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Social-Economic Assessment of Valorization of Faecal Sludge into Value-Added Products: Case Study of Selected Products in Johannesburg Metropolis

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Abstract. Faecal valorization is one of the viable solutions to the issue of inadequate sanitation because it encourages investment in sanitation systems. Despite the demonstration of production of value-added products from faecal sludge, information of socio-economic assessment of these products which could pave the way for their commercialization is very scarce. In this study, socio-economic assessment of some selected value-added products such as; crops treated with fertilizer derived from human waste, meat from animals fed with feed derived from human waste, energy from the combustion of products derived from human waste (biogas) was evaluated within Johannesburg metropolis (Wits University and its environs). Estimates developed from a quantitative review of existing literature demonstrated high potential revenues for products from faecal valorization and associated end products. The estimates were developed through examining current prices and consumption patterns in South Africa. Questionnaires were distributed at the University of Witwatersrand and its environs, posing as a case study of Johannesburg, in order to determine consumer interest in end products and the effect of different incentives on interest level. Statistical analysis was used to analyze the collected data due to sample size and controlling for factors such as age, sex and education level, the study mitigated sample bias. The analysis was conducted using repeated measure ANOVA testing and Tukey HSD testing. The interest level of the end product of faecal sludge was quantified using a 5- point Likert scale while a regression model was generated to understand which among the variables explored in this study were significant in predicting the participant's interest level. Analysis of the results reveals that there is demonstrated interest in products from valorized faecal sludge with 51% of participants willing to consume crops fertilized with faecal sludge, and 43% of participants willing to consume meat from animals fed with feed derived from faecal sludge, compared to 80% of participants who were willing to use energy from the combustion of products from faecal sludge. Therefore, the information provided in this study on faecal valorization could assist in addressing inadequate sanitation and other environmental problems throughout South Africa and the rest of Africa.

Key words: Faecal sludge, Faecal valorization, Consumer interest, End products, Johannesburg environs.

INTRODUCTION

Inadequate sanitation affects roughly two billion people worldwide, especially in developing countries [1]. The effects of inadequate sanitation negatively impact human health, the environment and social development [1]. Efforts to combat this issue have largely fallen short of their goals due to lack of financial and human resources for proper operation and maintenance [2]. The lack of successful prior projects has forced new efforts to focus on alternative, innovative methods that can provide adequate service, despite finance and resource restraints.

Faecal valorization, the process of transforming human excreta into usable products, is an example of such methods, due to its ability to incentivize private investment in sanitation systems. Historically, issues of sanitation have been very difficult to address because investment in sanitation systems is not financially viable for governments. However,

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faecal valorization creates an opportunity for private businesses to profit off the sales of products derived from faecal sludge [3]. The economic opportunity of products from faecal valorization represents a source of motivation for implementing onsite latrines that are capable of storing human excreta in a safe way while allowing easy access and also maintaining effective faecal sludge management systems and wastewater treatment plants (WWTP). Additionally, the products from faecal valorization can be used to address other issues. For example, some products can be used as alternative energy sources, benefiting the environment and helping to mitigate energy shortages [3]. Additionally, other products can be used as fertilizer or animal feed, produced at lower costs than traditional products, thus benefiting small scale farming [4].

Despite the demonstrated success of products from faecal sludge, the necessary economic interest of private businesses and governments to make industrial implementation of faecal valorization possible on a large scale is still lacking. This economic interest would be derived from demonstrated support of products, both from industrial and household level consumers. Some research has been dedicated to industrial interest in the products from valorized faecal sludge [3]. However, much less focus has been dedicated to understanding consumer interest in the end products from these respective industrial applications. Therefore, this study attempted to expand the understanding of consumer interest in end products derived from industries that make use of products from faecal sludge by identifying possible incentives and concerns of consumers and finally estimate the economic opportunity for each product and end product. In addition, socio-economic assessment of some selected value-added products, such as; crops treated with fertilizer derived from human waste, meat from animals fed with feed derived from human waste [4], energy from the combustion of products derived from human waste(biogas) was evaluated within Johannesburg metropolis (Wits University and its environs). The choice of location for the study was informed by the need to have improved sanitation and alternative affordable sources of energy. Within Johannesburg metropolis, the sanitation systems collect over 90 % of faecal sludge produced in the city, providing an opportunity for large scale faecal valorization operation [5].

