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Successful Appropriate Technology Commercialization for Sustainability

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Abstract

In this paper, we consider the case of two appropriate technologies (AT), one for water treatment, the other for treatment of organic wastes and production of renewable energy, and suggest that the reach of these AT's are tied to their commercial success. For this, the AT itself must be scientifically sound and technically robust, established through rigorous testing and prototyping. The AT must fulfill a need in a cost effective and environmentally benign manner. Research and development of the AT, based on laboratory studies and feedback and analysis of data from field trials, should be on-going. These cases also demonstrate that AT developers must work with appropriate funding and incubation models and financial institutions to ensure sufficient backing for technology development, implementation and scaling. Collaboration and partnership with state agencies is essential to ensure the regulatory and government infrastructure is in place to support the AT's adoption, dispersal and expansion. Finally, significant effort must also be expended to educate consumers and have adequate public outreach and training to promote, support, maintain and sustain the AT. In the end, the sustainability of the AT must be demonstrated by providing technology consumers with pre- and post-implementation support, and monitoring, evaluation and assessment of performance.

Keywords: Appropriate Technology, Commercialization, Sustainability, Monitoring, Evaluation, Assessment, Impact

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Elephant Coin: Pegging digital tokens to endangered natural resources as a means of conservation

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Abstract:

This paper focuses on elephant conservation, and the socio-economic problems facing elephants' continued existence. Ivory has undeniable value to humans, however conservationists are divided on how to best leverage the value of ivory to protect elephants from extinction. Does the sale of ivory need to be banned or can its sale be regulated, with elephant populations managed in a sustainable way? According to the IFAW 2013 Report Criminal Nature: The Global Security Implications of the Illegal Wildlife Trade, Ivory is used as an investment vehicle and store of value. If ivory is indeed used as a store of value then what financial instrument could replace the forgone ivory if it was left on live animals? Questions at the intersection of economics and protective biodiversity look at the arguments for and against the destruction of ivory stockpiles. The paper then investigates how blockchain technology could be utilized to create a currency whose value is linked to the global elephant population. The hypothesis is that if human populations in areas of elephant population have a vested economic interest in protecting the lives of elephants then the value of ivory can be sustainably culled from existing populations while decreasing poaching deaths. This hypothesis is examined in respect to blockchain technology, and to what extent it could achieve accountability in terms of distributing and managing the value in ivory.

Keywords: Economics, Conservation, Blockchain

Introduction:

This paper acknowledges as a starting place an irreconcilable problem in political philosophy concerning property, and specifically natural resources. This problem fundamentally centers on just who lays claim to a resource, and to what extent that resources may be considered a 'global commons'. Ivory, the natural resources that is the focus of this paper, was subject various political attempts to control its circulation in the last century. The international Trade in Endangered Species (CITES) banned ivory trade in 1989 in an attempt to decrease poaching and save elephants from extinction. However, after almost 30-years of the ban by many accounts ivory poaching has increased. (Murphree 2016). We can look at John Locke’s political philosophy to see that how “Men living according to reason, without a common superior on earth, to judge between them, is properly the state of nature.” (Two Treatises 2.19). The added twist for Lockean philosophy is that, in addition to humans, elephants also have a claim to ivory! Thus, the ivory at the center of this conflict is an asset intertwined in the lives of elephants and humans, both competing for a finite amount of natural resources.

The problem seems not to be what to do with ivory (it clearly has a value for humans, and no elephant should be murdered for its tusks) but who lays claim to compensation in the liquidation of that value, and how to mange the resources. In a state of nature poachers will accumulate personal property (ivory) through their own labor regardless of any international treaty. Thus, the problem of political philosophy presents itself as a matter of reason, one where the rationality to poach or not poach is being informed by two sides that are formed through identity and difference (Eze 2008). Instead of moralizing the argument for or against selling ivory how could we utilize technology to create a network that saves elephants from extinction? The 'software as policy' (Boiler 2012) model serves to regulate a species that simultaneously contains by-products which happens to be a valuable commodity and store-of-value. The need is especially salient in light of the fact that the geo-political regions where elephant populations reside suffer from an economics of inequality and face the subsequent political conflict central to redistribution of wealth (Piketty 2014).

Attempts to curb Ivory Trade or save elephants?

As outlined by Alejandro Nadal and Francisco Aguayo's 2016 paper on the economics of Ivory stockpiles there have been 3 ways to go about stopping poaching and protecting elephant populations from extinction. These are: “destruction of stockpiles, use of stockpiles as a deterrent against speculators (who may bank on extinction), and the sale of stockpiles in a legal market in order to reduce the incentives to poaching.” (1-2).

Options to end Poaching of Elephant Populations

1. Destruction of Stockpiles
2. Use of stockpiles as a deterrent against Speculators
3. Sale of stockpiles in a legal market in order to reduce poaching

Recently the largest burning of Ivory stockpiles in history took place in Kenya after a meeting the Giant’s club—an exclusive club comprised of African political leaders and celebrities who’s aim is to protect elephant populations. The ceremonially burning of 105 tons of ivory was meant to send a message to poachers that the only valuable ivory is on a live animal. Global news outlets picked up on the story, and various op-ed pieces came out arguing why destroying stock piles was a wise-action (see Alden & Ross, 2016 and Kahumbu, 2016).

Giant's Club Ivory Burn, 30th, April 2016.

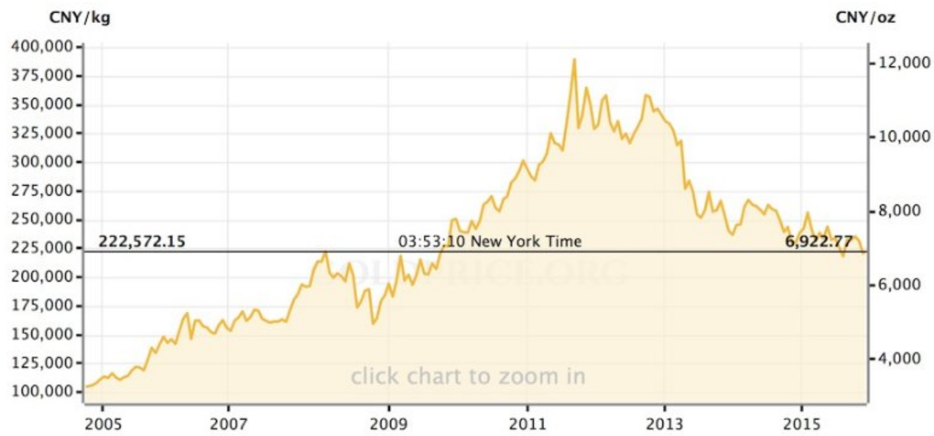
The core argument is that holding stores of Ivory "leads to anticipations that ivory may be sold in the future, feeding expectations of continuing ivory trade and reducing the effectiveness of demand reduction policies" (ibid 2).

The largest legal ivory reserves are in Hong Kong, with ivory that was grandfathered-in before the 1989 international ban on ivory trade. If these dealers believed that ivory stockpiles might be sold again in the future they have reason not to liquidate their reserves. "The prospect of capturing the rents from that future trade will lead traders and processors to remain in the business. In turn, this can lead to renewed investments, the creation of new institutions (such as schools for carvers) and consolidate the array of social routines that are related to market operations and regulations." (Ibid 5) Even if there is a reduction in price due to an influx of state-sanctioned ivory that comes on to the market, these traders will benefit. At least this is how many researchers (Alden & Ross, 2016 and Kahumbu, 2016) interpret the data derived from the one-off sale of CITES sanctioned ivory sale that took place 2008. Over 100,000 Kg of Ivory was sold between Botswana, Namibia, South Africa and Zimbabwe to China and Japan. However, researchers like Rice (2012) claim that in spite of these sales ivory poaching actually increased.

Daniel Stiles, an independent researcher residing in Kenyan has provided empirical evidence that disputes the relationship between increased poaching and one-off sales. He agrees that neither poaching-rates nor ivory prices decreased after the one-off CITES sale, but argues that the reasons for this are attributed to macro-economic factors. Stiles shows that the price of Ivory increased from $560-750 per kilogram in 2006 to $2,100 per kilogram in 2014, but that the increase in price is more closely correlated to the global financial crises of 2008 and the flight to safety than any one-off sales.

To put this data in historical perspective it's important to realize that in the 1980's stockpiling of raw ivory was going on in China and Hong Kong before the ban, as dealers knew that a ban was imminent. The African elephant was placed on the endangered species list in 1978, but with a 'special rule' that allowed for the commercial trade to continue. The poaching rate between 1978 and 1989 when ivory was eventually banned therefore can be attributed more to dealer demand than consumer demand: Stiles writes "If high consumer demand had been the cause of the increased poaching, the stockpiles would not have existed. The raw ivory would have been processed" (2014 pg 3). During this epoch, according to Stiles, the calls for international Ivory ban led to increased poaching because East Asian dealers chose to stockpile before the ban. It created a situation where "the two fed each other in a positive feedback loop—increased poaching, increased calls for control, leading to more poaching to stockpile, ad infinitum until the ban" (ibid. 3).

So from this historical backdrop it seems counter intuitive that a one-off 2008 CITES-approved ivory sale to Japan and China would lead to increased poaching. The ivory entering the market through sanctioned sales would either drive down price and/or be stockpiled. However in 2008, in addition to an increase in supply there was also an increase in consumer demand (Russo 2014). But where did the increased demand come from? Stile's sites the work of Yufang Gao, a researcher from China who points to factors such as (1) the Chinese government's designating ivory carving as national intangible cultural heritage and (2) then maybe more importantly an overall boom in art investment in China—especially after the global economic crisis. "As real estate and stock markets tumbled, a large amount of capital from individuals and professional investment companies started to enter the art market…carved ivory was touted as a profitable investment. Media coverage about he astronomical prices of auctioned ivory greatly boosted the perceived economic value of ivory products, new or old, which led to an explosion of ivory demand" (Stiles 8). During this time period the price of Ivory was closely correlated to the price of Gold (Schwartz 3).



Source: Stiles (2015) 'The real reason for the drop in illegal raw ivory prices in China'. *LinkedIn Pulse.* *https://www.linkedin.com/pulse/real-reason-drop-illegal-raw-ivory-prices-china-daniel-stiles*

We clearly see that macroeconomic forces play an important role in Ivory trade and poaching rates. In the 80's ivory was being stockpiled in anticipation of a trading ban; it was not being processed into high-value artwork. The macro-economic environment of the 80's gave investors many opportunities to achieve higher returns with their capital in other markets. With the economic crisis beginning in 2008 this was not the case.

Bio-economic models to avoid extinction

Are their existing models that can incorporate these macro-economic factor? The Gordon-Schaefer model is a bio-economics model, adopted by the Food and Agriculture Organization of the United Nations, designed to incorporate as many macro-economic variables as possible into managing natural resources, and was originally applied to sustainability in fishing. This model tries to show the cheapest long-run policy that eliminates extinction of the natural resources, and in the case of Ivory, the cheapest outcome is to keep the stockpiles. It is one option that at least that would prevent the positive feedback loops Stiles describes.

Critics of this model say that it only works if the goods are storable but not durable (goods that are not destroyed when they are consumed are considered durable) (Nadal and Aguayo 7) Ivory is storable and durable because even after it is sold, in most cases it remains extant as ornamentation (versus Rhino tusk that is consumed and therefore not durable). A further factor is that no economic model on Ivory has explicit price formation mechanism. There is not one unique market or exchange, so clearly lacks homogeneity. Additionally much of the illicit trade in Ivory occurs with other trade (whether it be weapons, drugs, other contraband).

One thing that is known for sure is that price is inversely related to population and that is the only rule we have. But to go from price to population and then look at supply and demand we must understand that consumer sentiment (demand) has a limit--regardless of supply. This is because Ivory is by-in-large a luxury item. Stiles makes the analogy that "it does not matter how many consumers want to buy ivory any more than it matters how many people want a Ferrari. What matters is how many want *and* can afford to buy. If one really wants to lower consumer demand, it is imperative that mainly very expensive ivory items are manufactured" (Stiles 2015 pg. 6). If the Gordon-Schaefer model shows that destroying ivory stockpiles does not make cost-effective sense to prevent elephants from extinction then provenance, registry, and management of these stockpiles becomes a paramount task. A possible way going forward to achieve this level of accountability would be to utilize blockchain technology, and will be discussed in the final section of the paper. The next section however will look at the (1) Yasuni-ITT initiative to see if analogues in conservation of natural resources with experimental models of economics can inform the debate on elephant conservation.

Controlling supply: the economics of no availability (or future availability)

In the field of bio-economics we can look at another project that has attempted to peg a natural resource to a store of value without actually harvesting the resource. This is the Ecuador's Yasuni-ITT initiative, started by Ecuador president Raphael Correa in 2007. It makes and attempts to peg a convertible asset to a natural resource. It was one, he said at the time of the launch, which 'seeks to transform old notions of economics and the concept of value'.

The market logic states that for a poor-country like Ecuador a reserve of oil can be extracted and bring significant increases in the GDP of the country. The Yasuni-ITT initiative marks an attempt to change this logic, and acknowledges the embedded context of any value exchange within a greater context of social and economic practices (Rival 3-4). This is not to say that the oil is worth more in the ground than extracted, but that with so many difficult to quantify tangibles concomitant to the extraction—depletion of primeval rainforest, displacement of indigenous peoples, and CO2 emissions coming from the combustion of such fuel—there has to be a cost-benefit threshold where the oil is worth more in the ground.

