A Multi-criteria Model For Sustainability Assessment Of An Agri-Industrial Technology Meant For A Developing Economy

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ABSTRACT

The purpose of this study was to develop suitable methodology for assessing appropriateness and sustainability of technologies intended for use in a developing economy. Sustainability factors were articulated through literature search and based on experience with potential users in sub-urban municipalities of a developing country. A number of decision methods considered suitable for the expected decision scenarios were then hybridized and validated with three fish smoking kilns.

The suitability of the decision model for evaluating the appropriateness and sustainability of a technology for use in a developing economy was illustrated by using it to assess the comparative sustainability of three fish smoking kilns.

Keywords - Agri-industrial technologies, Appropriate technologies, Decision analysis, Decision models, Foreign technologies, Indigenous technologies, Post-harvest, Technology transfer, Technology development, Multi-criteria decision

I. INTRODUCTION

Economies of many developing countries are based on Agriculture. The agricultural sector is characterized essentially by small holdings from individuals and families that largely depend on simple implements produced by using indigenous technologies. In attempt to achieve self sufficiency in food production and to improve earnings from this sector, governments of many of these countries established a number of agencies to import improved seeds, fertilizers and agricultural machinery which are supplied/ rented to the farmers at subsidized rate. Some governments also established state owned farms and government supported cooperative farms. Many of them also embarked on infrastructural development projects. These boosted the availability of agricultural produce and led to abundance during certain seasons. It also led to lots of wastes due to unavailability of adequate storage facilities [1]. Many of the local people process these agricultural produce in small quantities into various forms for delicacies and for preservation. In view of the enormous waste being experienced, it become apparent that large scale processing facilities are needed to process and preserve the products not only for off-season period but also for foreign exchange earnings.

In addition, some governments established markets, buyer organizations and price control mechanisms with the aim of encouraging and protecting these farmers and processors. However, due to deregulation of the economy and promotion of globalization, many of these aforementioned practices were abolished leaving the farmers and processors at the mercy of stronger competitors. Moreover, trade liberalization which led to increased importation of comparatively cheaper foreign technologies discouraged indigenous technologies' development. It also caused many farmers and processors to go bankrupt. In attempts to stay in business, many farmers and processors embarked on agricultural practices and agri-industrial processes that consume lots of resources and pollute the environment [2].

The unfolding of this unpleasant situation has put governments of these countries and their agencies under the pressure of having to make decisions that will result in the choice of appropriate technologies which encourage the development of indigenous technologies, improve the economic development, and standards of living of the people as well as preserve the environment. Some international organizations like ECA, UNIDO, EEC and OECD also embarked on a number of infrastructural development projects and environmental education in the developing countries with the aim of reducing poverty and promoting the use of sustainable technologies [3-7]. Technocrats are thus faced with the need for decision making tools that will facilitate making choices that are technically sound, economically rewarding, environmentally friendly and socially acceptable [8-13]. This paper therefore propose a simple methodology that can assist the decision makers in arriving at the choice of appropriate agri-industrial technologies based on holistic systems' lifecycle thinking. The model which is a hybrid of a number of decision making methods considers multiple and conflicting technical, economic, environmental and social factors and integrates the decision makers' preferences into the selection process.

II. METHODOLOGY

Although many decision analysis methods (Figure 1) can be found in the literatures and many are being used in practice, the questions are: "can we find an appropriate one for this decision scenario?" and "How can we determine their suitability?" According to Dunmade (2001), Chen and Hwang (1992), and Zimmerman (1987) [13-15], the decision making methods differ widely in the purposes they serve, their ease of use and theoretical soundness, and the evaluations they yield. An intending user must thus consider the appropriateness of the method to the problem in terms of the value judgments it asks from the decision maker, the types of alternatives it can consider, and the forms of evaluations it yields. Furthermore, the decision maker must also consider how much effort and knowledge the method requires. Literature review on this subject revealed that despite the availability of a large number of multi-criteria decision making methods and their widespread application there is no single one of them that adequately model this decision scenario. There is therefore a need to hybridize a number of these methods in order to adequately model sustainable agri-industrial technologies' decision scenarios in developing countries.

This methodology starts with the identification of the characteristics of post-harvest technologies in the developing countries through articulation of selection criteria to evaluation at each stage of the lifecycle. The methodology involves sequential elimination of weak options as the decision progresses through the lifecycle stages until the final decision is reached. The use of the methodology is illustrated with an example on cassava processing technologies.

2.1 Characteristics of Agri-Industrial Technologies Decision Scenario

Agri-industrial technologies as used here refer to methods and associated machinery used in transforming raw agricultural products into intermediate or consumable products. The decision making in this domain involve a consideration of the complex interaction between economic, technical, social and environmental factors. Figure 2 illustrates a typical agri-industrial decision scenario with arrow indicating the iterative nature of the agri-industrial technologies and the criteria for evaluating them at the various stages of the system lifecycle. It also shows that the decision made at one stage of the lifecycle affects the other level of the system lifecycle.

