processing equipment.	2 days
10	2.2.2		Developed processing techniques for sargassum.	2 days
11	2.3		Project Management Plan Developed	0 days
12	**3**		**Execution**	**84 days**
13	3.1		Proximate Analysis conducted on Sargassum seaweed	2 days
14	**3.2**		**Feed Formulation and Testing**	**3 days**
15	3.2.1		Sargassum processing (washing, drying, milling)	2 days
16	3.2.2		Sargassum and other ingredient processing (Crushing, mixing, Pelleting, Cooling, Crumbling, Sieving)	1 day
17	**3.3**		**Conduct feeding trials to assess the feed's nutritional value**	**84 days**
18	3.3.1		Monitoring animals' length, weight and health status	84 days
19	**3.4**		**Evaluate the project's sustainability.**	**3 days**
20	3.4.1		Analysis of Animal Trial Data	3 days
21	**4**		**Project Closure and Reporting**	**6 days**
22	4.1		Prepare project report.	5 days
23	4.2		Conduct a project closure review to identify lessons learned.	1 day
31	4.3		Implement quality control measures to ensure feed safety.	0 days

Figure 4.13: Activities embarked on in monitoring and evaluating the performance of sargassum fed animals.

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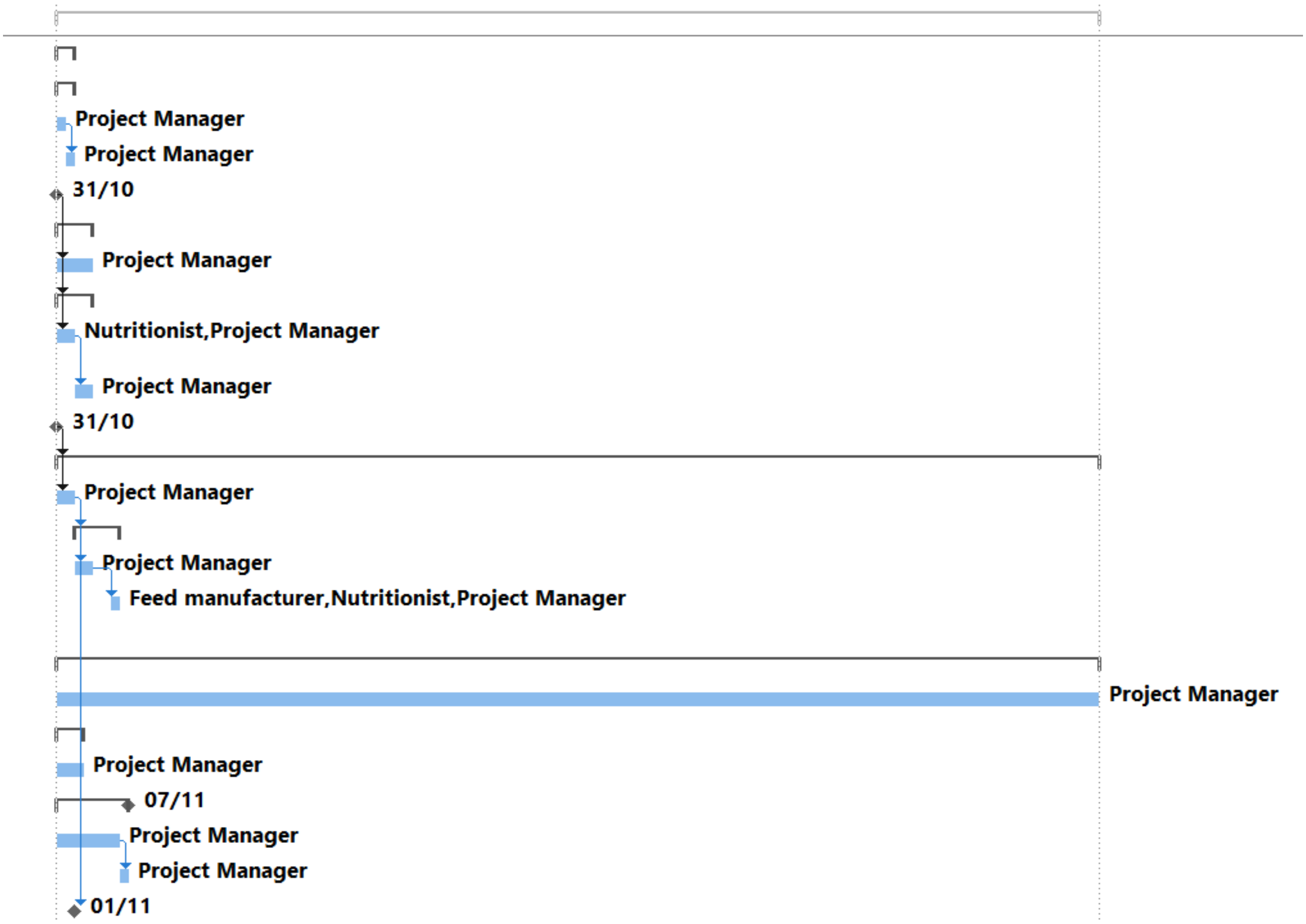

Figure 4.14: Gantt Chart of the activities embarked on in monitoring and evaluating the performance of sargassum fed animals.

4.3.4.3 Result-Based Logical Framework Development

The assumption adhered to in developing a result-based logical framework for objective four (4) in the objective is in the form IF-AND-THAT statement given below;

1. IF inputs are provided, AND the input-activity assumptions hold, THEN activities can be undertaken.
2. IF the activities are undertaken, AND the activity-output assumptions hold, THEN project outputs will be produced.
3. IF the project outputs are produced, AND the output-outcome assumptions hold, THEN outcomes should be realized.
4. IF the outcomes are realized, AND the outcome-goal assumptions hold, THEN the project goal is likely to be achieved.