This innovative proposal means that areas where there are conflicts between natural resource extraction and biodiversity protection may have another alternative to consumption of their resources in order to fuel they economy (Finner 2). This proposal seeks the same economic outcome but with alternative actions: It's one where value is made liquid in exchange for protecting the resources instead of extracting them. The crucial part that hasn't been determined yet is exactly how to go about accounting for the value of these natural resources. Initially in 2007 Correa had asked for around 750 million USD per-year for 10-years which would amount to roughly half the value of the projected revenues if the oil was extracted. Then in mid-2008, partly due to the global economic crisis and subsequent difficulty in finding contributions, the strategy shifted. Ecuador announced that it would issue 'Yasuni Guarantee Certificates' for the CO2 locked in the oil fields with the objective of making them fungible in the European Union's carbon credits market" (Finner 3).

A YGC would offset 1-ton of carbon emissions in the same way that other carbon credits offset carbon emissions. There are questions concerning what might happen with future governments, who could change the decision and decide to drill. In the proposed scenario however the proceeds from the YGCs would be held in a trust and only the interest on the trust would be used to fund government projects in the country. In the case that drilling in the Yasuni took place the assets of the trust would be liquidated and returned to their original owners.

The Yasuni-ITT initiative, going on 8-years since the initial proposal, has not been successful in the sense that the project is still in peril, and the possibility for drilling still exists (in fact permits for drilling were signed in 2014, with Correa saying that "the world has failed us" after only 13-million of the over 3-billion dollar goal had been earmarked for the project). Critics say that the project was doomed from the start because Correa was negotiating mining rights even has he brought the conservation project to the international community (Keyman

2015). Regardless the idea has sparked much debate and theorizing about a new-way forward to finance projects without destroying biodiversity. One of the ironies in the project is that blockchain technology was just beginning to be developed at the same time as the Yasuni-ITT initiative was first advanced. The possibility that this technology could be integrated with a bio-economic project will be the subject of the rest of this paper.

Pegging digital assets to natural resources

We know that individuals use Ivory as a store of value, especially in times of economic crises, because of its perceived status as a safe asset with low volatility. This means that it has inherent value as an investment vehicle. The problem is that elephants produce ivory, and the only way to possess the value of the ivory (as personal property) is by either killing the elephant, or waiting for the elephant to die naturally.

The Great Elephant Consensus was just completed and presented at the World Conservation Congress in Hawaii in August 2016. The joint project of Paul Allen and Elephants without Borders set the task of counting African elephant populations by air. Additionally thanks to Kathleen Gorbrush of Save the Elephants we have empirical data on the amount of natural deaths of elephants on a yearly-basis, as well as the amount of stockpiled Ivory, as well as the number of deaths due to PAC (problem-animal-control).

	Empirical method, 12 sites			Model-based method, 306 sites		
Region	2010	2011	2012	2010	2011	2012
Africa						
Population growth rate	0.978	0.976	0.977	1.001	0.971	0.979
Poaching rate	0.063	0.083	0.065	0.045	0.077	0.077
No. poached	29,124	41,044	31,616	21,477	39,692	38,828
Central Africa						
Population growth rate	0.979	0.795	0.790	0.969	0.926	0.932
Poaching rate	0.142	0.248	0.235	0.100	0.160	0.177
No. poached	11,228	21,148	16,148	7,871	13,649	13,607
East Africa						
Population growth rate	0.988	0.988	0.983	0.994	0.960	0.979
Poaching rate	0.054	0.054	0.059	0.042	0.074	0.059
No. poached	7,187	7,763	8,695	5,645	10,631	8,515
Southern Africa						
Population growth rate	0.978	0.974	0.980	1.019	0.996	0.996
Poaching rate	0.064	0.068	0.062	0.023	0.046	0.048
No. poached	15,800	18,176	16,583	5,740	12,285	13,303

From Wittemyer et. Al (2014)

Utilizing this data, and according Stiles (2015) calculations' 60 tons of legal ivory could be exported from Africa annually for at least ten- years, without a single poached tusk needed. This estimation is conservative when compared with a report given at the CITES October 2016 meeting Johannesburg, that estimate stockpiles at approximately 1,000 tons – or 1 million kilograms. At the current prices for a kilogram of ivory going for around $2000, 60 tons could easily generate $15-million in revenue per year.

This scenario of course only occurs if CITES lifts the ban on Ivory trade, in favor for state-sanctioned yearly auctions. The reasons for destroying stockpiles largely come from opponents who focus on the security-risk, and high cost of guarding the stockpiles and preventing illegal leaking. However if net-benefit can be realized than any operating casts can be justified, especially if using novel technology can help mitigate risk.

By utilizing a blockchain a database for the stockpiles can be created that would track inventory and provenance. A blockchain is a transparent accounting ledger maintained by a distributed network and agreed on through a consensus protocol (see Berger 2014, Stalnaker, 2014, Bolier 2012). As a technology, blockchain has gained most notoriety from the experiment in open-source currency called Bitcoin. It's possible to use either the same blockchain as bitcoin, issuing a digital asset on top of the bitcoin blockchain, or to create a new blockchain and issues assets over that blockchain, as well as track the provenance of those assets. Each scenario has benefits and drawbacks, but for the purposes of this paper in either scenario these tokens can represent anything the issuer desires and the value, like any commodity, virtual or otherwise is totally market driven.

So in additional to tracking and registering the ivory stockpiles it would also be possible to create a token that represents the total insitu ivory on the planet. This would allow conservationists to transfer--and engage in financing made available only through liquid capital--the value of such tokens without having them removed from living elephants.

While value of the stockpiles measures in the billions or trillions of dollars the value of the total insitu ivory is much greater. Here it must be noted that 'living' is not just a rhetorical device but literal because ivory continues to grow until the day that an elephant dies. The problem is the value of insitu ivory is not liquid, the same way that the value of oil reserves underneath the earth can't be accessed without drilling. We have empirical data that shows individuals invest in ivory as a store-of-value, especially in order to protect capital in times of economic volatility. So what if it were possible to invest in *insitu* ivory?

This is precisely what pegging ivory to a digital asset would try to achieve. Even though we have the technology to achieve this there remains secondary, non-technological factors to be considered. Currently, a problem exists with pegging a digital asset to a natural resource: namely the onboarding. With live elephants who is to be the authority that says how the elephant population is decreasing or increasing (in lieu of putting trackers on every elephant)? We need a group of curators or otherwise trusted individuals to verify the elephant population year-over-year. This however can surely be achieved by a trust. With the stockpiles security is still needed to prevent physical left, since even if a tusk gets red-flagged on the database for being stolen it can be still be sold through channels that don't use the system. But if the market is driven at only high-end collectors pieces then those would be more likely to be bought with provenance, and provenance would greatly increase the resale value of such a piece.

Another issue regards the typically inverse relationship between value and scarcity we find in economics. Normally the scarcer an asset is the more valuable it becomes. Gold, for example, is seen as a valuable asset because it is finite in value. With the case of insitu ivory the closer elephants come to extinction then the more finite ivory becomes. The value of a token representing insitu ivory must rise in value as elephant populations increase. A scenario where the elephant population dwindles to extinction-levels and the value of this token soars in value is not enviable. Rather, there must be reverse relationship to the normally inverse relationship of wealth and scarcity. This long-term goal is a scenario that would stop the positive feedback loop described by Stiles. Short-term benefits are also realized by giving tangible equity and buying power to tens-of-thousands of small-scale farmers that live in proximity to elephant populations. So while a decrease in population could trigger a price increase for ivory—and indirectly drive up the value of the token—over the long-term a larger (and older) elephant population means a much greater total value for the token.

People that will want to invest in this token will be those who want to see elephant populations grow and flourish. An investor in the token will be banking that elephant populations will reach levels where the ban on Ivory trade may be removed. Once the elephant populations stabilize and legal, transparent trade can begin then investors can redeem the tokens for the market-value or if choosing to hold the coins receive a dividend from the proceeds of future sales. How might this work? As Stiles writes, "the solution involves bringing African governments into a transparent, regulated trade that confers benefits on rural people who live with wildlife. These people are the foot soldiers of poaching. If Ivory and other wildlife products could meaningful contribute to their livelihoods in a legal manner, they would be motivated to manage wildlife for the future" (2015 pg. 3)

By applying two applications of blockchains, in combination, this goal can be achieved. First, as a decentralized database for tracking stockpile provenance. Second, as transaction settlement mechanism, tokenizing insitu ivory so that the value of the ivory can be transfered between parties without killing elephants. This combination would effectively create decentralized autonomous organization. Capital invested in tokens, either coming from individual investors or from the sale of ivory stockpiles can be used to employ communities who live in elephant conflict zones. Whether through direct-employment or through loans to develop entrepreneurial endeavors, the value of ivory would be used as a collateral to inject capital into communities that are on the front line of poaching, effectively making it more economically viable to protect elephants than murder them.

The token would also be an ideal investment for those same individuals who had previously bought physical-ivory during economic crises. In some cases it would even be more enviable because since it is a digitally controlled asset is much more liquid than possessing physical ivory. A large portion of the proceeds from the sale of the tokens would need to go to conservation trust. The communities that are closest to the elephants are those who in many respects (and like the indigenous communities of Ecuador) own the natural resources. If they can hold tokens as a community bank than their value can be leveraged for community projects and infrastructure that will bring wealth into the community without having to make the decision to murder elephants for capital gain.

Going forward future research needs to be done on modeling, starting with a test region before expanding further. Zimbabwe for example has 83,000 elephants. We know that the average tusk weight for 60-year-old elephants is 61 kg for males and 9.2 kg for females. However we need a algorithm that can capture population, age and ivory growth. Then a partnership is needed with an organization on the ground that can help to represent the local communities in terms of allocating resources coming from the crowd sale of the tokens. The final step is to start piloting the project on the ground, and to analyze data to see if the efforts increasing the elephant population.

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Open Source 3-D Printers: An Appropriate Technology for Developing Communities

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Abstract

The recent introduction of RepRap (Self-Replicating Rapid Prototyper) 3-D printers and the resultant open source technological improvements have resulted in affordable 3-D printing, enabling low-cost distributed manufacturing for individuals. This development and others such as the rise of open source-appropriate technology (OSAT) and solar powered 3-D printing are moving 3-D printing from an industry specific technology to one that could be used in the developing world for sustainable development. In this paper, we explore some specific technological improvements and how distributed manufacturing with open-source 3-D printing can provide sustainable development by creating wealth for developing world communities through the ability to print less expensive and customized products. Conclusions on the technical viability of 3-D printing to assist in development and recommendations on how developing communities can fully exploit this technology have been outlined.

Keywords
3-D printing, appropriate technology, OSAT, economic development, Recyclebot, developing communities, distributed manufacturing, solar powered 3D printers.

1.0 Introduction

Although proprietary and expensive 3-D printers have been available for decades, only recently has the introduction of the RepRap (Self-Replicating Rapid Prototyper) 3-D printing project [1-3] radically reduced the costs of 3-D printers and made them available for entry level markets [4-5]. Free and open-source hardware (FOSH) developed along with the RepRap 3-D printer models have asserted 3-D printing as not only an innovation platform for promoting distributed manufacturing systems, but also as a novel form of localized and customized production [6]. Using computer aided designs, it is now possible to fabricate and customize products cheaper, faster, and from the comfort of the user's home. Additive manufacturing in the form of open-source 3-D printing, combined with distributed generation through solar powered 3-D printers, has the potential to alleviate poverty in impoverished rural communities. Price declines and technological improvements are moving 3-D printing from an industry specific technology to one that could be used in the developing world [7-12]. For example, 3-D printing may radically improve access to eye care, and may be used to manufacture livestock feeding stations that reduce disease transmission and improve agricultural productivity [6,13]. In 2010, Pearce et al. [7] proposed a research plan for enabling people to print themselves out of poverty with open source 3-D printing and Gebler et al. have argued 3-D printing can aid in global sustainability [14].

This paper will review the current status of 3-D printing for sustainable development by evaluating the technical and economic viability of 3-D printing in the two main categories; 1) technological improvements, which includes a) RepRap evolution and its features appropriate for development, b) recyclebots and availability of local 3-D printing materials, c) off-grid solar-powered 3-D printing and, 2) applications for development. Necessary further development will be outlined and conclusions will be drawn on the technical viability of 3-D printing to assist in development.

2.0 Technological Improvements

2.1 3-D printers: RepRap Evolution and Features Appropriate for Development

The RepRap project was started by Adrian Bowyer at the University of Bath [3] in 2004 as the idea to make a 3-D printer that could self-replicate. Specifically, it was made to be a fused filament fabrication (FFF) rapid prototyping machine (RP) that could make most of its own parts [1]. FFF is an additive manufacturing technology—material is deposited in layers which are joined to each other through heat [15]. When it was first introduced, all the RepRap designs and software were made open-source for the world to have and improve upon [3]. The first RepRap produced was called Darwin, a box-like 3-D printer made of mostly metal and 3-D printed parts [1]. To fix problems Darwin was experiencing, the next RepRap 3-D printer was built—Mendel. Mendel improved upon Darwin by decreasing the weight of the printer, increasing axis efficiency, making assembly simpler, and allowing for extruder head change [7]. The RepRap machine has started the open-source 3-D printer community [15] and is now the most widely-used 3-D printer among the maker community [1,16].

2.2 Recyclebots and Availability of Local 3-D Printing Materials Feedstocks

3-D printing filament is traditionally manufactured from raw virgin materials, which is generally landfilled at the end of the life cycle of the 3-D printed product. This filament is also expensive, with minimum costs of about $20/kg for PLA in the Internet [18]. However these costs are significantly inflated as the cost of resin pellets ranges from $1-4 per kilogram [19]. In addition, these prices can be further reduced by obtaining filament using recyclebot technology. Recyclebots are open-source waste plastic extuders capable of turning post-consumer thermoplastic containers into 3-D printer filament [20-21].