Therefore, having identified the various agri-industrial technologies available to the farmer/ processor, adequate analysis and evaluation of technology alternatives that will result in selection of the 'best' option have to be carried out before commitment is made to the implementation [16-17].

2.2. Decision Options

In a typical agri-industrial technology decision situation there is usually a small number of options to choose from. These options can generally be classified into indigenous technologies, imported technologies, and integrated (improved indigenous) technologies.

2.2.1 Indigenous technologies

These are locally developed simple technologies which depend upon a variety of local conditions. They are crafts passed from one generation to the other [18]. Examples of these are local tanneries and blacksmith works. Agri-industrial activities by local processors depend heavily on implements produced by them because their products are simple, affordable and available. Most of these equipments are manually operated. They are thereby characterized by drudgery and small scale production. To facilitate high production and improved earnings from this sector of the economy, many governmental agencies embarked on the importation of foreign technologies.

2.2.2 Foreign/imported technologies

These are modern technologies that are often characterized by comparatively high cost, large scale production, and technical complexity. Some of them are also automated, thereby eliminating drudgery. Many of them are powered electrically or by the use of fossil fuel. They also have the potential to degrade the environment in view of the noise and emissions resulting from their use. Many of these technologies were found inappropriate in some countries because the technical know-how were not transferred. In some countries, the spare parts are not available. Consequently, a number of these technologies became unserviceable. It was then found that what is needed is a technology that is both adaptable to the technical know-how level of the locality. In addition it has to be sustainable in terms of maintainability, affordability, and parts availability. Such technology can only be obtained by the hybridization of the imported technologies with local ones and adaptation of imported technologies to suite the local conditions [3, 6].

2.2.3 Integrated/Improved indigenous technologies

The arrival of foreign technologies has caused the demise of many indigenous technologies in some countries while it caused technology proliferation and improvement in others. Inability to locally maintain a number of imported technologies coupled with high cost of importing spare parts and recruiting foreign maintenance experts have made some governments to encourage the development of improved indigenous technologies. These essentially involve mechanizing the local processes and eliminating the unessential practices. They are easier to build and cheaper to maintain. The technical know-how and parts are locally available. However, there are many versions of these technologies with variation in technical complexity, emissions, resource consumption and cost [19-20]. For example, a decision maker considering which garifying (cassava processing) technology to use may choose option A (semi mechanized batch type technology involving manual peeling, mechanical grater, and batch type garifyer); option B (completely mechanized batch type method consisting of batch type "peeler-grater–garifyer-parker"), or option C (continuous garifying technology which consist of automated "peeler-grater-garifyer-parker"). Several combinations of these are also possible.

2.3 Decision Criteria

In arriving at the decision on the option to select, he/she must have a basis for his/her choice. Since the desire of the decision maker is to choose the technology that is both sustainable and appropriate for his/her operation, it follows that a number of factors that can be grouped into economic, environmental and social attributes should be the basis of his decision [13, 21-26]. These attributes can be further classified into sub-attributes and indicators. Figure 3 shows these attributes and some of their sub-attributes and indicators [13-15].

2.4 Decision Analysis

Having determined the available options and articulating the basis for their evaluation, it is essential to determine the characteristics of the decision maker. In general, agri-industrial technology decision making in the developing country is such that the farmer/processor want to choose an option that maximize his utility. However, in choosing the best out of the available options, he/she may set some minimum limits/value on the performance of the options below which he will not be ready to accept to choose any of the options.

For a specific decision scenario, let A_j, $_{j=1, 2,\ldots, n}$ be the identified agri-industrial technologies options from which the farmer wants to choose while $x_{i,\ i=1,\ 2,\ \ldots,\ m}$ are attributes on which the agri-industrial technologies are to be evaluated. Let $w_{i,\ i=1,\ 2,\ \ldots,\ m}$ be the importance weight attached to each of the attributes $x_{i,\ i=1,\ 2,\ \ldots,\ m}$ such that $\sum_{i=1}^{m} w_i = 1$. As a rational decision maker who intends to maximize his utility, he/she will select the technology option

$$A_j = \max \sum_{i=1}^{m} w_i x_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

But if he/she has set some minimum performance limit of each technology option on the sustainability factors, this limit can be written as

$$\sum_{i=1}^{m} w_i x_i^o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where x_i^o is the required minimum performance for any acceptable agri-industrial technology A_j on criterion x_i.

Thus, he/she will choose technology A* that both satisfy his/her minimum performance requirements and maximize his/her utility. This can be written as

$$A^* = \max \sum_{i=1}^{m} w_i x_{ij} \geq \sum_{i=1}^{m} w_i x_i^o \quad \ldots\ldots\ldots\ldots\ldots (3)$$

2.5 Lifecycle Thinking

Selection of a technology that is both sustainable and appropriate for a decision maker's operating environment requires lifecycle thinking. In otherwords, the decision maker needs to consider the various lifecycle stages (Figure 4) of the technology in term of its economic, environmental and social implications.