Table 4.13 outlines the key components of the Sargassum-based feed project, detailing the resources, activities, outputs, outcomes, and impacts, along with indicators, data sources, stakeholder roles, assumptions, and risks.

The Sargassum animal feed project relied on several key resources, including Sargassum seaweed, other feed ingredients, water, drugs, animals, an animal farm, monitoring equipment, and funding. Indicators of success included budget allocation and the availability of necessary resources. Key stakeholders, such as CESAR LASU for Sargassum analysis, farmers, and funders, played vital roles. The project operated on assumptions like the availability of uncontaminated Sargassum and continuous stakeholder support. However, risks such as Sargassum contamination were mitigated through regular quality checks.

The project involved activities such as developing a project plan, producing feeds, conducting trials, and training community members. Indicators included the feeds produced, and animals included in trials.

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Nutritionists, extension workers, and researchers had specific roles in these processes. Assumptions included the availability of effective data collection tools and implementation strategies, while risks like inaccurate data collection were mitigated through proper training. The project produced several outputs, including Sargassum-based feeds, animals fed with the new feed, and health and growth reports. Key indicators of these outputs included animal health data and feed response rates.

Table 4.14: Logical Monitoring and Evaluation Framework for Sargassum Animal Feed Project

Components	**Details**	**Indicators**	**Data Sources/Means of Verification**	**Stakeholders Roles and Responsibilities**	**Assumptions**	**Risks and Mitigation**
Inputs (Resources)	- Sargassum seaweed - Other feed ingredients - Water - Drugs/Vaccines - Animals - Animal farm - Monitoring equipment - Funding - Stakeholders	- Budget allocated for resource deployment - Availability of time, personnel, and equipment	- Financial records - Resource inventory reports	- CESAR LASU: Conduct quality analysis of Sargassum - Farmer: Provide local collection support - Funders: Ensure timely financial allocation.	- Availability of uncontaminated Sargassum - Continuous stakeholder support - Sufficient funding	*Risk:* Contamination of Sargassum *Mitigation:* Regular quality checks and improved drying processes (HACCP).
Activities (Processes)	- Develop a project plan - Produce Sargassum-based feeds - Conduct trials	- Number of feeds produced - Number of animals included in feeding trials	- Feed production records - Trial documentation	- Nutritionists: Consulted for feed formulation	- Proper data collection tools available - Effective project implementation strategies	*Risk:* Inaccurate data collection *Mitigation:* Training in data handling and analysis methods.
Outputs (Products and immediate result)	- Sargassum-based feeds produced - Animals fed with Sargassum-based feeds - Growth and health reports	- % of animals responding positively to feed - Growth and health data collected	- Weekly growth and health records - Animal performance data	- Veterinarians: Monitor animal health - Farmers: Implement feed trials - Coastal communities:	- Effective monitoring and evaluation systems in place	*Risk:* Low farmer interest in adoption *Mitigation:* Demonstration trials to show feed

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	generated.	weekly		Participate in the Sargassum collection.		benefits.
Outcomes (Intermediate Changes)	- Increased adoption of Sargassum feed - Reduction in feed costs - Increase in survival rates - Cleaner environment - Numerous from reduced sargassum waste	- Increase in animal weight and length - Reduced disease incidence - Trained members applying skills	- Cost analysis reports - Environmental impact assessments	- NGOs: Conduct awareness campaigns - Feed manufacturers: Scale feed production - Researchers: Publish findings for broader application.	- Animal positively responds to feed - Consistent Sargassum supply and collection methods	*Risk:* Insufficient community engagement *Mitigation:* Awareness campaigns and participatory planning.
Impacts (Long-term Changes)	SDG 1: Reduced poverty SDG 2: Improved food security SDG 3: Good health. SDG 6, 14 & 15: Reduced environmental pollution. SDG 8: Economic growth SDG 9 & 10: Innovation and equality SDG 12: Sustainable feed production SDG 17: Collaboration	- % of farms adopting Sargassum feed - Poverty reduction in coastal communities - % decrease in pollution	- Market surveys - Adoption rate reports - Poverty statistics	- Policy-makers: Create enabling policies - Farmers: Promote adoption - Media: Highlight success stories for awareness	- Political and economic stability - Favourable market conditions	*Risk:* Market rejection of Sargassum-based feed *Mitigation:* Market feasibility studies and stakeholder collaboration.

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Source: Developed by the Researcher (2024)

Table 4.14 shows that the project's outcomes include reduced feed costs, higher animal survival rates, a cleaner environment, and trained community members. Indicators of these outcomes include improvements in animal growth, reduced disease incidence, and the application of skills by trained individuals. Assumptions such as positive animal response and consistent Sargassum supply were critical, while risks like insufficient community engagement were addressed through awareness campaigns.

The project’s long-term impacts involve sustainable feed production, increased adoption of Sargassum-based feed, reduced environmental pollution, and improved food security. Indicators of these impacts include increased adoption rates, poverty reduction, and lower pollution levels. Policymakers, farmers, and the media played key roles in promoting these outcomes. The project assumed political stability and favourable market conditions, while risks such as market rejection of the feed were mitigated through feasibility studies and stakeholder collaboration.