The Ethical Filament Foundation is a member-owned, not for profit organization, whose goal is to grow the waste plastic recycling industry through the underdeveloped world [22]. The people in the underdeveloped world could benefit greatly from 3-D printing by having the means to produce needed tools on their own time [7]. However, to do this, communities need reasonably priced filament. The Ethical Filament Foundation promotes having waste pickers—who now earn pennies a day—take plastics from landfills and use recyclebots to make low-cost filament while being paid fairly for their work. This will benefit both those people whose only job is to pick out waste from landfills and the environment, since these plastics will be used again instead of decaying over the centuries in landfills [23]. After the filament is produced, it will be tested for quality and given the Ethical Filament stamp of approval, which shows that the filament was ethically produced and is of high quality [24]. This allows people living in underdeveloped countries to have plastic filament without procuring additional costs from importing materials [24].

Table 1. Market survey for some entry level FFF open-source 3-D printers showing the cost, build volume, print speed, print materials, OS supported, and ability to print without a computer.

Characteristics	**LulzBot Mini 3-D Printer**	**LulzBot TAZ 6**	**Ultimaker 2+**	**Ultimaker 2 Extended +**
Cost	$1,250.00	$2,500.00	$2,499.00	$2,999.00
Build volume	3,650 cm^3	19,600 cm^3	10,194 cm^3	15,167 cm^3
Print speed	Up to 275 mm/sec	Up to 200 mm/sec	Up to 300 mm/sec	Up to 300 mm/sec
Print materials	ABS, PLA, HIPS, PVA, wood filled filaments, Polyester (Tritan), PETT, bronze and copper filled filaments, Polycarbonate, Nylon, PETG, conductive PLA and ABS, UV luminescent filaments, PCTPE, PC-ABS, Alloy 910	ABS, PLA, HIPS, PVA, wood filled filaments, Polyester (Tritan), PETT, bronze and copper filled filaments, Polycarbonate, Nylon, PETG, conductive PLA and ABS, UV luminescent filaments, PCTPE, PC-ABS, Alloy 910	PLA, ABS, CPE	PLA, ABS, CPE
OS supported	Mac OS X, Windows, Ubuntu, Linux	Mac OS X, Windows, Ubuntu, Linux	Mac OS X, Windows, Linux	Mac OS X, Windows, Linux
Ability to print without a computer	No	Yes	Yes	Yes
Characteristics	**Rostock MAX v2**	**Printrbot Play**	**Printrbot Simple**	**mElephant**
Cost	$999	$399	$599	$600
Build Volume	92,363 cm3	1,300 cm3	3,375 cm3	5,760 cm3
Print speed	Up to 300 mm/s	Up to 80 mm/s	Up to 80 mm/s	General print speed 50 mm/s
Print materials	PLA, ABS, PETG, Nylon	PLA	PLA	PLA
OS supported	Linux, Mac, Windows	Linux, Mac, Windows	Linux, Mac, Windows	Linux, Mac, Windows
Ability to print without a computer	Yes	Yes	Yes	Yes

Table 2. Market survey for entry level FFF open-source 3-D printer kits for cost, showing build volume, print speed, print materials, OS supported, and ability to print without a computer.

Characteristics	Ultimaker Original+	Printrbot Simple	Original Prusa i3	MOST Delta II (Athena)
Cost	$995.00	$599.00	$599.00$500.00	
Build volume	9,040.5 cm^3	3,375 cm^3	8,000 cm^3	11,781 cm^3
Print speed	Up to 300 mm/sec	Up to 80 mm/sec	Up to 200 mm/sec	110 mm/sec
Print materials	PLA, ABS, CPE	PLA	PLA, ABS, PET, HIPS, Flex PP, Ninjaflex, Laywood, Laybrick, Nylon, Bamboofill, Bronzefill, ASA, T-Glase, Carbon-fibers enhanced filaments	PLA without alterations anything with upgrades [17]
OS supported	Mac OSX, Windows, Linux	Windows, Linux	Mac, Windows, Linux	Mac, Windows, Linux
Ability to print without a computer	Yes	Yes	Yes	Yes.

2.3 Off-Grid Solar-Powered 3-D Printing

Most communities in developing countries are generally remotely located and isolated without access to a reliable road network or electricity grid. To address the challenge this poses to embracing 3-D printing technology in these remote rural areas, off-grid solar-powered 3-D printers were developed [25-27]. The most recent version of this technology was equipped with a battery that would charge during times of excess power being supplied by the solar photovoltaic (PV) modules and would discharge during times of low power output [25]. This new version, which uses a MOST-delta solar-powered RepRap 3-D printer is light to transport as a single unit. All the components including the printer can fit in a duffle bag for easy transit. Therefore, solar-powered 3-D printers have the technical potential to enable local customization of complex designs, whilst ensuring uninterrupted supply of essential needed parts for rural remote communities. Prototypes of solar powered 3-D printing systems have already been demonstrated for semi-mobile systems [27] and a highly mobile system [25]. The latter could be used to make, for example, replacements parts at any rural development center, school or even home. The former system is designed to become a permanent fixture at rural schools that are not connected to the electrical grid. Thus, the solar-powered 3-D printer could be used to make high-value products such as scientific tools for research or education [28-29], equipment for use in medical clinics [30], and other items which can be used for disaster relief [31]. Thus, this will help alleviate the problems of science equipment shortages in the developing world schools and medical centers by making available the much needed hardware at a fraction of a cost [32]. Solar-powered distributed manufacturing allows off-the-grid rural communities to leap to a more sustainable method of production.

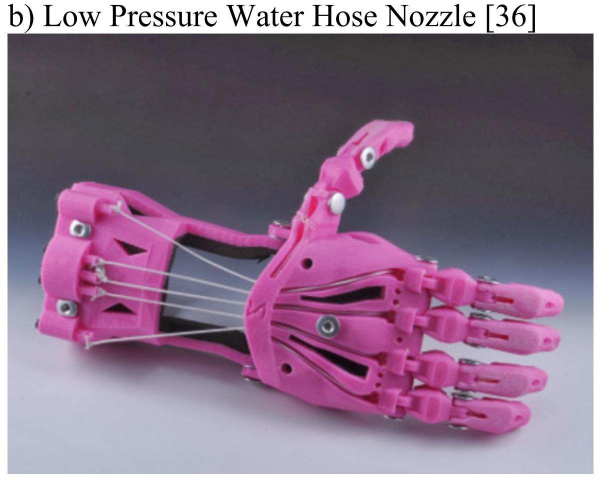
Fig. 1. Solar Powered MOST-delta 3-D printing, 3 x 12 V, 24 W solar panels, and printer with panel mounted in a duffel bag [25]. The PV modules are clipped to the frame of the RepRap for shipping.

3.0 Application for Development

a) Hammer [35]

b) Low Pressure Water Hose Nozzle [36]

c) Chicken Feed Holder [37]



d) Cyborg beast [38]

Fig 2. Sample OSATs for economic empowerment of communities in the developing world

The technical development of the open-source 3-D printer enables low-cost distributed production, which can be a key ingredient for economic emancipation of underprivileged resources starved developing communities. Distributed manufacturing with 3-D printing can empower communities through the ability to print less-expensive and customized products. The capacity to locally fabricate and optimize products such as the chicken feeder and other open source appropriate technology (OSAT) [33] products will be of great economic value to rural communities. Previous work has analyzed the case of organic farmers [34]. However, OSATs can be developed for any particular type of community or means of employment and can be easily printed by people in the developing world who have access to an open source 3-D printer. Examples are shown in Fig. 2.

Table 3 shows the economic comparison for the 3-D printed OSATs products in Fig. 3. As can be seen from Table 3, locally 3-D printed items are much more cost effective than buying them on the market or importing them from other countries. These and other similar tools could help transform resource constrained communities for the better since they are required for daily chores/tasks such as construction (i.e. the hammer), farming and agriculture (i.e. low pressure water hose nozzle, and the chicken feed holder).

3-D printing can also be used in medical applications in the developing world. One example of this is an organization called Enabling the Future. Enabling the Future is a global community of people owning 3-D printers who volunteer to print low cost prosthetics for children around the world. All of their hand designs are open source for anyone to print and further improve on. For children with partially functioning wrists, the wrist actuated designs including the Raptor Reloaded, Raptor, Talon, Cyborg Beast (Fig. 3), Ody Hand, Flexy Hand, Phoenix Hand, and Osprey Hand are ideal. There are also designs available for children without a functioning wrist such as the Team Unlimited Arm and the RIT Arm. The community has grown to over 7,000 online members [39-40]. These 3-D printable prosthetic hands have the potential to help many people—especially in developing countries—that do not have enough money to pay for expensive prosthetics sold commercially. They can give some people the opportunity to do work and make money in a way that they were not previously able to before because of physical constraints.

Organizations like Field Ready and iLab Haiti have already started bringing 3-D printing technology to disaster struck places and the developing world and providing technical training in that country. These organizations have shown that training people to use 3-D printers in the developing world is possible. Furthermore, Michigan Tech's project with Enabling the Future volunteers from Nicaragua also successfully brought 3-D printing to the developing world by first training people in the U.S. to provide technical support in country. These projects have helped people with a real need, and can be expected to increase utility in the future as additional OSATs are designed.

Table 3. Economic Comparison for Selected 3D Printed OSATs Products

Design	Amount of filament needed (grams)	Approximate capital costs (US$)	Total retail cost low (US$)	Total retail cost high (US$)	Percent change low	Percent change high
Hammer	235	6.31	7.31[41]	199.97 [42]	-58%	-3,069%
Cyborg beast prosthetic hand	70	36.61	225 [43]	100,000 [44]	-515%	-273,049%
Low Pressure Water Hose Nozzle	53	1.22	3.14 [45]	19.99 [46]	-157%	-1,539%
Chicken Feed Holder	290	6.66	12.23 [47]	28.95 [48]	-84%	-335%

This need for more designs also makes clear the primary current limitation to this approach. Although there are several million free and open source designs available, only a small fraction are of high-quality OSAT like those shown in this paper. This is a tiny fraction of the products normally available to consumers anywhere in the world. To put this into perspective in 2013 Amazon sold over 230 million products in the U.S. [49]. Many freely available designs are simply customized derivatives, or poorly executed non-functional designs, which are partly due to changes in the goals and license agreements for the largest design repository [50]. In order to make this method of OSAT deployment viable more and better (improved) designs are necessary in a wide range of products that would be of service for developing communities of any level of sophistication. Ideally, these free designs would be vetted, tested and housed in a reliable centralized repository [50]. Future work is needed in this area.

4. 0 Conclusions

This paper have presented some of the technological improvements and innovations of 3-D printing and how an open source-based distributed manufacturing technology can benefit resource-constrained developing world communities. Highlights on how these innovations have ignited the transition of 3-D printing technology from being sorely industry-based to being home-based technology are also presented. Cost reductions coupled with technological improvements such as open source highly portable 3-D printer models capable of operating off the grid can be the key drivers for the adoption of 3-D printers by individuals. Various examples presented in this paper on the use of 3-D printers for development suggest that there is a great potential for 3-D printing technology to be used as a tool for sustainable development in the developing world. This technology will enable developing-world communities to locally customize and fabricate need-driven OSATs for their day to day use and by so doing empower them to create wealth through establishing small sustainable enterprises. The use of appropriate 3-D printed OSATs has the potential to result in better products and improved agriculture yields, which will help reduce poverty, hunger and improve the general life style for many. There is however, the need for further research to improve and customize open source 3-D printers, recyclebot technology, open source photovoltaic powered 3-D printing, and the designing of more useful OSATs for the developing world. The ability to locally fabricate both 3-D printers and the printing filament using local materials is a key to the successful adoption and implementation of the 3-D printing technology in the developing world. Current work in these areas show enormous potential for bringing 3-D printing to the developing world in the near future.

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Bio-Digester Technology: Process selection through multi-criteria decision analysis

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Abstract

This paper reports on a case-study of a biogas project commissioned by the City of Johannesburg and executed by researchers from the University of Johannesburg. The goal of the project was to investigate the feasibility of setting up a pilot scale biogas production plant at a City of Johannesburg waste dump site. Waste produced at this site was quantified and characterised. The pilot biogas plant was to produce biogas of sufficient quality and quantity to power a city commuter bus. This work presents a critical review of the different anaerobic bio-digester technologies in existence, their applications, operating technical parameters, and their advantages and disadvantages. The aim of this paper is to report on the selection procedure that led to the recommended solution for the project. A multi-criteria decision analysis (MCDA) tool was applied to the identified technology options. Key selection criteria included ease of use, substrate availability and quality, climatic conditions and others. The ranked criteria were applied to selection of optimum solution among complete mix CSTR, up-flow anaerobic sludge blanket (UASB), plug flow, covered lagoon, fixed film, horizontal, vertical, multiple and single tank digesters. The CSTR best met the selection criteria and was recommended for implementation. The proposed plant had capacity to process at least 10 tonnes of biodegradable waste from the total amount of biodegradable waste generated per day, with the intention to scale up the capacity to 50 tonnes with time, subject to the plant's performance.

Keywords: Bio-digester, Biogas, Biomass, Criteria ranking, Multi-criteria decision analysis

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Summary-view: Biomass anaerobic respiration technology in South Africa

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Abstract

This paper reports on a biomass anaerobic decomposition technologies with particular reference to South Africa as a developing country taking strides on green energy production in an effort to lower the carbon foot print and preserve the environment. It explores the utilisation, implementation and operation of biomass anaerobic respiration technology in the production of biogas as an emerging alternative energy source. This review is a summary of different aspects of the design and operation of small-scale, household, biogas digester technologies. It covers different biomass anaerobic technology projects, both small and large scale (municipal solid waste, abattoirs, farms, wastewater treatment facilities) currently in operation and under construction in the republic of South Africa from the introduction of the technology through to the current generation of the technology. This also includes projects that were visited during the City of Johannesburg-University of Johannesburg waste to energy project capacity building exercise. Various efforts have been made in the past to assess the feasibility of the application of biogas technology in South Africa. These are identified mainly by reviewing the available literature. Recommendations are made on how best to tackle biogas production challenges and promote the notion of biogas production in South Africa.

Keywords: Anaerobic respiration, Bio-digester, Biogas, Biomass.