Thus, the agri-industrial technology that satisfies the desires of the farmer/processor at lifecycle decision stage $s_{k,\ k=1,\ 2,\ \ldots,\ r}$ is

$$A_k^* = \left[\max \sum_{i=1}^{m} w_i x_{ij} \geq \sum_{i=1}^{m} w_i x_i^o \right]_k \quad \ldots\ldots (4)$$

For the whole lifecycle of the technology, his/her desired choice can be modelled as

$$A^+ = \max \sum_{k=1}^{r} \left[\sum_{i=1}^{m} w_i x_{ij} \right]_k \geq \sum_{k=1}^{r} \left[\sum_{j=1}^{m} w_i x_i^o \right]_k \quad .. (5)$$

III. METHODOLOGY ILLUSTRATION

The use of this sustainability assessment model is illustrated by comparing the sustainability of three fish smoking kiln technologies.

3.1 Decision options

The three fish smoking kiln technologies are an imported AFOS smoking kiln, a locally fabricated Talon fish smoking kiln, and a University developed rotary fish smoking kiln prototype.

3.1.1 AFOS Fish Smoking Kiln

AFOS Double Maxi Fish Smoking Kiln Model is shown in Figure 5. It is a self contained semi-automatic machine constructed from 304 grade stainless steel. It consists of 2 kilns and a smoke producer. It has two 15 level trolleys. The capacity of the kiln is 125kg per cycle. The air/smoke is drawn horizontally over the product through a multi vane baffle wall. The air circulation in the kiln is facilitated by an electric motor driven fan. It also has steam cook facility.

3.1.2 TALON Fish Smoking Kiln

TALON Fish Smoking Kiln Model is shown in Figure 6. It is a kiln locally designed and fabricated by Talon Nigeria Limited. It is constructed from steel. It has seven trays stacked in 2 columns. The heat required for smoking is generated by burning wood.

3.1.3 University developed Rotary Fish Smoking Kiln

Figure 7 shows an experimental rotary fish smoking kiln locally designed by a university. The model kiln comprising of heat combustion chamber and smoking unit was constructed from double walled stainless steel properly insulated with fibre glass. A metal plate sheet on the combustion chamber conducts the heat and radiates it to the fish. Smoke escapes from combustion chamber through the chimney. Temperature of the system is regulated through the regulator vent. The major uniqueness of the kiln is that fish is hung on the basket, which is attached to a cranking system outside through which the fish is turned inside the smoking chamber.

The kiln was fuelled with saw dust and the temperature was regulated to 55^0C. The brined fishes were spread on the rotary tray inside the smoking kiln. The tray was turned manually every 30 minutes through the outer crank. Sampling of the fishes was done at intervals of 60 minutes for weighing and moisture content determination. All the smoked fishes were allowed to cool in the kiln, packed and sealed with vacuum sealer inside polythene nylon, and stored under ambient temperature.

3.2 Decision Criteria

The performances of each of the three smoking kiln technologies were assessed against relevant sustainability indicators grouped into three criteria at each stage of the technology lifecycle. The evaluation was carried out from the perspective of a decision maker who is a technology adopter. The illustration considered the entire lifecycle together.

IV. RESULTS AND DISCUSSION

Assuming the data in tables 1-3 were obtained during the performance tests of the three smoking kilns, sustainability value of each kiln is assessed as follow:

4.1 Techno-economic factor

This factor is a combination of cost of ownership of each product and technical convenience regarding their utilization. Table 1a shows the performance of the three product options and the minimum acceptable performance for techno-economic factor. The cost attribute for each product was listed in comparison to maximum cost for any of such product that is considered affordable by the user. Similarly, the technical attribute was also measured in comparison with the technical ease of utilization by the user. Cost, capacity and time elements had to be normalized to a non-dimensional value to enable compilations of both cost and technical attributes, as well as final compilation across techno-economic, environmental and social factors.

The normalization was made by ranking the three product options with reference to the highest value for each sub-attribute. Table 1b shows the normalized techno-economic performance of the technology options for each attribute and their overall performances.

Total techno-economic performance value for each product option was calculated as shown below using the AFOS kiln model as an example:

Unweighted techno-economic value of AFOS Smoking Kiln Model,

$$uT_{AFOS} = \sum_{i=1}^{m} x_i = 3+3+2+4+3+2+2+3 = 22$$

Weighted techno-economic value of AFOS fish smoking kiln model,

$$wT_{AFOS} = \sum_{i=1}^{m} w_i x_i = 0.34(22) = 7.48$$

A look at Figure 8 revealed that all the three products satisfied the minimum acceptable standard performance on each techno-economic element and for the total techno-economic value. However, University designed fish smoking kiln has the best techno-economic performance followed by the AFOS fish smoking kiln model.

