AALBORG UNIVERSITY
Department of Planning

CREATE-ing Sustainable Livelihoods in Rural Senegal

A nexus based strategy for building desertification resilience through capacity building and appropriate technology.

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Abstract:

Land degradation and its end point, desertification are causing great social and ecological losses in the Sub-Saharan region of Africa. Development aid providers have attempted, with limited success, to offset its impacts. This report aims to highlight the potential of the appropriate technology (AT) concept for increasing the climate resilience of remote rural communities in Sub-Saharan Africa. This is achieved utilizing a case study and in the Diourbel region of central Senegal, where the NGO CREATE! is applying a capacity building and appropriate technology for the same purpose. Data is gathered through interviews, transect walks and field observations carried out in nine CREATE! sites. By analyzing their activities and strategies, and determining the Senegalese context, appropriateness principles were determined and applied to eight reviewed interventions to theoretically assess their viability; Improved cook stoves, conservation agriculture, woody species intercropping, farmer managed natural regeneration and solar water pumps were shown to create a holistic resilience building loop whilst adhering to the determining AT principles. In addition three of the practices present on CREATE! sites with proven appropriateness; poultry rearing, community savings and loan programs and formalized tree planting were included in this system. Despite failures in development aid, it is still possible to create sustainable livelihoods in Africa by meeting basic needs and raising climate resilience through appropriate action, thus empowering Africans to drive their own development.

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Preface

The thesis was written during the spring semester of 2018 at Aalborg University under the supervision of Arne Remmen. We are extremely grateful for his valuable input throughout the whole report writing process. Even in the most difficult of times, Arne provided us with guidance and motivation we needed to pull ourselves through.

We would also like to send our deepest thanks to Barry R. Wheeler and the entire CREATE! Senegalese field team who transported us from site to site providing us with lots of information and fun. You made the field work a wonderful experience. We will never forget it and we will never forget you.

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Chapter 1

Problem analysis

1.1 Land Degradation and Desertification

Globally ecosystems are undergoing a process of degradation. Land degradation occurs when an area suffers sufficient topsoil, vegetation, and/or water resource damage. Over time this results in the reduction of the efficiency of natural water and nutrient cycles, reducing biodiversity and productivity to the point of ecosystem service cessation. Dryland regions, which make up around 41% of the earths land area and are home to around a third of the global human population (Millennium Ecosystem Assessment, 2005) are particularly susceptible to land degradation, making their inhabitants vulnerable to it's impacts(Mueller et al., 2013). Drylands encompass; arid, semi-arid, and dry sub-humid areas. If left unchecked, land degradation in these may result in the breakdown of several biophysical processes eventually leading to desertification. The name "desertification" can lead to confusion. It is not the expansion of deserts. As defined by the UNCCD:

> *"Desertification is not the natural expansion of existing deserts but the degradation of land in arid, semi-arid, and dry sub-humid areas. It is a gradual process of soil productivity loss and the thinning out of the vegetative cover because of human activities and climatic variations such as prolonged droughts and flood"* (UNCCD, 2018)

The united nations convention to combat desertification (UNCCD) states that there are two major drivers of desertification; human activities and climatic variations. These factors are interlinked, with unfavourable combinations resulting in land degridation and it's end point, desertification. This process can significantly effect the livelihood of dryland populations which tend to rely directly on the provision of ecosystem services for survival(Mueller et al., 2013). The main driving forces of desertification will be explored in the following section.

1.1.1 Drivers of desertification: human activities

The exploitation of land and resources through human activities plays a crucial role in driving land and soil degradation. This can occur over a long or short period.

Cultivation is a primary use of land. However, over-cultivation, the excessive use of the land resources and services leads to the loss of productivity and services as resources are used faster than they can replenish, causing the breakdown of natural cycles. This process is re-enforced by harmful cultivation activities such as:

- **Ploughing**: Exposing the topsoil to expose nutrients and to take out weeds that would be harmful for the cultivars. However, this activity exposes the topsoil to erosion by external factors such as wind and heavy rain, in turn increasing nutrient and organic matter loss (Fawcett og Towery, 2003).
- **Excessive use of fertilizers**: Overuse of fertilizers has a negative impact both on soil health and water resources. When used excessively and available nutrients out weight plant uptake, the excess drains into water reserves, resulting in euthrophication. Moreover, long-term use of these can cause soil quality to decrease by causing compaction and depletion of organic matter (Sullivan, 2004).
- **Overuse of water resources**: Water resources in drylands tend to be scarce, but, some cultivars require continuous watering through irrigation systems. When excessively used, it can cause salinisation to the soil. Salinisation is the excessive precipitation of salts provident from the water. When plants take up the water, they leave behind the salts that the water contains. this effect is compounded when irrigating during hours when evaporation rate is higher. The salinisation of soil affects the productivity of plants and microorganisms, and if extreme, the land can become unsuitable for them to grow and therefore it becomes infertile. (Jones et al., 2013).
- **Vegetation clearing and deforestation**: The clearing of woody vegetation from land. Woody vegetation is often cleared to prepare land for agriculture. However in many drylands poverty is high and wood is a primary fuel making energy provision an additional driver for deforestation in these regions. Vegetation helps prevent erosion from wind and water (Pimentel, 2006). Roots maintain soil structure and increase infiltration of water. Foliage provides a cover of organic material, reducing element exposure and evaporation ,increasing water storage capacity, soil organic content and nutrient availability(Directorate Communication, 1999). Additionally woody vegetation sequesters and stores carbon, whilst some species also affix nitrogen, increasing soil fertility(Bright et al., 2017).

  In some occasions, vegetation is cut and cleared with fire. This practice is known as *'slash and burn'* and can be an especially harmful way to clear vegetation. Apart from the negative impacts of vegetation loss outlined above, fire deeply affects soil structure. There exists a natural balance between wildfires and ecosystem recovery. When there is this balance, fires can be beneficial to ecosystems; it creates space for new species to grow and allows a change in species composition (Orgiazzi et al., 2016). However, when this balance is broken due to human activities, soil biodiversity is greatly affected due to high temperatures, and does not have time to recover their populations if the land is ploughed and cropped immediately after. Although nutrients of the burned vegetation may be useful for crops, the lack of land recovery will eventually make the soil infertile.

A considerable amount of human drivers of desertification are linked to crop cultivation. However, cattle farming can also result in soil degradation. Continuous overgrazing can strip vegetation, reducing vegetative productivity and density, resulting in soil quality reduction and erosion. (Robertson, 1996). Furthermore, the soil may become compacted by weight of continuous cattle passes through an area. Moreover, cattle can also cause soil and water euthrophycation as a result of their waste.

1.1.2 Drivers of desertification: Climate variations

Climate change is predicted to affect temperatures worldwide, raising them faster in this century than they have risen on the last 10.000 years (Pachauri og Reisinger, 2007). It is not clear the exact effect of temperature rise on land degradation, but it has been observed that The effects of temperature rise is triggering the shift of several plant and animal species related to soil that can not withstand the change on the environment conditions (Orgiazzi et al., 2016). Additionally changes in weather patterns and precipitation are expected. Although it is not clear if the absolute volume of precipitation will be reduced in dryland regions. However, it is predicted that the distribution of rainfall will be affected, occurring with reduced frequency and predictability but greater intensity. (Pachauri og Reisinger, 2007). Increased temperature and shorter, less predictable rainy seasons are likely to result in droughts in dryland areas, whilst increased precipitation intensity increases the risk of lowland flooding and soil runoff.

Soil biodiversity is adapted, to an extent, to suffer some droughts in dryland regions, as it is a natural process. However, the increased frequency and length of these, is likely to negatively affect soil biodiversity. Extended droughts partch soil, reduce vegetative density and as such reduce the provision of organic components and enzymes.

Increased temperatures and insufficient water also slows soil microbial processes, resulting in a lowering of soil fertility (Orgiazzi et al., 2016). Moreover, when water availability is threatened persistently, drops in vegetation density are observed, even in those species endemic to drylands which are adapted to short droughts periods.

Too little water can cause severe consequences to soil fertility. However so too can water inundation. High intensity precipitation can result in runoff and flooding, which is specially harmful when the soil has already been compacted or exposed. Fertile toplayers of soil are removed and compacted soil becomes severely clogged, due to the reduced rainwater infiltration (Orgiazzi et al., 2016).

On the following figure 1.1, a representation of the impacts of over cultivation in addition with climatic effects is shown.

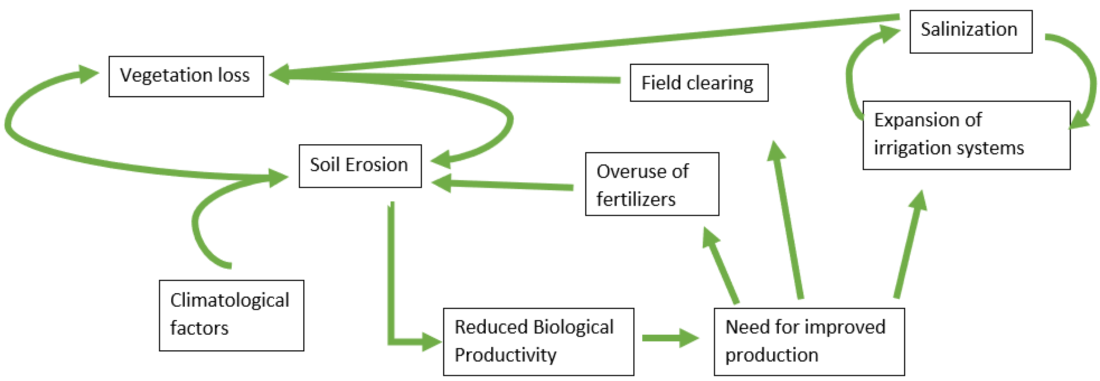


Figure 1.1: Interrelations between over cultivation drivers of land degradation and climatic variations

It becomes clear that the anthropogenic causes for land degradation are resultant from a combination of interrelated activities carried out in order to improve agricultural productivity. Populations in drylands are predominantly rural and disproportionately work in agriculture(Sow, 2017). Climatic shocks reduce crop yields and increase poverty which in turn drives unsustainable agricultural practices forming positive feedback cycle (Keeble, 1988) known as *'the poverty trap'*. Therefore, it is essential to analyze the social factors that cause this cycle to start and the consequences deriving from it.

1.1.3 Social consequences of desertification

Due to the characteristic hydrogeography of dryland areas, water resources are scarce and soil stability is low, making the ecosystem fragile and vulnerable to degradation (Jones et al., 2013). Furthermore, populations in arid regions are prone to poverty, as natural resources are scarce, complicating community and economic development (UNCCD, 2018). Poverty is a driver for over exploitation of natrual resources and as such environmental degradation. This naturally impedes the onset of sustainable development and reduces environmental climate resilience, increasing the risk of desertification (Keeble, 1988). Thus, desertification can have a great impact to communities where food and water security are lacking. This is most relevant in communities almost entirely dependant on agriculture, which in low income environments, relies entirely on ecosystem functions to succeed but also acts as a driver for ecosystem service cessation and desertification. Socioeconomic issues begin to emerge when the land is no longer suitable for cultivation, compromising food and water security. The loss of these basic ecosystem services eventually results is in the migration of entire communities to fertile, unaffected areas or urban centres. It is estimated that 135 million people may be displaced by 2045 as a result of desertification (UNCCD, 2018). The effect of the this on the displaced is large, however so too is the impact on receiving environments. Agricultural expansion may lead to ecosystem fracture, without agricultural change, the cycle starts again. International immigration in turn fuels anti-immigrant rhetoric and reduces the available national work force in countries of origin.