Introduction

Biogas technology has been implemented all over the world. Despite efforts in place on green technology advancements in South Africa, the growth of biogas technology is still lagging behind (Roux 2013). Energy plays a central role in national development process as a domestic necessity and major factor of production, whose cost directly affects price of other goods and services. It affects all aspects of development, such as social, economic, political and environmental, including access to health, water, agricultural productivity, industrial productivity, education and other vital services that improve the quality of life (Amigun , Sigamoney and Von Blottnitz, Review: Commercialisation of biofuel industry in Africa 2008). The history of anaerobic digestion of biomass for energy production can be traced back to the 10th century BC with the earliest available record being around the 19th century. The first remarkable application of biogas as a fuel was recorded in England in 1859 (Bond and Templeton 2011). Biogas is currently used in many developing countries as an alternative and renewable source of energy for wide spread range of applications. Currently in Germany and other first world countries, biogas technology is in advanced stages and being used to produce green electricity in the megawatt range. Economic production of biogas can be achieved for both large and small scale applications (Kumar 2013).

The high dependence on fossil fuels in South Africa and the world in general over time has led to rising energy costs and environmental concerns in the recent past that have in-turn sparked sustained interests in biogas as a potential clean energy alternative. Efforts to address the growing issues have seen the formation of organisations such as Southern African Biogas Industry Association (SABIA) tasked with the responsibility of streamlining knowledge transfer and policies which are all still a work in progress (Roux 2013). It is important to note that African countries need sustainable energy supplies to be in a position to improve their overall net productivity and become major players in global technological and economic progress. Unreliable energy supply may account for the low levels of private investment the African continent attracts and the poor economic productivity of its limited industries. Improvement in the quality and magnitude of energy services in developing countries is required for them to meet developmental objectives including the Millennium Development Goals (MDGs) (Bank 2003). Generally, authors have encouraged the development of biogas technology in South Africa, with its implementation on commercial farms being regarded as economically viable under certain circumstances (Rivett-Carnac 1982).

Anaerobic respiration of Biomass

The anaerobic digestion process involves placing the waste organic material in tanks or digesters protected from oxygen and maintaining the digester temperature between 35 °C and 37 °C (ADEME 1988). The process is based on microbial activity taking place in oxygen free (anaerobic) conditions and results in two end products, energy rich biogas and nutrient rich digestion residue, i.e. digestate. During the anaerobic degradation process several different microbial consortia degrade the raw materials in parallel and/or subsequent degradation steps. Figure 1 shows a detailed schematic of this process of anaerobic digestion of biomass (Luostarinem, Normak and Edstrom 2011). Biogas has an approximate composition of 50-70% Methane (combustible), 30-50% Carbon dioxide and other trace gases depending on the nature of biomass. The typical calorific value of raw biogas is in the ranges of 21-24MJ/m^3 (Kigozi, Muzenda and Aboyade, Biogas technology: Current trends, oppotunities and challenges 2014). On average biogas may also include smaller amounts of hydrogen sulphide (typically 50 – 2000 parts per million [ppm]), water vapour (saturated), oxygen, and various trace hydrocarbons (Krich , et al. 2005).

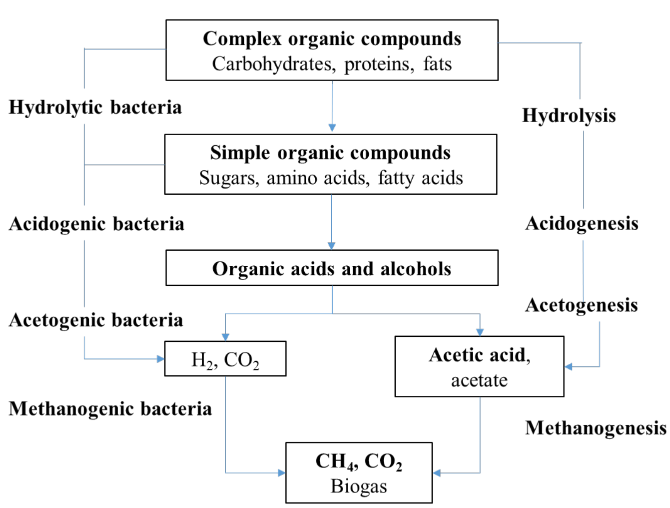

Figure 1: Flow chart of anaerobic digestion (Khavi 2013)

The quality of biogas can be further improved through various upgrading techniques to remove the non-combustible components and as a result increasing methane content to approximate natural gas quality (75-98% (Vijay, Subbarao and Kapdi 2006). The gas produced, in its raw state still has high energy content and can be used in many applications such as heating, cooking, power generation, lighing and as a biofuel that can be injected into the gas reticulation network of a city. However, upon refining, the gas can be used in other advanced applications like automobiles as an alternative fuel. In addition, the digestate (or fermentation residue) produced by the digestion process is a good fertilizer (stabilized mud rich in nitrogen and low carbon) that can be used as manure to fertilize soils that are poor in organic matter (Oilor 2000).

Introduction of biogas technology in South Africa

In South Africa, various efforts were made prior to 1990 to investigate the application potential of biogas technology. (Rivett-Carnac 1982). While not as common as in Europe and Asia, domestic biogas digesters have been installed in South Africa and Kenya since the 1950s. The most widely used biogas model is that of household biogas digester using household and domestic animal waste. Most African countries show a low level of technology development with South Africa listed as having a high level (Amignum and VonBlottnitz 2010). However, as of 2012, it was estimated that there were as few as 150 biogas digesters in South Africa (Payne 2012). In fact biogas systems were first introduced to South Africa in 1957 by a pig farmer in the south of Johannesburg who turned his pig manure into energy. He ran a six-horse-power Lister engine on biogas for a number of years (McCabe and Eckenfelder 2013). The average pig population was 1000. The farm was a model farm on 25 acres. The pigs produced two tons (wet weight) of manure daily. It is this manure that would be fed into digesters for decomposition to produce biogas. Digesters were made from 50 gallon oil drums with the tops cut off and containing slurry of pig manure in each drum. A measured quantity of "starter," was added some from the sewage works and some from a sump located at the lowest point below the piggery. The system produced 8000ft^3 of gas per day (Fry and Merrill 1973). The plant set up is as shown in Figure 2 and Figure 3.

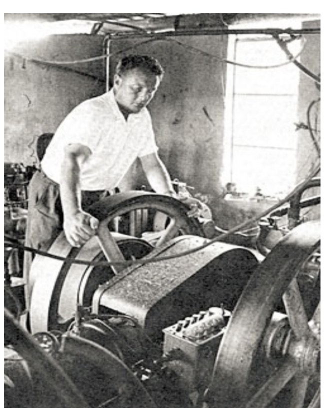

Figure 2: Farm engine fired by biogas produced at a pig farm (McCabe and Eckenfelder 2013)

Figure 3: Biodigester units made from drums (Fry and Merrill 1973)

Following the introduction of the technology, a number of biogas plants were installed around South Africa mostly by individuals who had an interest in the technology. These installations included house hold, farms, learning institutions etc. The following systems are some of the projects to have been set up around South Africa in the early days of the introduction of the technology in South Africa.

Mr Niel Alcock at Mdukutshani farm near Tugela Ferry set up a number of small digesters around the area in the 1970's (Naeser 1983). Professor Dieter Holmb built a 9 m^3 digester on a small lot holding close to the Hartebeespoortdam in the 1970's that was used to decompose biodegradable material to produce biogas. The system was a demonstration model mainly for experimental work (Holm, Holm and Jordaan n.d.). A 136 m^3 digester was built by Mr N Steyn on a farm near Barkly-East, and was in operation during the 1980's (Williams and Eberhard 1986). A small digester was installed at a primary school close to Hillcrest in Natal, by Mr James Rivett-Carnac of the Institute of Natural Resources in the early 1980's (Rivett-Carnac 1982). A small-scale digester was installed at the Economic Rural Development Workshop of the Gazankulu Development Corporation in Giyani in the 1980's (Coertze 1991).

All the biogas plants described above used livestock manure as a substrate that is fed in the digester for decomposition. However, some used human excreta as well. In some cases, animal manure and human excreta are mixed together. The gas produced was used for open flame applications mostly cooking and space heating up. Figure 4 shows some of the biogas plant designs.

Figure 4: A: The floating-drum biogas plant that was built at the homestead of the Mathabela family in Gazankulu. B: The biogas digester that was installed at the Mzimhlophe Secondary School in KwaNdebele. C: The floating-drum biogas plant that was installed at the University of Pretoria's experimental farm. D: The galvanised iron mould used to build the Ferro cement digester at the homestead of the Mathabela family (Thom 1994).

Morden biomass anaerobic digestion technology projects in South Africa

To date there are approximately 700 digesters scattered around South Africa. Most of these are small domestic units and a few non-governmental organisations driven initiatives. Approximately 40% at existing Waste water Treatment Works (WWTW), 50% small scale domestic /rural digesters and only around 10% commercial installations (Tiepelt 2015). Biogas in South Africa has much greater local job creation potential than other forms of renewable energy. It is estimated that biogas as a renewable energy source has the potential to generate five times more permanent job opportunities than solar energy. These digesters are utilising a variety of waste such as from slaughterhouses, municipal wastes, industrial waste, animal dung and human excreta (Omer and Fadalla, Biogas energy technology in Sudan 2003).

Bio2Watt biogas plant

The Bronkhorstspruit biogas plant shown in Figure 5 is the first of its kind in Africa. The plant uses a thermophilic digestion process to decompose biomass and produce biogas which in turn is used to fire engines to produce green electricity up to 4.2MW design capacity (Carr 2014). The project makes use of significant quantities of mostly cow dung manure produced in the surrounding farms. Mixes of other viable biomass waste streams produced from nearby industries are also incorporated (S. Thomas 2016). The project is located in Bronkhorstspruit in the Tshwane Metropolitan area, a 40 min drive from Johannesburg or Pretoria and an agricultural stronghold in the Gauteng province. Situated on the premises of one of South Africa's largest feedlots, Beefcor, the location provides proximity to key fuel supplies, grid access and sufficient water supplied by Beefcor's storm water collection dams. Bio2Watt owns and operates the plant. The plant produced its first power into the national grid on 10 October 2015. The plant's initial life cycle has been estimated to be 20 years. The project has resulted in the creation of long-term direct and indirect employment in peri-urban South Africa, which currently experiences high levels of unemployment (S. Thomas 2015).

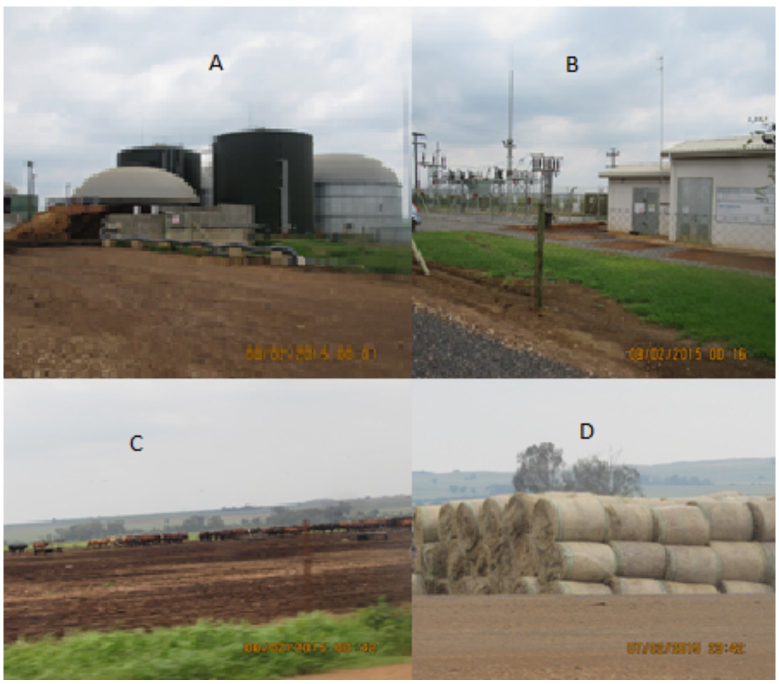

Figure 5:A-Biodigesters and gas holder tanks, B-Generator rooms and power plant unit,C-Cattle pan, D-cattle feed (S. Thomas 2016).

Bio2Watt biogas plant phase 2(Cape Dairy Biogas Plant (Pty) Ltd)

In the wake of its success with the first South African biogas project in Bronkhorstspruit, Bio2Watt will build, own and operate a second commercial biogas project in the country. Situated in Malmesbury in the Western Cape, the project is housed in a special purpose vehicle – the Cape Dairy Project (Pty) Ltd. The Cape Dairy Biogas Project is located on one of SA's biggest dairy farms, Vyvlei Dairy farm owned by Morester, with its principal business being the supply of milk to Clover from an estimated 7,000 dairy cows permanently residing on the farm. Pre-feasibility studies commenced late in 2010 with the signing of an exclusivity agreement with the farm owner and the beginning of an Environmental Impact Assessment ("EIA"). It was submitted to the Renewable Energy IPP program under the Expedited RFP on 11 November 2015. As the plant is fully licensed, should the project preferred bidder be announced, the construction will start in April 2016 (S. Thomas 2015). The project makes use of considerable quantities of slurry manure with a mix of other waste streams available within the surrounding region. The design capacity for the power plant is 4.8MW. The location provides the plant with proximity to key fuel supplies, grid access and sufficient water from water collection dams, boreholes and small streams (S. Thomas 2016).