Decision

The monitoring and evaluation framework effectively captured the logical progression of the Sargassum-based animal feed development project, from inputs to long-term impacts. It systematically outlined key components, identified measurable indicators, and incorporated risk mitigation strategies to enhance project sustainability. Additionally, the framework ensured alignment between project design, intended outcomes, and broader sustainability goals, particularly in reducing environmental waste, improving food security, and fostering economic growth. By addressing potential challenges and integrating adaptive measures, this framework serves as a robust tool for assessing the project's long-term viability and impact.

4.3.5 Impact of Monitoring and Evaluation of the Sargassum-Based Animal Feed Development Project on Environmental Sustainability

The monitoring and evaluation (M&E) process was instrumental in assessing the environmental sustainability of the Sargassum-based animal feed development project. Data collected through field observations, periodic assessments, laboratory analyses, and comparative studies demonstrated that the controlled harvesting and utilization of Sargassum contributed positively to coastal ecosystem stability by mitigating the negative environmental impacts of its unchecked proliferation. Prior to the intervention, excessive accumulation of Sargassum along shorelines led to ecological imbalances, including oxygen depletion in marine habitats, destruction of aquatic biodiversity, and greenhouse gas emissions from decomposing seaweed. However, the systematic removal and repurposing of Sargassum into animal feed significantly reduced these adverse effects.

Through the M&E framework, key environmental indicators such as waste management efficiency, coastal eutrophication levels, and biodiversity preservation were systematically assessed. The findings indicated a measurable reduction in coastal eutrophication, as excessive organic matter from decomposed Sargassum was redirected for productive use. The project also demonstrated a reduction in land-based waste, as excess Sargassum biomass, which would have otherwise contributed to landfill accumulation, was transformed into a valuable feed resource. Additionally, biodiversity assessments showed improvements in marine life conditions due to the reduction of decaying Sargassum deposits.

These findings reinforced the critical role of M&E in ensuring that environmental objectives were met while optimizing the ecological benefits of Sargassum utilization. By continuously evaluating and refining operational strategies, the project aligned with sustainability principles and demonstrated that structured M&E was essential in enhancing the environmental impact of the Sargassum-based feed development project.

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Furthermore, the insights gained from this evaluation provide a foundation for future policy recommendations on sustainable seaweed utilization and coastal ecosystem management.

4.3.6 Impact of Monitoring and Evaluation of the Sargassum-Based Animal Feed Development Project on Social Sustainability

The M&E process also played a significant role in assessing the social sustainability of the Sargassum-based animal feed development project. Data gathered from stakeholder engagement sessions, community impact assessments, and feedback mechanisms highlighted the project's contributions to employment generation, local economic empowerment, and improved food security. The structured removal and utilization of Sargassum created new job opportunities, particularly for coastal communities involved in harvesting, processing, and distributing the seaweed. Through continuous M&E efforts, the project ensured equitable distribution of these economic benefits and provided stable and sustainable income sources for community members.

The evaluation process revealed a significant improvement in farmers' knowledge of sustainable feeding practices and resource management. This educational component enhanced long-term social sustainability by equipping individuals with skills that extended beyond the project's immediate implementation. Training and capacity-building initiatives empowered farmers and laborers with knowledge on sustainable harvesting, efficient feed processing, and responsible environmental practices, ensuring the longevity of the project's benefits.

The M&E framework also assessed the acceptance and perception of Sargassum-based feed among livestock farmers. Findings indicated high levels of acceptance, reinforced through collaboration with agricultural extension services, which facilitated knowledge dissemination and encouraged widespread adoption. Additionally, the project contributed to food security by enhancing livestock productivity at a reduced cost. Monitoring data showed that improved access to affordable and nutritionally viable feed enabled small-scale farmers to maintain steady animal production, ultimately increasing the availability of animal protein in local markets.

By ensuring the sustainability of social benefits through continuous engagement, feedback loops, and policy integration, the project demonstrated that an effective M&E framework was essential for promoting long-term social sustainability. These findings provide valuable insights for policymakers and development agencies seeking to implement similar initiatives aimed at fostering environmental and social resilience in coastal communities.

DISCUSSION

5.0 Preamble

This chapter discussed the findings of the study. Prior studies highlighted the importance of utilizing alternative eco-friendly ingredients in animal feeds instead of land-based feed crops, which are predominantly used in conventional feed production. The findings of this study reinforced this perspective by demonstrating the feasibility and sustainability of incorporating Sargassum in animal feed formulation.

The Theory of Change provides a structured framework for understanding the logical sequence of the Sargassum-based animal feed development project. This study established a clear pathway linking project inputs, processes, outputs, outcomes, and long-term impacts. The findings showed that the transformation of Sargassum into animal feed contributed to sustainable waste management by reducing the overaccumulation of seaweed along coastal regions. This intervention mitigated coastal ecosystem disruptions, reduced methane emissions from decaying Sargassum, and provided an innovative solution for addressing feed scarcity. The research findings further confirmed that effective monitoring and evaluation were essential for tracking these changes, ensuring that the intended environmental and economic benefits were realized.

From an Implementation Theory perspective, the study emphasized the importance of systematic project planning, stakeholder engagement, and continuous monitoring in ensuring the successful adoption of

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Sargassum-based feed. The findings indicated that the availability of uncontaminated Sargassum, effective processing techniques, and stakeholder collaboration played critical roles in achieving the desired project outcomes. The structured implementation process enabled the integration of Sargassum into animal feed without compromising nutritional value, thereby enhancing animal performance and reducing dependence on conventional feed ingredients.