Estimates developed from a quantitative review of existing literature demonstrated high potential revenues for products from faecal valorization and associated end products. The estimates were developed through examining current prices and consumption patterns in South Africa [5]. Questionnaires were also distributed at the University of Witwatersrand and its environs, posing as a case study of Johannesburg, in order to determine consumer interest in end products and the effect of different incentives on interest level. The sample ranged widely in age and education level with about equal proportions of male and female participants, ensuring as representable a sample as possible using convenience sampling. Statistical analysis was used to analyze the collected data due to sample size and controlling for factors such as age, sex and education level, the study mitigated sample bias. The analysis was conducted using repeated measure ANOVA testing and Tukey HSD testing. The interest level of the end product of faecal sludge was quantified using a 5- point Likert scale while a regression model was generated to understand which among the variables explored in this study were significant in predicting the participant's interest level. Therefore, this study evaluated the social-economic assessment of valorisation of faecal sludge into value-added products: Case study of selected products in Johannesburg Metropolis

METHODOLOGY

Products Derived from Faecal Sludge

Studies have demonstrated the potential of different products derived directly from faecal sludge. There are four products that emerged as potentially useful, identified primarily by Diener et al. [3]. The products are as follows; dry sludge as fuel, biogas, animal feed protein, and fertilizer. These four products pose as substitutes for traditionally used products in their respective industries. These industries produce the following end goods which are the focus of this study; energy from the combustion of dry sludge or biogas, crops treated with fertilizer derived from faecal sludge and meat from animals fed larvae grown using faecal sludge.

Choice of Study Location

This study chose to examine Johannesburg, South Africa as it represents a strong opportunity for implementation of faecal valorisation technology, with a population of 8 million and an estimated 38% of the country's population without adequate sanitation [5, 6]. Additionally, South Africa's need for alternative sources of energy and more affordable farming materials makes it a strong potential market for products from faecal sludge [7, 8]. The University of Witwatersrand and its environs were chosen as a case study in Johannesburg because of the diversity of age, race

and education level in the area. The University of Witwatersrand has almost 40,000 students and 1,000 staff members, located in the neighbourhood of Braamfontein [9]. Additionally, the campus is located around several technical colleges and many stores near the centre of Johannesburg, providing a diverse sample of Johannesburg residents, ranging in age and education level.

FIGURE 1. Map showing Johannesburg, Gauteng province, Southern part of Africa (https://www.nationsonline.org/oneworld/map/za_provinces_map2.htm)

Data Collection

The main method used for quantitative data collection in the study was a questionnaire (survey). The purpose of the questionnaire was first, to determine if consumers are willing to use the products. Second, to examine if consumers are willing to substitute traditional end products with goods that come from industries using products from faecal valorisation. Then, to determine if cost, environmental or social effects of the end products impact peoples' willingness to use them.

The questionnaire was distributed to 200 members of the Wits community and surrounding environs. The questionnaire was distributed to students, faculty and workers at Wits University and technical colleges. It began with a filtering question which asked the participant if they have knowledge of products derived from faecal valorisation. Participants were then instructed either to read the description of faecal valorisation attached to the survey or to continue directly to the questionnaire, acting as a control group. Following the introductory section of the questionnaire, participants were asked, for each product, their willingness to consume or use the product. The following four questions explored participants' willingness to choose the product in different situations, exploring those factors such as cheaper cost, environmental benefit and improved sanitation systems.