Uilenkraal dairy farm biogas plant

Uilenkraal dairy farm is located about 20km north of Darling, Swartland 'B' Municipality, Mamelsberry, Western Cape on farm number: 44110. It is home to more than 1 500 dairy cows with capacity to produce 54,000 litres of milk per day. The farm is highly mechanised withan automatic scraper on the floor of each shed that scrapes the manure into a dung channel three times a day. Dung is then pumped into the central dung-collector, and from there it goes to the bio-digester shown in Figure 6 (Basson 2016). 300 tonnes of cow slurry is pumped into the digester on a daily basis. As a by-product, the plant also produces high-quality bio-fertiliser. The facility is able to produce more than 1 000 t/y of methane through a 7 000 m^3 fully mixed, fully heated, lined lagoon bio-digester and a 500KVA power plant (Creamer 2015).

Figure 6: A-Lagoon digester adjacent to generators, B- Dairy cows, C-Gas engine, D- Control room (Basson 2016).

ZANDAM CHICKEN AND PIGGERY

ZANDAM chicken and piggery farm is located 130 km north of Cape Town CBD. The farm is furnished with a 400 m^3 volume capacity digester shown in Figure 7 that is financially viable and compact. IBERT designs biogas plants which run exclusively on waste materials like, animal slurry, food waste, green waste, slaughter waste and most other biodegradable material, small footprint, low maintenance and higher than normal gas yield. In this case, the biogas plant makes use of piggery waste which is collected from the pig sty as its substrate, taken through a channel via the mixing point (chopper pump) where the slurry mixture is mixed to a suitable density. The slurry is then fed to the digester and retained for some days during which biogas is produced. Approximately 30 tonnes of pig waste is generated a day. The biogas produced is stored in a gas tank. The gas is then tapped to fire the gas engine which produces electricity. The power generation has capacity of 75kW CHP. The electricity produced meets the farm's electricity needs including digester heating up (Unterlechner,, et al. 2016).

Figure 7: A-Switch room, B-live stock housing, manure sump, C and Digester unit under refurbishment (Unterlechner,, et al. 2016).

CoJ-UJ-PIKITUP Waste to Energy project

The City of Johannesburg commissioned a waste to energy project at one main waste dump in the city in which the University of Johannesburg research team had to carry out a feasibility study and plant design exercise for the implementation of a pilot scale biogas production plant (Figure 8 gives an overview). The bio gas plant capacity will start off with 10tonnes/day of biodegradable waste and then scale up to 50tonnes/day once the plant is in up and running. Towards developing a sustainable city, the concept of anaerobic decomposition of biodegradable waste is considered a viable and economic solution for the CoJ landfill waste to energy project. A team of researchers comprising of Phd and Master's students from the University of Johannesburg carried out a waste quantification on a waste dump and the Johannesburg Fresh Produce Market to determine quantities of viable biodegradable waste that can be used as feedstock for bio-digesters. Biomethane potential analysis was also carried out on the potential substrates to determine the potential for biogas from the waste production. The feasibility study concluded that an average total of 1,44,772 ton/year of waste is generated in the CoJ. Of this total, 562,028 ton/year is discharged at Robinson deep. The contributions of the stream of interest are 298,493 ton/year (817.8 ton/day), 8,655 (23.7 ton/day) ton/year and 18,213 ton/year (49.8 ton/day) for RCR, Dailies and JM waste respectively. Based on the quantification, the organic mass of the three waste sources is 327.7 ton/day. The contribution of the sources are 277.9 ton/day, 3.4 ton/day and 46.4 ton/day for RCR, dailies and JM waste respectively.

Historical data for garden waste, a potential substrate for anaerobic digestion, was also recorded with about 168 ton/day. This put the total organic waste at 495.8 tons/day or 180,959 ton/year.

If all organic fraction of waste is available for anaerobic digestion, a theoretical 14,096,057 m^3/year of biogas can be produced equivalent to 291,274 GJ/year. The annual biogas yield is equivalent to 8.4 million cubic meter of natural gas, 8 million litres of diesel, and 9 million litres of petrol. The theoretical annual CO_2 reduction when the waste is diverted for use is 124,327 tCO_{2eq}.

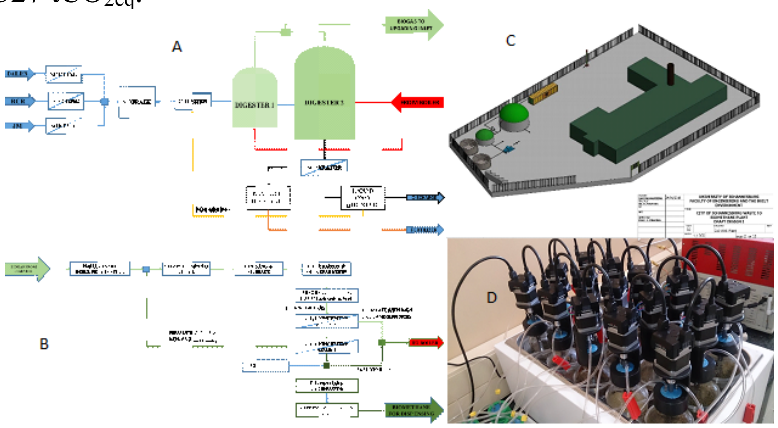

Figure 8: UJ-CoJ waste to energy project.

Other projects

Other anaerobic digestion technologies around the country include the following (Munganga 2013).

1. Joburg zoo biogas plant project, Figure 9: The project was done by the University of Johannesburg research team. The plant is awaiting implementation.

Figure 9: UJ-Johannesburg Zoo waste to energy project

2. Ceres fruit farm-UASB digester, Veolia (1998)
3. Brakpan biogas plant located on a livestock facility and using slurry for the production of biogas
4. Refurbished digester - Joburg Northern Works facility it was commissioned in the year 2013 and has a power plant capacity of 1.2 MW.
5. Eastern Cape-EOI for 110 domestic digesters. The facility was commissioned by South African National Energy Development Institute (SANEDI), and Fort Hare the project was commissioned in 2013
6. Cape Flats biogas digester-dewatering sludge, it is mainly used for waste stabilising currently with a huge potential of generating green energy in the form of biogas(2003)
7. CAE Project:
    - Humphries Boerdery outside Bela-Bela the project has an installed power plant capacity of 30KW
8. iBERT Projects:
    - Abattoir-Jan Kemdorp has and installed power plant capacity of 100kw
    - Cullinan has an installed capacity of 190Kw
    - Robertson has an installed power plant capacity of 150kW
    - Jacobsdal has an installed power plant capacity of 150KW

Socio-economic benefits of biomass anaerobic respiration technology

The anaerobic digestion process has many advantages over other methods of organic waste treatment. The main obvious advantages of biomass anaerobic digestion are, high degree of waste stabilization is possible, low production of waste biological sludge, low nutrient requirements, no oxygen requirements. Methane is a useful end product of anaerobic digestion (McCarty 1964). One of the distinct advantages of such biogas production technology is its ability to be located anywhere where waste feedstock is available. This makes it particularly suitable for rural areas where farming is the main economic activity. As long as the biodigester is supplied with a sufficient quantity of feedstock, power generation is not linked to any specific time periods and can be generated when and where needed. When installed in a rural community, the electricity, heat, gas for cooking or a combination of these promote rural industrialisation (Amignum and VonBlottnitz 2010). Other values can be added, e.g. the improved value of sludge as a fertilizer (Taleghani and Kia 2005).

Obstacles to biomass anaerobic digestion technology in South Africa

In South Africa, the growth of the technology is undermined by stringent non-supportive energy development policies as well as lack of enough plants/resources, research facilities for knowledge transfer as well as perceived slow economic returns (Kigozi, Muzenda and Aboyade, Biogas technology: Current trends opportunities and challenges 2014). The implementation of the biogas technology on a large scale may be prevented or slowed down by a number of constraints. They may be grouped as follows: political, social-cultural, financial, informational, institutional, technical and training (Omer and Fadalla, Biogas energy technology in Sudan 2003). The economy of a biogas plant system set up is characterised by high initial investment costs, some operation and maintenance costs, mostly free raw materials (animal dung, aquatic weeds, terrestrial plants, sewage sludge, industrial wastes, poultry litter etc.) and income from the sale of biogas or electricity and heat (Amigun and VonBlottnitz, Investigation of scale economies for African biogas installations 2007). Good understanding of the relation between capital costs and plant size can provide useful information in assessing economic viability of biogas plants, and providing means whereby decisions are taken on developmental of a new project. In a developing economy, local market opportunities frequently restrict the size of process plants. Scale effects influence costs per unit of capacity (specific cost). The scale economies concept is therefore of key concern because it can help in determining the optimal size and type of a biogas digester (Amignum and VonBlottnitz 2010). However, though there are a number of mechanisms and measures in place to encourage medium scale biogas projects. The Eskom Integrated Demand Management (IDM) offers an incentive for reduced consumption under their Standard Offer Programme (SOP). For every kWh generated by the biogas plant between 18h00 and 20h00 weekdays, for the first three years of operation, Eskom will contribute R1,20. This contributes significantly to reducing the capital cost of the plant. The Industrial Development Coporation (IDC) will provide a below prime loan for green technology investments. Further tax benefits may be available in the near future. Energy savings will be further increased when the influence of the carbon tax (implemented in 2015) on the electricity price is realised (Griffiths 2013).

Pro-Biogas production bodies and their roles: South Africa

In an effort to promote the technology in South Africa, various organisations have been and some are still being formed to try and simplify the complex policies and other obstacle factors. (Kigozi, Muzenda and Aboyade, Biogas technology: Current trends opportunities and challenges 2014). These bodies are comprised of project developers and pressure groups. They include some of the following, Agama, BiogasSA, Solek, Trade Plus Aid, CAE, Bio2watt, EnviroServ, Biogas Africa (Biogas Nord), Lesedi, Talbot & Talbot, iBERT, Prime Solutions, Electrawinds, Aerolog, ENER-G, Biotherm, Veolia, CA Component, Enovation (Munganga 2013). Generally, in Africa the interest in biogas technology has been further stimulated by the promotional efforts of various international organisations and foreign aid agencies through their publications, meetings and visits. Most of the plants have only operated for a short period due to poor technical quality. There is thus a need to introduce more efficient reactors to improve both the biogas yields and the reputation of the technology. The development of large-scale anaerobic digestion technology in Africa is still embryonic, but with a lot of potentials (Amigun, Parawira, et al. 2013).

Discussion

It is important to note that the use of biogas as a fuel in Africa is general still in its infancy since most applications are limited to open flame application like household cooking. However, in South Africa initiatives are in place to take the use of biogas to the next advanced level for example, the City of Johannesburg Metro Bus Company has taken a lead by having some of its buses being fuelled on biofuel. Currently the fleet has about a hundred buses partially running on natural gas.

Biogas production in South Africa has potential both on a small scale (domestic / smallholding / small farm) and on a commercial and industrial scale. A large section of the rural households have no access to electricity and no likelihood of receiving such in the near future. Most of these households have access to suitable feedstock (sewerage, animal manure, food / fruit / vegetable waste) that could provide energy for cooking and lighting. Large scale commercial digesters could be implemented at any number of municipal sewerage works, abattoirs, fruit and vegetable packaging plants, food processing plants, etc. and could typically provide 50% to 70% of the plant's energy requirements. Normally, only a basic assessment and not a full Environmental Impact Assessment (EIA) is required. However, the concept of biogas production has thus far received little attention in South Africa, considering that it has the potential to displace a sizable quantity of Mega Watts on the electricity grid and other thermal power supply options in the country.

Because of the present limited practical experience with the anaerobic process for the treatment of industrial wastes, pilot plant studies should be conducted before full scale design is undertaken. Renewable energy could provide the much desired sustainable rural revitalization in most parts of South Africa especially for low income communities. An ideal renewable energy source is one which is locally available, affordable and can be easily used and managed by local communities.

Conclusion

This work has presented a summary of the development and growth of the anaerobic bio digester technology in the Republic of South Africa. The work looked at biogas technology from its first inception in South Africa by John Fry when livestock slurry/manure was the most common bio digestion substrate available. Typical projects from the introduction era are cited in the work including John Fry's first biogas plant in Johannesburg. Modern/current biomass anaerobic respiration systems in operation, both large and small scale biogas systems have also been presented. Upcoming projects have also been covered. The summary-view also presented obstacles to the development and growth of the technology in South Africa and other third world countries, measures in place and plans being developed by both government and private sectors to propel the growth of the technology and its acceptance.

Overall, the work presented one of the steps South Africa is taking to live up to green energy and sustainable development initiatives under the millennium development goals. It is notable that the technology of producing biogas as an alternative source of energy has a significant potential as evidenced by several remarkable advancements in the biomass anaerobic respiration technology with private players like Bio2Watt setting up plants to produce green electricity and feeding into the national grid. In addition, the government through municipalities and research projects also contribute to the notion as seen on the current City of Johannesburg-University of Johannesburg (CoJ-UJ) waste to energy project that is underway.

Acknowledgements

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Appropriate Technology Innovation – Equipment Design for Sustainability

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Abstract

Successful innovation in all sectors of the economy can be achieved through the use of new technological knowledge, market knowledge, and business models that can deliver a new product or service. The product/service combinations should have customers ready enough to purchase at prices that enable continuous functioning and sustained profits. However, for governments and some non-governmental organisations the thrust is not profit driven but skills, innovation and economic development driven. It should be remembered that from the 1970s to the 1980s appropriate technology (AT) became a worldwide grassroots innovation movement that sought to redefine technology as a tool for development. Innovation comes in many forms and it is imperative that institutions of higher learning should be in the leadership in innovation through research. The challenge being faced mainly by small manufacturers in the sheet metal working environment is non flexibility of fully dedicated machine tools (DMT) which cannot accommodate changes in product design and lack of funding. Also the prices of Computer Numerical Control (CNC) machine tools which have more features than are required are too high for manufacturers. It is therefore this challenge that researchers and engineers need to address by designing for sustainability that is, design appropriate machines to address local requirements. The question to be answered in this paper is "How do practitioners identify the local requirements in line with the new technology of Reconfigurable machines and how do these machines answer the industrial needs?". Research will be carried out through reviews of written papers on reconfigurable manufacturing systems and reconfigurable machine tools. The results of the research give a direction for reconfigurable machine adoption into industries as a substitute to dedicated machines and computer numerical control machines for sustainable manufacturing.

