Research Report

Kardashev Kommunities

A Conceptual and Theoretical 'Ladder' Style Development Model for Regenerative Development in Desert Environments.

> *You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.*
>
> *R. Buckminster Fuller*

Abstract:

This research examines the theoretical possibility of utilizing minimal inputs of seawater, sunshine and desert land, to create usable outputs through regenerative development technologies. Specific technologies are considered to determine whether they can be built with non-polluting and fully recyclable materials, constructed and maintained at a local level with minimal training, and can be implemented incrementally; all towards creating a developmental ladder for poorer economies to grow economically improve local ecosystems, and offset atmospheric CO_2.

Towards achieving this goal, a broad trans-paradigm perspective of Humanity, and it's developmental pathway as a civilisation, is examined through the viewpoint of the Kardashev Scale. This scale considers the technological capacity of civilisations, from having no capacity through to being able to implement capacity at a galactic level. After this consideration is then focused on individual technologies that can be used together to create increased levels of desirable outputs, but that can be constructed using free or cheap recycled materials, so that even the poorest in societies can begin to build their own way out of poverty.

First the development of a single module is considered, from starting with almost nothing at T0.1 and then towards achieving full technology advancement at T0.5. Finally, the creation of multiple modules is contemplated, through stages T0.6-0.9, and the effects on a regional and global scale.

The conclusion supports the possibility of a ladder of development technologically, but holds that further research is required to create the systems to make it happen.

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Introduction

Despite decades of research into sustainable development (SD) solutions to the climate crises little has transferred into real-world impacts. Individual technological solutions, silo-based thinking, and the paradigm of ‘sustainability’, which seeks to arrest current damaging practices, continues to hinder efforts towards addressing the underlying crises. Overall the problem lies in the lack of an economically viable, scalable, ecologically beneficial development model that not only halts damage done to the eco system, but also repairs it.

The concept of regenerative development (RD) aims to address the underlying flaws within the SD paradigm, taking a holistic and systems-based approach, along with a much broader trans-paradigm perspective of the overall development pathway of a galactic level civilisation enables novel insights and understanding of possible impacts of intervention at system leverage points. The problem requires a solution that not only works in first-world economies, but also the poorest; indeed, it would be best if the economically and environmentally poorest economies benefited the most.

The aim of this research is to demonstrate that it is possible to model a pathway of development. Using minimal resources, inputs and desert land, such as the Sahara, to create a ladder out of poverty, water and food insecurity, and ecological decline; along with a glance at some other concepts which might also be beneficial. The model demonstrates a series of levels that, if achieved, can benefit individuals, communities, and humanity towards our future as a space-faring civilisation.

Therefore, the research question will be:

Based on currently available research of sustainable technologies:

i. What minimal key components can be used together to support economically disadvantaged communities in desert environments, through low-cost and minimal resources, to climb out of poverty?
ii. What socio-economic mechanism promotes a fairer distribution of wealth; from rich to poor, and to future generations?
iii. How does the mass adoption of this development relate to the paradigms of RD and civilisation-level development models?

Literature Review

An in-depth literature review of the broad church that is SD, with its multiple disciplines contributing differing perspectives, is well beyond the scope of this paper; however, along with the broad viewpoints of groups within the SD community, a more in-depth review of the disciplines considered within this research was undertaken.

A philosophy with particular resonance is that of RD, poised to become a major force in SD, which shares many of the thoughts about the failings within SD practices. RD could be the next evolutionary step from SD, seeking multiple pathways towards holistic and practical solutions to big picture problems by using "*systems thinking and abductive logic"* (Gibbons et al, 2018, pp. 3). RD believes it is possible to heal and regenerate ecosystems when undertaking development, rather than just halting the current destructive practices approach of SD (Muller, 2017).

Researchers acknowledge that at some level "*work that regenerates addresses the unrealised potential inherent in the relationship between a given system and the larger systems within which it is nested*" and that "*… what exists now can move toward what could be in the future*" (Mang and Haggard, 2016, pp. XXX). In considering the next 50-100 years, and the distant future, 100-1000 + years, novel insights and perspectives can be gained. Often such literature is considered as irrelevant, but history demonstrates that fringe/popular science-fiction can drive the creation of technological development.

In relation to individual technological solutions to SD problems, issues such as high costs, complexity and implement-ability often arise. Omitting such solutions the more simple, reliable and cost-effective opportunities become easier to detect.

Water

The use of seawater brings with it interesting technologies for solar desalination for freshwater and salt production. This report examines the construction of simple incremental infrastructure, that provides life-saving quantities of water to individuals, which scales for livestock, crop production and ecological regeneration.

Food

Aquaponics using seawater is considered for the farming of saltwater fish, and hydroponics for growing algae and halophytic plants, so that land can be used as a method of farming without causing damage to the ecosystem. The use of seawater removes the bottleneck of a lack of freshwater resources, enabling an alternative pathway for growth. Towards increasing output levels of agricultural produce, the use of LED and vertical farming methods, where LED lights are used to increase growing periods and where plants are grown vertically, allow more production per given area of land.

Energy

Anaerobic digester (AD) technology demonstrates how traditional waste streams produce methane and fertiliser outputs, and concentrated solar power (CSP) generation can produce electricity for export, use within the community, or for agro-industrial practices. CSP technology can also be used in conjunction with AD methane as a transitional technology to provide continuous electrical output (Devabhaktuni, 2013). Hot dry rock (HDR) geothermal energy generation could also be considered towards providing continuous and stable quantities of electrical output.

In most cases none of this material is particularly new or ground breaking, with Muller’s (2007, pp. 1) opinion being “*We have more information and knowledge than needed to save our planet, yet we have not been able to transform it into wisdom, enlightenment and action*”. This paper argues that this is due to solutions being considered in isolation to each other, within their own silo, and therefore the effectiveness is measured based on the outputs of a single technology – usually in monetary terms. Even if considered from a financial angle, often perspectives or assumptions are made that blind others to the real possibilities of using a technology, whether individually or taken together for multiplier effects. Often the cost of building some infrastructure is X, and with income of Y this infrastructure is not cost efficient. Perhaps developing in a normal business way this would be so; but what if the cost of building some infrastructure was negligible? What if building X and Z together meant that it would triple the income of Y instead of doubling it? What if a different mechanism of measuring success was used?

Despite our human nature to ‘fence in’ and control the issues associated with unsustainable development, which depletes resources and damages ecosystems, a ‘solution’ will not be found looking inwards, closer to the problem, but in looking outwards, towards the broader nature and processes of the systems that enable a trans-paradigm perspective from which truly innovative solutions can be achieved (Meadows, 2008). To solve complex problems it is necessary to have interdisciplinary and transdisciplinary perspectives, work with systems and the interactions over the component parts of a system (Gibbons et al. 2018; Muller, 2017).

Silo-based perspectives, such as a focus on biofuels rather than the impact producing such fuels creates on the agro-economy, are often formed by scholars with deeply held beliefs that drive the assumptions and directions of their research philosophies. That is not to say that these models are wrong and do not work; only that each model could represent a facet of the truth. However, the concept of RD, where any development undertaken, whether economic, industrial, or ecological, has a restorative effect on local or global ecosystems, is more relevant to this paper.

Literature of how we go about living in space can offer insights as to how we can live well on the Earth. While the pathway for development of Humanity towards becoming a pan-galactic race might seem irrelevant, being able to measure and record our progress on this pathway can begin to give our civilisation a much broader perspective in relation to our timeline and our possible impacts. The model used to measure the technological capacity of any given civilisation, the Kardashev Scale, figure 1, was developed by N. S. Kardashev. It was adapted by Carl Sagan (2000) to give more flexibility through splitting the Type numbers – with Humanity currently being a T0.7 civilisation (Soubane, 2017). Dobruskin (2021, pp. 180) supports the use of this paradigm as a method for measuring the state of human society, "*the Kardashev idea seems quite reasonable for assessing the development of human society; for example, the level of a country's development is often compared to the amount of energy consumption per capita.*". However, rather than being taken literally, the Kardashev Scale is indicative of the levels of complexity and the magnitude of the technological capacity of a civilisation, but is a useful tool for measuring where we are in the civilisation development ladder.

Figure 1: Kardashev Scale

Kardashev Type 1 (T1):
A civilization manipulating energy resources of its home planet
Kardashev Type 2 (T2):
A civilization manipulating energy resources of its home star/planetary system
Kardashev Type 3 (T3):
A civilization manipulating energy resources of its home galaxy

(Adapted from: Ćircković, 2016, pp. 2)

In progressing forward as a civilisation, we need to be able to efficiently and sustainably harness the power of nature to achieve Type 1, and the potential of renewable energy supplies is enormous, being able to provide multiple times the total global energy demand (Gupta et al, 2015; Devabhaktuni, 2013). The challenge is whether a civilization as energy intensive as Humanity's can be sustained for long periods of time is a question that has been considered by Frank, Kleidon and Alberti (2017, pp. 2) who conclude that considering the Anthropocene as a "*generic consequence any planet evolving a successful technological species"* has *"considerable benefits in understanding the true nature of the environmental challenges we face and articulating paths towards solutions"*. To achieve advancement to a Type 1 civilization we need to do so as "*part of a larger philosophy or master plan"*, rather than a reaction to existential factors (Fourie, 2021, pp. 4).