Furthermore, the study demonstrated that integrating Sargassum into feed formulation aligns with the circular economy by promoting resource efficiency and minimizing agricultural waste. By converting seaweed waste into a valuable feed resource, the project contributed to sustainable feed production and economic growth. The monitoring and evaluation framework provided critical insights into feed performance, adoption rates, and the economic feasibility of scaling up production.

5.1 Comparison of the nutritional content of Sargassum-based animal feeds to conventional animal feeds

The analysis of the nutritional composition of Sargassum-based feed compared to conventional feed revealed a notable presence of essential minerals, vitamins, and bioactive compounds beneficial to animal health. Sargassum was found to be rich in trace elements such as iodine, calcium, magnesium, and polysaccharides, which contribute to improved immune function and growth performance. Sargassum-based feed demonstrated balanced nutritional attributes, particularly in fibre content, which aids digestion. The study specifically

discovered that Sargassum-based feeds are nutritionally comparable to conventional feeds for chickens, fish, pigs, and rabbits, meeting essential nutritional requirements through optimized formulations. This aligns with findings from Anetekhai *et al*. (2024) and Rodríguez-Hernández *et al.* (2023), highlighting the role of sustainable practices in improving productivity and ecosystem services. Similarly, Tobin *et al.* (2022) emphasized the value of innovation for sustainability, a principle reflected in Sargassum feed formulations. Sarnighausen *et al.* (2021) advocated for dietary innovations to reduce greenhouse gas emissions, and Sargassum-based feeds offer an eco-friendly alternative in line with these recommendations. The findings underscore the potential of Sargassum as a sustainable, and environmentally friendly feed ingredient, supporting broader goals in livestock health and agricultural sustainability.

5.2 Comparison of the Weight, Length, and Survival of animals fed to Sargassum and those fed without Sargassum.

The results from the experimental trials indicated that Sargassum-based feed performs comparably to conventional feed, with no significant differences in animal growth metrics (weight, length and survival rate). Fish, pigs, and chickens exhibited promising weight gain and feed conversion efficiency, though species-specific metabolic adaptations influenced variations. Additionally, rabbits benefited from the fibre-rich composition of Sargassum, which improved gut health, digestion, and nutrient absorption. This result aligns with studies by Wicha *et al.* (2023) and D'Urso *et al.* (2023), who emphasized the importance of efficient monitoring systems for livestock management. Additionally, non-invasive methods used by Isaac (2021) and Arellano *et al.* (2020), support the conclusion that Sargassum-based feed does not adversely affect animal welfare or growth, offering a viable alternative to conventional feeds for sustainable animal husbandry.

5.3 Assessment of the Economic Viability of Developing Sargassum-Based Feed to Sustain Its Market Readiness.

The results of the economic viability of Sargassum-based feed revealed its significant advantages over conventional feed, showing reduced production costs, improved profitability, and higher return on investment (ROI). Cost analysis revealed that incorporating Sargassum in animal feed formulation could significantly reduce feed costs, given the relatively low cost of sourcing and processing seaweed compared to conventional feed ingredients. The potential for local production and processing of Sargassum-based feed offers a cost-effective alternative, reducing dependency on imported feed components and enhancing the economic resilience of farmers. For instance, the cost of producing 1 kg of meat decreased substantially for rabbits (₦9,859.96/kg to ₦3,536.13/kg) and chickens (₦2,603.85/kg to ₦1,540.35/kg), leading to notable increases in

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profit margins and ROI. These results align with other studies on resource optimization, such as Mendeja *et al.* (2023) and Tholhappiyan *et al.* (2023), who highlighted the benefits of efficient resource management through innovative technologies. The findings also support the principles of economic evaluations in Jankovic and Faria (2022), demonstrating that Sargassum-based feed offers a superior cost-benefit ratio. Overall, Sargassum-based feed is economically feasible, cost-effective, and sustainable, presenting a promising alternative for livestock farming.

5.4 Development of a Monitoring and Evaluation Framework for Assessing the Sustainability of Sargassum-Based Feed Development Project.

The findings of this study provide significant insights into the performance, economic viability, and sustainability of Sargassum-based feed as an alternative to conventional animal feed. These findings serve as the foundation for the development of a Monitoring and Evaluation (M&E) framework that ensures systematic assessment and continuous improvement of the Sargassum-based feed development project. The is result agree with the Çelikyürek *et al.* (2019) and Mwangi & Moronge (2020), who emphasize the role of the Logical Framework Approach (LFA) in ensuring the identification of clear and measurable indicators to evaluate project performance. The study highlights the importance of effective data management systems in tracking key performance indicators (KPIs) such as weight gain, feed conversion efficiency, survival rates, cost savings, and economic returns. These KPIs are essential for assessing the effectiveness of Sargassum-based feed in achieving its intended economic, environmental, and social benefits.

The findings further illustrate that the Sargassum-based feed development project has significant potential to contribute to the achievement of several United Nations Sustainable Development Goals (SDGs), reflecting its multifaceted impact across social, economic, and environmental sectors.

5.4.1 Economic and Social Impact: Contributions to SDGs 1, 2, 8, and 10

SDG 1: No Poverty

The study demonstrates that Sargassum-based feed provides a cost-effective alternative to conventional feeds, significantly reducing feed costs by 41.1% for chickens, 17.7% for fish, 35.2% for pigs, and 55.5% for rabbits. The findings indicate that the cost-effectiveness of Sargassum-based feed can significantly enhance the profitability of small-scale animal farming, particularly in coastal communities where access to conventional feed is often limited. This aligns with Weber and Matthews (2008), who emphasized that low-cost, sustainable agricultural inputs can create opportunities for poverty alleviation. By reducing feed costs, smallholder farmers can reinvest savings into farm expansion, improved animal care, or other income-generating activities, ultimately fostering economic resilience in vulnerable populations.