1.2 Desertification in the Sahel region

Desertification primarily affects drought prone arid regions.(D'Odorico et al., 2013) Within these regions it is rural populations which rely most closely on provisioning ecosystem services for necessities such as food, water, fuel, fiber and fodder that are most likely to find their livelihoods adversely effected by it's onset whilst also lacking the socioeconomic means to adequately offset the loss of these ecosystem services (Gaur og Squires, 2018). In addition, growing global populations increase the requirements for the production and procurement of these necessities, especially in areas prone to poverty in which social mobility and the ability to buy required materials are limited (Bowyer et al.).

The Sahel region of Africa is one of the areas most affected by this phenomena and as such is categorized in one of the highest risk bands for desertification in the world(Eswaran et al., 2001). The Sahel is a region stretching from the western to the eastern coast of Africa. Covering an area of 3.053 million km^2 and Encompassing; Senegal, southern Mauritania, central Mali, northern Burkina Faso, the extreme south of Algeria, Niger, central Chad, much of Sudan, the extreme north of Cameroon, Eritrea and extreme north of Ethiopia (Britannica, 2014). It acts as an eco-climatic boundary zone between the hyper arid Sahara to the north and the humid savannas to the south(Britannica, 2014). The region is typified by low (100-200mm) and highly variable highly variable (20-30%) mean annual precipitation (MAP)(UNEP, 2017). Precipitation in dry land regions such as this vary significantly both seasonally and annually. The Sahel is one of the areas in the world with the highest rate of precipitation fluctuation(Buontempo, 2010). However, MAP within the Sahel region has been in a fluctuating state of decline since the 1960's, this is particularly apparent in the western most areas, where MAP has been seen to be in decline(Buontempo, 2010) and has declined by a total of 20-30% since the beginning of the 20th century (Nicholson, 2013). This reduction in precipitation has been compounded by an increase in temperature of 1.3°C on average over the same time period (Hulme, 2001). The result of this is a marked increase in aridity, a key factor in limiting climate and desertification resilience(Miranda et al., 2011).

Whilst the changing climatic conditions in the last century, throughout the Sahel region are a decisive factor in limiting ecosystem function and vegetative productivity, their effect has also been compounded by detrimental human activities on both a global and local scale. Locally deforestation plays a major role in the reduction of vegetative cover, for example, the world bank estimates that in Senegal 450Km^2 of forest are lost annually(Worldbank, 2014). Rural populations rely directly on felling trees for wood, energy and income, however much of the land clearing is carried out in order to free up productive land for cultivation or grazing, making these activities major drivers form land use change (Nkonya et al., 2015). When coupled with the aridity driven rise in 'natural' thinning of forest vegetation, these activities further undermine the climate resilience of the Senegalese dry land ecosystems.

In SSA an average of 61% of the population lives in rural areas, there is a high variation across the continent, varying from 35% in South Africa to 88% in Burundi and 77% in Chad (World Bank, 2016). Despite this, the overall rural population continues to increase. Total rural population in Sub Saharan Africa has almost doubled between 1991 and 2016, from 381,000,000 to 637,000,000 (Worldbank, 2016).

Rural population in Sub-Saharan Africa make up a disproportionate amount of the poverty stricken population. In 2008, rural individuals made up around 75% of those living in extreme poverty (<1.25USD/day) and more than 60% of those living in poverty (<2USD/day) in SSA (IFAD, 2011). Significant reductions in extreme poverty have been made globally since 2008. However, the level of poverty in rural areas is still far higher than in urban settings (IFAD, 2016). Additionally, the majority of these gains have been seen in east and northern Asia with Africa lagging behind (IFAD, 2011). This is exacerbated in SSA, which contains 10 of the 19 most unequal countries in the world, with sited causes such as urban centred policy approaches, 'poverty traps' or 'resource curses', limited redistribution of wealth and gender or ethnic bias (Odusola et al., 2017), this inequality currently shows little sign of changing (Shimeles og Nabassaga, 2018).

These poverty stricken individuals in rural areas disproportionately work in subsistence agriculture (Jnr, 2014), relying directly on the continued function of their ecosystem to meet basic needs such as food and water availability.

Food security is a large issue for the rural poor of Africa. Food pricing is unstable and may consume a large potion of household wages, leaving little left for schooling or investment in livelihood improving technologies and practices, for example, FAO sponsored surveys in Chad, Togo and Sudan showed that around 70% of household income was being spent on food (FAO, 2009).

This agricultural subsidence lifestyle is highly susceptible to climatic shock. This risk is exacerbate in the face of climate change which threatens to increase the overall risk of drought and flood frequency in west and east Africa respectively (Nicholson, 2013). Additionally, in 2000 more than one quarter of Africans did not have regular access to drinking water (FAO, 2007). These realities are likely to reinforce the 'poverty trap' increasing poverty, reducing food security and increasing environmental degradation unless action is taken to increase the climate resilience of rural Sahelian agricultural communities.

In the following sections the ability of agricultural activities to reduce the climate resilience of dryland ecosystems in the Sahel will be explored, within these sections the primary exampled used will be that of the western Sahelian nation of Senegal.

1.2.1 Agriculture and Crop Cultivation in the Sahel

Much of the rural Sahelian land is utilized for agriculture, in 2014 80-90% of the regions population was actively involved in some form of agriculture (**?**). Here too land degradation has resulted in a reduction of the productivity of the available land (Jnr, 2014). This reduction in agricultural productivity when coupled with a rising global trend in population, a trend which is often accelerated in the poor, drought prone countries which make up the Sahel (Cohen, 2003). In Senegal, for example, the majority of rural agriculture exists as smallholder farms and community gardens (Stefanie Keller), the labour required to maintain yields in these cropping systems is provided by familial and community populations. This reduced yield results in the requirement for more intensive agriculture for which larger families are able to provide labour for, however during unfavourable growth seasons it creates an often unbearable strain on resources. As was seen in the Sahelian drought which occurred between 1968 and 1972 during which starvation was rampant, ultimately leading to the death of an estimated 250,000 people (Timberlake, 1985).

Within the Sahelian agricultural sectors, there exists a prevalence of cash crops, meaning crops which are sold for profit rather than food crops which are used to feed the populous. A key example of this is the western Sahelian country of Senegal. Agriculture is the primary employment sector within Senegal with 51-81% of the total population considered as agricultural workers(World Bank, 2013), 48% of the overall land cover is utilized in crop based agriculture(FAO, 2013), and activity which provides 17% of the countries GDP. Despite this Senegal is a net food importer and the second largest importer of rice in Africa(New Agriculturalist, 2013). 32% of agricultural land in Senegal is used in the production of ground nuts (peanuts) whilst another 31% is used to cultivate millet. (FAO, 2016), nuts are primarily a cash crop while millet may be sold or used as circumstances demand. The tertiary cash crop, sugar cane, shares the remaining 27% of available agricultural land with the growth of other food crops. Research has shown that monocultured cultivation of ground nuts effectively strips nitrogen from the soil. Even when rotated out with millet there is still a detrimental effect on soil structure through the reduction in availability of soil organic matter(Gonzalez et al., 2010). The reality of this is visible in the central agricultural zone of Senegal, named 'the peanut basin' once lush, now typified by dry, sandy, infertile soil.

As most agriculture in the Sahel is rain fed limiting the growing season to a three to four month period between July and September(Sivakumar, 1990). The prioritization of cash crops reduce the availability of food crops, whilst the water and nutrient intensity of these crops coupled with market volatility in their prices results in the increasing need for intensification, culminating in land degradation.

1.2.2 Land degradation in Senegal

Senegal has been selected as the main focus of these explorations because it contains striking examples of the interplay between climatic and human driven drivers for desertification and is currently one of the areas of the western Sahel with the largest are of severely degraded soil relative to it's size as seen in figure 1.2

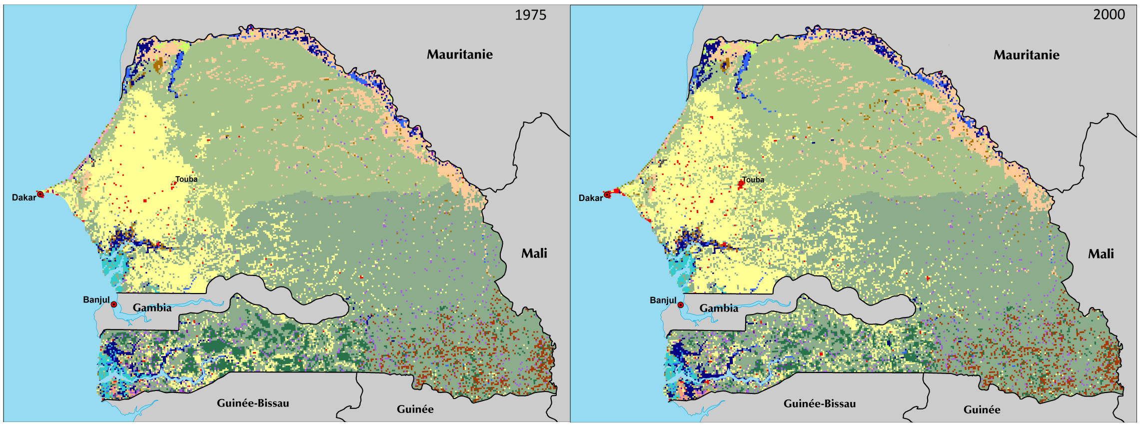
Figure 1.2: Map highlights in red areas of high or very high soil degradation in the western Sahel. (European Commission, 2013)

Senegal is the western most nation both of the Sahel and of the larger belt of at risk drylands which stretches from Dakar to Mongolia. The majority of it's 196,712 km^2 land mass is encompassed by two broad categories of terrestrial eco regions; The Sahelian Acacia Savanna (SAS) and the West Sudanian Savanna (WSS). Both regions are highly seasonal and typified by low mean annual precipitation (MAP) of 200-400mm and 400-600mm per year respectively, almost all of which falls in the rainy season, usually between July and September, however fluctuations in onset date are common (Sivakumar, 1990).

The primary zones of agriculture are typified by higher than average rural population densities and both significant agricultural activity and land degradation (European Commission, 2013). In these areas human activity have altered the natural, wooded savannas beyond recognition. Deforestation, followed by mono-cropping of nutrient and water intensive cash crops has resulted in disastrous land degradation in some areas, the primary ecological symptom of which is nutrient deficient soils with a reduced water storage capacity. (European Commission, 2013)

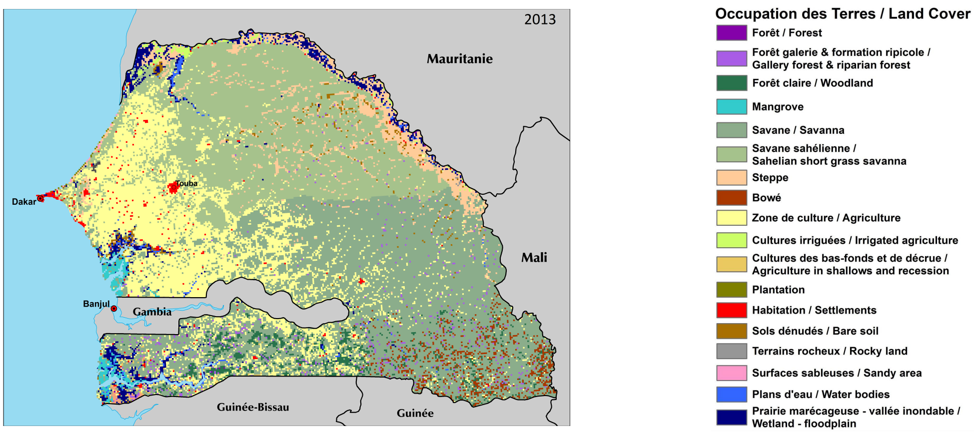
On a human scale, this land degradation translates into reduced yields and has lead to additional agricultural intensification and expansion in an effort to maintain or increase yields. A key example of this mechanism in action is an area of land known as the 'peanut basin', situated in central Senegal and which comprises about 30% of the country's area. This area has been utilized for the production of ground nuts and nut products in a monocropping regime almost since the introduction of peanut cultivation by french colonialists in the early 19th century. These activities, over time degraded an area once characterized as wooded savanna into one typified by dry sandy soils with a low water storage capacity, low vegetative productivity and as such, low crop yields. Whilst poverty in these areas is high, malnutrition is higher in other, non agricultural regions to the north and west.