4.2 Environmental factor

Table 2 shows the preference (or importance) weight and environmental performances of the products and the acceptable minimum performance for each element of the environmental factor.

Total environmental performance value for each product option was calculated as shown below using the AFOS kiln model as an example:

Unweighted environmental value of AFOS Smoking Kiln Model,

$$uE_{AFOS} = \sum_{i=1}^{m} x_i = 4+3+3.5 = 10.5$$

Weighted environmental value of AFOS Smoking Kiln Model,

$$wE_{AFOS} = \sum_{i=1}^{m} w_i x_i = 0.33(10.5) = 3.47$$

Examination of figure 9 shows that AFOS kiln model did not meet the acceptable standard for the resource consumption. It also showed that it did not satisfy the total acceptable minimum environmental performance standard.

4.3 Social factor

Table 3 shows the preference (or importance) weight and performances of the products in social aspects and the acceptable minimum performance for each element of the social factor. Calculations based on the data in table 3 showed that the unweighted value of AFOS Smoking Kiln Model with regard to social attributes,

$$uS_{AFOS} = \sum_{i=1}^{m} x_i = 4+2+4+4+3 = 17$$

Weighted value of AFOS Smoking Kiln Model with regard to social attributes,

$$wS_{AFOS} = \sum_{i=1}^{m} w_i x_i = 0.33(17) = 5.61$$

Figure 10 reveals that AFOS Fish Smoking Kiln did not meet the minimum requirements for infrastructures impact but the three technologies satisfied the minimum acceptable standard on social factor.

4.4 Decision strategies

There are two possible decision strategies in determining the best overall sustainable technology from the three models of fish smoking kiln:

4.4.1 Uncompromising decision strategy

The first decision strategy is a decision in which there is no compromise on any of the constituent elements of sustainability, whether techno-economic, social, or environmental. In that regard, both AFOS Fish Smoking Kiln and University designed Fish Smoking Kiln Model did not meet acceptable minimum standard on all the elements of sustainability. From figure 9 one can see that University Kiln model did not satisfy the minimum requirement on resource consumption while AFOS Kiln model failed to satisfy minimum requirement regarding environmental impact sub-attribute. Figure 9 also showed that AFOS Kiln did not satisfy the minimum requirement on infrastructures impact sub-attribute. The only technology option that satisfies all the minimum requirements at sub-attribute and overall level is TALON Fish Smoking Kiln Model. That is the technology option that would be chosen by the uncompromising decision maker.

4.4.2 Compensatory decision strategy

The second decision strategy is the compromising/ compensatory minimum acceptable standard in which the screening is focused on the satisfaction of the overall minimum standard and not on meeting individual sustainability sub-attribute.

The technology option that satisfied the minimum overall requirements for the three sustainability factors and at the same time has the maximum utility as can be seen in figures 11 -12 is the University designed fish smoking kiln model. Consequently, it will be the choice of the compromising utility maximizing decision maker.

V. CONCLUSION

A simplified multi-criteria model for sustainability assessment of technologies meant for use in developing economies was presented. It would enable farmers, processors and other stakeholders to assess sustainability potentials of technologies being considered for adoption at indicator, sub-attribute, and attribute levels. It enables the decision maker to both satisfy his/her minimum requirements and to maximize his/her utility. This methodology will be found useful by designers, manufacturers, marketers and operators of agri-industrial facilities in selecting the. These will consequently facilitate the selection of the most suitable of the various technologies available, lead to technological advancement, improved standard of living, and environmental conservation in the developing country.