Key words: Technological Knowledge, Sustainable Development, Reconfigurable Machines, Dedicated Machines, Design, Development, Adoption and Collaboration.

Introduction

Appropriate technology can be defined as a set of common characteristics that attempt to shape technologies for development (Fressoli, Arond, 2015). It harnesses several aspects such as low capital cost and is reliant on local materials. It creates jobs employing local skills and labour and small enough in scale to be affordable for small groups. Appropriate technology should be understood, controlled and maintained by local people wherever possible. It does not require a high level Western-style of education that involves some forms of collective use and collaboration. It avoids patents and property rights and other similar characteristics (Fressoli, Arond, 2015). The prosperity of an organisation may be measured by its successful innovation, use of new technological knowledge, market knowledge, and business models that can deliver a new product or service. The combination of the product/service must be matched with customers who are ready to purchase at prices that will provide profits and sustainability (Yunus, Moingeon, and Lehmann-Ortega, 2010, 308). An example of appropriate technology innovation is a machine, (Universal Nut Sheller), made by Jock Brandis, shown in Figure 1. Prior to the development of the machine, growing and harvesting peanuts in Africa was a time-and-labour intensive affair that had been relegated to women and children (Ablaza, and Tejada, S.a.). It is said that the simple hand powered device is capable of shelling 50 kilograms (110 lb) of raw, sun-dried peanuts per hour and has proved to be very popular in making the African nut farming plausible. The machine requires less than $50 in common materials to make, lasts 25 years, and just one sheller can serve the needs of a 2,000-person village, (Ablaza, and Tejada, S.a.).

Figure 1: Universal Nut Sheller (Ablaza, and Tejada, S.a.)

Appropriate Technology Innovation

History has it that from the 1970s to the 1980s appropriate technology (AT) became a worldwide grassroots innovation movement that sought to redefine technology as a tool for development (Fressoli and Arond, 2015). Innovation comes in many forms and it is imperative that institutions of higher learning in partnership with industry, government and communities work together to foster new strategies for sustainable development as leaders in innovation research. The following two subsections will give an overview of the roles of universities and government in addressing the issues of appropriate technology innovation.

Universities and the Role of Technology Innovation

In every developmental and innovation issues it is important to note that universities play a key role in the process of economic growth as both a source of new knowledge and a trainer of scientists and engineers who work in industrial laboratories (Hill, 2006). Therefore, these institutions are considered to be the principal strength of the national innovation system. Some researchers have argued that the basic principle of appropriate technology innovation is having institutions providing technologies appropriate to their areas and situations (Smith, Fressoli, and Thomas, 2014, 114). This means that development includes a successful technology transfer. Development of any form is a very complex process because it functions within equally complex social, technical, political and economic variables. It has been noted through research that even within the technological components of development alone there are variables whose positive and negative effects cannot always be fully foreseen or predicted (Zelenika, and Pearce, 2011, 12). As universities play a critical role in development, it has been highlighted that one of the important roles of universities has been to make some changes possible (Group of Eight, 2013). These changes could be in values, attitudes, competition growth, increase in mobility, addressing problems of pandemics, disasters, food security, communication etc. Universities have done this by educating a greater proportion of the population and broadening its perspectives by performing research that creates new understanding, new technologies and the potential for action. They also provide a store of knowledge and capabilities that society as a whole has been able to draw upon. In particular, governments understand that research can help drive the innovation which results in economic growth, national development and improved human welfare, (Group of Eight, 2013). Innovation, growth and value creation create a driving force for prosperity and improved competitiveness within a community and industrial settings. It has been argued that the first stream of the primary role of universities is education and the second is research (Veugelers, and Del Rey, 2015). The third stream of activities builds upon the first (education) and second (research), which however is not a 'core' activity in the same way as the first two streams of university activity. Universities 'third role is to turn those scientific developments into useful innovations whenever possible and desirable (Veugelers, and Del Rey, 2015). Another study indicated that most successful universities seem to excel in all three missions, exploiting the complementarity between them, teaching, research and technology transfer (D'este, and Perkmann, 2011, 316). Governments however, throughout the world are seeking ways to strengthen the "third stream" role of universities as agents of innovation based growth, looking for a more direct and larger scale involvement of universities in knowledge transfer than ever before (Veugelers, & Del Rey, 2015; Geuna & Muscio 2009, 93).

Government Role in Appropriate Technology Innovation

The crucial role of any government is to create an enabling environment for the communities, industries and researchers to freely function within the confines of the law in pursuance and development of innovative ideas. Research has shown that the set of privatisation, liberalisation, and deregulation policies enacted by governments have clearly demonstrated their limits for promoting sustainable growth in the developing world (Aubert, 2005, 3554). Similarly, policies focusing on modernisation, in the sense of building infrastructure and institutions with a more interventionist government, have not yielded the expected fruits. The United Nations task team highlighted that debates on how best to promote sustainable and inclusive development are incomplete without a full consideration of issues of science, technology and innovation (STI) (PBSO, 2012). Access to new and appropriate technologies promote steady improvements in living conditions. These improvements can foster lifesaving opportunities for the most vulnerable populations and drive productivity gains which ensure rising incomes. To create a sustainable science, technology and innovation environment, governments must ensure that there is more participation and inclusion of the public. This includes a full spectrum of social actors, including women, young people and indigenous communities. Governments in many countries directly support scientific and technical research; for example, through grant-providing agencies (like the National Science Foundation in the United States) or through tax incentives (like the research and development -R&D tax credit), (Bernanke, 2011, 37). At their best, government policy and technology, research, development, and demonstration (RD&D) interact in complementary and mutually reinforcing ways. Well-designed policies and regulations can generate a market pull for technologies that are already developed and close to commercialization (Watson, Crawford, and Farley, 2003; Maharajh, Sall, and Karuri-Sebina, 2012, 3026).

Equipment/Machine Design

Equipment/Machine Design is the transformation of a vision into reality through the application of engineering and mathematical science to produce machines in the desired form as per need. The design and development of the machines must be appropriate to the development needs of the organisation and the community. As part of development strategies appropriate technology innovation seeks to answer questions like, "how can the right machinery be at the right place at the right time to meet required production requirements, how can the right machinery be manipulated to produce customised products as customer requirements and products designs change, how do practitioners identify the local requirements in line with the new technology of reconfigurable machines and how do these machines answer the industrial needs?" To answer these questions, the research focuses on sheet metal production machines, with particular emphasis being made to configurable and reconfigurable machines, a case being the development of a new reconfigurable guillotine shear and bending press machine. This machine seeks to combine two different operations into one by incorporating features of both machines into a single machine. The current position is that two machines, a guillotine shear and a bending press machine are employed in sheet metal working as standalone units for cutting and bending sheet metal. With the development of a new reconfigurable guillotine shear and bending press machine, a single machine is envisaged to carry out both functions using reconfigurable technology. The machine development is based on the principle of reconfigurable machines and therefore an overview of different manufacturing systems and machines will be made, namely the dedicated, the flexible and reconfigurable systems.

Reconfigurable manufacturing systems and machines bring in a new paradigm shift from the traditional dedicated and flexible manufacturing systems that use dedicated and computer numerical control (CNC) flexible machines, to the development of reconfigurable manufacturing systems and reconfigurable machines. Reconfigurable manufacturing systems and machines are designed such that machine components, machines, cells, or material handling units can be added, removed, modified, or interchanged as needed to respond quickly to changing product requirements (ElMaraghy, 2005, 261). The advent of developing these machines lies in the quest for sustainable development on the African continent and the world at large.

A look at industry reveals that most machines are imported from China, the United Kingdom, America, Germany etc., already designed to meet those countries' industrial requirements. Those needs/requirements are not necessarily the African requirements, hence the need for the development of such machines as prescribed by the local/African requirements. In developing countries there is evidence of failed attempts of transferring foreign highly-mechanised and energy-intensive technologies (Zelenika, and Pearce, 2011,12). The transfers were done in anticipation of successful uptake of such technologies by developing countries. Poor assumptions however, were made in the hope that the highly mechanised technologies would exhibit identical technical results in different geographical, social and political realms (Zelenika, and Pearce, 2011, 12). They also noted that the emphasis of projects focused solely on technology, or the wrong type of technology that does not match cultural, social, economic or political circumstances. It is therefore incumbent upon researchers and all stakeholders to develop appropriate technological machines that address the needs and aspirations of the populations they save. Focus can be directed towards small-scale manufacturers who have no capacity for high cost CNC flexible machine tools and low cost fully dedicated machine tools (DMT). CNC flexible machines are designed prior to the knowledge of operational requirements and thus they incorporate features that may not be required in operation, pushing their prices up. DMTs are custom designed for specific machining requirements making them less expensive but they cannot be changed/converted or reconfigured to suit changing product design requirements. According to researchers this type of machine tool is custom designed for specific operational requirements with high production volumes. Its resources can be minimised, the machine cost is low and its performance is robust (Pasek, 2006, 141). However, these machines cannot be cost effectively converted when parts designs change. To address this challenge, flexible CNC machines were developed and adopted in many industries. By contrast to DMTs that are designed around a specific part and therefore are inexpensive, CNCs are designed before the operation requirements are known. These machines therefore have more features than will be required in production hence making customers pay for features they do not need. The challenge now is to design machines that are product change responsive and appropriate to the needs of the communities. These machines are known as reconfigurable machines.

Reconfigurable Manufacturing Systems and Machines

In order to develop a reconfigurable machine, a reconfigurable manufacturing system must be developed to give the machine a platform on which to operate. A reconfigurable manufacturing system is defined as a system designed at the outset for rapid change in its structure, hardware, software and modules in order to quickly adjust its production capacity and functionality in response to sudden market or intrinsic system changes (Koren, 2005). It has been indicated that the major characteristic of reconfigurable machines is modularity of both the mechanical structure and the controller (Koren, and Shpitalni, 2010, 130). The machine comprises a database of modules for various requirements. Changing the hardware and software modules enables the machine to be configured and reconfigured according to production requirements. The software works in conjunction with the control system to facilitate the machine operation. Machines are produced in industry with varying degrees of modularity. Most used design methodologies for reconfigurable machines are based on modular hardware (Meng, 2010, 81). The software used is defined for part family and quick change in capacity and functionality of the machine according to changes in product architecture demands. Figure 2 demonstrates the manufacturing system reconfiguration as manufacturing demands change. According to researchers the dominant production requirements for large machining systems are (1) mix (i.e., set of parts to be produced), and (2) volume (amount produced per unit time of each part), as well as changes in the parts set and volumes over the lifetime of the machining system (Duflou et al., 2012, 587). Several factors influence the change in part designs and volumes. These factors may result in design modifications of parts to be produced. New parts being introduced on the one hand, according to new design specifications as defined by customers while on the other hand, the operational requirements for the machine consist of the set of features that are produced and their cycle times.

With the reconfigurable manufacturing system in place, it goes without saying that the need for the development of equipment to be used in this system gets underway. Researchers have provided an overview of the modular design of a machine tool including interactions with the environment (e.g., operators and other machines) and the determination of control modules (Landers, Ruan, and Liou, 2006, 79). There has been a development through research, of a method to analyse the dynamic stiffness of a machine tool using pre-calculated component information (Quintana and Ciurana, 2011, 363). Reconfigurable machine tools (RMTs) are designed to be easily reconfigured such that they process a family of parts. They are based on the principle of modularisation to accommodate new and unanticipated changes in the product design. Reconfiguration is achieved through changing modules when required and thus changing the degrees of freedom of the machine to accommodate the new requirements (Rashid, 2012). Reconfiguration, however, extends beyond a customised assembly of modular elements. It is important to understand that reconfigurable systems are: (i) modular in their construction and therefore can be reconfigured by swapping modules as needed, (ii) convertible, that is, individual modules can be repositioned or re-oriented without changing the topological characteristics of the machine (Katz, and Koren, 2008, 145). Thus, reconfigurability helps in making quick changes to accommodate changes that occur in the product family. Reconfigurable machine tools can be designed to provide varying levels of reconfigurability. The design process starts with a thorough understanding of peculiarities (geometry, processes, tolerances, cycle time, reconfiguration time) of a given family of products to be machined (Katz, (2007, 430). Since the machine is designed around a part family, the reconfigurable machine offers customised flexibility at lower cost, that is the right kind of flexibility without any wasted-flexibility.

With a reconfigurable guillotine shear and bending press machine in mind, the operational sequence of the machine begins with the identification of parts to be produced, that is blanks to be cut from sheet metal. After the blanks have been produced the machine is reconfigured to start bending the parts to predetermined shapes. Examples of parts to be produced are computer covers/housings, electric stove housings (one plate, two plates, three plates,) etc. These parts are grouped into part families and modules generated for the production of these part families.