How we begin our first steps on this journey will define how we will get there. Continuing on a pathway, where the rights of the individual are above the rights of the community, is unlikely to achieve a resolution to our current needs. It will be necessary to develop in ways that strengthen our societies politically, economically, and environmentally, with stronger culture and spirituality through increasing participation in defining our future and making it happen. The concept of the commons needs to be strengthened and increased. It has been argued that this might be achieved through a socially beneficial, non-consumptive, public good development and ownership model, called ‘waqf’ (Muller, 2017). A waqf has been defined by Kahf (1998) as “*an action that involves investment for the future and accumulation of productive wealth that benefits future generations.*”, and establishing one is generally considered to be for the benefit of humanity (Zuki, 2012, pp. 175). Though a significant religious activity, imbued with the attributes of piety, a waqf has at its core social justice and equality; historically it has been a tool for delivering public goods, such as the Al-Azhar University in Egypt, at no cost to governments, reducing government expenditure and helping to redistribute resources.

As a consequence, transitioning to an RD pathway will leave behind more than physical infrastructure and an impact on social communities and ecosystems; it will also be developing new capacity and capabilities in the individuals that it effects (Mang and Haggard, 2016). An intergenerational perspective, where future generations are considered to have an equal right and we consider the type of human civilization we want to be and have, is also key in the RD process (Africa, 2021).

There are some similar papers, such as that of the Weather Makers, where the possibility of regenerating the Sinai Peninsula and the success of China in regenerating the Loess plateau is discussed. This team of “*holistic engineers*”, founded by Ties Van der Hoeven, Gijs Bosman and Maddie Akkermans in 2017, believe that it is possible to transform a desolate desert environment in to an abundant ecosystem. Chopping down trees, and destroying ecosystems, reduces local rainfall, and it is the hypothesis that restoring trees and ecosystems will increase local rainfall; supported by the successful transformation already achieved in the Loess plateau. Transforming the Sinai Peninsula would sequester billions of tons of carbon from the atmosphere; but is has been identified that the main challenge is not so much technological, but instead our lack of imagination and inability to see alternate futures to our current dystopian pathway towards pandemic, climate change, and biodiversity loss (Rose, 2021).

Research regarding the reforestation of the Sahara and Australian outback has been conducted to explore this as a method for sequestering CO_2 to combat climate change, through planting with irrigated forests. Within a few years the forests could be harvested and replanted to increase yields and carbon offsetting, though there are challenges to developing the infrastructure necessary to develop such capabilities. Providing the freshwater necessary for such irrigation methods under normal developmental methods could also have additional carbon emitting issues, though not if 'green' power sources are used, and at current levels the cost will be expected to be around \$0.53m^3 (Ornstein et al, 2009).

These works are large scale interventions, requiring large amounts of financing and political backing to achieve development, let alone success; both of which are not assured. The results from such developments do not necessarily have positive effects to local economies or help to transition away from unsustainable practices of agro-industry. These aims could be achieved through similar smaller-scale developments where the benefits aggregate together for increased impacts. The barriers that restrict larger projects can be overcome by local community involvement, reducing costs, including agro-industrial and ecosystem recovery together, and alternate 'ownership' models that empower communities and do not aggregate wealth to a small number of individuals (Muller, 2017).

In light of the research already undertaken, this paper aims to establish a scalar theoretical model which demonstrates a number of simple and cheap technologies together, that can be used in a desert region such as the Sahara, to provide enough freshwater, food and energy for subsistence level existence at the beginning. Further development through this model aims to demonstrate how the use of these simple technologies can be used to provide a pathway out of poverty, and ecosystem regeneration. At conclusion the model should demonstrate the possibility of humanity achieving the first stage of civilisation-level development without current destructive methods and a way to resolve global climate crises though carbon off-setting.

Gibbons et al (2018) define a list of outstanding needs for the expansion of RD as a paradigm, figure 2, from which this paper aims to fit within their 'conceptual and theoretical development' section. They further identify that becoming a practitioner of RD is as much an art as it is a science, and those wishing to practice need to develop, possess and consistently nurture new skills, mindsets, and aspirations.

Figure 2: Needs for Advancing Regenerative Development

1. Conceptual and theoretical development
2. Methodological Frameworks
3. Assessment tools
4. Educational Programs
5. Implementation

(Gibbons et al, 2018)

Methodology

For this research a meta-ethnographic approach was considered best to achieve a qualitative analysis of the technologies that could be used towards the identified goals using secondary sources of data. In considering technologies the author seeks to determine whether they meet certain criteria for inclusion, figure 3; and evaluates the extent they can work well together to generate multiple impacts.

Figure 3: Selection Criteria for Technological Consideration

1. Can it be used with only one, or a combination, of the three limited inputs of sunlight, seawater, and desert land?
2. Does it produce a useful output in the Water, Energy, and Food (WEF) and Climate Change nexus?
3. Can the technology be implemented incrementally and is it scalable?
4. Can the technology be built and maintained at a local level with minimal training?
5. Can the technology be built with non-polluting and fully recyclable materials?
6. Does the technology or its outputs have ecological benefits or restore the land?
7. Does the technology have a significant life span and could it be used towards an industrial permaculture?

(Author)

In contemplating technologies for this research the author aims to eliminate those not considered suitable on sustainability grounds, such as the technology being consumptive, uses toxic components, depletes/damages ecosystems, uses rare materials, or is a highly advanced technology. Successful technologies are then considered against the criteria list to determine the possibility of playing a role within a network of other technologies. Groups of technologies should increase one or more of the quantity, quality, efficiency, or range of outputs, above the individual components themselves, whilst benefiting the local ecosystem and global environment. The ease of use, implementation, and whether it is incrementally scalable in a modular manner will then be considered, as well as what minimal resources are necessary for building, installing, maintaining, and operating the technology. The aim is to minimise the quantity of infrastructure to gain the very first rung on the developmental ladder; further up the ladder it may be advantageous to replace with alternative technologies. The key criteria has been to use 3 minimal inputs to be the foundation of a regenerative agro-industrial permaculture that is capable of demonstrating the antithesis current practices.

It is assumed that those undertaking this developmental ladder will not have access to many resources, therefore the author will endeavour to determine the minimal resources necessary for taking the first step of the development ladder, and that it may require either a minimal seed capital to begin or the use of free recycled material can be used. As development begins to provide outputs these could be further used as inputs for, or in conjunction with, other technologies to maximise uplift on the developmental ladder, ecosystem recovery, and economic benefits.

Towards these aims this paper assumes some fundamental boundaries at the beginning of the developmental model, figure 4:

Figure 4: Fundamental Boundaries

1. *The model is a group activity of 50 adults*
2. *The model provides an area of 1km^2 for each group*
3. *The 50m boundary edge of the model area is considered commons, to which the general public have access and where the group is required to develop commons infrastructure at certain key development stages*

(Author)

This research was expected to be a technologically driven experience, with the identification of neglected areas of engineering that could be brought together. However, it became apparent that not much digging was necessary in identifying useful technologies; which raised the question, why then do we still have a problem? The conclusion, the problem is humankind; that by their very nature fail see the future, the possibilities, the benefits. This can be observed throughout history where nay-sayers decried in turn the very possibility of achieving sixty mph, one hundred mph, breaking the sound barrier, and going to the moon.

People very rarely get the opportunity to stop, look around, think, and then act. Too much is going on, right-now, to see what will be going on far, far in the future; but this is what is needed to understand our place in history.

The overall strategy selected for this research was to take the largest possible perspective towards achieving the largest possible aims, with the least possible inputs. How is it possible, with a wire coat hanger, toilet roll tube, and some sticky-back plastic, to change the world? In seeing from a higher plane, it is possible to understand a system from a new perspective, figure 5, to completely redefine how to achieve the outcome desired without using the old system at all. For example, questions are often asked about how plastics can be used safer, greener, better; but how could we achieve the same thing if plastics never existed? We once had a world without plastics, so we know this is possible; we just have to consider things from this new perspective.