Land use trends in Senegal are far from static as can be seen in figures 1.3 and 1.4. Between 1975 and 2013 there has been a shift in land use all across Senegal. When viewed at a national scale these changes seems relatively minor. For instance, there was a recorded loss of 4% of savanna between 1965 and 2000(Tappan et al., 2004), whilst between 1975 and 2013 the overall increase in agricultural land was 26%(Survey, 2013). However, when viewed on the smaller scale, it becomes clear that it is the method rather than total area of change which is determining the severity of ecosystem and land degradation.



(a) 1975 **(b)** 2000

Figure 1.3: Figure shows the land use change (LUC) in Senegal between 1975 and 2000, legend available in figure 1.4b shown is the infiltration of agricultural land primarily into the eastern wooded savanna. (USGS)



(a) 2013 **(b)** LUC Legend

Figure 1.4: Figure shows the land use change in Senegal in 2013 and legend. 1975-2000 available in figures 1.3a and 1.3b. Further and accelerated infiltration of agricultural land primarily into the eastern wooded savanna coupled with heavy infiltration into the wooded savanna, wetlands and surrounding gallery forests to the south. (USGS)

Probing agricultural expansion to the north is putting pressure on pastoral land which in some cases is already under strain from the effects of over grazing (Freudenberger et al., 1993)

Meanwhile, the degraded agricultural land in the central part is being abandoned as farmers spread west and south looking for fertile land on which they can earn a livelihood (USGS). Here their agricultural activities fragment natural ecosystems, damaging biodiversity, soil structure and reducing the climate resilience of these areas (**?**)(Pimentel, 2006). This change is offset in national statistics by the regeneration of degraded agricultural land in central Senegal, which are then reclassified as savanna, reducing the perceived severity of the degradation associated to land use change at the national level (USGS).

Land degradation is a serious problem in Senegal, the much of the central Agricultural zone is in a high risk category for desertification (European Commission, 2013), and the spread of the activities which resulted in this land degradation into the natural ecosystems to the east, south, south west and to a lesser extent to the north(USGS). These activities primarily relate agricultural and deforestation, they reduce the resilience to desertification. However, these actions are currently essential for the people's livelihoods and are carried out to provide food, income and energy sources to the communities. Therefore, sustainable agriculture and energy practices must be develop in these areas to provide solutions capable of ensuring the livelihoods of local populations now, whilst also preventing desertification. Thus, ensuring those same livelihoods in the future.

The world is not blind to these problems and many major organizations, are aware of the problem of Sahelian land degradation, of the high risk of desertification and of the human activities which reduce climate adaptation. The need for developing communities which are able to withstand these effects is direly urgent, thus, the concept of resilient communities arose.

1.2.3 Resilient communities

Despite their limited input to global GHG emissions, indigenous and rural communities are often the first and most severely affected bye the impacts of global climate change (UNDESA, 2008). For example in rural Africa, a change in the distribution of precipitation in arid environments is already occurring. Local people have a limited ability to offset these impacts through socio-economic mechanisms as wealthier communities might (Duraiappah et al., 2005). As such adapting to the effects of climate change and desertification is key for the survival of rural communities in the Sahel. The concept of building *resilience* to unforeseen climatic events is central to this. According to the community and regional resilience institute, it can be defined as:

> *The ability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change* (Community and Regional Resilience Institute, 2013)

This concept encompasses a broad range of potential activities to reduce exposure to or the impact of external risks and disasters such as drought and eventually, desertification. Within poor, rural agricultural communities this is likely to centre around the increased use of sustainable methods and technologies to increase food, water and income security whilst simultaneously preventing environmental degradation and increasing the current quality of the land, increasing the availability of resources and the resilience of the environment to climatic shocks. The uptake of these methods and technologies should be supported by the development of infrastructure and capacity over time to in allow communities to anticipate and bounce back to a state of self reliance and sustenance.

The next section will explore the efficacy of key projects aiming to reduce the onset of land degradation and desertification and their qualities to provide resilience to rural communities.

1.3 The Current state

A large body of research is available concerning the biophysical aspects of desertification. The result of which is an expansive understanding of the physical processes occurring within desertifying dryland ecosystems.

Based on this knowledge, methods and technologies to provide resilience against desertification and climate change are developed with rural, poverty stricken dry lands such as the rural Sahel in mind. Whilst the theory and knowledge upon which these interventions are developed is sound, often they are found to be contextually unsuitable once implanted in the socio-econoimc, cultural or environmental context of rural SSA. Thus highlighting the importance of integrating contextual information and existing indigenous knowledge into the design and planning phases of climate change mitigation strategy (Nyong et al., 2007).

Past attempts to transfer a sustainable agricultural approach in Africa have proven to be largely ineffective (AGRA, 2017). Many of these failures are linked to the attempted integration of technologies or practices which, whilst theoretically effective, proved inaccessible for smallholders or unprofitable in the existing policy context (AGRA, 2017). This provides an example of how barriers outside the biophysical context can greatly limit the implementation and proliferation of outside interventions. International organizations and governments often attempt utilize a top down approach to technology or knowledge transfer. The lack of indigenous and local participation inherent to this approach limits the potential for integration which in turn limits long term adoption (Reynolds et al., 2007). For example, in Nigeria, government efforts for tackling desertification were ineffective as the designed policy did not fit the local community reality (Nasiru Idris Medugu et al., 2011). Moreover, many of these projects were cost intensive, resulted in little other than wasted resources (AGRA, 2017).

Thus, considerations relating to the receiving context is crucial for successful integration of interventions. Additionally, including the community members in the development of these strategies has been shown to have a positive effect in some cases (Reynolds et al., 2007).The integration of their context specific knowledge can be determining factor for avoiding failure. Not only governmental organizations, but NGOs also should embrace this process to increase the effectiveness, as said by Michael Oluwabukola Nelson, the former executive director of the Dreams Project for Africa;

> *"This is where most other NGO's fail. When you tackle issues without bringing those who would benefit from the issues into an understanding of the problem they are facing, you are likely to fail"* (Ojo, 2015)

The failure in including context specific features and social inclusion make practices inappropriate and ineffective. This is exacerbated in SSA, as the context is often defined by significant socio-economic and environmental limitations. Failure to take these contextual realities into account is linked to an increased rate of development intervention project failure (Nasiru Idris Medugu et al., 2011)(Urmee og Gyamfi, 2014)(Murphy et al., 2009) (Chambers, 1995).

Despite this trend, there are NGOs that are tackling the issue of desertification in a socially inclusive way by creating small scale benefits on a community basis. This is the example of the Center for Renewable energy and appropriate technology for the environment (CREATE!), an NGO based in Senegal which practices a community based holistic approach to combating desertification. They do so within the framework of the *Appropriate Technology* concept. This approach will be further explored and developed throughout this report (section3.1.1). In addition to the concept of appropriate technology CREATE applies a holistic mindset resulting in the implementation of a series of interventions within the areas of land, water and energy management. Treating the issues derived from desertification in an individual way has shown to be very ineffective on the past (Nasiru Idris Medugu et al., 2011) and the process and usefulness of approaching desertification intervention in a holistic manner will be explored in the following sections.

1.4 From Silo Thinking to an Integrated understanding

A more holistic perspective which encompasses not only biophysical aspects, but also socio-economical realities, such as extreme poverty, lack of education, and cultural characteristics, is needed, therefore shifting from a silo thinking perspective to a holistic and integrated one. Due to the great amount of factors included into the concept of desertification, it enters within the definition of a 'wicked problem'. First defined by Horst Rittel in 1973, a wicked problem is considered an issue with these following 10 characteristics (Rittel og Webber, 1973):

- There is no easy definition of the problem as it would with other more simple issues
- There is no stopping rule, as for desertification, there is not a point where you are certain that you reached the solution
- Solutions can not be objectively deemed as good or bad, it is a matter of judgment
- There does not exist a definitive or immediate solution to it
- Implemented solutions to a wicked problem bring consequences that cannot be undone.
- Every wicked problem is unique.
- There is not a defined set of criteria that can solve the problem. They all haven been identified or considered
- It is composed by other multi-interrelationed issues which at the same time do not have a single origin
- It is a socially complex issue that affects to a numerous range of stakeholders in different ways.
- There is no right to be wrong on the solution, as consequences of a badly implemented large change can have a severe impact.

These characteristics fit within the desertification concept, and need to be kept in mind for the developing of future solutions. Wicked problems are defined to an extent by their complexity, interventions which target specific aspects may be incoherent with the broader mitigation or prevention strategy. Wicked problems, such as desertification are driven by a broad spectrum of problems spanning both the biophysical and socio-economic issues. As such when single aspects of a broader problem are tackled in isolation and the wider notion of environmental and social interactions are not taken into account, also known as 'silo thinking', interventions are unlikely to be effective at solving the larger problem(Nasiru Idris Medugu et al., 2011). When considering just one aspect of a problem, the comprehension of systemic intricacies is lost. Characteristics of the problem can be easily overseen, as often they are a result of the interactions between sectors, needs or resources(Sherwood, 2002).

This paradigm of prevention and mitigation strategy building must be broken down in favour of an integrative approach. Moreover, the integration of and participation with affected communities and assessment of how potential interventions may interact within the receiving context also contributes to the effectiveness. The Nexus approach to resource management and intervention provides a potential starting point for this purpose and is explored in the following subsection.

1.4.1 Nexus

The resource nexus is the connectivity between essential resources, like energy, water and land(figure1.5). Therefore solutions to problems such as desertification which are typified by resource constraint must be similarly connected in order to be effective.

To exemplify the importance of the nexus, the following paragraph puts an example of the inability of silo-thinking to solve multifaceted issues such as desertification:

One of the major problems within desertification is that rural populations lack the means to effectively combat it and increase their resilience. Poverty often limits the options available to rural Sahelian populations leaving no alternative to the existing, detrimental practices. Changing this behaviour often requires the input of external knowledge or funding. For example, rural populations in Senegal are not able to shift to a more reliable energy source rather than wood, as they do not have the financial capacity needed for buying alternative energy technologies or the knowledge to produce them, meaning that a reliance on inefficient wood burning 'cook stoves' or three stone fires. In this example, the inter linkage between the issues can already be seen, as energy provision for these people is linked to deforestation, which at the same time is maintained because of the lack of alternative options. Solving the deforestation problem by replanting trees to increase density would only provide a shirt term solution if the locals are not provided with a reliable energy source not based on wood or with an energy source which increases efficiency of wood use. Additionally, the transfer of knowledge pertaining to the importance of tree density for ecological stability and crop growth is required to prevent potential overuse of forest resources for income generation or contrition in the future.

This is a single example of the interplay between water, energy and land management within the context of desertification, but it highlights the importance of a holistic approach to resource management and climate mitigation strategy. The complexity and diversity seen in drivers of environmental degradation and desertification in the Sahel eliminates the possibility for a single ’best’ solution. However considering the fragility of these environments and the vulnerability of those affected, urgent action is needed to determine holistically effective interventions to build climate resilience both for the environment and the communities who rely on it.