Statistical Analysis

The sample used for data collection was a convenience sample. However, due to the sample size and controlling for factors such as age, sex and education level, the study mitigated sample bias. Therefore, statistical modelling was deemed appropriate to analyse the collected data. The modelling made use of linear regression analysis and hypothesis testing was completed using one-way ANOVA and Tukey post hoc analysis to test the differences between means for different products and situations. To begin, the sample population ranged in age from 18 to 62, with an average age of 24 and an average education level of 'some college'. The gender breakdown was about even, with just a few more females than males. Interest level was quantified using Likert scales and then adjusted to be out of 100 points, though some visualizations make use of raw scores out of 25 [10].

RESULTS AND DISCUSSION

Interest Level of the Products Derived from Faecal Waste

When scaled to 100 points, responses from 30-39 suggest neutrality, with scores higher than that suggesting likeliness to use the products. Though the products differed in demonstrated interest level, the questionnaire responses suggested that overall there is interest in end products from human waste.

Interest level can be broken down further by examining, the different situations explored in the questionnaire and predictor variables. Examining averaged responses reveal there was much more demonstrated interest in energy than the other two end products, meat and crops. Additionally, averages suggest that interest level was higher in situations which included incentives, in the form of benefits either to the participant or wider society. To test the significance of these observed differences, repeated measure ANOVA and Tukey HSD test were used. Significant differences were found between crop and energy interest levels as well as meat and energy interest levels. This suggests that the products which would be directly consumed by respondents were less appealing than energy, in which respondents would not have to directly interact with the products derived from faecal sludge.

Additionally, significant differences were found among the different situations under which respondents were asked to state their interest level. There is a significant difference between the respondent's willingness to substitute traditionally used products and each of the situations which included incentives. The trends visible in Figure 2 are suggestive of respondents' behaviour under these different pressures. Interestingly, there was no significant difference in participants' interest level under the influence of the different incentives of cheaper cost, environmental and sanitation benefits, suggesting that the societal impact of the products was just as important as personal benefit.

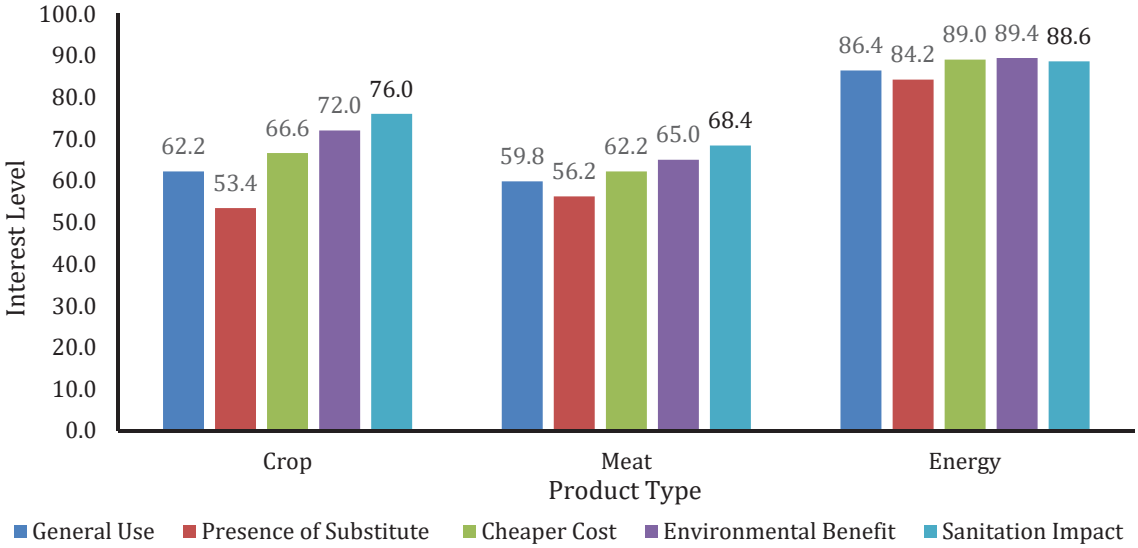

FIGURE 2. Level of interest per product per situation

Following a similar procedure, based on the observed difference in response by gender, as shown in Figure 3, a significant difference between male and female responses was found. Though the difference was small, males tended to record higher interest levels than females, particularly for products which are directly consumed, such as crops and meat.