SDG 2: Zero Hunger

The use of Sargassum as animal feed has demonstrated positive outcomes in terms of improving feed efficiency and nutrient absorption, leading to higher meat yields and better animal health. The findings align with Rajauria (2015), who states that nutrient-rich macroalgae can enhance the nutritional quality of animal products, ultimately contributing to food security. The observed improvements in weight gain, survival rates, and feed conversion efficiency further reinforce this benefit.

SDG 3: Good Health and Well-being (Health and Nutritional Benefits)

The findings of this study reinforce the work of Nandithachandraprakash (2024), who emphasizes the bioactive compounds, antioxidants, and essential nutrients present in Sargassum, which contribute to improving livestock health and product quality. The study observed higher survival rates and enhanced feed conversion efficiency, aligning with previous research that suggests marine bioactives play a role in improving nutritional quality. Furthermore, the convergence of both quantitative and qualitative data in this study supports the assertion that Sargassum-based feed promotes animal health, which indirectly benefits human health by improving the nutritional quality of animal products. This connection underscores the broader

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implications of using Sargassum in animal nutrition for SDG 3 by supporting both good health and well-being for animals and humans alike.

SDG 8: Promoting Inclusive and Sustainable Economic Growth.

The findings of this study suggest that the commercialization of Sargassum-based feed holds significant potential for stimulating economic growth in coastal regions abundant in Sargassum. Consistent with Sowah *et al.* (2022), the development of a Sargassum-based feed industry could create a variety of employment opportunities in areas such as harvesting, processing, and distribution. This would not only contribute to job creation but also strengthen the economic stability of rural communities that are often dependent on marine resources. By fostering new industries, Sargassum-based feed has the potential to drive economic diversification, increase local incomes, and enhance socioeconomic development in these areas, thereby aligning with

SDG 9: Industry, Innovation, and Infrastructure

The findings of this study underscore the growing need for innovative feed technologies in response to the increasing demand for sustainable feed alternatives. This is in line with Anetekhai (2023), who highlights the importance of technological advancements in the agricultural sector to promote sustainability. The development of Sargassum-based feed processing facilities not only fosters industrial innovation but also stimulates infrastructure development in coastal regions. This project, by integrating Sargassum into feed production, supports economic diversification and plays a pivotal role in job creation within the marine-based agricultural sector. These findings align with SDG 9, emphasizing the role of innovation and infrastructure development in advancing sustainable industries.

SDG 10: Reduced Inequality

The findings highlight that the affordability of Sargassum-based feed can significantly enhance access to high-quality feed for small-scale and marginalized farmers. This is in line with the United Nations (2024), which emphasizes the importance of equitable resource distribution in addressing economic disparities. By offering a cost-effective alternative, Sargassum-based feed has the potential to bridge the gap between small-scale and large-scale livestock farmers, contributing to more inclusive agricultural practices. This, in turn, fosters economic growth by enabling smallholder farmers to compete more effectively, reduce inequalities, and improve their overall productivity and livelihoods.

5.4.2. Environmental Sustainability: Contributions to SDGs 6, 12, 14, and 15

SDG 6: Ensuring Clean Water and Sanitation

The findings reveal that utilizing Sargassum for animal feed provides an effective strategy to address coastal

pollution. Consistent with Spillias *et al.* (2023), this study confirms that Sargassum overgrowth contributes to water quality degradation, negatively impacting coastal ecosystems. By repurposing Sargassum into a valuable feed resource, the project not only mitigates waste accumulation but also promotes cleaner coastal environments. The study further demonstrates that Sargassum harvesting can play a crucial role in improving water sanitation, as it reduces the harmful effects of seaweed decay in marine and coastal waters. These findings align with SDG 6, emphasizing the importance of sustainable environmental practices in enhancing coastal water quality and sanitation efforts.

SDG 12: Responsible Consumption and Production

The findings support Farghali *et al.* (2023), who emphasize the role of sustainable agricultural inputs in promoting responsible consumption and production. By utilizing naturally occurring Sargassum, the project reduces dependence on land-based feed crops, which are often associated with environmental degradation. This sustainable use of Sargassum as a renewable resource not only minimizes the need for resource-intensive

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agricultural feedstocks but also encourages environmentally responsible feed production. The study underscores how the use of Sargassum contributes to SDG 12, supporting sustainable agricultural practices that reduce land degradation and promote more eco-friendly methods of feed production

SDG 14: Life Below Water

The findings of this study align with Doyle and Franks (2015), who highlight the negative impact of Sargassum overgrowth on marine ecosystems, particularly in depleting oxygen levels and disrupting aquatic biodiversity. The results demonstrate that controlled harvesting of Sargassum can help mitigate these effects by reducing overgrowth, thus promoting marine balance. This not only benefits marine ecosystems but also provides economic opportunities for coastal communities. The study supports the assertion that Sargassum harvesting is a sustainable solution for SDG 14, contributing to marine conservation while addressing the challenges of overgrowth and habitat degradation

SDG 15: Life on Land

The findings of this study support the arguments presented by N'Yeurt and Iese (2014) and Kumar *et al.* (2012), who emphasize the importance of reducing reliance on land-based feed crops such as soybean and maize. The use of Sargassum as a feed resource provides a sustainable alternative that helps reduce pressure on terrestrial ecosystems. This shift not only mitigates land degradation but also supports the long-term conservation of land resources. The findings demonstrate that by tapping into marine-based feed solutions, this project contributes to sustainable agricultural practices, offering a viable path for environmental conservation in the context of SDG 15.