This approach has shown its effectiveness with other wicked problems, such as with transatlantic resources (Andrews-Speed et al., 2012). The main idea of it, is that acknowledging the interconnection between resources which determine a wicked problem is the basis to create solutions. In the case of desertification, the resources nexus can be seen represented on the following figure 1.5.

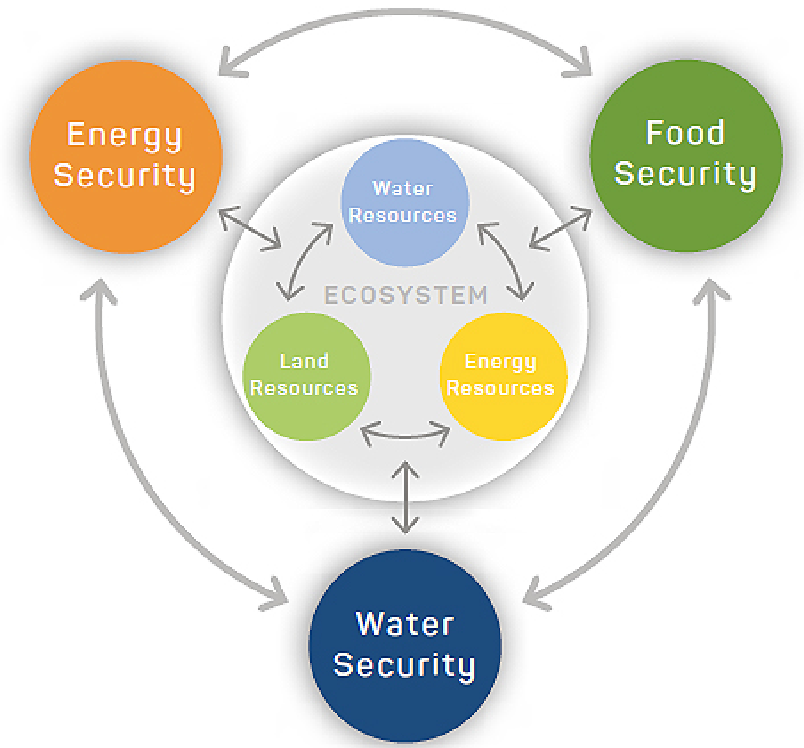


Figure 1.5: Graphical representation of the resources nexus. Figure it can be seen how water, land and energy resources interact between each other, which makes the security of these interrelated as well. (The Water, 2018)

Chapter 2

Problem Statement

In addition to climatic and ecological factors; human activity driven by socio-economical needs can act as a driver for desertification. Several well established practices within Senegal and SSA, such as a market based on nutrient intensive crops, resulting in extensive monocropping and the continuous need for increased productivity can be detrimental to ecosystem health whilst also acting as limiting factors to the implementation of new sustainable practices. Trends of declining precipitation and increasing temperatures expose the dire need for creating climate resilience in desertification risk areas such as Senegal in both the short and long term. In order to achieve this resilience, through the minimization of land degradation in Senegal, the social context has to be included in research to improve its efficiency. In more recent years the application of social science has become more common in methods that determine social, institutional and economic barriers limiting implementation of sustainable principles and technologies to build resilience within dryland regions. However, the fluid nature of these barriers and drivers for change across borders means that this area is far less understood than the biophysical aspects.

Several barriers can arise during the implementation of new practices. Due to their basis on biophysical factors, the social and economic barriers may be overlooked during planning phases. These barriers can come from a conflict between the required resources for the new practice and the existing infrastructural, behavioural, natural and socio-economic resources available to the local communities. Also, the lack of integrated approaches that take into account the interrelation of the several environmental, social and economical problems has shown to be negative for the projects success.

Therefore this project aims to identify which practices are capable of generating desertification resilience when combined, and how they should be adapted in order to function in the rural Senegalese context. These will be carried out with the objective of providing an example of a holistic approach and assessment of potential interventions to act as a guideline for future projects, action plans and policy. This will be done by more effectively targeting key success factors of technologies and utilize key drivers, thus increasing their efficacy in both the short and long term. In accordance to the objective of the project, the following research question and sub-questions were formulated.

2.1 Research question

How can the efficacy of developmental interventions aimed at increasing climate resilience in rural Sub-Saharan African communities be increased through improved application of sustainable technologies, practices and capacity building?

2.1.1 Sub-questions

1. Which interventions are considered best practice for building climate resilience in rural Sub-Saharan African drylands within the areas of land, energy and water management?
2. How appropriate can existing resilience building interventions be for implementation in small, remote communities in rural Senegal?
3. How can the use of appropriateness assessments by development aid providers increase the efficiency of resilience building interventions, projects and programs in rural Sub-Saharan African dryland communities?

Chapter 3

Theoretical and Methodological framework

In this chapter the theories and methods used with the objective of answering the research questions will be developed. These consist of two theories (Appropriate Technology and Action nets) and three different methodologies (State of the art review, transect walks and semi-structured interviews). Additionally, the structure of the research will be outlined on the last section of this chapter

3.1 Theoretical Framework

3.1.1 Appropriate Technology

Appropriate technology (AT) defines a strategy to technology transfer and development built around the idea that, to perform optimally, interventions in developing countries must be decentralized, labor intensive, energy efficient, environmentally sound and self sustaining within local communities(McCLOY, 2003). Interventions should meet basic user needs, in developing countries these needs are often linked to food and water security, health, hygiene, education, income generation or energy efficiency(Wicklein, 1998). However, understanding of existing needs within a community is often more reliably gained by taking a participatory approach(Murphy et al., 2009). Meeting basic needs is a cornerstone of AT as it creates specific, tangible value for the community in which it is integrated (Wicklein, 1998).

Technologies and techniques should always be context specific and designed to work in local environments. A lack of this can become problematic when transferring interventions into vastly different environments. Interventions must be adapted as necessary when moving from one region to another to ensure performance and reliability(Urmee og Gyamfi, 2014)(Murphy et al., 2009).

In rural communities of developing countries, interventions must provide an affordable alternative to the current strategy for the majority of the population. Otherwise financing can become an overwhelming constraint, limiting the dissemination of techniques or technologies(Wicklein, 1998). However, this does not mean that interventions must be low tech or the lowest costing solution, simply that the it must match both the willingness and the ability of the population to pay(Murphy et al., 2009). Willingness to pay is in general linked to the need met by the solution and the value placed on meeting that need.

To ensure the ability to pay, AT should remain flexible to a variety potential economies, as financial resources and user preferences can vary drastically even between villages and households. Additionally the utilization of existing local materials and skills, reduces both the reliance on outside inputs and costs(Murphy et al., 2009). Using local materials and skills for the manufacture of technologies or tools increase the potential for repair, replacement and reproduction, potentially boosting dissemination and preventing the loss of benefits upon breakage.

Within the AT concept, sustainability can be used to mean one of two things. Environmental sustainability, requires that an intervention does not, directly or indirectly lead to additional environmental degradation, as doing so would compromise the needs of the future to meet current needs. Secondly Local sustainability refers to the ability of local communities to understand, control, maintain, repair, replace and replicate the introduced intervention(Murphy et al., 2009).

Appropriate technology can be used to tackle a multitude of development issues and the dissemination of inappropriate technologies is generally attributed to long term project failure due to rejection or breakdown and may introduce unforeseen negative impacts on communitiesMurphy et al. (2009).

However, technologies are only a part of 'appropriate technology'. The complexity of techniques and technologies must be adapted to the absorptive capacity of the receiving communities whilst also taking into account cultural realities which may hamper the dissemination and use of interventions(Urmee og Gyamfi, 2014)(Murphy et al., 2009). Capacity building plays an important role in the AT strategy. AT must be human centred, meeting core needs and ensuring the correct level of complexity help to meet this criteria but raising the absorptive capacity of communities can allow for more complex interventions. Additionally, building capacity within communities aids the dissemination, efficiency and long term prospects of any intervention by ensuring that the majority of the population understands and can carry out or operate the imparted methodologies or technology(Urmee og Gyamfi, 2014).

Capacity building can take many forms and can be undertaken at several different levels. At a village level, capacity building may involve training in the use of specific tools for sustainable agricultural methods or the operation and maintenance of solar pumps for example. At a regional level workshops concerning the importance of energy efficiency in rural villages can be held for scientifically minded community members, village chiefs and key regional or national decision makers as a means to generate and encourage supportive infrastructural and policy developments for improved technology dissemination. Important factors in developing capacity through training include; Flexibility in participation and complexity levels, ensuring the presence of key decision makers either at a village level or higher and providing a varied workshop format by blending theory with practice. Additionally in the developing world, simultaneous translation or ideally local speakers are thought to vastly improve the absorptive capacity of participants. The importance of capacity building for ensuring the impact of an intervention in both the long and short term on small and large scales cannot be understated. However, capacity building techniques also provide an ideal opportunity to foster a participatory approach to technology transfer methods and project design all of which play important roles in project success(Murphy et al., 2009).

Whilst the name 'appropriate technology, may seem to suggest a technocratic approach to some understanding, capacity building is intrinsic to the concept. The existing absorptive capacity constrains the complexity of any solution to ensure usability. This capacity is in turn raised through training, and utilization of technologies and techniques transferred. The increase in capacity drives innovation and sustainable development creating the potential to enable self sufficient rural communities to eliminate poverty and environmental degradation.

Throughout this paper the term 'appropriate technology' (AT) will be used to describe both the hard and soft aspects of the AT method meaning the interventions and the supportive capacity building, as both are central to the strategy. Interventions explored may not be technological in nature. However, the inherent flexibility within the characteristics of AT allow for it's application in a multitude of interventions, regardless of their nature.

Throughout this paper AT considerations will be used to highlight the success criteria in existing practices carried out by the NGO CREATE! in Senegal and to characterize reviewed interventions viability in this same context. This is done in order to highlight the importance of AT in development projects.

3.1.2 Action Nets

The concept of an action net is derived from actor network theory. It's theoretical base is defined by the notion that discovering the interconnections between actions requires the translation of actions into one another(Czarniawska, 2004). This fits well with the concept of appropriate technology in which the social and environmental ramifications should be considered and with the concept of the land water and energy nexus which suggests the importance of the interconnectivity of effects between interventions within these three areas.

Here the action net is used to conceptualize the interconnections between interventions, existing social and ecological systems. From an action net perspective, The determination of actions is the first step(Campos og Zapata, 2012), this is achieved through a review of state of the art climate resilience building interventions. This is in defiance of the conventions of typical network theory which states that actors and networks are prerequisites for organizing actions(Song og Van Osch, 2015). However, generating a net of actions to be achieved without accounting for the organization which may achieve them allows the net to become seamless, preventing the division of actions down organizational lines as this may limit the exploration of potential connections between actions in the net. In this manner, the effect of actions and interventions on other actions, society or the environment, be they positive or negative can be explored and visualized, potentially exposing unknown connections. The action net here is aimed at studying the interactions between interventions, so the inclusion of existing actions is limited to those which are determined to directly or indirectly interact with proposed interventions.

3.2 Methodology

3.2.1 Review of the State of the Art Interventions

The primary purpose of the state of the art review, or SotA, is to determine the preeminent sustainable interventions and practices that are able to combat desertification by increasing community climate resilience in SSA. Utilizing literature focusing on their expected benefits, proven efficacy, proliferation, barriers and drivers for implementation. This review also provides the data for which the viability of the reviewed interventions in a rural Senegalese context will be explored based on their ability to incorporate AT considerations in their base state, or be adapted to do so.