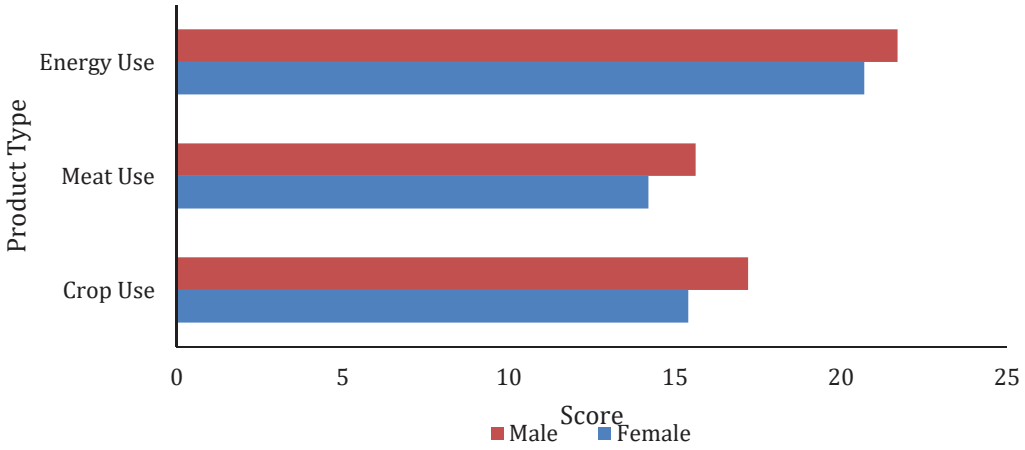

FIGURE 3. Effect of gender on interest level

The last predictor variable examined in such a way was education level. As evident in Figure 4, there is not a perfectly evident trend in the data. However, the average interest level for each education level proved to be significantly different, with the suggestions that higher education positively relates to interest level and a significant increase for participants having completed college, particularly in regard to interest level for crops and meat.