5.4.3. Social Sustainability: Strengthening Global Collaboration, Contribution to SDG 17

SDG 17: Partnerships for the Goals

The findings emphasize the importance of multi-sectoral collaboration in the successful development and promotion of Sargassum-based feed. Partnerships among government agencies, research institutions, NGOs, and private sector stakeholders have facilitated knowledge exchange, resource mobilization, and policy support, aligning with FAO (2022). These collaborations have driven technological advancements, regulatory frameworks, and community engagement, ensuring the project's sustainability. The study highlights that such partnerships are essential for scaling up marine resource management initiatives and achieving long-term sustainability, reinforcing the objectives of SDG 17.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.0 Preamble

This chapter presents a summary of the research, highlighting the major findings and conclusions. It also includes

policy recommendations for the sustainability of the Sargassum-based animal feed development project emphasizing the role of monitoring and evaluation in ensuring its long-term viability. Additionally, the chapter discusses research limitations and provides suggestions for further studies.

6.1 Summary of the Study

The study assessed the impact of project monitoring and evaluation in promoting sustainable agricultural practices by comparing Sargassum-based and conventional animal feeds. The specific objectives were to: (i) compare the nutritional content of Sargassum-based and conventional feeds; (ii) evaluate differences in the weight and length of animals fed with and without Sargassum; (iii) assess the economic viability of Sargassum-based feed to sustain its market readiness; and (iv) develop a monitoring and evaluation framework for assessing the performance of Sargassum-based feed projects. Collaboration with key stakeholders

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facilitated comprehensive data collection, management, and integration, ensuring alignment with strategies for sustainability.

The experimental feeds used in this study were formulated with a 50% Sargassum inclusion rate, ensuring safety through HACCP protocols. Using randomized controlled trials and longitudinal tracking, the study focused on four animal species, chickens, fish, rabbits, and pigs, to assess whether a 50% inclusion of Sargassum-based feed affected their growth performance, health status, and vitality compared to conventional feed for 12 weeks.

This study employed a mixed-methods approach integrating both qualitative and quantitative data for a comprehensive assessment. The mixed-methods approach combined the strengths of both methodologies, allowing for triangulation, where qualitative findings provided contextual depth to the statistical outcomes, and quantitative data enhanced the generalizability of the results. Quantitative metrics such as weight gain, length gain, feed conversion efficiency, and mortality rates were analyzed alongside qualitative indicators, including behavioural observations, physical appearance, stool consistency, and overall vitality. This dual-layered analysis ensured a holistic understanding of the effects of Sargassum-based feed across different species.

The mixed-methods approach enabled the study to identify both convergences and divergences between the qualitative and quantitative findings. Convergences indicated strong agreement between numerical data and observed animal health indicators, reinforcing the reliability of the findings. By triangulating quantitative data with qualitative insights, the findings revealed significant cost savings, enhanced profitability, and the nutritional adequacy of Sargassum-based feed, demonstrating its potential as a sustainable alternative in animal farming

6.2 Summary of Empirical Findings

6.2.1 Quantitative Findings

The nutritional analysis confirmed that Sargassum-based feeds, optimized using linear programming models, are nutritionally comparable to conventional feeds for chickens, fish, pigs, and rabbits. Performance metrics, including weight gain, feed conversion efficiency, and survival rates, showed improvements across multiple species. Fish fed with Sargassum-based feed exhibited superior weight gain (0.974 kg vs. 0.829 kg) and higher survival rates (89% vs. 78%) compared to the control group. Rabbits demonstrated the most significant improvements, with weight gains of 204% compared to 118% in the control group and length increases of 43.50% versus 19.80%. Pigs and chickens performed comparably to their respective control groups, further validating the cross-species efficacy of Sargassum-based feed as a sustainable alternative. Statistical analyses, including t-tests, Chi-square and ANOVA revealed no statistically significant differences in growth and health metrics ($p > 0.05$), supporting the statement that Sargassum-based feed is a viable substitute for conventional animal feed without adverse effects on performance.

Economic findings revealed substantial cost savings in feed production, ranging from 17.7% for fish to 55.5% for rabbits. These cost reductions translated into improved profit margins and higher ROI across all species, underscoring the financial sustainability of Sargassum-based feed. These outcomes highlight the feed’s potential to reduce production costs while promoting ecological conservation, making it particularly advantageous for resource-constrained farming systems.

6.2.2 Qualitative Findings

The qualitative findings, derived from detailed behavioural observations and health assessments, indicated that animals in both control and experimental groups maintained stable health statuses and exhibited normal behavioural throughout the study period. No signs of stress, disease, or adverse reactions to the experimental Sargassum-based feed were observed. Behavioural consistency, including feeding habits and interaction with other animals, remained unchanged. Stool consistency was normal across all groups, further corroborating the feed's compatibility. Mortality rates in the experimental groups were comparable to or better than those in the

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control groups, with 100% survival observed in rabbits and pigs across both groups. These observations affirm the safety and general acceptance of the Sargassum-based feed, complementing the quantitative results.

The framework for monitoring and evaluating the project's effectiveness was successfully implemented, highlighting key inputs, activities, and outputs while addressing potential risks and mitigation strategies for Sargassum animal feeds development. Observations from the project demonstrated that the logical flow from inputs to impacts, ensured effective progression across stages. This application of logical monitoring and evaluation principles was evidenced by smooth project execution and timely achievement of milestones, confirming the framework's ability to support the project's intended outcomes and impacts.