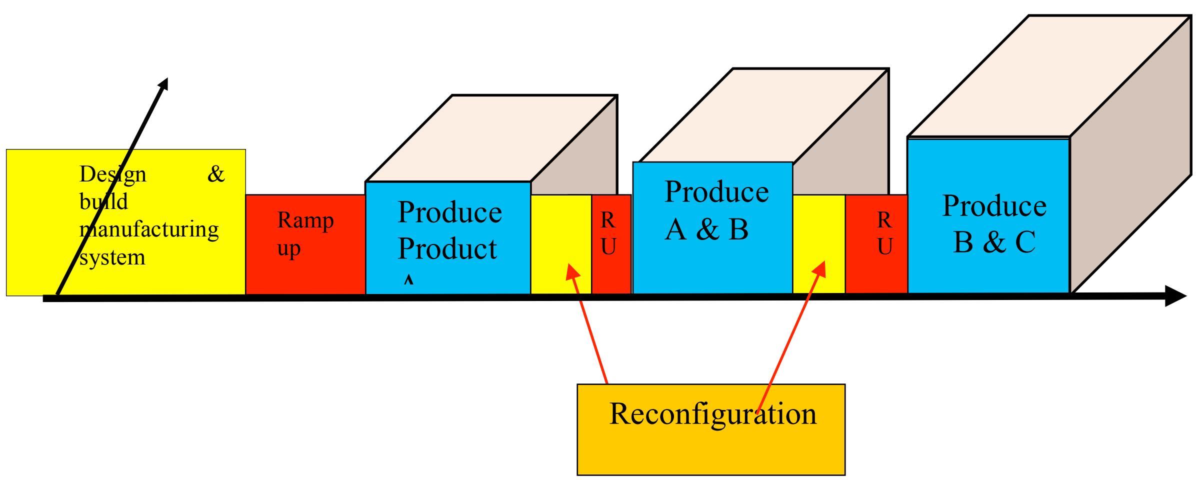

Figure 2. Lifetime reconfiguration of an RMS as product designs change, (Koren, 2005)

Framework for Appropriate Technology Innovation – Reconfigurable Machine Development

In order to have a machine developed, a certain methodology should be followed. The framework shown in Figure 3 below gives the methodology that should be followed and it provides the development needs of the reconfigurable machine in line with appropriate technology innovation. The questions that are answered by the framework among others are, "How can the right machinery be at the right place at the right time to meet required production requirements, how can the right machinery be manipulated to produce customised products as customer requirements and products designs change, how do practitioners identify the local requirements in line with the new technology of reconfigurable machines and how do these machines answer the industrial needs?"

As can be seen from the framework in Figure 3 the information in section "A" generates the Conceptual Model of the machine. These are the inputs that take into account several aspects including preliminary research into the market needs, industrial requirements, products, and other various requirements that need to be satisfied or incorporated before a design is made. Similarly, section "B" is the input to "C" and "C" to "D" respectively. If these inputs are analysed and manipulated appropriately a design for sustainability that addresses all the needs is developed, then the three questions asked above can be answered. The initial step is determining fundamentals for an appropriate technology from a range of possibilities as a key to the successful operation or development of the system. If, however inappropriate choices are made on the onset then the developed technologies are likely going to fail to function adequately as a result. More often than not it is always difficult to make these choices but from a conceptual point of view, questions that lead to choices may be generated.

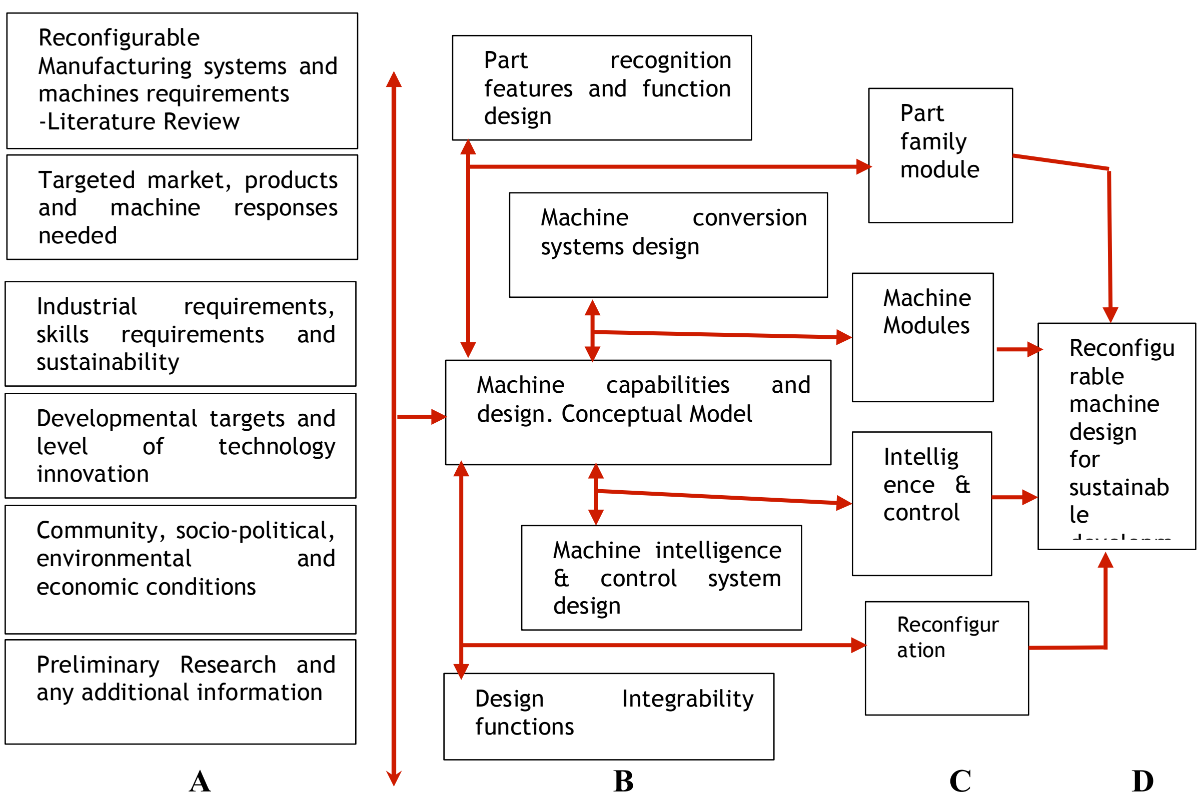

Figure 3 Framework for machine design

To develop the machine requirements several questions can be generated from the framework. Such questions can be in the form of core and sub questions that can be used as guidelines for making relevant choices versus the required outcomes. Examples are shown below:

Core Question

- How will the literature on dedicated, flexible and reconfigurable manufacturing systems and machines, principles and designs contribute to the design and development of the new machine?

Sub Questions

- ➢ How will the flexible manufacturing systems contribute to the development of the new reconfigurable machine?
- ➢ What kinds or characteristics of reconfigurability are sought after in reconfigurable manufacturing systems and reconfigurable machine tools?

Core Question

- How will the analysis of various sheet metal working machines, designs and principles contribute towards the development of new concepts for the new machine tool?

Sub Questions

- ➢ What are the shortcomings in the dedicated and flexible machine tools?
- ➢ How can these limitations be used to develop a new machine that addresses these shortcomings?

Core Question

- How will the local, socio-political environmental and economic conditions contribute towards developing a machine that satisfies African and local needs?

Sub Questions

- ➢ What skills will be required for the development and use of the new machine?
- ➢ What are the requirements for sustainable development?

Core Question

- What types of designs of sheet metal working machines (reconfigurable sheet metal working machines) are currently in use today?

Sub Questions

- ➢ What technological trends are industrialists and users looking for in sheet metal working machines for constantly changing product varieties?
- How can the new machine, hybrid reconfigurable machine, be designed to conform to the technology of reconfigurable machine tools (RMTs)?
- What parts or part families can be manufactured by the new machine?
- What machine configurations are possible in order to meet changing product demands?
- What is the best interface or platform that can be incorporated into the machine for end users to manipulate the machine?

Answers to these questions give the direction that best suits both the local industry and community in the development of a machine for sustainable development and appropriate technology innovation. For instance, literature lays the foundation for research as it shows the ground that has been covered and the gaps that exist and thus direct the research in terms of areas that need to be addressed. Literature on the three manufacturing systems identifies the evolution of these systems, the role they have played in industry and how new developments can be mapped from such systems. Reconfigurable manufacturing systems as they are a new paradigm that seeks to address the short comings of the dedicated and flexible manufacturing systems are designed for rapid change in structure, hardware and software components to adapt to product changes. This lays a foundation for the kind of machines that can operate in this environment and thus the development of reconfigurable machines. The questions as shown, give a direction of research when developing a reconfigurable machine, such as industrial requirements, technological requirements, operational requirements, reconfigurability requirements, control requirements, modular requirements and part family requirements among others. From the framework the development of a reconfigurable machine can be shaped to meet all necessary requirements.

Discussion

The primary goal of Appropriate Technology (AT) is to increase the standard of living for the developing world without condescension, complication, or environmental damage (Sarewitz, 2010). Appropriate Technology Innovations seek to make the researchers and all other stakeholders develop machines, equipment etc., to suit local requirements at affordable prices. It takes a lot of work, thus being labour intensive, requires fewer resources, and use low cost or readily available materials wherever possible to develop and make systems and equipment that tape into the locally sustainable talent within the area of operation. Local requirements have to include special attention being paid to the social, cultural, and ethical aspects of the communities the technology is intended for. For sheet metal working industries this brings in the aspect of the development of reconfigurable machines. These machines bring in an innovative approach of customised manufacturing called Reconfigurable Manufacturing Systems (RMS) engineered to address the needs created by rapidly changing markets and rapid introduction of new products. One of the primary goals of RMS is to reduce design lead-time, manufacturing set-up time and ramp-up time while providing a cost-effective solution to the community challenges particularly the small-scale manufacturers. Reconfigurable systems and machines provide exactly the functionality that is needed exactly when it is needed. Although many reconfigurable machines have been developed, most of them were implemented as results of research or prototypes in industry. Compared with the dedicated machines and flexible CNC machines, reconfigurable machines are designed for improving profit of the manufacturing industry. Reconfiguration enables a machine to be converted from one form to another so that it can operate according to the design requirements of products, product families or product designs as defined by customer requirements. In using appropriate technology for equipment design there is an advantage of identifying all machine and part family requirements prior to the machine development. It looks at the process design and the flexibility required for the product or part family or customised products as well as the process flexibility. These become the basics for the machine development. Appropriate technology innovation seeks to ensure that the machine development, the production system and manufacturing process are geared for handling any changes in the product requirements. Automation of the reconfiguration system, design and process planning functions are very critical in achieving diagnosability. A well designed reconfigurable machine in line with the principles of appropriate technology is proficient in accommodating changes, satisfying local or African requirements and simplifies the operational procedure. Reconfigurable manufacturing systems and machines are mainly designed for mass production applications, to allow customised flexibility, a cost-effective production system and an inspection of a family of parts. The process is based on the design for modularity as a broad principle for reconfigurable machine design. The machine design process includes the use of software such as 3D solid modelling software (SolidWorks), dynamic analysis software (Cosmos Motion), control system and simulation software (Simulink) and others like Mat lab etc.

Conclusion

Appropriate Technology Innovation and Science for Sustainable Development program aims to realise sustainability in societal livelihoods and stability. This can be achieved through developmental activities and innovations that try to develop and establish appropriate technology. Appropriate technology works through new ideas, community engagement and through the field of science that aims to build characteristic regional development systems that are unparalleled by conventional development techniques. In line with this, sheet metal working activities require systems and machines that can answer to aspirations of the continent, local communities and industries. It is on this note that the gap closed by the development of reconfigurable machines best answers to the aspects of appropriate technology innovation. Reconfigurable machines and manufacturing systems have superseded the dedicated manufacturing systems and dedicated machines on the one hand and flexible manufacturing systems and flexible CNC machines on the other hand. This is due to limitations of these two systems and reconfigurable manufacturing systems and machines have taken the best aspects of the two systems to develop a customised cost effective system that addresses the plight of small manufacturers. The research has highlighted the basic requirements for sustainable and stable societal developmental needs. The key to achieving this being the development of appropriate equipment/machines that integrate regional specific technology with new environmental conscious technology. The development and conservation of eco-region infrastructure that incorporates appropriate technology at the same time taking into account socioeconomic systems that accept appropriate technology innovation and use it. The develop of reconfigurable machines and manufacturing systems enable a swift response to changes in product designs. To provide customised flexibility the reconfigurable manufacturing system and machines must have the capacity and capability/functionality to process a family of parts as defined. Reconfigurable machines must be built around a family of parts to be produced. The framework shown in Figure 3 gives a direction to be followed and questions to be answered for the machine development in line with appropriate technology innovation to be realistic. Once the questions raised have been answered the research and development of the machine will have a guiding line to follow.

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Smart Community Development Framework (SCDF): An Approach To Empower Vulnerable Communities Movement Towards Sustainable Development

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Abstract
The Smart Community Development Framework (SCDF) is a methodological frame that combines several other approaches such as Permaculture, Sustainable Livelihood Approaches (SLAs), Community-based Social Marketing (CBSM), Environmental Impact Management (EIA) and project management tools to effectively design and introduce appropriate technologies for and with vulnerable and poor communities worldwide, ensuring permanent and sustainable changes. A community in Guatemala was used as a model to list and evaluate the framework parameters because of its vulnerability condition, aggravated by the effects of climate change. This framework tries to integrate several approaches to systematically guide developmental projects to empower vulnerable communities, support poverty reduction, and sustainable development. The SCDF model is a workflow model to establish the vulnerability level and identify the problems; select the target actions, determine resource availability and major obstacles; an optimized permaculture design strategy incorporating specific appropriate technologies and social programs; an environmental impact assessment and implementation plan; an empowerment impact analysis, and power transfer guidelines. Local leaders, environmentalists, project managers and policy-makers can use the SCDF model to collaborate in the formulation of effective action plans worldwide.

Keywords: community development, empowerment, SCDF, smart community development framework, sustainable development, vulnerability

Introduction

Community development in vulnerable and poor communities is a complex and multidimensional study. Vulnerability and poverty levels of communities are dependent on economic, political, social, cultural, environmental, technological and time-response aspects. Several studies have highlighted the importance of community empowerment in sustainable development and poverty reduction. Though many approaches have been developed to address some of the global issues in a sustainable way, they lack integrative approaches to effectively guide the development of vulnerable and poor communities.