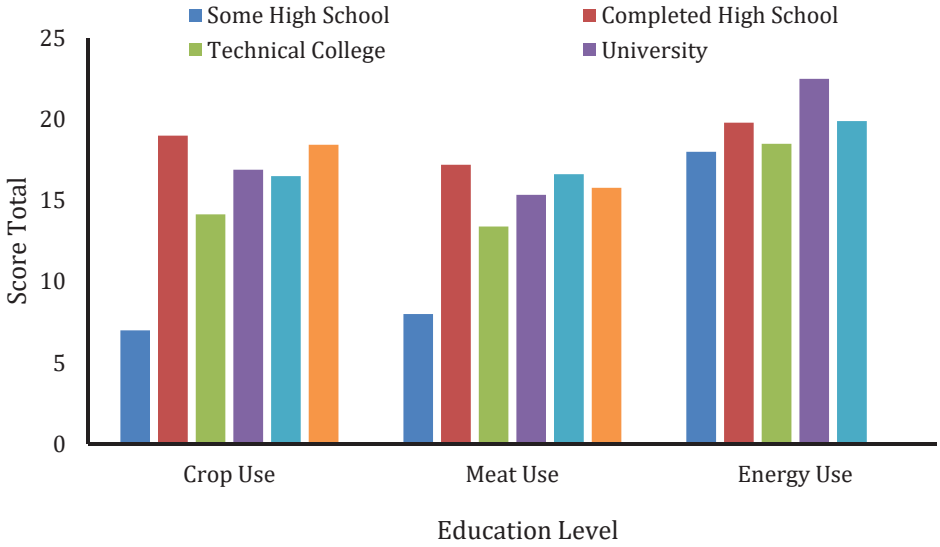

FIGURE 4. Effect of educational background on interest level

The Control variable was explored prior to regression analysis. Previous knowledge of faecal valorisation acted as a control in the study. The questionnaire filtered participants who had prior knowledge from those who did not, providing a description of faecal valorisation to those who were not aware of the process. This acted as a control group, minimizing the potential bias in the provided description. In analysing the control and test group, it became evident that, there was a significant difference between the groups, with an effect size of 0.47. Participants that possessed prior knowledge on the subject recorded higher interest levels compared to those who relied on the

description for their understanding of faecal valorisation. It is possible that those who had prior knowledge of faecal valorisation were aware of its potential benefits because the provided description did not go into such detail.

Regression Model Analysis in Predicting Participant's Interest Level on Faecal Products

Using the data from the questionnaire, a regression model (Eq. 1) was generated to understand which among the variables explored in this study were significant in predicting a participant's interest level. The model suggests that all of the predictors, excluding age, were significant in predicting interest level. The categorical variables were coded using effect cell coding, generating the following regression model;

$$\beta = 3.413 + 0.00261\alpha_1 + 0.1189\delta_1 - 0.1189\delta_2 - 1.198\eta_1 + 0.418\eta_2 - 0.1896\eta_3 + 0.294\eta_4 + 0.3188\eta_5 + 0.3575\eta_6 - 0.2902\delta_1 - 0.4549\delta_2 + 0.7451\sigma_3 - 0.1164\varphi_1 - 0.3754\varphi_2 + 0.0179\varphi_3 + 0.1651\varphi_4 + 0.3088\varphi_5 \quad (1)$$

Where β is the Interest level, α_1 is age, δ_1 is Male, δ_2 is Female, η_1 stands for some high school, η_2 is completed high school, η_3 stands for some college, η_4 is completed college, η_5 is postgraduate and η_6 is PhD.
σ_1 represents for crops, σ_2 stands for meat, σ_3 is energy, φ_1 is general use, φ_2 is presence of substitute, φ_3 stands for cheaper cost, φ_4 is environmental benefit and φ_5 is aids sanitation improvement.
The predicative ability of this model is of much less interest than implications of the coefficients of significant predictors. Analysing the coefficients yields the following understandings; prior knowledge and higher education tended to have a positive effect on interest level, gender impacted interest level, with males recording higher responses, consistent with the ANOVA testing, and finally interest level was affected differently by the types of products and situations. This model has a coefficient of determination at 25.34 %.
To gain a deeper understanding of the significance of individual predictors, partial coefficient analysis was conducted. This portion of analysis revealed that the only predictor with a coefficient of determination value higher than 5 % was the product type. While other predictors remain significant in understanding overall interest level, the large predictive power of product type is a major take away of the study as it suggests that the type of products developed will have a large effect on consumer interest level.

Crops Treated with Fertilizer from Faecal Sludge

Fertilizer from faecal sludge has the potential to provide quality fertilizer, as it is similar in composition to chicken manure [4]. Chicken manure is used widely in South Africa, estimated at 350,000 t/year [11]. From the current amount of sludge collected in Johannesburg about 142,958 tons of fertilizer could be produced. The average price for a ton of chicken manure is 243ZAR (6.2USD) [12], providing a total revenue for the sale of fertilizer from sludge, at chicken manure prices, of 892,060USD/year.
In the regression model the product type, crop had a slightly negative coefficient. However, 51 % of participants indicated that, they are likely or very likely to consume crops treated with fertilizer from faecal sludge under at least one of the five situations. So, while the product was not met with overwhelming interest, in certain situations with proper incentives, consumers did demonstrate a willingness to use the products. Due to the large market potential of crops, specifically maize, the demonstrated interest level is worth expanding upon through investment into marketing and understanding consumer concerns.