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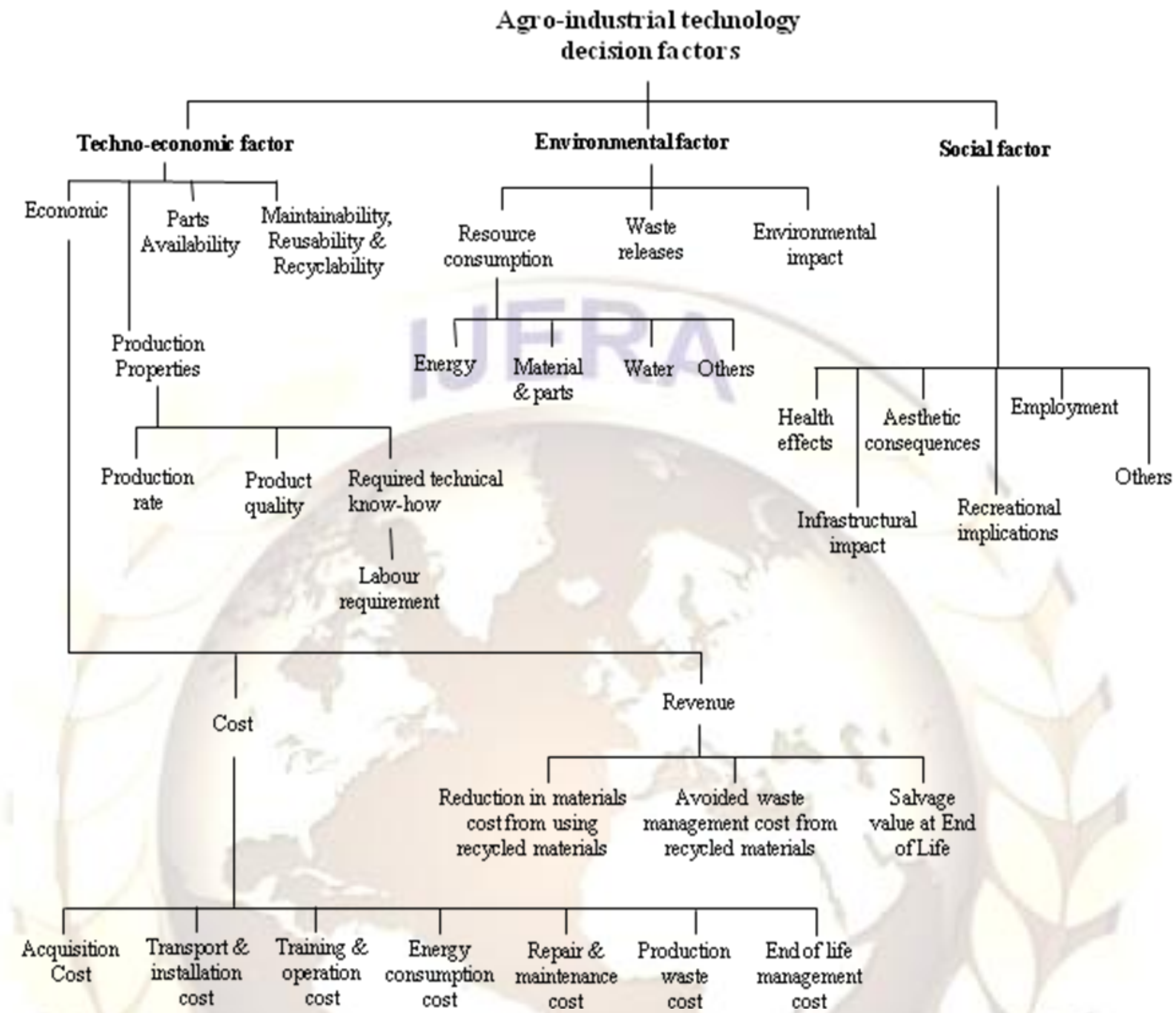

Figure 3 A typical agri-industrial technology decision criteria and their sub-divisions

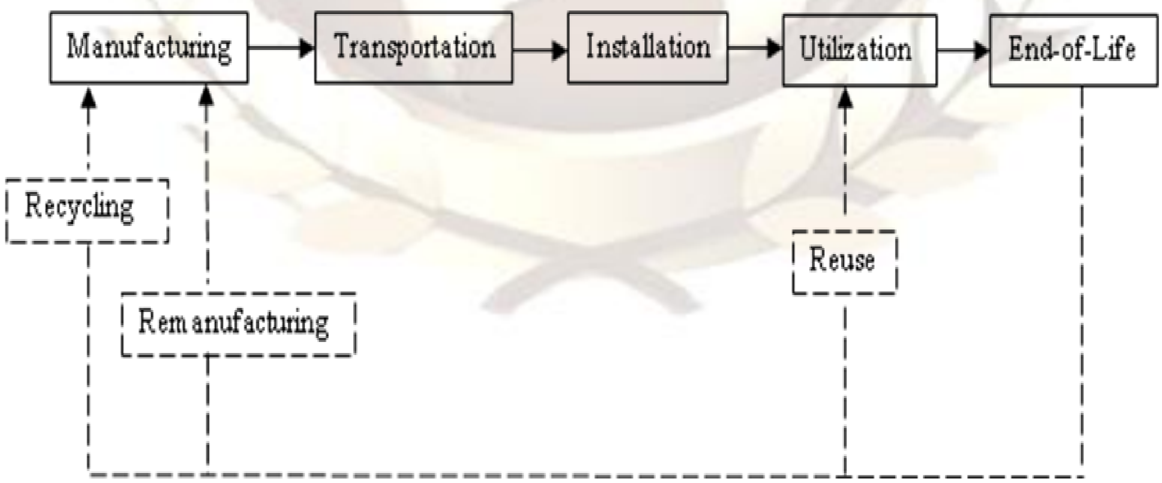

Figure 4 A typical agri-industrial technology lifecycle stages

Figure 5 AFOS Fish Smoking Kiln
Source: http://fis.com

Figure 6 Talon Fish Smoking Kiln
Source: http://www.talonagro.com

Figure 7 University designed Fish Smoking Kiln
Source: Dunmade et al (2010)