Figure 5: Trans-Paradigm Perspectives

> *"Change comes first from stepping outside the limited information that can be seen from any single place in the system and getting an overview. From a wider perspective, information flows, goals, incentives, and disincentives can be restricted so that separate, bounded, rational actions do add up to results that everyone desires."*
>
> *(Meadows, 2008, pp. 108)*

Within systems thinking, in which not only are individual elements considered, but also the interactions between them and the overall purpose to the system, there is considered to be a number of opportunities to intervene in the system's operation, leverage points, of which one of the world's foremost systems analysts catalogues 12 types of leverage points in increasing order of effectiveness, figure 6 (Meadows, 2008). The first eight of these points are the most considered, reviewed and modified in attempts to change the undesirable effects of a system, but are also the least effective at having a significant impact. The last four, self-organization, goals, paradigms, and transcending paradigms, often the least considered but having the greatest impact, are analysed in the strategic review of this research.

Figure 6: Places to Intervene in a System

12) *Numbers*
11) Buffers
10) Stock - & - Flow structures
9) Delays
8) Balancing feedback loops
7) Reinforcing feedback loops
6) Information flows
5) Rules
4) Self-organization
3) Goals
2) Paradigms
1) Transcending paradigms

(Meadows, 2008, pp. 194)

The more complex and expensive something can be, the more it will become, and the less likely it will be to happen. The easier and cheaper it can be demonstrated the more people will give it a go and therefore more will succeed. This is especially true in poorer economies, whose populations are driven by necessity for life improvement, but have not the funds for traditional methods of doing so.

The advice for researchers, wanting to have a broader impact, is go big in considering the nature of the problem, and the systems in which they reside. The advice for those wanting research that has a greater uptake in its application, is make it as simple and cheap as possible. For those wanting to make a dent in the world; do both.

In considering the conceptual and theoretical possibilities within this paper the design process has been split; the first stage being the technological development of a single module, while the second stage being the construction of multiple modules for regional and global impacts.

The designs and techniques within this paper have glaring issues and omissions, such as how long it would take to construct the designs, the financial value of outputs, and the training necessary to undertake such a project. It is not the place of this paper to attempt to address such issues. These methods were chosen to demonstrate that, through small-scale human driven interventions, it is possible to begin to have global-scale positive impacts, even if nothing else changes on the global stage. If each unit requires 50 people to develop a fully functional agro-industrial ecosystem, this concept demonstrates that it only needs 500,000 people to go from A to B to C … to Z and achieve multi-gigaton annual CO_2 offsetting.

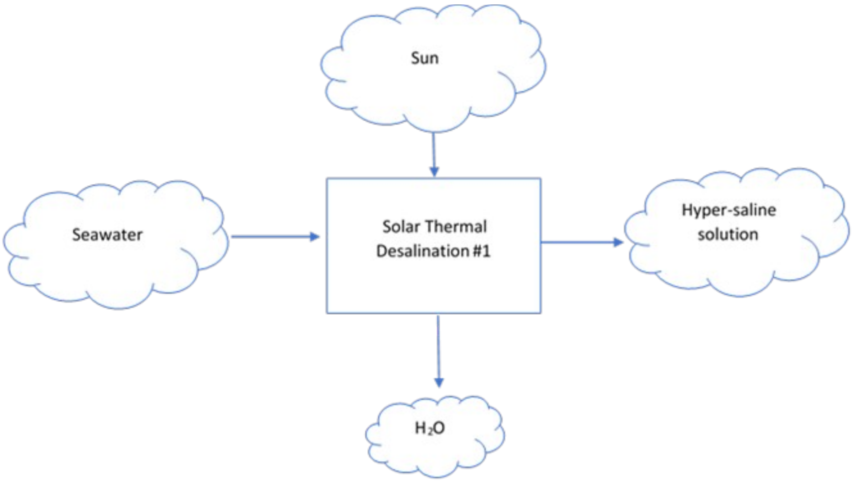
Stage 1: Single Module Development

T0.1: Making Stone Soup

The target for T0.1 is to provide the minimum capacity for supporting 50 individuals, to ensure that each member of the group undertakes subsistence-level development producing just enough sustenance to survive using sun, seawater and desert land.

In survival situations, securing the provision of freshwater is the primary objective, therefore every individual within the group is required to construct a method of transforming seawater to freshwater, in quantities ensuring survival. Amounts given for water security vary from 100L - 1,000L/day, though for survival a figure of 10L/day has been selected (Encyclopædia Britannica, 2015). Solar stills are a simple technology capable of this transition using inexpensive materials and that have been used by the poor around the world (Belessiotis, 2016). It is possible to construct stills using locally available materials to give a well-constructed facility with a lifetime of 20-25 years and output of between 2-6L/m^2/day. Assuming an output of 3.3L/m^2/day, it would require constructing only 3m^2 of solar still to produce the minimum level of water; all achievable with recycled materials, such as glass bottles and aluminium cans. Having constructed Solar Thermal Desalination stage #1 (STD #1) each individual would only need to add seawater once per day, and remove the hypersaline solution twice per week, to produce their daily allowance of freshwater, figure 7.

Figure 7: STD #1



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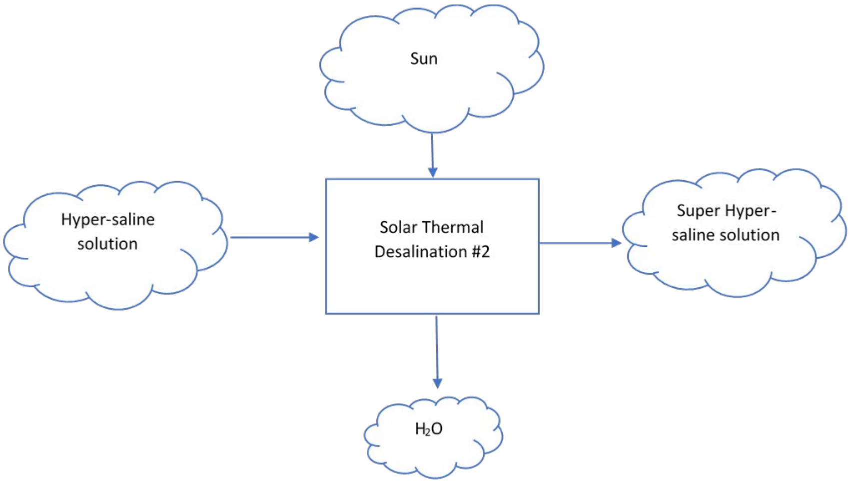
Using sunlight the hyper-saline solution remaining can be further evaporated in another stage, STD #2, to produce any remaining freshwater whilst concentrating out the remaining trace components of the seawater, which may be a benefit in the future, figure 8.

Figure 8: STD #2



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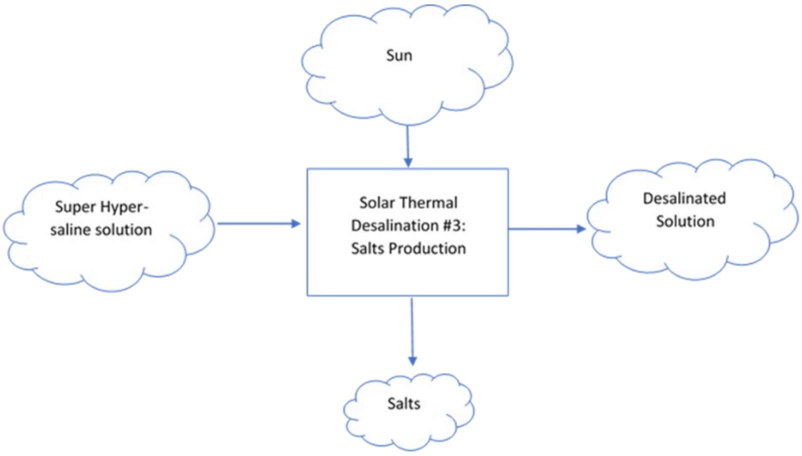
The super-hyper-saline solution output from STD #2 can be evaporated further towards extracting salts from this water, figure 9, and at different degrees of salinity different types of salt can be extracted using a process called fractional crystallization (Duffie and Beckman, 2006). Salts are removed mechanically when saturation levels are reached, and it may also be possible to distil the evaporate for further freshwater production

Figure 9: Salts Production



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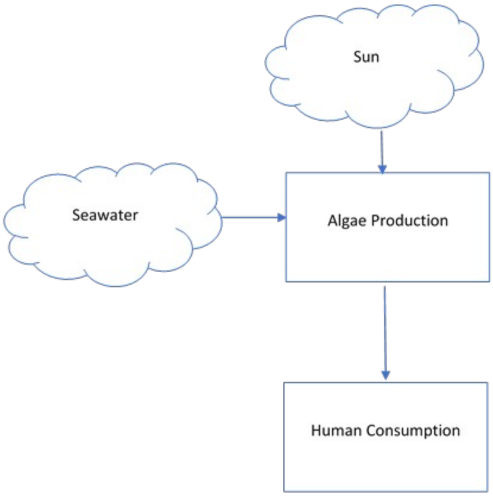
At this stage of development individuals need to ensure access to supplies of foodstuffs, to that end algae can be cultivated to provide nutritional requirements, figure 10. *Spirulina platensis* grown directly in seawater can more than double in population every day, given enough nutrients and sunlight. It is an ideal food and is almost designed to fully meet nutritional requirements; it is 65% by weight protein, 15% carbohydrates, 7% minerals, and 6% fats, with all essential amino-acids in quantities equivalent to milk, eggs or meat, and with many other vitamins and minerals (Savage, 1994).