Meat from Animals Fed Larvae Grown Using Faecal Sludge

Livestock feed commonly makes use of fishmeal as a source of protein for the animals. It is comprised of 70-80 % digestible protein, serving as some of the best protein sources for animal growth and development [13]. However, it is an expensive product, averagely sold at 1520USD/ton. Additionally, producing fishmeal at current rates could negatively impact ocean life, as the fish used in fishmeal are commonly sources of food for other ocean life [13]. Animal protein from faecal sludge is similar in protein composition to fishmeal. It is produced by feeding larvae faecal sludge and then using the larvae as protein in the feed. Johannesburg faecal sludge production could produce roughly 1,501,062.5 kg of protein/year and if sold at current prices for fishmeal, producing a revenue of 1.6million USD [14]. However, meat from animals fed larvae grown using faecal sludge was met with less interest than crops from plants treated with fertilizer from faecal sludge. In the regression model meat has a negative coefficient almost twice the size of the crop coefficient. When counting responses, only 43% of respondents stated they were likely or very likely to

consume meat from animals fed larvae grown using faecal sludge in any situation, making the social aspect of meat production using human waste not as feasible and less profitable.

Energy from the Combustion of Dry Sludge or Biogas

Energy in South Africa is primarily supplied by Eskom, notable for 'load shedding', planned blackouts in times of short supply, during the past decade [15]. Dry sludge and biogas represent two potential sources for alternative energy. Dry sludge was found to have a similar composition to some ranks of coal [16]. Similarly, anaerobically digested sludge when combined with methane to form biogas, can be a substitute for petrol or other liquid fuels, also comparable to some ranks of coal in regard to MJ/kg [17].

Current energy prices in South Africa are about 1.068ZAR/kWh (0.12USD), significantly higher than kWh prices from the combustion of dry sludge. This additional source of energy could provide electricity for 139,554 households per year. As for petrol it is consumed at 7500ML/year, priced at about 14ZAR/liter (1USD). The collected sludge would produce about 20445 m^3/day of biogas, sold at current petrol costs would produce a potential revenue of 4.9 million USD [18].

Energy from the combustion of dry sludge or biogas had a positive coefficient much larger than the absolute value of both previous products. Additionally, 80% of respondents said they would be likely or very likely to use energy from the combustion of products from human waste in at least one of the five situations, demonstrating wide-spread consumer support for energy from the combustion of products from faecal sludge. The development of a market around such products is further supported when looking at the need for energy in South Africa.

While potential revenue for energy from the combustion of products from faecal sludge was lower than that of crops, the large demonstrated interest from consumers and the sharp need for energy in South Africa makes it the most feasible. Additionally, because of the large positive environmental benefit of alternative energy sources, producing energy from human waste is a very attractive economic and environmental opportunity.

General Use

Figure 5 shows the participants' percentage probability of using the products derived from faecal wastes. When asked simply for the likeliness to use a product, participants were evenly split among the rating scale for both crops and meat. Energy was an exception, with the majority of respondents recording they were likely to use the products. The relatively low percentages of participants that were generally willing to use the products suggests the need for incentives.