Overall, the findings validated the effectiveness of the monitoring and evaluation framework in capturing key project milestones and assessing its sustainability. The study underscored the significance of strategic implementation and evidence-based decision-making in advancing eco-friendly innovations in the agricultural and aquaculture sectors. By addressing potential risks, incorporating mitigation strategies, and fostering a collaborative approach, this research contributed to the broader discourse on sustainable feed solutions and environmental conservation.

6.3 Theoretical and Practical Implications of the Findings

These findings have important inferences for animal nutrition and feed formulation, thereby offering both theoretical and practical implications.

6.3.1. Theoretical Implications

The results of this study offer a theoretical foundation for exploring sustainable feed alternatives, as well as practical solutions for addressing economic, ecological, and agricultural challenges, with a specific focus on the sustainability of the Sargassum-based animal feed project in Badagry, Lagos State, Nigeria. These findings underscore the potential of Sargassum-based feed to transform the agricultural sector while promoting environmental conservation and improving local livelihoods. Within the frameworks of Implementation Theory and the Theory of Change (ToC), the study illustrates how the project's monitoring and evaluation mechanisms—centred on well-defined inputs, activities, and outcomes—drive positive change. The role of M&E in tracking progress and ensuring sustainability is reinforced through the logical frameworks outlined in Implementation Theory. Furthermore, the study validates the ToC by demonstrating how targeted interventions, assessed through M&E processes, lead to broader impacts such as enhanced food security, improved economic resilience, and environmental sustainability. Thus, the integration of monitoring and evaluation in the project contributes to ensuring that the Sargassum-based feed development remains sustainable and beneficial in the long term.

6.3.2 Practical Implications

Through a structured M&E framework, the study effectively tracked the feed's performance in terms of cost reduction, profitability enhancement, and its environmental and health benefits. The results indicate that Sargassum-based feed not only offers an affordable and sustainable alternative to conventional animal feeds but also aligns with the broader goals of sustainable agricultural development, which the M&E framework helped to monitor.

The M&E framework ensured that the project's implementation was on track, identifying potential risks and providing a foundation for course corrections where needed. This process of continuous monitoring helped assess the effectiveness of stakeholder engagement, and how well project inputs, activities, and outcomes aligned with the overarching goals of economic resilience, environmental sustainability, and improved livestock productivity. Thus, the findings underscore the importance of M&E in evaluating the long-term viability and success of the Sargassum-based feed project, providing valuable insights into its potential for scaling up and achieving sustainable development goals in Badagry, Lagos State, Nigeria.

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CONCLUSION

This study assessed the role of Monitoring and Evaluation (M&E) as a strategic tool for promoting sustainable animal feed development, particularly in evaluating Sargassum-based feed as an alternative to conventional feeds. The findings highlight that a structured M&E framework was essential in tracking the feed's nutritional quality, economic viability, and environmental impact. Through continuous monitoring, the study identified key performance indicators, facilitated data-driven decision-making, and provided insights for scalability.

Nutritional analysis confirmed that Sargassum-based feed is comparable to conventional feed, supporting optimal growth, health, and feed conversion efficiency. Animals fed with this alternative feed showed significant weight and length improvements, validating its effectiveness across multiple species. However, these conclusions were made possible through a robust M&E system that systematically measured and analysed feed performance.

Economically, M&E findings revealed that Sargassum-based feed is a cost-effective alternative, reducing production costs while increasing profit margins and return on investment (ROI), particularly in coastal regions where Sargassum is abundant. Additionally, M&E played a vital role in assessing sustainability outcomes, ensuring that project goals align with Sustainable Development Goals (SDGs), including poverty reduction, food security, environmental sustainability, and innovation.

In conclusion, Monitoring and Evaluation is the backbone of sustainability-focused projects, ensuring accountability, efficiency, and long-term impact. By enabling systematic tracking of environmental impacts, stakeholder engagement, and institutional effectiveness, M&E enhances the success of adaptive projects, waste management strategies, and marine and blue economy initiatives. Future research should explore scalability through M&E-driven models and establish policy frameworks that support the industry-wide adoption of Sargassum-based feed. Strengthening M&E practices will be essential in transforming agricultural systems and promoting sustainable development in Nigeria and beyond

RECOMMENDATIONS

Based on the conclusion, the underlisted are recommended to guide policymakers, the feed industry, academics, and the general public in promoting long-term project success through effective stakeholder engagement and M&E frameworks.

i. Standardized Testing & Certification Through M&E

Monitoring and Evaluation frameworks should be institutionalized to establish standardized testing and certification procedures. This will ensure that alternative feeds meet established nutritional benchmarks and are continuously monitored for safety and efficiency. Regulators should integrate M&E-driven assessments to validate feed quality over time and promote collaborative research that refines industry standards for Sargassum feed formulations based on species-specific nutritional needs.

ii. Optimizing Feed Formulation Using M&E Data

Considering the significant improvements in the weight and length of animals fed with Sargassum-based feed, the feed industry should implement an M&E framework to optimize formulation strategies. Data-driven tracking mechanisms should be used to assess species-specific feed efficiency, ensuring that formulations are tailored for maximum growth and feed conversion efficiency. M&E-based performance metrics should guide feed innovation, reducing variability and enhancing consistency across different animal species.