Figure 10: Algae Production



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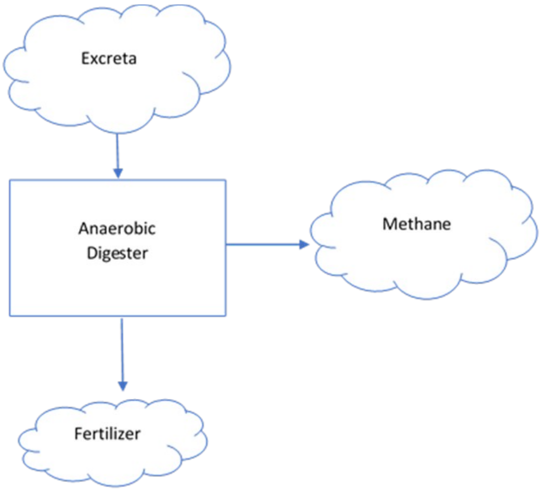
Growing algae requires the construction of tanks, which are beneficial on a number of fronts (Lucas and Southgate, 2012). A simple technology, it is highly scalable, possible to construct from recyclable materials, and operates on small, medium and large scales. It is highly controllable; from being able to monitor and remove toxins, micro-plastics and other persistent oceanic particles, through to the nutrient content of water and the selection of algae grown in the tank. Hermetically sealing the tank with glass panels will minimise undesirable evaporation losses.

It is possible to produce approximately 60g/day/m^2 of algae (Lucas and Southgate, 2012); with the average calorific requirement of an adult being 2000-2500 calories/day, provided in its entirety by 600g of algae, only 10m^2 of infrastructure will meet daily requirements.

As the algae and freshwater produced is consumed by individuals their outputs, i.e. faeces and urine, will remain locally as an input for an AD, figure 11. An AD provides an environment lacking in oxygen for bacteria to digest the input materials, producing two highly useful outputs; (1) methane, and (2) fertiliser (Goodall, 2008). These two outputs are consumed within the group, with the fertiliser used within the algae production system and methane for cooking or power generation. This combustion is highly desirable as CO_2 emissions have a much lower greenhouse effect, and can be used as a feed in the algae production process to increase yields.

Figure 11: Anaerobic Digester



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Based on the total 13m^2 of land for freshwater and algae production, to supply the needs of 50 individuals at the T0.1 level will consume 650m^2 of the land available to the group.

Table 1: Outputs Achieved at T Level 0.1

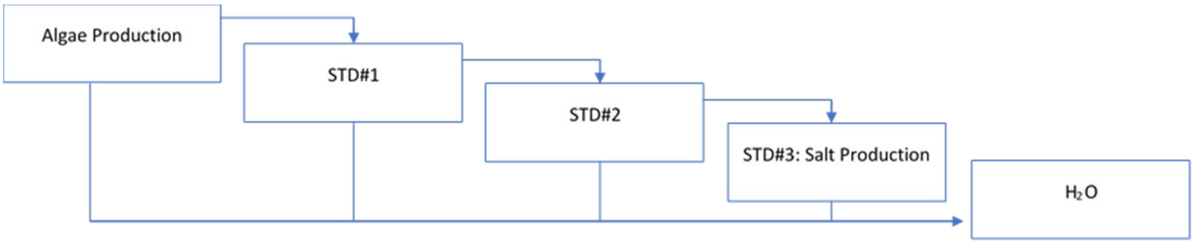
T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.1	500	30	500		30			

T0.2: Rinse and Repeat for Effect

With T0.2 being a factor 10 greater than the output of T0.1 it is assumed that there has been no significant change in the group's financial circumstances, and infrastructure development is along the same lines as T0.1. As each individual created the infrastructure to achieve T0.1 they will be able to repeat this process, with access to materials, to expand output levels. Increasing production levels gives the group a choice of increasing variety within what is produced for consumption, as well as the ability to sell excess outputs for financial income.

The focus is on achieving growth through simplicity during this stage of development, with the aim of growing quickly as possible rather than increasing internal variety. This can be achieved in a manner such that there are incremental increases in outputs as infrastructure comes online, figure 12. Each production module is primarily driven by two key functions at this stage; (1) algae production, and (2) freshwater production for human consumption.

Figure 12: Constructing Module Equivalent to T0.1 Output



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The primary pressure remains the shortage of freshwater. Though survival is ensured at 10L/person/day, this is not enough for ancillary functions; even at 100L/person/day this is still considered to be water poverty, but through careful choice of use and efficiencies this increase in water availability can have transformative effects for the group. Significantly, much of the use of this new water is non-consumptive, such as washing clothing, creating a new output – greywater, used but still useable water. Assuming that 80% can be captured as greywater, this would give an output of approximately 4000L/day for additional uses. At this stage the group would focus entirely on animal consumption, that could be used for food within the group or for export and so will need to be fast growing and have minimal harmful impacts on the environment; most likely to be either chicken or goat.

The group will have increased algae production by the same factor 10, and if the group is now supporting animal consumption a significant portion of this increase will be used towards feeding these animals. The excess algae is an export crop, with a wide variety of values based on how the crop is processed, marketed, and used. Even at its most basic it can be sold as a highly nutritious food additive for human consumption or animal feed (Lucas and Southgate, 2012; National Research Council US, 1990).

While animals will have consumed significant quantities of resources they are also excreting significant quantities, which can be added to the AD system increasing its outputs. This increase in fertiliser and the methane can be used either onsite or can be exported to generate an income. Salt production will also have increased significantly, to a stage where it might be possible to generate a useable income for the group.

With development at this stage being a direct factor 10 increase of T0.1 the area of land consumed is correspondingly larger, giving a total area of 6,500m^2 being used.

Table 2: Outputs Achieved at T Level 0.2

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.1	500	30	500		30			
0.2	5000	300	5000	4000	30	240	30	

T0.3: No Longer Living on the Breadline

The group is now more secure, having developed out of subsistence level operations to produce an excess providing an income or variety. However, they are still considered to be operating at water poverty levels, 100L/person/day, and the first consideration at T0.3 is towards achieving the 1,000L/person/day output putting the group in water security. Also, the group is now considered to have an income stream enabling the implementation of cheaper alternative technologies.

At this stage a significant fork in the development pathways presents itself. Though continuing to scale would already be demonstrably successful, and a simple method of climbing the developmental ladder, if all the groups did this then there would be a failure to demonstrate the feasibility to replace currently unsustainable industries and practices.

As the ‘scaling’ model is simple to continue to develop, the author will discuss concisely the effects of this pathway at the start of each level going forwards, before examining a model that endeavours to ‘diversify’ outputs more comprehensively.

Scaling Model

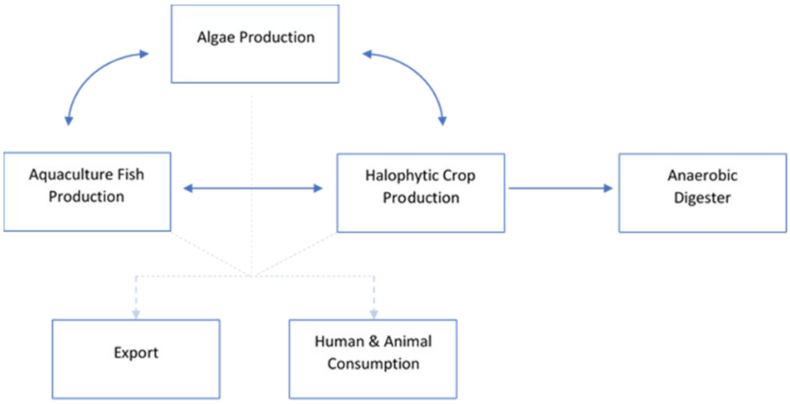
With output of freshwater production reaching 1,000L/person/day algae production has also reached 60kg/person/day, an amount that gives a significant excess necessary for human or animal consumption. The group as a whole produce 50,000L/day of freshwater, leaving 40,000L/day of greywater when used by the group. Using this greywater, with fertiliser from the AD and any algae necessary, it is possible to begin the recovery of the soil within a defined area and local ecosystem. Alternatively, as the increase in total algae production is approximately 20% carbon by weight, 114kg/day, it is possible to be paid for offsetting CO_2 emissions if a secure method for offsetting can be realised, such as the use of biochar (Savage, 1994; Goodall, 2008).