The geographical focus is on global dry land ecosystems, however whenever possible, this will be limited to Africa, the Sahel or Senegal. Reviews are grouped into one of three categories integral to the land, water and energy nexus. Interventions are separated based on their area of effect. To determine which practices to review, a scoping of literature is done to discover the predominant practices within each of the categories analyzed in Sub-Saharan Africa. These can vary between regions, but the articles reviewed were focused as much as possible to the area of study.

PICO and PICo methodology for review

The review will be handled systematically, focusing where possible on quantitative analysis of the efficacy of practical agricultural interventions. For this purpose a modified version of the PICO and PICo systematic review frameworks will be applied to relevant quantitative and qualitative literature respectively. Traditionally, PICO and PICo frameworks are used to answer clinical research questions, however, wider applications include the development of literature searches and reviews. A summary of the PICO and PICo frameworks is shown below in table 3.1

Table 3.1: Global caption

P	Problem or Population
I	Intervention
C	Comparison or Control
O	Outcome

P	Problem or population
I	Interest
Co	Context

The PICO framework is designed for use with quantitative literature, beginning with outlining the problem being researched, followed by a description of the intervention and either a comparative intervention or control group, finally the outcome, which explains the efficacy of the intervention in comparison to alternative interventions or controls.

The primary purpose of the review in this paper is the determination of the efficacy of interventions within the three nexus areas at directly or indirectly increasing climate resilience in ecological and socio-economically similar conditions to the Sahel and specifically, rural Senegal. As such reviewed interventions will be focused in arid and semi arid dry land environments in Africa, within poor or extremely poor rural communities.

Considering the currently limited proliferation of sustainable agricultural intensification in Sub-Saharan Africa(Benjamin, 2018), the secondary purpose of this review is to examine and determine the efficacy of supportive socioeconomic and policy based interventions aimed at increasing the adoption rate of the aforementioned sustainable agricultural intensification methodologies. Literature surrounding these interventions are rarely quantitative in nature and as such the qualitative review framework PICo (table 3.1) is utilized for literature which contains qualitative or no specific data, often these sources are chapters from books and reports which focus on the introduction and effects of supportive interventions without providing their own specific data surrounding the topic.

When no suitable quantitative literature is available regarding a specific intervention or when the intervention definition is sufficiently broad, a review of alternative interventions within one technology umbrella are used. For example, supportive financial interventions take many forms, as such a comprehensive, yet qualitative review which encompasses many potential interventions is used in order to maximize the knowledge gained. In these cases the qualitative PICo framework is used.

The first step within this framework still focuses on the problem at hand, however the overarching problem focus here is that of limited resource availability and environmental degradation. The second step focuses on discovering and understanding the activities and experiences of those attempting to solve the problem while the third step defines the context within which these activities take place. The ecological contextual focus is global dryland, arid and semi arid ecosystems; The geographical focus is global as a broad range of potentially effective supportive activities should be reviewed, but whenever possible this focus will be narrowed to the Sahel or to Senegal.

Determining Requirements and Barriers

Whilst the Frameworks detailed above allow the achievement of the primary and secondary purposes of the SotA review, the tertiary purpose, the exposition of requirements and barriers to implementation requires the inclusion of an additional step:

Requirements refers to the requirements for implementation of either a technology or practice or a supportive socioeconomic or policy measure to increase their adoption.

Defining the requirements will give an insight into the potential barriers which inhibit the efficacy of nexus based interventions in sub Saharan Africa and may give indications of appropriate measures which can be taken to minimize their impact, aiding in the analysis of validity in section 5.2.2.

3.2.2 Field data collection

To gain first hand knowledge and data from a Senegalese context in which practices for increasing resilience were implemented successfully, field work was undertaken in collaboration with CREATE!. This was done in order to gather data and contextual knowledge surrounding rural Sahelian communities and the potential of NGOs to create resilience through the use of appropriate technology. The focus of the data collection is three fold:

1. Gaining contextual knowledge which will enable the determination of intervention viability in section 5.2.2. First hand experience of the ecological and socio-economic context in which interventions must be applied is likely to increase the validity of viability determination.

2. Determination of the characteristics which have thus far allowed CREATE! to successfully increase climate resilience through increased food, water and income security, coupled with reducing deforestation and land degradation. This information will be combined with considerations for AT to inform the selection of potentially viable interventions for rural Senegal.

3. Discovering the perceptions of community members at a variety of sites at differing training stages. Local perceptions of the capacity building approach taken by

CREATE, difficulties and how they were overcome and the importance of individual interventions increases our awareness of the interventions and their transfer methods which are most likely to increase community integration and sustainability.

In order to do so, two primary methods were utilized: semi-structured interviews with community members and transect walks with field observations in the CREATE! action areas reinforced by the input from the agricultural technicians in charge of each site. Nine sites were visited in total: Walo, Gagnick, Darou Djadji, Fass Koffe, Fass Kane, Thieneba, Keur Daouda, Diender and Mboss. These were through different stages of training of CREATEs five year program, providing us with a more varied data source. Visited sites are concentrated in the same region of Senegal, The central agricultural zone (figure 1.4). However, these communities are generally remote, limiting communication between sites. Providing us with first hand and unmodified data sources.

Due to the lack of a common language between the interviewers and the interviewees, a translator from CREATE was provided. Interviews were thus carried out in the native language: Wolof, with answers dictated by the translator to the interviewers in English.

Transect walks

Transect walks are a method of data collection comprised of promenades through a project area. In this case the nine active CREATE sites were visited, in order to get a comprehensive understanding of the activities which are being carried out (Figure 3.1). It helps to be able to describe location, distribution, resources, landscape uses among other characteristics of the area (Stefanie Keller).

This method allows for the identification of cause effect relationships between land uses, major problem factors, how are they are perceived among the different users and an understanding of the existing technologies and practices (Stefanie Keller). Moreover, this method focuses the data collection carried out with the interviews in specific topics or practices that were considered of high relevance through the transect walk. Transect walks are carried out before interviews, this allows for a better adaptation of these to the specific area in case, as questions can be adapted to incorporate site to site variation. Exposing potentially unique characteristics that are deemed important for the topic in question.

Despite being a useful method of community data collection, there are methodological restrictions. Specific features may not present or visible at the date of collection due to seasonal differences or other factors, potentially undermining the data. This is counteracted through questioning technicians, who provide insight into all of the processes in order to avoid missing data during the walks. Moreover, they provided information both spontaneously and when questioned, resulting in more reliable and holistic data and field notes.

During transect walks interviewers question CREATE! technicians regarding the interventions carried out and the knowledge and technology transfer methods applied. Additionally, information regarding the broader agricultural practices, land energy and water contexts was gathered in order to support the more academic understanding of these factors gained through literature and shown in section 1.2, 1.2.2 and 1.3.

Figure 3.1: Photo taken during the transect walk of Keur Daouda, with technicians, the country director of the NGO and the translator

Semi-structured interviews with community members

Following transect walks, community members were interviewed in a semi structured manner. Interviews are carried out either with single, prominent community members or with site workers as a group. This is dependant on the site and moment of interview. During group interviews, wide participation was encouraged in an attempt to reduce the bias inherent to interview data.

Interviews comprise a pre-defined interview guide constructed to target this projects research questions. However, the interview guide does not act as a rigid structure, as questions can be derived spontaneously to further explore topics of interest exposed during transect walks or interviews or to further probe respondents.(Keller og Conradin, 2018). The interview guide for the community members can be found on Appendix A

The questions were focused on getting data on the following aspects of the research sub question number 2:

- The perception that community members have about the practices carried out by CREATE!
- Importance of specific technologies, practices or other aspects of the CREATE program, in order to identify crucial practices
- Resources and which they deem more important for improving community livelihoods and conditions.
- Difference of perception regarding communities that are in different stages of implementation.
- Effectiveness of practices, communication and knowledge sharing between communities.

Along with the transect walks, this method was carried out with the objective of determining the success factors of technologies in the Senegalese context, assessing their effectiveness and the perception of those who get benefits from them, therefore obtaining the data to answer the research sub-question number 2 and providing the basis for answering the sub-question number 3.

3.3 Research Design

The following table 3.2 outlines the research design is structured, accordingly to which methods and theories answer which research sub-questions. Moreover, the section of the report in which they can be found answered is shown:

Research Sub-questions	**Theories**	**Methodologies**	**Section**
1		State of the art review - PICO/PICo	4
2	Appropriate Technology	Transect walks Semi-structured Interviews	5.1, 5.2
3	Appropriate Technology Action Net	State of the art review - Determining Requirements and Barriers	5.3 , 6

Table 3.2: Research Design

Chapter 4

Review of state of the art interventions

The aim of this chapter is to outline the different methodologies that the literature deems to be effective or review its effectiveness to increase the resilience against climate change and desertification. These methodologies are divided into three different sections representing the most influential factors related to desertification. These are: Land management, Water availability and Energy provision. The main concept behind these methodologies and concepts will be explained at the beginning of each section.

Once the concept is outlined, the predominant practices, technologies capable of increasing climate resilience through within each category are explored. Following this literature pertaining to each identified intervention will be systematically reviewed using the PICO or PICo framework for qualitative or quantitative research respectively. These reviews will focus on the ability of each intervention type to increase community climate resilience, the requirements a community must meet to gain these benefits, attention will be drawn to the difficulties of meeting these requirements when appropriate to do so. The purpose of this section is to provide an understanding of the currently available technologies, techniques and social interventions capable of directly or indirectly enhancing community climate resilience in rural communities in developing countries. Articles are selected based on the results of initial searches for interventions in land, water and energy management. The effect can be direct i.e direct manipulation of a biophysical effect or indirect such as interventions which reduce the prevalence of a driver for non sustainable resource use. Both peer reviewed articles and reports from NGOs or organizations with experience in SSA will be used. The secondary aim of this section is to highlight a broad range of diverse potential interventions which in section 5.2.2 will be assessed for their 'appropriateness' through their potential to integrate appropriate technology principles highlighted in section 3.1.1 and further explored in section 5.2.2. The viability of these interventions in the Senegalese context is explored later using field observations and interview data.

4.1 Land Management

As previously explored the Sahelian region is typified by low vegetative productivity. Agriculture in much of the Sahel is rain fed and the income generated in the three month rainy seasons are a major part of the annual income of many rural households. Traditional agricultural models in this region typically focus on maximizing the crop yield in a short period by clearing potentially competitive vegetation such as low diameter trees and shrubs with fire, known as 'slash and burn agriculture' (Jenner, 2013). This model reduces labour costs and restores some nutrients from the burned biomass however it, is damaging to the environment and to crop yields in the mid-long term, resulting in a 'poverty trap', a positive re enforcement cycle which drives subsidence farmers further into poverty, which in turn drives further unsuitable activity(Keeble, 1988). When ecosystems are not given sufficient time to recover, the cycle of such practices have been shown to compound the problems of soil nutrient and water deficiencies common in the region(Powell). Soil degeneration typically takes 1-4 years to begin reducing crop yield , at which point the field may be left fallow. This loss of land is generally not acceptable to subsistence farmers leading to extensification and further ecosystem degradation.

The implementation of integrated land management practices which focus on the protection and regeneration of the soil and vegetation in such areas has been shown to have a positive effect on both environmental health and in some cases crop yields. Many of these practices are linked together under the umbrella of conservation agriculture (CA). CA is explored more thoroughly in the following section 4.1.1, the following serves merely as a brief introduction. The principle aspects of CA include the following:

- Minimum soil disturbance, this involves the minimization or elimination of tillage which is pervasive throughout conventional agriculture. This process has been shown to result in increased erosion and evaporation from the soil reducing quality and water content.
- Permanent soil cover with crop residue, biomass or green manure cover crops aides in weed suppression, limits evaporation ,increases soil organic matter and aids nutrient re-balancing.
- Crop rotation this practices seeks to alleviate the pressure of continued growth on the environment by rotating crops with different nutritional requirements. crops such as legumes may be used to affix nitrogen but unlike inter cropping crops are planted sequentially, once one is harvested another is planted.