Maslow's Hierarchy of Needs categorizes the types of common needs ranging from physiological and safety (basic needs), to love, belonging and self-esteem (psychological needs), and self-actualization (being needs) (Cao et al. 2013, 170-190). One community empowerment method for addressing multiple societal and educational limitations that is grounded in Maslow's Hierarchy of Needs (and similar taxonomies) is the collaborative design and implementation of permaculture systems. Permaculture systems are a holistic design that provides basic and social needs by integrating nature, people, traditional knowledge and modern science (Veteto and Lockyer 2008, 47-58). Permaculture systems support the implementation of appropriate technologies, that is, products and systems that include social and cultural aspects and are affordable and appropriate to local needs and skills (Sianipar et al. 2013, 1007-1016) in order to improve environmental quality, sustainable food supply, equitable access to clean water, energy and shelter, and informal education.

However, there is a great debate on how best to define priorities regarding basic needs. Bradshaw's classification of needs determine four aspects of human needs: felt need (subjective), expressed need (communicated), normative need (determined by someone) and comparative need (determined by comparison) (Carver et al. 2014, 76-82). The nature of a specific need and how vulnerable people perceive it influences the importance of such need. Moreover, there are concerns on establishing and addressing the root causes of these needs, not just to mitigate the issues caused by the needs not being met. The present work tries to fulfill this gap creating a framework that attempts to guide intervention projects to address the root causes of vulnerability, poverty and inequality, by focusing on local perspectives. The Smart Community Development Framework (SCDF) combines several approaches such as Permaculture, Sustainable Livelihood Approaches (SLAs), Community-Based Social Marketing (CBSM) and project management tools to effectively design and introduce appropriate technologies in vulnerable and poor communities worldwide, ensuring permanent and sustainable changes.

A community in Guatemala was used as a model for this project assessment and to both list and evaluate the framework parameters. Guatemala is a country with much potential, but many challenges as well. There are a variety of ecosystems, affluent rivers and a rich cultural diversity. However, significant challenges related to widespread poverty and malnutrition, gender inequities, and low education attainment levels lead to significant community vulnerabilities, particularly with the impact of projected climate change continuing to erode prosperity and environmental quality.

In the Union Victoria Community, in the municipality of Pochuta, Guatemala, 400 families live their lives based on agricultural work, mainly coffee, and are subjected to lack of electricity, piped water and sewer service. Medical care access is limited and the population suffers of chronic malnutrition, with a basic diet based on beans and corn. Although there are close water birth, fertile soil to grow variety of vegetables and fruits and enough land and favorable climate to install proper energy, water and waste management systems, the lack of knowledge and financial resources to create and implement them is the major obstacles. Thus, an intervention that builds knowledge, engage the vulnerable population in new and sustainable behaviors and implement appropriate technology systems using local resources and cooperativism is essential to tackle those problems.

The work that the NGO *Comunidades de la Tierra* has done in the Union Victoria Community, along with the problems experienced by both the local community and the project team, inspired the development of the SCDF. Like Union Victoria, many other communities around the world have struggled with the lack of resilience, poverty and inequality. A generalized approach was taken and verified in the literature to allow worldwide applicability. It is important to note that this article does not aim to describe the examination of the village, but simply state that the analysis of the Union Victoria Community served to help the development of this comprehensive model.

Methodology Discussion and Evaluation

The SCDF proposed is composed of six major steps, each one with specific tactical actions and recommended resources (Figure 1). The framework deployment is approached in sequence and described in the following sections.

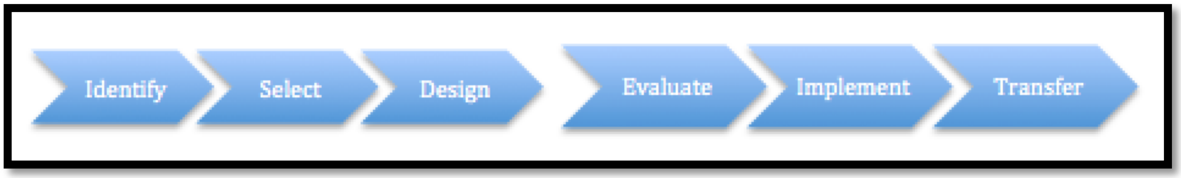

Figure 1. Smart Community Development Framework (SCDF)

Identify

The starting point of the project flow is to precisely identify the reasons to design and implement an intervention project. Vulnerable communities often have a multitude of problems that differ from one another depending on the political, economic, geographic and cultural environment they are subject to. It is during the contextual analysis of the community that the needs and influential forces are defined. The information gathered is used to explore opportunities and alternatives that will both reduce vulnerability and improve livelihoods, lifestyles and welfare, moving towards a more sustainable planet.

The identification process starts with a baseline assessment to identify current data with respect to:

(i) Access to basic needs (water, energy, food and shelter);
(ii) Environmental quality (water, air and soil);
(iii) Health and nutritional level;
(iv) Education attainment;
(v) Income security & employment;
(vi) Existing conditions (geography, natural resources, local infrastructure and accessibility); and
(vii) Existing local aid programs.

Then, it is important to understand the means of subsistence and pattern of life in the community, and so, a lifestyle and livelihood analysis is applied. This second step is an adaptation of Sustainable Livelihood Approaches (SLAs), which, through several tools and observations, tries to identify the assets and capabilities of community households, and the institutions, processes and vulnerability contexts that shape livelihood strategies and outcomes, as well as influence lifestyles (Scoones 2015). According to this author, SLAs bring into consideration valuable elements. First is the idea that there are five different capital assets: human (skills and knowledge), physical (shelter, water, energy and other systems), social (networks), natural (environmental resources) and financial (capital). Second is the concept that there are structures and processes that transform the daily life in the community such as governments and NGOS, legislation, social norms and environmental changes. The awareness and understanding of these elements help to select better strategies to foster sustainable behaviors and design sustainable systems in the community.

Based in the work of Scoones (2015), this framework proposes some questions to guide the livelihood and lifestyle analysis:

- Identifying ownership of assets and resources: *Who owns what?*
- Identifying social divisions and differentiation: *Who does what and gets what?*
- Identifying livelihoods and lifestyles: *What do they do with it?*
- Identifying social networks: *What are the institutions and social classes, and how do they interact with each other?*
- Identifying resilience: *How do environmental changes shape livelihoods and lifestyle?*

Furthermore, it is essential to consult the community to identify perceptions of current needs and importance rate, as well as community history (social, cultural and political factors). There could be differences in the collected data from what the community perceives to be a major problem or wishes to be firstly addressed. This action will ensure the bottom-up perspective from local people. This phase is based on an intercept survey guided by two questions (McKenzie-Mohr 2011):

- Identifying perceived problems: *What, if anything, makes it difficult or challenging to have a better quality of life?*
- Identifying perceived solutions: *What, if anything, do you see as beneficial or worthwhile to have a better quality of life?*

Finally, combining all of the information from previous actions to identify vulnerability levels and major problems in the community will provide an accurate panorama to guide the project design.

Select

No matter the context and problems a community is subjected to, a wide array of necessary changes and actions can be established. These changes might include physical changes (incorporating new systems or modifying existing ones), behavior changes (adopting new practices and attitudes) or, as is usually the case, a combination of both. These options lead to the desired goal of improving the quality of life in a sustainable way, making it necessary to target those that are most valuable and worthwhile within the context (McKenzie-Mohr 2011). It is necessary to list and prioritize the options when considering the context assessed in the previous phase, the resources available and the likelihood of making and sustaining them. This involves analyzing the following questions:

- *What are different actions and their potential to bring about the desired change?*
- *How often the actions are likely to happen and in which context?*

McKenzie-Mohr (2011) suggests that the selection be based on the best combination of impact, probability and penetration for better results. Once the target actions are selected, the next step is to identify the barriers that prevent the implementation. This involves analyzing internal and external barriers:

- *What are the contextual barriers (physical, technological, political, legal and economic) that prevent the implementation of the desired changes?*

- *What are the internal barriers (behavioral, cultural, social, and skills) that prevent the target population from engaging with the desired changes?*

Knowing which factors are major obstacles to implement the target actions is an essential step in developing engineering and marketing strategies.

Design

Having the target actions selected and the barriers established, it is time to design the project to implement the target physical systems and to promote the target behavior changes in the community.

To address the physical systems, a permaculture design is recommended. The permaculture planning must incorporate engineering problem-solving and appropriate technologies in order to create or enhance food, water and energy systems, sanitation & health, infrastructures such as shelter and public spaces, transportation & accessibility, and landscape.

(i) Information Map: a map that overwrites the information from soil & vegetation, hydrography, rain & wind, natural resources, local regulations and local infrastructures to strategically plan the area (Aranya 2012);
(ii) Zoning: the division of the land in accordance to the information map to help position the systems and technologies and optimize space, access and movement (Aranya 2012);
(iii) Design & positioning of the engineering systems & the appropriate technologies.

The technological features may be co-designed with local people to ensure the satisfaction of their needs and may be as environmental friendly and simple to operate as possible.

To address the behavior changes, social marketing strategies are an excellent tool to ensure they are permanent. They motivate local people to engage in different actions and promote changes in their livelihoods and lifestyle, fostering sustainable behaviors. Recommended strategies include public commitment, social norms, social diffusion, prompts, incentives and convenience (McKenzie-Mohr 2011).

Evaluate

Any intervention in the infrastructure of a place is likely to affect the natural ecosystem. Depending on the type, complexity and location of the project, an Environmental Impact Assessment (EIA) is required. EIA is a process used to assess and evaluate impacts of major development projects in order to get implementation approval from local bodies (Carroll and Turpin 2011). According to Carroll and Turpin (2011), a standard EIA process consists of eight steps:

(i) screening;
(ii) scooping;
(iii) terms of reference;
(iv) baseline studies;
(v) impact assessment and significance;
(vi) mitigation;
(vii) application; and
(viii) monitoring.

Consultation is also part of every step. This paper does not focus on deploying this process because interventions using permacultural designs and appropriate technologies are pro-nature and usually small. However, some projects may face regulatory obstacles and so an EIA is used to address the issues. If this is the case, the literature has plenty of work in the field that can guide interested parties through the process.

Regardless of the need for an EIA, a simple risk assessment is useful to develop a prevention, mitigation and monitoring plan to ensure human and environmental safety. It provides the likelihood of the occurrence of unacceptable risks and strategies to manage or avoid the consequences (Carroll and Turpin 2011).

Implement

At this point, the project, the intervention strategies and the impact management plan are designed, and so the implementation phase starts. The goal here is to implement the project cooperatively (a co-building process) while evaluating the community empowerment and other community-based impacts, such as perceptions, values, knowledge and behaviors changes, either during or post-building.

Power Transfer

The end of a project always finishes with an evaluation of the achieved goals and comparison with initial proposal, and with a review of trials and errors. All these findings must be reported in a technical review to serve as basis for future projects. As a developmental project focused in empowerment, this framework encourages planning the power transfer from the intervention team to the local people, that is, enabling local ownership. This plan should ensure that local people have the capacity, knowledge and input necessary to operate and maintain the new systems and behaviors, considering all of the partners, resources and support required, along with ways to access them.

The previous discussion deployed the six key steps of the SCDF into several actions, which are summarized in the Table 1. Also, Table 1 is enriched with a toolbox that suggests best resources and tools to support each action. There are many other tools that could be added here, but the important thing to consider is how appropriate are them for each context (Scoones 2015). This framework is not prescriptive, thus both the lineage of recommended actions and the suggested tools must be adapted to integrate the particularities of each context.

Several challenges may emerge anytime an intervention is planned and executed, such as incorrect evaluation and comprehension of needs, barriers, resources and systems involved; and changes in the schedule and budget due to unpredictable forces, for instance, natural disasters, inflation and sickness. Thus, a great integration between engineers and designers and the local people, along with resilience building, will provide the adaptive response needed in these unpredictable situations.

Table 1. Resources and Tools for Actions

ACTIONS	RESOURCES AND TOOLS
Action 1: Baseline assessment	Existing statistical and information databases; government and NGOs documents and literature review.
Action 2: Lifestyle and livelihood analysis	Surveys (social, income/expenditure, asset ownership); ecological, social, organizational and activity mapping; seasonal calendars; life histories; GIS analysis.
Action 3: Community consultation	Community meetings and focus groups guided by the intercept survey.
Action 4: Combining information	Group discussions; Mapping; Gap assessment analysis; problem tree; affinity diagram; mind mapping.
Action 5: Selecting specific changes	Brainstorming; technical/case reviews; expert surveys
Action 6: Identifying barriers	Observation; focus group; technical/cases reviews; expert surveys; vulnerability matrices; force field analysis; problem tree.
Action 7: Optimized permaculture design	Permaculture frameworks; Appropriate Technologies databases (e.g., Banco do Brasil Foundation); review cases, expert consultation.
Action 8: Social marketing strategies	Community-based Social Marketing (CBSM) framework, review cases, expert surveys.
Action 9: Identifying environmental impacts	Environmental Impact Assessment (EIA) frameworks; technical/cases reviews; expert surveys; vulnerability matrices.
Action 10: Pilot the project	Issue log; communication and motivation tools; project management frameworks (e.g.: PMI, PMD Pro)
Action 11: Implementation phase	Issue log; communication and motivation tools; project management frameworks (e.g.: PMI, PMD Pro).
Action 12: Evaluating community-based impact	Observation; community meetings and focus group; outcome measurements; impact surveys.
Action 10: Project transition	Transition planning matrix; check-lists; social marketing frameworks.

Conclusion

Vulnerable and poor community development is a complex and subtle issue that requires a holistic, bottom-up approach. More than that, it requires techniques based on Psychology and Marketing sciences that ensure endurable and sustainable changes while empowering the local population. This study proposes a holistic approach to implement appropriate technologies and address real needs.

The Smart Community Development Framework (SCDF) is a resource to efficiently implement appropriate technologies and foster sustainable behaviors in order to reduce vulnerabilities and create a sustainable community. It is a flexible frame, meaning that not all steps need to be addressed and the order can also be changed, depending on the community context. The combination of recognized approach and the flexible design is what allows its effectiveness on enhancing livelihoods, lifestyle and life quality of vulnerable and poor people

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