Table 1a Preference weight and performances of each technology option on techno-economic sustainability factor in comparison with the set minimum performance requirements

	Techno-economic factor							
Pref. Weight	0.34							
	CPC	**OPC**	**PDC**	**PTQ**	**RTP**	**RTK**	**PAV**	**MRR**
Model	$	$	kg/cycle	5 (very high) - 1 (very low)	minutes	5 (very low) - 1 (very high)	5 (everywhere) - 1 (scarce)	5 (very high) - 1 (very difficult)
AFOS Kiln	8000	500	125	4	65	2	2	3
TALON Kiln	6500	570	125	3.8	70	3	3	3
University Kiln	6000	500	130	4	120	3.5	3	3
Minimum acceptable standard	10000	700	100	3	120	3	3	3

CPC – Capital Cost
OPC – Operations Cost
PDC – Production capacity
PTQ – Product quality
RTP – Required time per cycle
RTK - Required technical know-how
PAV – Parts availability
MRR – Maintainability, reusability & recyclability

Table 1b Normalized performances of each technology option on techno-economic sustainability factor in comparison with the set minimum performance requirements

Options	CPC	OPC	PDC	PTQ	RTP	RTK	PAV	MRR	T_{UW}	T_W
AFOS Kiln	2	3	2	4	3	2	2	3	21	7.14
TALON Kiln	3	2	2	3.8	2	3	3	3	21.8	7.412
University Kiln	4	3	3	4	1	3.5	3	3	24.5	8.33
Minimum acceptable standard	1	1	1	3	1	3	3	3	16	5.44

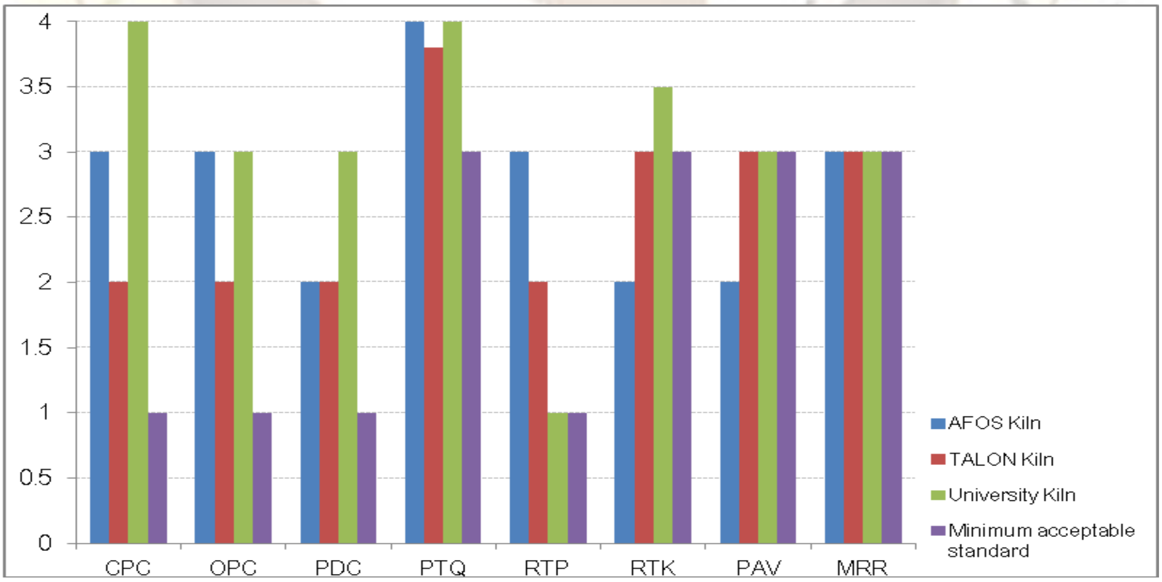

Figure 8 Normalized performances of each technology option on techno-economic sustainability indicators in comparison with the set minimum performance requirements

Table 2 Preference weight and performances of each technology option on environmental sustainability factor in comparison with the set minimum performance requirements

	Environmental Value				
Pref. Weight	0.33				
	RSC	**WTR**	**EVI**	E_{UW}	E_W
Model	5 (very low) - 1 (very high)	5 (very low) - 1 (very high)	5 (very low) - 1 (very high)		
AFOS Kiln	4	3	3.5	10.5	3.47
TALON Kiln	3.5	3.5	3	9.5	3.14
University Kiln	2.5	3	3.5	9	2.97
Minimum acceptable standard	3.5	3.5	3	9.5	3.14