Inter cropping and mixed cropping involves mixing a variety of species on a single plot of land. This produces a myriad of effects dependant on the species, common species and effects might be the nitrogen affixing seen when inter cropping legumes or the soil structure and water storage capacity increase seen with woody species.

Trees and shrubs provide a multitude of benefits to environments and agricultural communities which rely on them. High densities of woody vegetation has been shown to reduce wind erosion and have the capability to increase the fixation of essential nutrients whilst also increasing the water storage capacity and water soil infiltration. These effects are highly sought after in areas which have been intensively farmed however careful consideration must be given to the vegetative density implanted into agro-forestry systems. Trees and shrubs commonly used for such purposes require water and as such can reduce the soil moisture content (SMC) as such aggressive tree planting in arid environments with a limited potential for irrigation may have adverse effects on water availability.Artificial tree planting campaigns in water strained arid environments may be replaced with farmer managed natural regeneration (FMNR); this process involves limiting traditional clearing and tending naturally occurring seedlings within agricultural lands. This method imparts the benefits of increased woody vegetation whilst limiting competition for scarce water supplies.

Often the implementation of conservation agriculture practices requires additional materials or training, this may result in additional cost. In these cases or in cases where extreme weather effects do cause crop failure, communities can be supported by resilience building supportive infrastructure. These often take the form of insurance, food for work schemes, enhanced produce storage facilities, or increased market linkages. Increasing climate resilience in Rural SSA communities is only partially dependent on environmental health and these supportive infrastructures do much to increase community resilience as well as incentives or enable greater environmental stewardship.

In the following sections the concepts within CA will be explore followed by reviews of literature pertaining to each practice. Additionally literature concerning farmer managed natural regeneration will be reviewed along with an overview of some potential resilience building supportive infrastructural developments.

4.1.1 Conservation Agriculture

Soil disturbance and degradation is abundant in conventional agricultural practices based on tilling the land. Tillage methods have proven to be harmful to the soil composition, structure and resilience capacity, exposing it more to external hazards. In order to improve soil quality and also the production of crops, no-tillage systems were started to be considered in the USA during the 1930s, as they tried to maintain an organic cover on the soil surface (Kassam et al., 2014). Since then, the methods have evolved through many pieces of research, and finally evolving to the concept of Conservation Agriculture (CA).

CA involves three principles which are inter-linked between each other. These are (Food and Agriculture Organiation, 2015):

- Reduce as much as possible soil disturbance (no tillage for seeding)
- Continuously having a crop cover to have an organic layer of plants
- Diversify crops and intercrop them on the yield to maximize soil quality and resilience.

CA shares many of the same principles as organic farming (OF). Both utilize natural mechanisms and inputs to ensure soil fertility; such as crop rotations and cover crops. However, there are some key differences which predominantly stem from the purpose for application. CA is a holistic method which aims to maximize ecological efficiency and preserve ecosystem services through the remediation of land. This is achieved by facilitating natural cycles and inputs to ensure soil organic content, nutrient and water balances. A primary mechanism for achieving this is minimum soil disturbance which reduces water loss, erosion and prevents the breakdown of SOC(FAO, 2015). OF is largely focused ensuring soil fertility whilst eliminating inorganic inputs, this has the added benefit of achieving a certain level of soil rehabilitation. However, other practices within organic farming are more conventional, particularly tillage which is used to control weeds(FAO, 1999). CA on the other hand allows for the use of inorganic inputs for weed control and when needed additional fertilization, it merely suggests that their use should be informed and efficient to reduce the potential damage. That is not to say the two systems cannot be used in tandem. A mixture of practices from either umbrella can be effective in meeting the goals of both.

CA principles have proven to be a way to sustain ably intensify crop production, providing with several ecosystem services such as water conservation, climate regulation, nutrient cycling and carbon sequestration that with tillage based crops can not be provided (Kassam et al., 2014). Moreover, some side effects can be derived from these services, as if the production is increased, less land is required for producing the same amount as conventional farming, which may reduce habitat fragmentation and deforesting common in exiting SSA agricultural systems (Kassam et al., 2014). Countries with degraded soil and low agricultural productivity, could benefit more from these techniques, as the room for improvement is greater. Nonetheless, despite similar introduction as in other regions, Africa has the lowest CA uptake(Brown et al., 2017) and the lowest area of arable land dedicated to CA(0.3%). This low rate of adoption is though to be tied to the transfer mechanism and a lack of context specific adaptation. To improve the dissemination of CA, identification of functioning CA components is required, specifically in SSA. To aid determination of achievable practices and methods of implementation.

Thus, the focus of this review is to explore the efficacy of the components and their proliferation in global arid regions with a focus on the Sahel and Senegal whenever possible. To discover the supportive interventions which have been shown to support the proliferation of CA in global arid zones, focusing on the Sahel and Senegal whenever possible. The section will be divided into the principles of CA mentioned above.

Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa (Brown et al., 2017)

P-Problem

Conservation agriculture has shown a great uptake with consistent results in North America, South America, Australia and China, but despite of being introduced during the same period in Africa, it had low uptake in terms of cropped area and percentage of total cropland.

I-Intervention

The article aims to cover the reasons which CA uptake was successful in the previously mentioned countries through a literature review, and analyze which predetermined implications should the CA implementation in Africa have for increasing its uptake. Moreover, the dominant types of CA used where uptake has happened will be determined, along with the implications these could have on the African continent.

Co-Context

As defined by the FAO, CA is the simultaneous implementation of the three principles defined on the subsection below. The literature reviewed suggests that many CA practitioners often adapt practices to fit their needs and eliminate others. Case studies show high implementation of the no-tillage aspect. However, the implementation of the remaining practices remains ambiguous, which varies significantly between regions.

The rarity of 'complete' CA implementation suggests that modification of the principles is more likely the outcome following implementation. Increasing the flexibility of CA in this manner increases the efficacy in regions with vastly different environments to those in which CA is typically practiced. In Africa, the adaptation of the principles to the local needs and conditions is likely to increase uptake. However, long-term objectives of implementing all aspects of CA would be useful to enhance ecological regeneration.

The processes that enabled the higher uptake of CA in several countries were long effects, taking more than fifty years to completely increase the uptake, and they can be divided in two groups: commercially oriented in North and south America and Australia, and smallholder based in South America, South Asia and China.

Commercially oriented processes

- Perceptions of the benefit while substituting tillage for herbicides is a determining factor, as the tilling process is perceived as very cost-intensive by the farmers
- Structural changes on the market and institution can create a great pretext for CA. As when more production is needed, sustainable intensification is often chosen as an option to move forward.
- Community exchange mechanisms that met the demand of products related to CA, such as herbicides or minimum tillage equipment, provided the farmers with the necessary tools
- The formation of innovation groups of farmers, closely collaborating with industry, enabled the environment for creation of techniques and material which could further adapt CA locally and share knowledge with other farmers.
- The creation of right institutional environments was led by the governments once they saw the benefits of CA, changing policies which now helped farmers economically to adapt better to these methods.

Smallholder farmers oriented processes At the beginning, CA was mainly focused on large scale farmers, which had great outputs and inputs. But, there has happened several processes that enabled a shift to smallholders in South America and South Asia. Both went to similar processes, which can be resumed in:

The fact that they perceived the reduced labour and costs of large scale farmers, and for smallholders they could use the extra labour to other income activities, the development of markets to provide these farmers with tools adapted to the small fields, institutional reforms to allow more investment and the development of stable farmer associations, which enabled them to participate in public research.

Chinese adaptation to CA was similar, but site specific qualities made it more difficult, as smallholders in China have very small fields, which made unsuitable for most of the CA machinery, therefore, the process of adaptation to proper seeders (sometimes 75% smaller) was crucial for fostering the practice of the no-tillage principle.

R-Requirements

The African context is quite different from the ones previously analyzed. Smallholders have very limited access to mechanization in Africa, which limits the actions they can take. Also the size of smallholder farms are similar to the ones in china, but contrary to them, they do not have such high agronomic inputs. Despite being introduced during the same time, CA has very Little uptake, predominantly due to:

- Lack of economic incentives for farmers to adopt the new technique. Due to the low inputs and outputs of African agriculture, capital accumulation for intensification is not available. This low input also causes that there is little demand and functionality of markets
- Herbicides are viewed as way to increment costs, instead like in other countries, where it is seen as a viable option instead of tilling. This is due to the undervaluation of labor hours. Therefore, they do not have a beneficial perception of CA.
- There is a lack of farmer innovation groups in order to contribute to local research
- Even though some African countries have shown the willingness to implement favourable policies, these are usually not carried out due to the low economical capacity of the governments.

Summary

In order to facilitate the uptake of CA in Africa, the paper outlines three practical implications:

- The principles of CA should be integrated flexibly , being adapted to each case or in order to increase effectiveness.
- There is a need for institutional support in order to accelerate the adoption of CA practices, but it would still take a considerable amount of years for it to success
- Farmer innovation groups, and increase in the good perception of CA have proven to be effective in other countries, and could act as Drivers for the effectiveness of CA implementation.

The article is a thorough literature review covering future challenges Africans will take in order to sustainably intensify crops. However, it fails to explore the need for a more inclusive introduction of the principles to the smallholders, as if the perception is low, they will need convincing evidence to note that CA can be helpful for them. Also, the creation of farmer-driven groups should be incentivated, instead of waiting for it to happen, which would speed up the uptake process.

4.1.2 Woody Species Inter cropping

A crop diversification study will be reviewed specifically for this practice. The article provides an example of woody species intercropping in Senegal, using an indigenous plant to improve the productivity of the crops.

The main objective of this practice is to diversify crops in order to exploit resources that otherwise would be unusable whilst enabling soil quality improvements. A diversity of plants, in particular woody species are though to support crop growth by increasing available nutrients in higher soil horizons through affixation and organic mater provision. Moreover, it can lead to an increase of the diversity of beneficial mycorrhizal fungi and bacteria which are beneficial to plant growth. Another useful quality of rotating crops or diversifying them is the prevention of crop-specific diseases to spread (Food and Agriculture Organiation, 2015).

Long-term *Piliostigma reticulatum* intercropping in the Sahel: Crop productivity, carbon sequestration, nutrient cycling, and soil quality (Bright et al., 2017)

This study claims that some aspects of CA have a limited potential for wide scale adoption in the Senegalese peanut basin and that in order to maximize an interventions suitability to Sahel regions it must both improve yields whilst remaining rooted in the ecological and socio-economic context of the region. As such the purpose is to quantify the benefits of intercropping with P. reticulatum, which is an endemic species prevalent from west africa. Concretely, the measurements taken aimed to outline its contribution to soil quality, rainfall water use efficiency (WUE), crop productivity, nutrient cycling and carbon sequestration.

P-Problem

The problem focus of this research is food insecurity and erratic crop yields caused by unpredictable precipitation in the rainfed agricultural systems of central Senegal, the dearth of experimental evidence surrounding the effect of woody vegetation intercropping, it's long term ability to provide drought resilience in rural agricultural areas with sandy soils and the lack of efficient of crop yields when providing services to farmers.