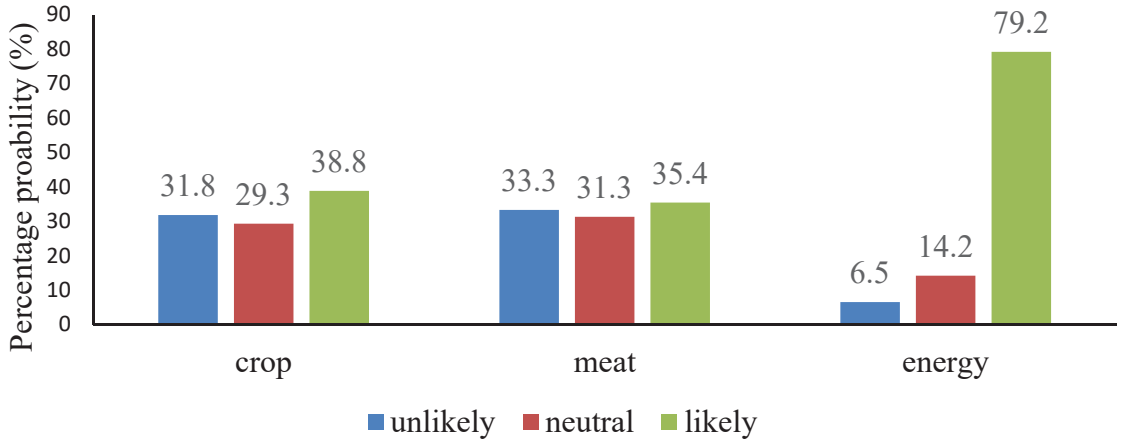

FIGURE 5. Participants' percentage probability of using the products derived from faecal wastes

Presence of Substitute

The presence of a substitute had a relatively large negative coefficient. This suggests that even though participants indicated they'd use and, in some situations, choose products from faecal sludge over traditional products, in general, respondents were more likely to stay with the products they normally consume. This further suggests that for consumers to actively choose products from faecal sludge there would need to be strong incentives. Some possible incentives such as cheaper relative cost, environmental benefits and improved sanitation system, are examined below.
Cheaper Relative Cost**:** With the low potential operating cost of sludge management systems [19], production costs may also be kept low, this is particularly true for certain products, such as fertilizer [4]. As South African industries face higher costs for farming and livestock production materials and energy rates increasingly rise, the option to have cheaper alternatives is important to the economic prosperity of consumers. In the regression model, cheaper relative cost had a small positive coefficient, suggesting that cheaper cost did entice some participants to choose products from faecal sludge but was not the most influential.
Environmental Benefit: The environmental benefits of valorising faecal sludge are numerous including; decreasing pollution and the spread of disease, providing alternative, less polluting energy sources [3, 16], and creating waste treatment systems that are less energy intensive [20]. By purchasing products from valorised faecal sludge, consumers are supporting the development of faecal sludge management systems and in doing so, the environmental benefits. In the model, environmental benefit had a larger positive coefficient, suggesting its strength as an incentive to consumers.
Improved Sanitation System: As discussed previously, creating products from valorised faecal sludge incentivizes investment into sludge management systems [3]. This then spreads the availability of adequate sanitation as private companies attempt to optimize faecal sludge as a resource through good quality sludge management systems. By purchasing products from valorised faecal sludge, consumers are supporting the development of faecal sludge management systems and in doing so, the expansion of adequate sanitation, a strong social good. Similarly, to environmental benefit, the potential of improved sanitation was a strong incentive, with a positive coefficient twice the size of that of environmental benefit.

CONCLUSIONS

The data gathered through the questionnaire, when combined with the economic values from the literature review can be used to determine which products have the strongest opportunity for marketing and development. Weighing these both, alongside factors such as environmental impact, the production of energy from human waste appears to be the most socially and economically feasible. Additionally, environmental and sanitation benefits appear to be the strongest incentive, suggesting that, marketing strategies of these products should focus on the societal benefit of the products Overall, there is demonstrated interest in products from valorised faecal sludge and the power of incentives involving cheaper cost and societal benefit, suggesting that products from faecal valorisation have the potential to be marketable. Therefore, faecal valorisation may serve as the means to address inadequate sanitation and other environmental problems throughout South Africa. Although, based on the results and information obtained from this current study, the economic opportunity has been demonstrated for both crops and meat, however, more research should be dedicated to determining specific concerns consumers have about the products and specific means to address these concerns before development is seriously considered.

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