Diversify Model

The first stage of the diversify model assumes that the group does not have the funds to significantly change the infrastructure types already implemented, and would therefore only be able to build tanks similar to those already used for algae production; these can be used in aquaculture for farming fish. The types of fish capable of being farmed are many, with many different food sources from algae, through plant detritus, to other fish; some of which can be farmed together to increase yields (Lucas and Southgate, 2012). At its simplest algae already farmed can feedstock for fish in another tank system, which could even be underneath the algae tanks meaning no further land is consumed in their creation.

Alternatively, a cyclical system can be developed so that excess outputs are used for other crops, figure 13. Water from algae ponds, denuded of nutrients, can be used next in a hydroponic tank for the growing of halophytic plant life which, like peas and beans, can fix atmospheric nitrogen into the water. Next the water can be used in an aquaculture tank, for fish production, the excreta from which is added to the water and is used for growing algae. It is even possible to grow plants on the surface of the aquaculture tank, with fish eating the roots and leaves of these plants as they grow, increasing efficiencies of outputs per given area of land.

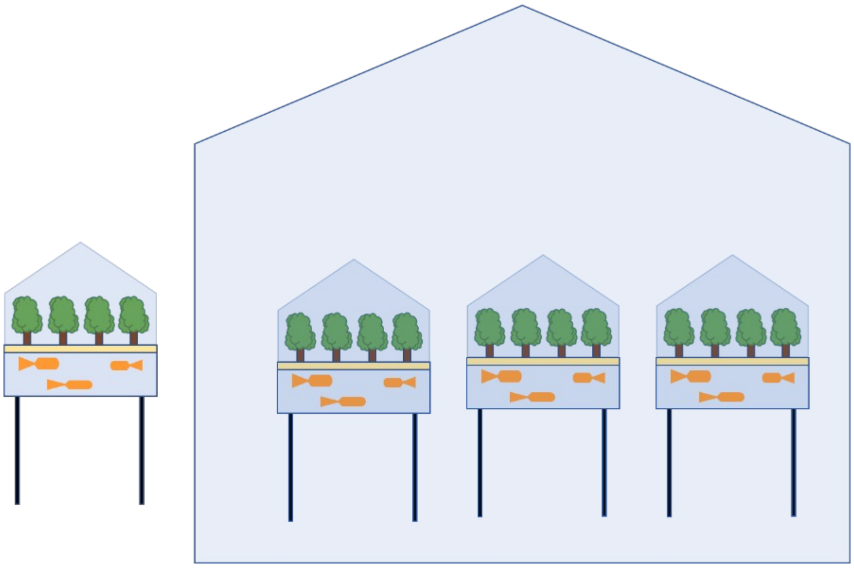
Figure 13: Cyclical System



(Author)

With such a circular system water can be moved from one stage to another, in any order, to make alterations as necessary to water nutrient levels. With the production of halophytic plants there is likely an increase of water loss, through evapotranspiration, without consideration towards eliminating this. As the group already has experience with building solar stills the building of hermetically sealed greenhouse structures, recapturing the evapotranspiration for reuse, seems the most beneficial progression. This can be achieved at small scale, being built on top of a tank system, before scaling up to larger commercial greenhouse facilities containing multiple tank systems capturing all the evapotranspiration if desired, figure 14.

Figure 14: Aquaculture Greenhouse



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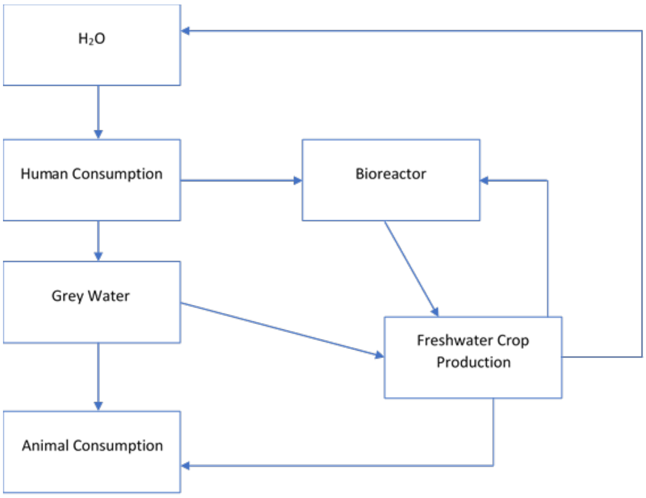
At this level the group produces a large quantity of greywater every day enabling the production of freshwater plant life, figure 15. The benefit of growing freshwater produce is a well-established market, with values widely known. In using hydroponic methods water efficiencies can be achieved of over 90% that of traditional farming methods, increasing desirability and saleability of traditionally water hungry crops, such as cotton. With multiple independent tank systems, it is possible to create the salinity level most desirable for improved plant outputs, for example some tomatoes grown at increased salinity levels produce sweeter fruits.

Figure 15: Freshwater Cycle



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With development at this stage being a direct factor 10 increase of T0.2 the area of land consumed is correspondingly larger, giving a total area of 65,000m^2 being used.

Table 3: Outputs Achieved at T Level 0.3

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.1	500	30	500		30			
0.2	5000	300	5000	4000	30	240	30	
0.3	50000	3000	50000	40000	30	2400	570	

T0.4: Now We're Cooking with Biogas

Based on the output figures from T0.3 the group will be considered to have developed enough income and savings to purchase materials and technologies, and begin the implementation of more technically complex infrastructure development.

Scaling Model

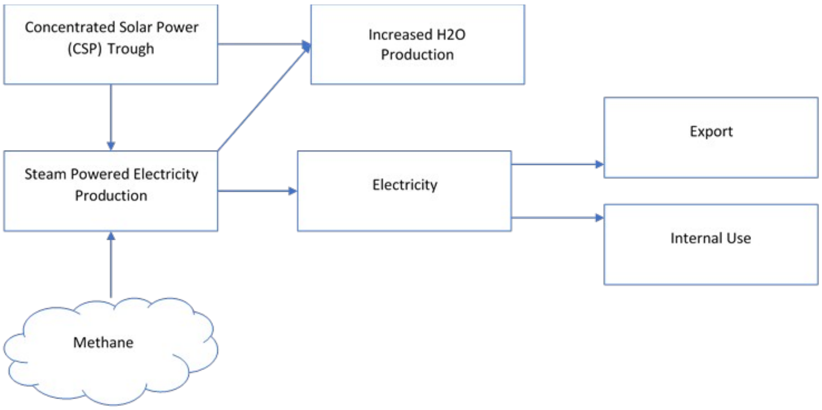
Under the scaling model T0.4 will produce 10,000L/person/day of freshwater and 600kg/person/day of algae, or a total of 500,000L/day of freshwater and 30,000kg/day of algae. Even removing the quantities of water and algae required for community survival there remains a significant excess of both for export or incremental ecological recovery of land, ensuring the long-term survivability of the land regenerated. Carbon offsetting using the algae, produced at 20% carbon by weight, gives about 5514kg/day – or a total of approximately 2012 tonnes/year. Assuming offsetting a tonne of CO_2 is around £50, and each tonne of carbon offset is equivalent to 3.66 tonnes of CO_2 offset; therefore the 2012 tonnes of carbon is equivalent to 7,363 tonnes of CO_2, giving a value of £368,196/year.

Diversify Model

At this stage the group are considered to have enough funds to purchase more complicated infrastructure items, but not enough for the most complex and expensive. Progressing towards the next stage foresees the group undertaking the development of CSP, using the solar trough method, where it is possible to incrementally install and expand the CSP infrastructure based on the demand for electricity and the finances to pay for it (Duffie and Beckman, 2006). Once able to produce more electricity than for their own domestic use, the group can consider using excess within other products they export, as an embedded resource, therefore having greater control over the price received.

In selecting the CSP technology the group are again using a method with alternative inputs and outputs in its systems, that could be useful to other areas of their infrastructure. CSP is the concentration of solar rays to increase the temperature of a working fluid travelling through a high-pressure pipe, then used to produce steam, powering a turbine, giving electricity, figure 16.

Figure 16: CSP Electricity Production



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Much of the waste heat as possible can be recycled towards the steam production process; but after this remaining heat can be used to pre-heat seawater in the desalination processes to increase outputs. CSP does not produce heat during times of low light, but with an AD producing methane this can be burned to produce steam. Even an old petrol engine, converted to burn methane, could be used to generate an almost ‘immediately-on’ supply of electricity if required.

Using most of the electricity internally gives much greater control over demand, working mostly during daylight when supply is greatest. Even if exporting to a local grid, most demand will come during daylight hours, as most people will be asleep during the night reducing demand.