I-Intervention

The intervention of this study was to quantify the optimization of yields (concretely millet and groundnut) with P. reticulum during a period of over 11 years. The biomass of the cultives was added to the soil to enhance the organic matter in soil, with the exception of groundnuts, as it is commonly used for animal fodder in the region. With that experimental design, the data regarding WUE, yield , over ground biomass, soil organic matter and other macro and micro nutrients were taken 3 times per year measured. In order to measure the WUE, which the article highlights as one of the most important measurements, the yearly precipitation was taken into account.

C-Control

Half the total plots acted as control plots (-shrub plots), existing instances of P. reticulatum were removed, several groups with different quantities of fertilizer applied to the soil. Millet biomass still used as ground cover following harvest, no shrub biomass used for ground cover and ground nut biomass removed as with +shrub.

O-Outcome

The difference in yield was not seen to be significant between fertilizer bands. Whilst there were differences in the some other indicators of agricultural efficiency the focus here is predominantly focused on subplots to which no inorganic fertilizer was added as additional inorganic inputs are rare in SSA due to economic constraints on small holders, this limits the use of findings from additional sub plots to which they were applied.

Increased yields of groundnuts and millet were seen across all plots with shrubs compared to the control plots between 2011 and 2015 with positive correlation between total annual shrub biomass and crop yields. This increase was only statistically significant for ground nuts in 2014, for millet the difference was significant in all tested years. However, less significant in the short term. In 2015 unfertilized +shrub plot showed 105% increase in millet yield compared to control while in 2007 the difference was 14

Increases in WUE was seen in all plants on +shrub compared to control. No data was present for groundnut WUE between 2005-2012 or for millet WUE between 2007-2011 however the pattern of existing data suggests that differences were far less significant during this time period. Also observed was an increase in above ground crop biomass for groundnuts and millet in +shrub plots, providing additional mulch and animal fodder.

An overall increase in carbon sequestration and total available carbon was seen in +shrub plots, this is seen to be a primary factor determining the yield increase along with increased WUE.

Finally, additional micronutrients (Magnesium, Potassium and calcium where available in unfertilized +shrub plots.

R-Requirements

Despite the benefits outlined, the implementation of this practice has some requirements which could diminish the attractiveness of the measure to local farmers to implement. Nonetheless, these are outlined on the article. The main constraint is lack of short term results, therefore farmers would be required to have a long term perspective regarding their yield productivity.

Summary

- Intercropping with woody biomass (P.reticulartum) Had a significantly positive effect on; Crop yields, above ground crop biomass, crop water use efficiency, water infiltration and storage capacity and the concentration of several beneficial macro and micronutrients within the soil of +shrub plots.
- The highest increases in the above factors were seen between 2011-2015 (105% increase in pearl millet yield in 2015), 7-11 years after planting. Early results from 2004 were less encouraging (14% increase in pearl millet yield)
- Intercropping with with P.reticulartum can aid in the regeneration and cultivation of sandy, sahelian soils, increase climate resilience, sequester carbon and increase crop yields. However, the slow rate of tangible improvement may disincentivize adoption.

The length of this study (2003-2015) increases the validity of the conclusions. The geography and soil taxonomy of thee experimental plot (Sandy, monocropped, degraded soil in the southern area of the Senegalese' central agricultural zone) results in the ability to extrapolate these conclusions out to other areas of Senegal and Sudan in which similar soil types, agricultural practices and P.reticulatum are common.

The empirical focus of the study covers several areas of environmental and soil health; Rainfall WUE, C, N, K, Ca, Mg, S, Mn and Cu fractions. Most of these criteria focus on the ability to increase crop yields and useful above ground biomass. Soil and plant carbon fractions indicated the potential for climate buffering through C sequestration.

WUE data from between 2004 and 2011 is unavailable meaning the overall trend of change between 2003 and 2012 was used to estimate the change over time. The paper also theories several mechanisms by which the water competition of woody crops is overcome by millet or groundnut crops. The suggested mechanisms; increased soil water storage capacity, reduction in evaporation through soil cover and increased nutrient availability are all present in other sources.

In summary the conclusions in this article seem to be based on a robust methodology although the focus on P.reticulartum and the Senegalese central agricultural zone limits the potential to extrapolate results to other areas of the Sahel unless they share the characteristics of this area.

4.1.3 Tree management

Dry land tree management for improved household livelihoods: Farmer managed natural regeneration in Niger (Haglund et al., 2011)

P-Problem

Deforestation is a significant aspect of environmental degradation and reduces environmental climate resilience. However, reforestation through tree planting necessitates the planting and nurturing of seeds or saplings in nurseries followed by replanting, representing a potentially unaffordable drain on human resources.

A change in the actions of farmers in Niger towards native trees on farmland thought to have a significant effect on the countries 're-greening', These changes involve the protection and management rather than removal of sapling which naturally occur and is termed farmer managed natural regeneration (FMNR). FNMR utilizes the existing root stock, meaning there is no need to plant seeds or tree, this circumvents the nursery stage, simplifying reforestation. In addition a selected number of existing trees are managed to provide benefits such as reduced erosion, protecting the soil nutrient balance, increasing peculation and soil water storage capacity along with fruits and nuts, whilst minimizing the effective competition with other crops.

As the principles of FMNR are quite different to typical agroforestry methods there exists an uncertainty as to the ability of general agroforestry adoption studies to inform FMNR projects. Thus the main problem focus is the determination of the adoption of FMNR practices across Maradi region in the south of Niger a region characterized by sandy soils with a low organic matter content, Identify the drivers for adoption and estimates the impacts of FMNR adoption on the livelihoods of practicing households.

The research carried out in this paper is post hoc in nature, data is collected from households which do and do not practice FMNR and the impact is estimated based on the differences between the two. Non practicing households are treated as the control group and the same information is gathered from both groups. For ease of communication the 'Intervention' and 'Control' sections of this review have been combined.

I + C- Intervention + Control

The physical intervention examined is that of Farmer managed natural regeneration, this describes a group of agricultural and land management practices which protects and manages the natural regeneration of native woody shrubs and trees which occur on agricultural land. These practices, as carried out in the sample area include; the selection, pruning and otherwise nurturing of stems growing from stumps of previously felled trees, the protection and fencing off of singular seedlings or areas of land with high seedling density, coppicing of appropriate shrubs and trees.

The determination of drivers for FMNR and the assessment of it's impact on rural livelihoods is carried out in the Maradi region of Niger, the most densely populated and most agriculturally productive region of the country. Data regarding the application of FMNR was carried out with the aid of Niger's 'Ministère de l'Environnement et de Lutte Contre la Désertification' (ME/LCD), in order to ensure adequate representation of remote rural communities within drier areas all villages in the Maradi area were categorized based on their market access (more than 6km from large settlements and their agro-climatic zone (growing season of less than 75 day). As FMNR had been formally introduced to some villages in the area, an even number of 'program' and 'non-program' (control) villages were selected from those which met the initial criteria. In each 10 households were randomly selected for assessment (total of 410). Household surveys focused on; household demographic, availability of human (knowledge), physical, social, financial and natural resources, FMNR practices, agricultural plot and activities, tree preference and household finances.

Identification of FMNR practitioners was carried out by two questions: do you deliberately encourage the growth of young trees on farmland by 1) pruning young trees 2) by protecting young trees. Participants that answered yes to both were considered practitioners as this shows aspects of both tree management and protection. A probit regression model was used to determine the factors which increase the probability of FMNR adoption. The factors considered in this model were: Length of growing period, soil type, market distance; the age, sex and years of education of the household head, total land area owned and living in a program or non program village.

The impact of FNMR is measure based on differences between the: household income, food security (grain per capita/number of months where food is scarce) and health of the surrounding environment (woody vegetation density and diversity).

O-Outcome

When characterizing adopters and non adopters the authors discovered that FMNR adopters where more likely to: Be female headed households; have the ability to read and write; have received more years of schooling; have agricultural holding on non sandy soil and to live more remotely.

The above factors all act as determining factors for FMNR adoption, although there was strangely no correlation between adoption probability and formal FMNR introductions. Adopters also grow a larger variety of crops and have higher density and diversity of trees on their land.

The most significant determining factors of adoption were: Years of education (2.8%

increase per year), living on non sandy soil (27& increase) and the distance from markets (increase up to distance of 15km then decrease). Soil types are speculated to increase native tree diversity and as such provide more valuable species ’worth protecting’ alternatively, tree-crop competition is higher in sandy soils so trees in these environments may be seen as unfavourable. Education is thought to increase the understanding of the practice of FMNR or to increase innovative capacity in general making more educated households more open to novel ideas they have encountered.

The impacts assessment of FMNR showed that there was a significant positive impact on household income, crop diversity, tree density and diversity and interestingly per capita outward migration. There is the suggestion that the increase in income allows for household members to more freely travel and seek more lucrative opportunities elsewhere. Once extrapolated these results suggest that a significant number (62,000) household in the Maradi area practices FMNR providing additional income of 17-21million USD per year and increasing the tree density by 12-16 trees ha.

The high levels of adoption are attributed both to the income generating effect and the minimal cost to farmers. The additional income does not come from an increase in grain production which was not seen in FMNR adopters and instead may come from an increase in non biomass based forest product such as fruits, or from additional fodder for livestock. FMNR adoption did not seem to affect food security, it did not increase grain yields and did not increase the perceived number of months of food shortage. This is thought to be caused by one of two factors, either the proxies used to determine food security do not accurately represent it or there is an temporal imbalance between the receipt of additional income and times of high food insecurity.

R-Requirements

The resources required for the implementation are nominal, this paper suggests that the majority of tools and skills required are already available to the majority of sahelian smallholders. however, as mentioned in the above outcome section, this paper also outlines some driving and limiting factors which were shown to affect the adoption rate;

- Probability of FMNR practice increased by 2.8% per year of education undergone by the head of household, showing that increasing access to education in rural areas has the potential to buid capacity for FMNR implementation.
- Soil type acts as a heavy determinant for FMNR adoption. smallholders subsisting on sandy soils are 27% less likly to practice FMNR. Potentially due to the decreased water availability in these soils. On sandy soil, remediation may be required to increase adoption.
- Market distance shows a non-linear relationship with FNMR adoption with 15km suggested as the ideal distance. This provides access to markets for sale of forest products whilst the distance acts as a buffer for theft or excessive grazing, more common closer to urban centres.
- FMNR requires an existing root stock. Cropping systems in which stumps of felled trees or coppiced bushes are not removed therefore provide the best environment for addoption.

Summary

- FMNR has the potential to increase per capita income, tree density and diversity and crop diversity in Sahalian rural communities. Although food security was not shown to increase.
- The most significant determining factors for adoption are; years in education (linear relationship), soil type (non-sandy), and distance to market (inverse relationship)
- Additional benefits include increased ease of firewood provision, increased cattle fodder, access to non biomass based forest products. These factors explain how income can increase while food grain yield does not.

The sample selection in this paper is rigorous. Bias in selection from both the researchers and villagers is eliminated and equal numbers of program and non- program villages are used. It is possible that the proxies used for food security do not accurately represent the concept, limiting the ability of the study to make conclusive remarks in this area, this is however noted by the authors.

The authors state that FMNR increases the crop diversity, but there is no explanation of a natural or social mechanism leading to this, it is possible that increased crop diversity is simply linked to the same criteria as FMNR adoption instead.

4.1.4 Supporting infrastructure

Agriculture provides and occupation for a huge amount of the SSA population. (80%) The majority of these are smallholders which form the base of their respective value chains as producers. Movement towards sustainable intensification practices is rarely cheap or easy, particularly in SSA where the funds and knowledge required to implement many of the practices are limited and where the ability tolerate the often diminished yield in the first years of implementation is low. Therefore, there is a need for supporting infrastructure which may help smallholder farmers make the shift to sustainable agricultural practices more economically and socially feasible.