iii. Economic Viability & M&E for Cost Analysis

The study revealed that Sargassum-based feed is economically viable, reducing production costs while increasing profitability for farmers—particularly in coastal regions. Policymakers should establish M&E-driven financial assessment models to track cost savings, return on investment (ROI), and long-term sustainability. Additionally, public support for M&E-backed feasibility studies can guide policy incentives that encourage Sargassum farming and reduce reliance on imported feeds.

iv. Institutionalizing Advanced M&E Systems for Sustainable Feed Development

Policymakers should mandate comprehensive M&E frameworks for agricultural projects, integrating real-time data collection technologies such as mobile data tracking and remote sensing. These tools can enhance project oversight, ensuring alignment with sustainability goals. Furthermore, the feed industry should adopt AI-powered analytics and blockchain-enabled traceability in M&E systems to drive continuous improvement. Academic researchers should explore innovative M&E methodologies that enhance monitoring precision, stakeholder feedback mechanisms, and decision-making efficiency.

v. Strengthening Stakeholder Engagement Through M&E

The study highlights that multi-stakeholder involvement is crucial to the success of Sargassum-based feed projects. M&E should be leveraged as a participatory tool that tracks stakeholder contributions, engagement levels, and resource mobilization outcomes. Policymakers should develop inclusive M&E-driven stakeholder engagement platforms, ensuring that researchers, farmers, local communities, and industry players actively participate in decision-making. Additionally, academics should study stakeholder engagement models within M&E frameworks to identify best practices for enhancing collaboration and transparency.

vi. Enhancing Environmental and Social Sustainability Through Monitoring and Evaluation.

Monitoring and Evaluation (M&E) systems should be integrated into waste management, marine conservation, and community engagement to enhance environmental and social sustainability. Environmentally, M&E should track the impact of Sargassum harvesting, ensuring sustainable practices that protect marine biodiversity while assessing carbon footprints and emissions reduction. Socially, M&E frameworks should monitor job creation, income growth, and food security in coastal communities, with stakeholder feedback guiding inclusive economic opportunities. Policymakers should implement M&E-driven training programs for local communities, particularly women and youth, fostering entrepreneurship and social equity. By institutionalizing M&E-based sustainability measures, the Sargassum-based feed industry can contribute to marine protection, economic resilience, and inclusive development.

6.6 Contributions to Knowledge

This study provided empirical evidence on the feasibility and sustainability of Sargassum-based animal feed as an alternative to conventional feed. By assessing its economic viability, nutritional value, and environmental impact, the research contributed to the growing body of knowledge on circular economy applications in livestock production. Furthermore, by integrating marine-based resources into agricultural sustainability strategies, the study reinforced the intersection between the blue economy and livestock farming, reducing dependency on conventional land-based feed ingredients.

The research employed Logical Framework Analysis (LFA) and Hazard Analysis and Critical Control Points (HACCP) to ensure systematic project oversight, emphasizing quality assurance, risk mitigation, and performance tracking. Additionally, a Linear Programming Optimization model for feed formulation was introduced, demonstrating how quantitative decision-making tools can enhance resource allocation and project efficiency. The findings validate the importance of real-time monitoring, data-driven decision-making, and adaptive evaluation models in sustainable agriculture.

By assessing project costs, profitability, and resource efficiency, the study contributed to understanding the

economic feasibility and scalability of integrating alternative feed sources into livestock production. Findings from this research provided valuable recommendations for policymakers, industry stakeholders, and livestock farmers regarding the adoption, regulation, and commercialization of Sargassum-based feed, influencing policy discussions on sustainable livestock production and coastal resource management.

6.7 Suggestions for Further Studies

This study has contributed to advancing project monitoring and evaluation (M&E) in sustainable agriculture by demonstrating the importance of assessing alternative agricultural innovations and laying the groundwork for future advancements in sustainable project management. To further enhance the effectiveness of M&E in agricultural projects, future research should explore the long-term impact of different monitoring approaches on agricultural sustainability, particularly in evaluating project outcomes, efficiency, and stakeholder engagement. Studies could also examine the role of participatory M&E frameworks in improving decision-making, ensuring that agricultural projects align with sustainability goals while promoting accountability.

Additionally, research should assess the effectiveness of various M&E methodologies in tracking the progress of agricultural projects, focusing on how real-time data collection, predictive analytics, and performance-based evaluation models contribute to project success. Future studies should also investigate how smart farming technologies, such as automated data collection systems, remote sensing, and IoT-enabled monitoring devices, can enhance real-time evaluation and improve agricultural project oversight.

Further studies should explore the integration of technology-driven M&E frameworks into sustainable agricultural project management, focusing on how mobile technology, GIS mapping, and cloud-based data analysis tools can enhance decision-making, streamline resource allocation, and improve project tracking. Additionally, researchers should examine the role of big data analytics and artificial intelligence in optimizing agricultural project evaluations, particularly in areas such as risk assessment, impact measurement, and project scalability.

Moreover, future research should focus on scalability and sustainability in agricultural project monitoring, assessing how cost-effective, adaptive, and technology-driven M&E models can be implemented in both small-scale and large-scale agricultural projects. Studies could also explore the effectiveness of automated reporting systems, predictive modelling, and participatory stakeholder engagement techniques in enhancing accountability and transparency within agricultural project management.

Lastly, future research should investigate the effectiveness of different M&E models in ensuring sustainable agricultural project implementation, including adaptive M&E frameworks, results-based monitoring systems, and impact evaluation techniques. Assessing the role of government policies, industry collaborations, and public-private partnerships in strengthening M&E frameworks will provide valuable insights into best practices for sustainable project development and long-term agricultural impact assessment.

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