RSC – Resource consumption WTR – Waste releases EVI – Environmental impacts

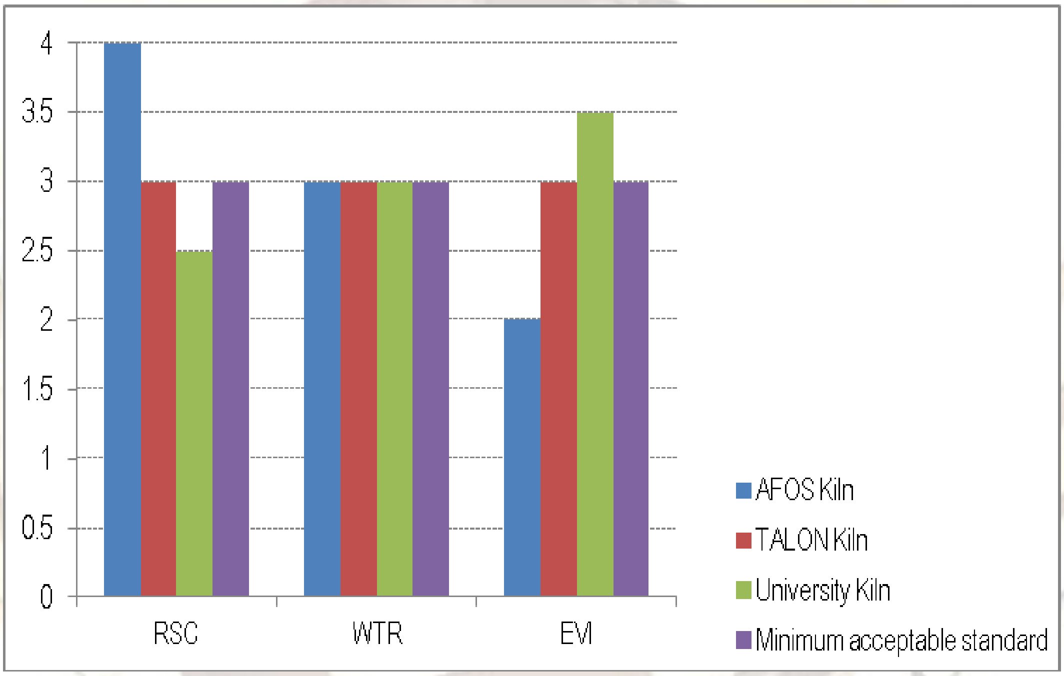

Figure 9 Performances of each technology option on environmental sustainability factor in comparison with the set minimum performance requirements

Table 3 Preference weight and performances of each technology option on social factor in comparison with the set minimum performance requirements

	Social Value						
Pref. Weight	0.33						
	HLI	**IFI**	**ASC**	**RCC**	**EPT**	S_{UW}	S_W
Model	5 (very low) - 1 (very high)	5 (very low) - 1 (very high)	5 (very low) - 1 (very high)	5 (very low) - 1 (very high)	5 (very high) - 1 (very low)		
AFOS Kiln	4	2	4	4	3	17	5.61
TALON Kiln	4	3	3	4	3	17	5.61
University Kiln	3	3.5	3	4	3	16.5	5.45
Minimum acceptable standard	3	3	3	3	3	15	4.95

HLI – Health impacts IFI – Infrastructures Impacts ASC – Aesthetic consequences
RCC – Recreational impacts EPT – Employment impacts