With development at this stage being a direct factor 10 increase of T0.3 it will have consumed 650,000m^2 of desert land to do so.

Table 4: Outputs Achieved at T Level 0.4

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.1	500	30	500		30			
0.2	5000	300	5000	4000	30	240	30	
0.3	50000	3000	50000	40000	30	2400	570	
0.4	500000	30000	50000	40000	30	2400	27570	450000

T0.5: Completing the Technological Journey

At T0.5 the primary issue will be the total consumption of the land available for development, given only an area of 1km^2 was set aside for use; at the completion of T0.4 650,000m^2 will have been consumed. To achieve the next factor 10 increase in output levels it is no longer possible to simply scale infrastructure; instead there will have to be significant improvements through efficiencies (Savage, 1994). What, or how, these efficiencies are made, or even if they are achievable, may not be knowable at this time. However, the industrial and agronomical practices in this report are at the beginning of their developmental timeline, and will be improved through research in their respective fields.

At the completion of the development to T0.5 it is assumed the maximum quantity of outputs possible will have been achieved in both models, all efficiency developments have been made, and that future advances will not significantly increase output levels of the resources produced.

Scale Model

To achieve the target outputs at T0.5, of a total 5,000,000L of freshwater and 300,000kg/day of algae, the group will need to fully utilise the remaining land available and increase production efficiencies, which may include advanced improvements in genetic lines to speed up growth cycles, the use of LED lighting to convert unused wavelengths of sunlight to more efficient wavelengths whilst extending growing through night periods, and possibly growth cycles that require no sunlight at all (Dutta Gupta, 2017).

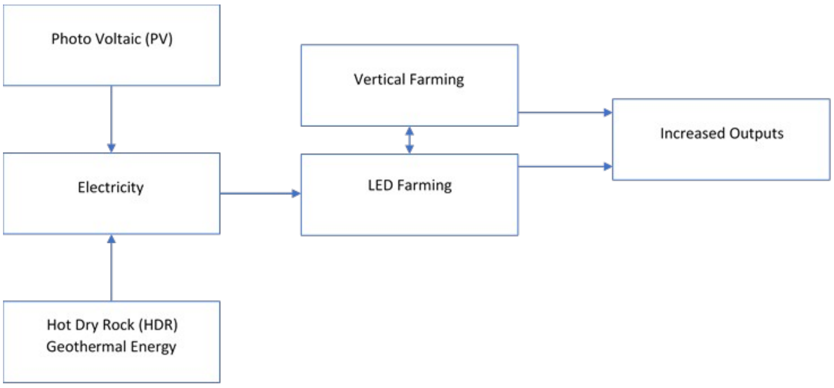
In achieving target outputs, the group has completed the developmental process and can focus on other aspects of the systems created. In becoming economically stable, and recovering the local ecosystem, the group could play a significant part in the recovery of the wider global climate through carbon farming, the offsetting of significant quantities of CO_2 emission at rates much higher than reforestation. At full capacity the group could offset approximately 60 tonnes/day of carbon, or about 21,6000 tonnes/year, equivalent to 219 tonnes/day of CO_2 and 80,154 tonnes/year CO_2. At £50 per tonne of CO_2 offsetting this would give an annual income of about £4,007,700.

Diversify Model

At the T0.5 stage the group is considered to be generating enough income to undertake more technically complex infrastructure. To increase electricity output-levels photovoltaic (PV) could be used which are quick and easy to install, though expensive. However, the installation of hot dry rock (HDR) geothermal energy is the technology likely to have a much greater impact for the group, developing a baseload infrastructure providing a level of security to the group unavailable in traditional renewable electricity production. This technology drills down in to the Earth and, using fracking techniques, creates reservoirs of water to extract heat from the Earth's mantle for electricity production and preheating seawater for desalination.

This increase in electrical output could be used internally to increase the output of other plant life products through the use of LED farming methods, figure 17. Used in conjunction with vertical farming techniques, even more crops could be grown on a given area of land as a wall of plant life can be sustained by the increases in both water availability and access to LED lighting (Dutta Gupta, 2017). LEDs can even be used within current algae, and other crop, production to quickly and simply increase outputs without any of the efficiency methods already discussed.

Figure 17: Vertical and LED Farming



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In achieving T0.5 it is assumed that the group has reached its maximum development potential, and though other technologies may exist to further increase outputs, such as nuclear, they are not currently within the selection criteria for inclusion in this research.

Table 5: Outputs Achieved at T Level 0.5

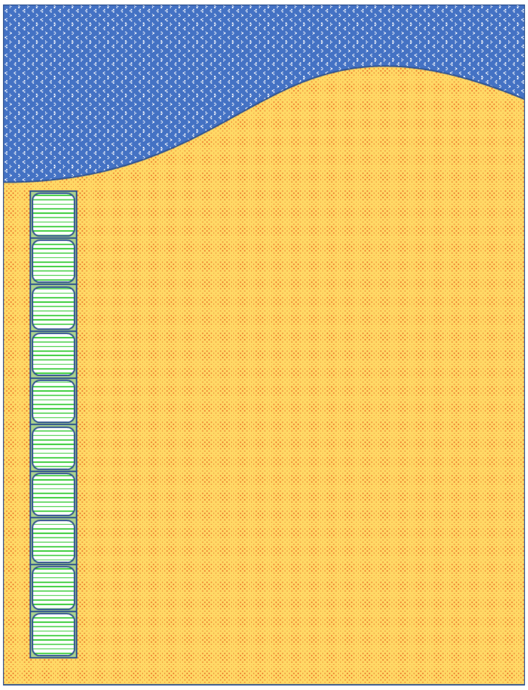
T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.1	500	30	500		30			
0.2	5000	300	5000	4000	30	240	30	
0.3	50000	3000	50000	40000	30	2400	570	
0.4	500000	30000	50000	40000	30	2400	27570	450000
0.5	5000000	300000	50000	40000	30	2400	297570	4950000

Stage 2: Multiple Module Development

T0.6: Copy and Paste

Having achieved the full developmental capacity of a single area of land (1km^2) by the group, further increase in outputs requires replicating the practices undertaken in T0.1 – T0.5. The increase by a factor 10, necessary for T0.6, simply necessitates an area of land ten times the size of output at T0.5, (i.e. 10 × 1km^2), to achieve full development. These areas could be in any ratio with direct access to the coast, from 1km coastal through to 10km coastal, with any remaining areas connected inland accessing necessary inputs via commons infrastructure. In this instance a single 1km coastal access is assumed, with a further nine 1km inland developments, as a demonstration model of the technique, figure 18.

Figure 18: 1km Coastal : 10km Internal



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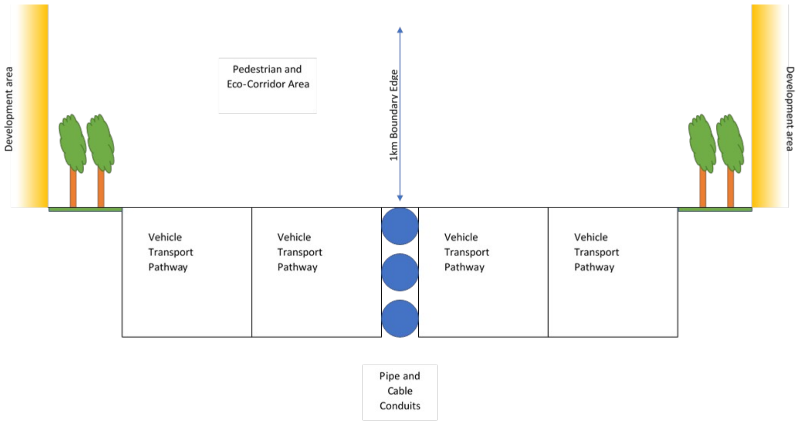
Indenting the border of each development provides an area for commons access, an eco-corridor for the wildlife returning to the area, and to provide park-like areas for residents, figure 19. Excavating these regions between developments, in a cut and cover method, will enable the construction of underground metro-type facilities and other infrastructure, such as laying pipe and cables. By having this tunnel method further incremental installation, inspection, maintenance, and improvements can be achieved without additional excavation work.

Figure 19: Eco-Corridor and Common Good Provision



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At this T0.6 stage this small area of land could offset 801,540 tonnes/year of CO_2 equivalent, at £50 per tonne the local economy would receive a benefit of approximately £40,077,000.