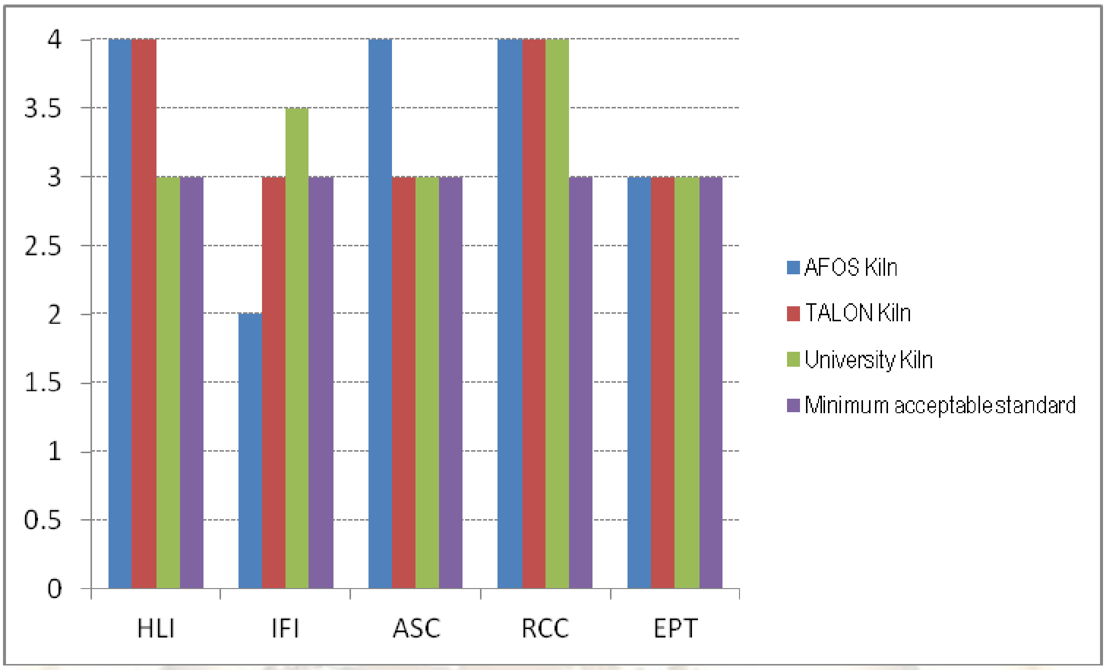

Figure 10 Performances of each technology option on social factor in comparison with the set minimum performance requirements

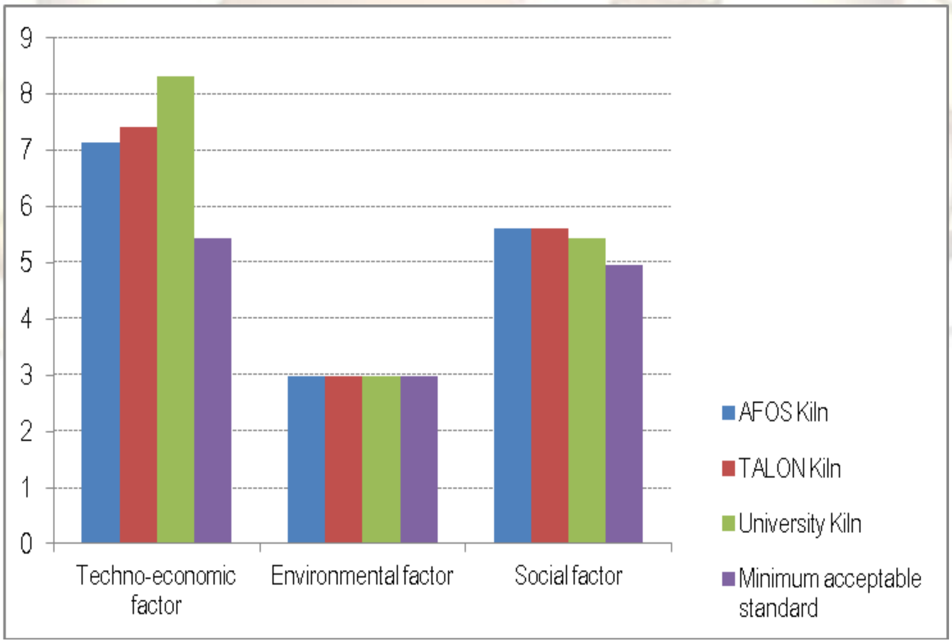

Figure 11 Performances of each technology option on each sustainability category in comparison with the total minimum performance requirement

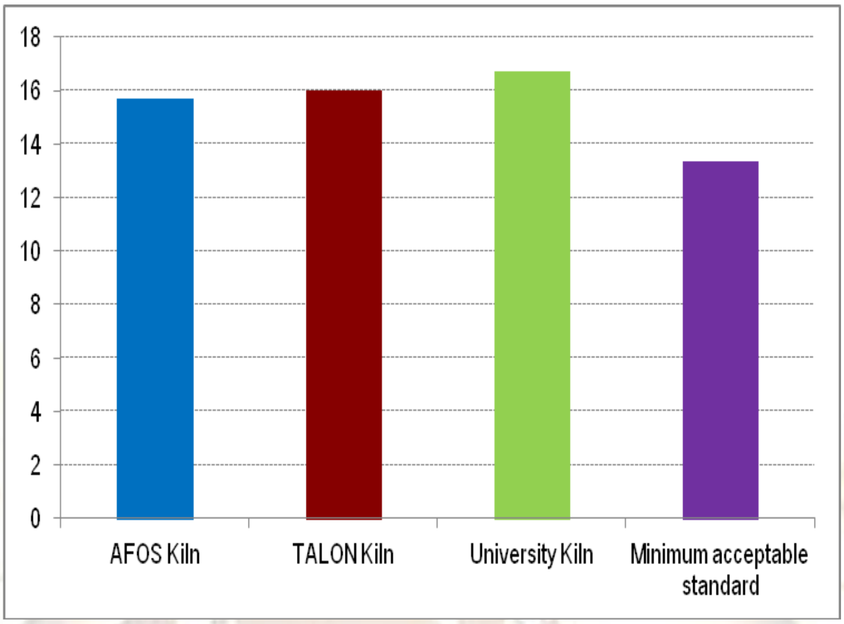

Figure 12 Overall performances of each technology option on all the sustainability factors in comparison with the total minimum performance requirement