Table 6: Outputs Achieved at T Level 0.6

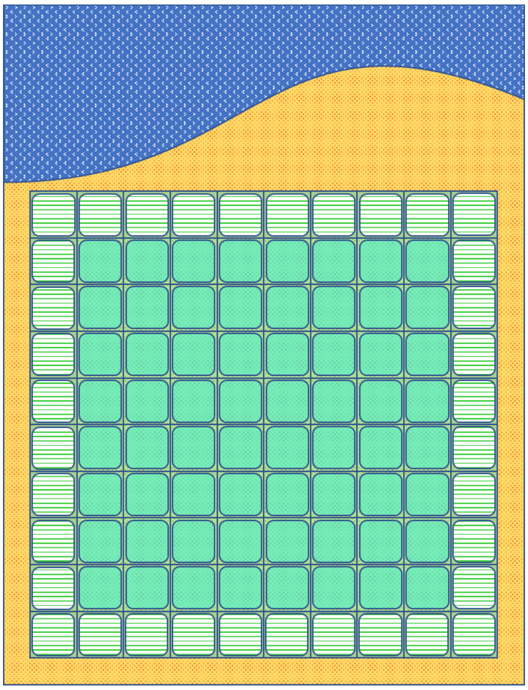
T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.6	50000000	3000000	500000	400000	300	24000	2975700	49500000

T Level	Carbon Offset (20% of Algae Weight) (kg/day)	C:CO_2 (1:3.66 Offset)	Income (@ £50/tonne/day)
0.6	595140	2,178,212	108,910

T0.7: Islands of Safety

For T0.7, instead of a single coastal development an expansion to ten developments is proposed, while still retaining the 1:9 ratio, creating an area 10km by 10km of development necessary to achieve the output levels of T0.7, figure 20.

Figure 20: 10km Coastal : 10km Inland



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A benefit during the construction stage is presented where it is possibility to develop the outer modules of the region first, as a means of providing security in conflict regions, before construction to fill the interior zones. Securing an outer perimeter, and limiting access to the interior during the construction phase, is likely to reduce the size of outer-wall construction within internal developments, compared to the exterior developments, speeding up construction. In highly volatile areas these developments could provide islands of safety and security on a journey towards achieving the end of conflicts, through improving local economies and access to jobs for local populations.

At this regional (local) scale achieving T0.7 outputs would give 500,000,000L/day of freshwater, 30,000,000kg/day of algae, and 8,015,400 tonnes/year of CO_2 equivalent, at £50 per tonne the local economy would receive a benefit of approximately £400,770,000.

Table 7: Outputs Achieved at T Level 0.7

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.6	50000000	3000000	500000	400000	300	24000	2975700	49500000
0.7	500000000	30000000	5000000	4000000	3000	240000	29757000	495000000

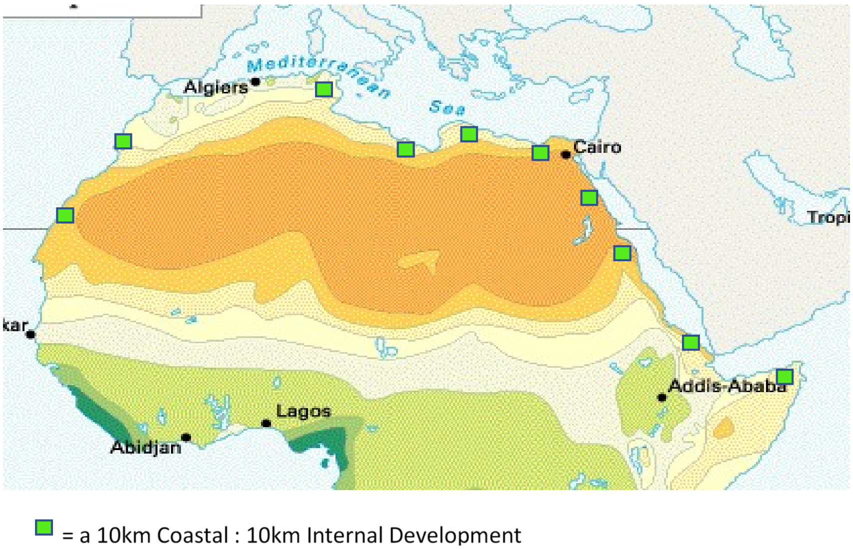
T Level	Carbon Offset (20% of Algae Weight) (kg/day)	$C:CO_2$ (1:3.66 Offset)	Income (@ £50/tonne/day)
0.6	595140	2,178,212	108,910
0.7	5951400	21,782,120	1,089,100

T0.8: Now We are Really Geoengineering

The increase required to achieve T0.8 could be achieved through a variety of form-factors; such as retaining a 10km coastline and covering the distance of 100km inland, to a 100km coastline covering a distance of 10km inland, or alternatively a number of developments in separate regions.

For the flexibility and ease of construction, the preference is for a number of different developments, where ten separate T0.7 scale developments are created along coastline regions where the geology and community prefer, figure 21. Although there may be a large coastline in the Sahara that could be considered as suitable for development, from the perspective of being within a desert region, it is assumed that much of this area is unsuitable for development due to local climate conditions, geology, or being previously developed. Therefore only 10% of the coastline is assumed to remain for consideration, giving plenty of room for 10 seperate regional (local) scale developments to be constructed in ‘areas of most need’ for economic, social and environmental security.

Figure 21: Coastline Developments



Adapted from Encyclopædia Britannica, 2015

Though separate, for the purposes of this paper this level of development will be considered as an area taken together, and will be considered as a regional (district) scale development when achieving full T0.8 level outputs of 5,000,000,000L/day of freshwater, 300,000,000kg/day of algae, and 80,154,000 tonnes/year of CO_2 equivalent, at £50 per tonne the local economy would receive a benefit of approximately £4,007,700,000.

Table 8: Outputs Achieved at T Level 0.8

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.6	50000000	3000000	500000	400000	300	24000	2975700	49500000

0.7	500000000	30000000	5000000	4000000	3000	240000	29757000	495000000
0.8	5000000000	300000000	50000000	40000000	30000	2400000	297570000	4950000000

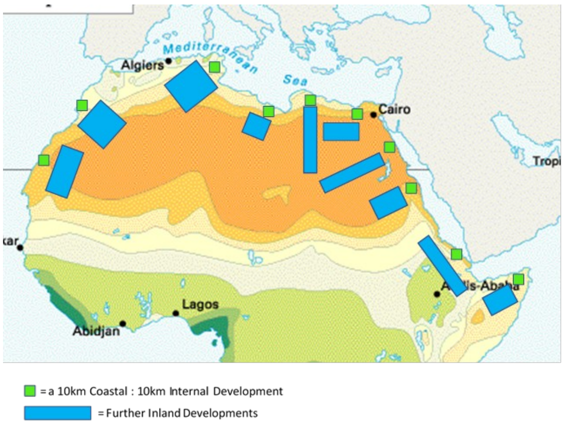
T Level	Carbon Offset (20% of Algae Weight) (kg/day)	C:CO₂ (1:3.66 Offset)	Income (@ £50/tonne/day)
0.6	595140	2,178,212	108,910
0.7	5951400	21,782,120	1,089,100
0.8	59514000	217,821,200	10,891,000

T0.9: Now …, the End is Near.

The land necessary to achieve scaling up to T0.9 might seem to be a simple increasing of the number of regional (district) scale developments; however, this is not likely to be quite that simple. Previous developments have been concentrated in coastal regions, providing direct access to the sea, which is assumed to be 'mined out', meaning more internal than coastal development moving forwards.

The Sahara has around 8,600,000km^2 of surface area, but like previously it is assumed only 10% of this land is usable for the development process, giving an available area of 860,000km^2 (Encyclopædia Britannica, 2015). This seems like enough, but the further inland the more expensive, financially and in resources, it becomes to transport seawater. At some point it is possible to become completely uneconomical to do so, therefore only 10% of this land is assumed as usable for this research, figure 22. Still enough to achieve T0.9.

Figure 22: Further Inland Development



Adapted from Encyclopædia Britannica, 2015

This stage of development will be regarded as a regional (basin) scale development, as each individual development remains within a single desert region, and will likely be having a direct impact on the ecosystem within that region. It may be possible, in concentrating these developments within certain geological structures, to have micro-climate impacts much greater than those within the larger whole, such as using mountain ranges to trap evapotranspiration increasing local precipitation. At this scale such geoengineering is likely to be detectable, especially in larger desert regions; but in smaller geographical areas achieving this degree of impact may happen earlier between T0.8 and T0.9.

In achieving T0.9 the outputs from the developments will be 50,000,000,000L/day of water and 3,000,000,000kg/day of algae; and the possibility of offsetting 801,540,000 tonnes/year of CO_2 equivalent, at £50 per tonne the local economy would receive a benefit of approximately £40,077,000,000. This quantity of algae is enough to feed 5,000,000,000 people/day, or a similar quantity of animals to enter the food chain.

Table 9: Outputs Achieved at T Level 0.9

T Level	H_2O Output (L/day)	Algae Output (kg/day)	H_2O Consumed (L/day)	Grey Water (L/day)	Algae Consumed (Human kg/day)	Algae Consumed (Animal kg/day)	Algae Exportable (kg/day)	H_2O Exportable (L/day)
0.6	50000000	3000000	500000	400000	300	24000	2975700	49500000
0.7	500000000	30000000	5000000	4000000	3000	240000	29757000	495000000
0.8	5000000000	300000000	50000000	40000000	30000	2400000	297570000	4950000000
0.9	50000000000	3000000000	500000000	400000000	300000	24000000	2975700000	49500000000

T Level	Carbon Offset (20% of Algae Weight) (kg/day)	C:CO_2 (1:3.66 Offset)	Income (@ £50/tonne/day)
0.6	595140	2,178,212	108,910
0.7	5951400	21,782,120	1,089,100
0.8	59514000	217,821,200	10,891,000
0.9	595140000	2,178,212,000	108,910,000

Strategic Effects

This paper considered a developmental model within the Sahara Desert region, but there are more deserts globally where a similar pathway could also be enabled. Discounting the two largest desert areas, due to being ice-covered polar deserts, this still leaves around 19.4 million km^2 of land that could be regenerated towards creating a sustainable future for the Earth's ecosystems and Humanity.

In returning these once desolate lands to vibrant agro-ecosystems we are no longer tied to the necessity of using verdant land for crop production or industry, and could rewild lost forests and ecosystems of nation-states around the world, exporting the sustainable production of foods and manufacturing to the places best suited for doing so. The decarbonisation of industries will become easier, as these development hubs will have the knowledge, skillset, and inclination to transition to sustainable methods, breaking through the 'sunken cost' mindset of current political and industrial leaders, to really begin to reduce CO_2 emissions at a global scale. According to the IPCC, to avoid violating the 1.5°C target set in Paris in 2015 more than 7 billion tonnes of CO_2 needs to be removed from the atmosphere annually (Vaughan, 2022). An achievable figure using this regenerative model if T1 can be attained.

Just like the discovery of fossil-fuel in the middle-east, this development pathway would enable currently majority poor nations to grow their economies and become world leaders. Done the right way, the transition from current methods to regenerative practices could lift many people out of poverty and leave a socio-economic legacy to benefit future generations and Humanity as a whole. However, with current capitalistic ideology the transition is likely to lead to the further concentration of wealth in the hands of the few, with little care or thought to the larger picture; the future of the human race.

An alternative ideology, to an outright capitalistic future, can be found using the waqf model of 'ownership'. A blending of these two philosophies enables the rewarding of entrepreneurial individuals, successful in enacting these developments during their lifetime, whilst also securing the future of these assets for both their descendants and the wider community.

There are many different forms of waqf, allowing a significant degree of flexibility during their formation to the founder (the waqif). This allows for the waqif to benefit personally whilst alive, and for them to dictate both the purpose and the beneficiaries of the waqf for when they die, including for family members. Securing assets in this way ensures, as much as is possible, that they are not consumed and will continue to benefit others for generations to come; such that an inheritor could not squander the lifetime's accumulation of income and assets, traditionally associated with inherited wealth.

In the regeneration of multiple desert regions Humanity would be on the final step towards achieving T1.0 on the Kardashev scale, and in such a way as to reduce the likelihood of both the destruction of our planetary ecosystems and ourselves. As a civilisation we would have demonstrated enough social and technological maturity to be classed as being at the beginning of the Age of Adulthood of our race; a good place to begin our future.

All this could be achievable without the necessity of government or large-scale individual actors towards making it a reality. This developmental model demonstrates how small groups of dedicated and incentivised people, working together, could change the world forever.

Opportunities and Barriers

The opportunities within this model stem from efforts towards making the cost of entry as low as possible, with as few resources as possible, to create a positive feedback for growth, stability and regenerative effect. However, there remain many barriers towards undertaking such a model; from how to create the systems, knowledgebase and transfer mechanisms, as well as reliable access to the minimal resources required for construction. Having these 'solutions' safely within the minds and pockets of a small group in the UK does not help those within the areas requiring development.

Further Areas for Research

Two key further areas of research present themselves. Firstly, would be the creation of further conceptual and theoretical models of alternative technological developmental pathways; such as for different industrial processes, like a papermill, server-farm, or smelter. Secondly, would be to progress higher up the list of Identified Needs for advancing RD towards finding answers to actually achieving increased real-world effects; such as methods for enabling access to marketplaces, knowledge stores, and systems for those within the poorest regions in the world.

Conclusion

This paper successfully demonstrates, at a conceptual and theoretical level, that it is possible to create an incremental developmental pathway from minimal resources, using only three inputs of sunlight, seawater, and desert land. It provides a vision of how those with very little can lift themselves out of poverty, whilst simultaneously regenerating local ecosystems. Using a modular system, a single development is examined towards achieving full technological advancement, before considering the effects of multiple modules on regional and global economic, ecological and environmental outputs; all within the context of a larger paradigm of a pathway towards becoming a spacefaring civilisation.

However, it does not provide answers to the methods, processes and pathways towards actually making such a concept a reality, which is beyond this paper’s scope. Further research towards achieving the vision of this paper’s findings are highly recommended, on a risk-reward basis, with possible benefits to Humanity greatly outdoing any costs to undertaking such research.

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Appendix A

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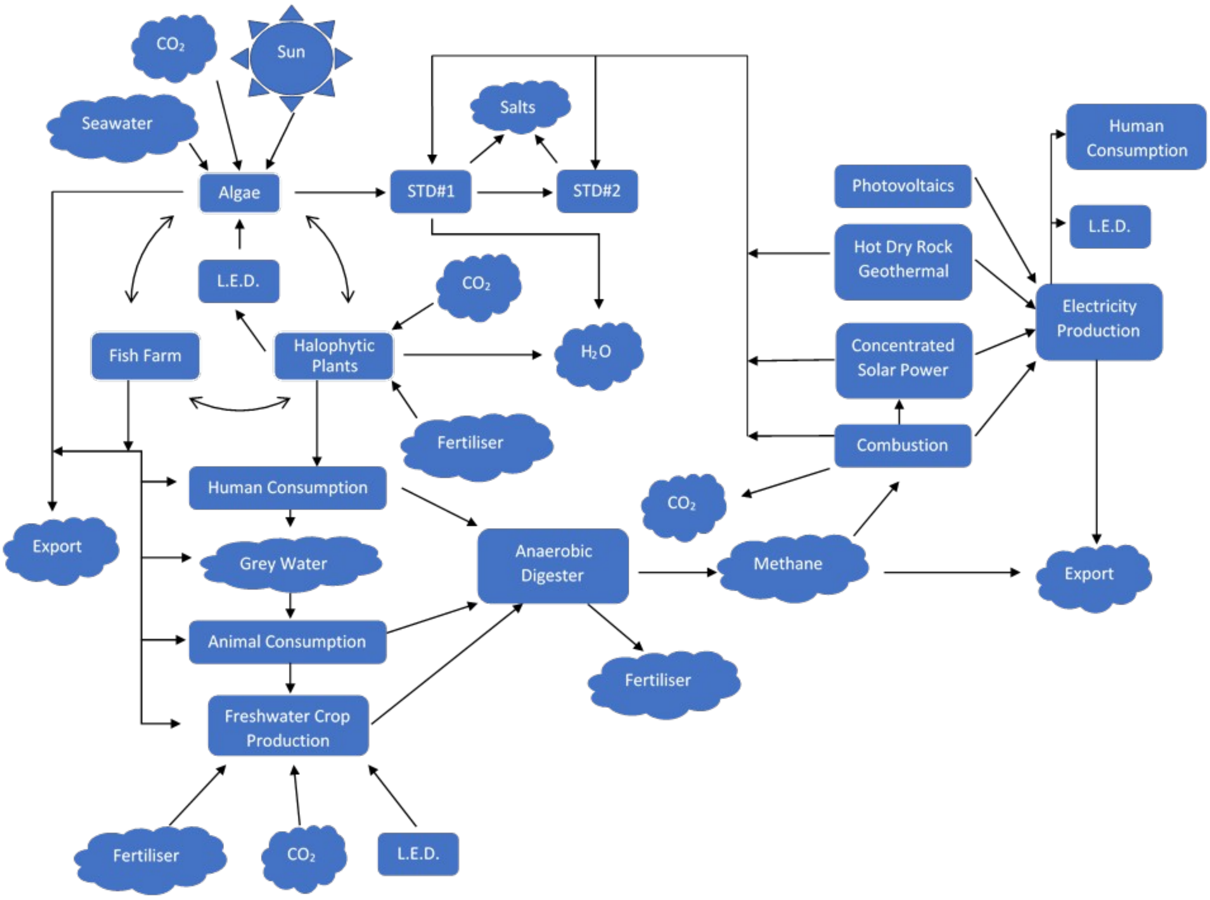
Appendix B

Overall System Diagram



Appendix C

Anaerobic Digester