Creating Resilient Value Chains for Smallholder Farmers in Africa (Africa agriculture status report 2017, chapter 5)(AGR)

This chapter poses the Idea that resilience for small holders is supported by the resilience of a series of supporting infrastructures and their integration into a value chain which is able to support and improve the practices of all actors involved whilst increasing their ability to absorb the economic and climatic shocks which can otherwise devastate the livelihoods of smallholder farmers in SSA.

P-Problem

Land degradation reduces the resilience of smallholder farmers to climatic, and ecological shock, which may cause reduced yield of crop failure. Uptake of techniques which may reduce land degradation such as CA or integrated soil management is currently low, potentially due to the inherent cost and risk of behaviour modification. Further integration of smallholders into sustainable value chains which encourage sustainable intensification and enable greater profitability form crops may hold the potential to allow smallholder to move beyond the current, precarious, subsistence based agricultural model. However, value chain sustainability must be holistic spanning several organizational levels, potentially from international to household level. Examples of successful integration of so many actors and sectors into sustainable value chains is rare and exploring the manner in which this can occur may provide opportunities to reduce poverty and environmental degradation through the implementation of sustainable farm level practices.

I-Intervention

To increase resilience on the agricultural value chain by strengthening the sustainability of each component of it. By making the value chain more resilient, the risk of climate change related impacts will decrease, making it easier for smallholders to sustain the potential damages without compromising their food and economical security. The chapter explores the different ways to increase the resilience by adding several components to the value chain. These include:

- Sustainable intensification: A goal which may encompass several interventions defining the production of greater yields with less land, therefore increasing their revenue per hectare. The chapter suggests several ways of doing so;
  - Using ecological principles to increase productivity and soil quality. Conservation Agriculture is put as an example for doing so, and also agroforestry, integrated pest management, and organic farming.These methodologies reduce the cost of sustainable transition by lowering the required inorganic inputs.
  - Using genetic base of selection of crops and livestock, using species that are more adapted to increase the adaptability to the new changing climatic situation.
  - Increasing the links between smallholders, creating knowledge sharing networks through cooperatives or associations, therefore taking into account the socio-economical aspect of the sustainable intensification, This can increase the availability of required materials and skills, enabling more efficient and less damaging use of the land.
- Publicly backed or guaranteed loans: Sustainable intensification methods ensure the livelihoods of smallholders through the sustainable increase of yields, income and environmental health which in time can form a positive feedback loop. However, the initial monetary investment required is considered prohibitively high. Access to financial services is rare and when present the 20-50% deposit held as collateral poses a large risk and disincentivizes smallholders leaving them unable to procure the inputs, tools or labor required for more profitable and sustainable practice.

  The removal of this collateral down payment, enabled by the development of a centralized credit guarantee fund resulted in the growth of overall percentage of bank loans in Nigeria given to agricultural practitioners rising from 0.7% to 5% between 1997 and 2015. The scheme, which is funded by the Nigerian central bank and government allows for local banks to recoup up to 75% of defaulted loans in agricultural sectors, enabling low risk lending to smallholders. Limiting the financial barrier to sustainable smallholder development.

- Insurance: In the long term, sustainable agricultural practices increase yields in drylands and the resilience to climatic and ecological shocks. However, particularly in the short term the risk of yield reduction or even crop failure is high, this can be a devastating blow to subsistence based smallholders and acts to disincentives sustainable transition despite long term benefits. Agricultural insurance acts as a risk transfer measure for smallholder farmers who incur a small, manageable loss in order to mitigate the risk of a larger disruptive one. Insurance of this type exist in many forms and on many scales, from direct insurance given to smallholders in the form of micro financing and insurance schemes to national level policies which utilizes rainfall, meteorological or satellite data to estimate crop loss and reimburse accordingly. Additionally, insurance of this type can be included as part of a financial stimulus package where loans for inputs, tools and labour are provided and coupled with insurance, provided locally and backed internationally, smallholders utilizing these funds for sustainable intensification increase profits and incentives for all involved.

- Storage: Post-harvest systems are important to the value chain, as if not handled properly, post-harvest productivity can be affected by a between 12-20% loss of product. The chapter outlines three components of it. The diversification of national food reserve systems, a properly designed warehouse reserve system and encouraging localized marked interventions such as home grown school feeding. With these approaches, the authors expected effect is to increase the resilience of the food networks after the food has been harvested by encouraging more participation between smallholders.

- Food processing: Small and medium enterprises (SME) are suggested as a potential future of agri-food systems, providing additional income and increasing resilience. As such should be incentivized as much as possible on the food processing component of the value chain. During the last decade, SME have become more relevant and important for the food chain. The chapter proposes that smallholders take a shift towards small to medium enterprises for food processing needs. Resulting in a mutually beneficial relationship. Nonetheless, this would require a shift on the farmers perspective to produce a more commercial product. But, if achieved, the resilience of food processing could be greatly increased.

- Increased market linkage: cross border and local economic shocks due to price volatility can have a serious effect on the livelihoods of any farmer who is not entirely subsistence based. Staple internationally food sources grown in SSA such as rice and maize and other cereals are prone to serious fluctuations, whilst the fluctuations in staples which are not intercontinentally traded is even higher. These fluctuations create the risk of undervalued sales, over valued commodity cost, reduced nutrition as the price of nutritious food increases forcing consumption changes and a reduced productivity level compared to a more stable economic landscape. These risks are significantly higher for the poorest consumers and producers, such as smallholder. The limited capacity to predict economic gains also reduces the ability to effectively plan or alter production methodologies as investment in inputs, tools or the additional labour required for sustainable intensification becomes high risk and the risk of reduced yield in the first years following transition are unaffordable. Thus the rate of agricultural development is slowed and the propagation of sustainable intensification remains low. It can be seen that the inter=annual variability in crop yields, a key driving force of commodity price fluctuations in Africa is lower on a regional

> scale than at the national scale as ecological shocks which affect production rarely affect an entire region. Therefore it is proposed that increased market integration between regional partners can reduce the risk of price volatility and it's knock on effects by increasing the area of production and consumption, ensuring both supply and demand in the face of ecological or economic shocks respectively. Suggested improvements include cutting trade tariffs between international partners and selective elimination of informal barriers to trade such as cultural differences.

Integrated regional markets have the potential to reduce price volatility, increase food security, productivity and profit and as such support sustainable development in the region. 'Safety nets' such as the Ethiopian 'Productive safety net program' which provides food on a pro-rata basis during times of shortage, have been proven to significantly increase short and long term food security and should be put in place to alleviate the impact of market failure.

Co-Context

The focus of the whole paper is the African countries, and mostly sub-saharan ones, as they are the ones suffering more from degradation. Nonetheless, other non sub-saharan countries are also included with several examples. Because of the African context, the chapter explores the resilience of value chains within the socio-economic characteristics of the continent. It is important to now that 80% of African family farms are smallholders, with less than 2ha farm size. The crops in these farms are generally run by rainfed water, as only 6% of cultivated land is irrigated in the whole continent. They are therefore vulnerable to climatic variations and very dependant on the productivity of the crop due to the small size of the fields. Thus, the proposed actions on the chapter are based on the vulnerability and great amount of these smallholders.

Summary

- Sustainable and resilient value chains (SRVC) can provide increased production and income to farmers whilst also increasing resilience to climatic or economic shocks and enabling sustainable intensification
- Examples of SRVC components capable of providing these benefits include; Loans and insurance coupled with integrated programs which can act as safety nets and disseminate sustainable intensification knowledge, increased market linkages facilitating increased national and cross border trade and additional produce storage and processing infrastructure which increases market flexibility and resilience.
- Systemic rural resilience relies on the sustainability of each component of the value chain and it's linkages to other components, interventions, communities and other actors.

No original data was collected to support the model of a sustainable value chain for rural Africa suggested in this chapter. However, individual components and the importance of their linkages is supported by case studies throughout the Sahelian region, largely focusing on east African smallholder communities and a number of international panels on climate resilience such as the global panel on agriculture and food systems for nutrition, which highlights the climate risks faced by smallholders and the Montpelier panel, which highlights the importance of sustainability focused value chains for securing climate resilience. Additionally individual components are supported by testimonials in the form of interview data gathered from smallholder farmers facing climate based risk in Tanzania and benefiting from; Precision farming as a method of intensification in Rwanda, community co-operatives in Mozzambique and agroforesty and water conserving agricultural practices as a method of integrated soil management in Niger.

The chapter highlights the potential of several components of the a SRVC and supports it's arguments rigorously, however there is a general lack of critical analysis within each component, the extent to which they may break the barriers of building resilience are present, but the barriers to implementation of each component are more rarely discussed.

4.2 Energy provision

Energy availability in Africa represents a large roadblock for both poverty alleviation and sustainable development. This is particularly apparent in rural parts of SSA where electrification is rare and the primary sources of energy are biomass and charcoal. Over 70% of the SSA population relies on these energy sources for cooking and heating (Smith et al., 2015). The heavy use of biomass in these regions has both environmental and social impacts. Inefficient '3 stone' cook stoves are the largest contributor of GHG emissions in rural SSA (Bailis et al., 2005) whilst also reducing the life quality and expectancy through fine particle inhalation (Bailis et al., 2005)(Chafe et al., 2015). In addition, the requirement for fuel wood and charcoal for the 727million SSA citizens to whom it is the primary (or supplementary) energy source (Hancock, 2015), results in significant deforestation and ultimately the loss of essential ecosystem services and the undermining of the climate resilience of the local environment (Iiyama et al., 2014) which in turn reduces the resilience of those same rural inhabitants who rely on those services for survival (Zulu og Richardson, 2013). These impacts are particularly acute along the Sahel due to the inherently low vegetative productivity in the region. Whilst the total avoidance of biomass within cooking is currently difficult in many of these areas due to the low availability and ability to absorb non biomass cooking technology, the implementation of improved cook stoves reduce the use of wood by 30-50% (Iiyama et al., 2014). Representing a significant potential reduction to deforestation. Additionally bio-gassification is suggested as a lower carbon, safer alternative to traditional biomass use, which is capable of utilizing existing waste materials and as such further limiting deforestation (Baurzhan og Jenkins, 2016), Methods for implementing biogassification range from a community to a household scale with the benefits, system complexity and material requirements increasing with the size of the intervention (Baurzhan og Jenkins, 2016).

Rural populations in Saharan Africa have the lowest access to electricity in the world(Chaurey og Kandpal, 2010). Access to electricity is often seen as a significant driver for economic development(Dagnachew et al., 2017), whilst poverty is sited as a significant driver for environmental degradation(Keeble, 1988). Rural electrification provides more reliable access to technologies which both to increase the quality of life and climate resilience of rural populations. Provision of lighting allows for night time study increasing human capital, whilst reliable access to telecommunications increases the anticipatory capacity of rural communities through increased access to weather forcasts, their absorptive and adaptive capacities are also increased through increased ease of communication, both directly following disaster and through the facilitation of knowledge sharing(Scott et al., 2017).

The potential advantages of electrification, coupled with the low availability has resulted in a growing number of initiatives both nationally and internationally led focusing on increasing the availability of electricity. However in the face of global climate change and the fragility of many rural African communities to it's effects, efforts are being made to achieve this goal without the use of Africa's abundant coal and oil supplies. Although pushes are being made towards building renewable energy infrastructures. Solar photovoltaic generation is currently favoured.(Chaurey og Kandpal, 2010) Unlike hydroelectric dams, PV cells come in a variety of sizes, are easy to decentralize and are not associated with the same 'food vs fuel' augment as bio fuel generation. Within decentralized solar PV generation two predominant methods stand out, PV systems are susceptible to significant economies of scale meaning micro grids offer a potentially lower cost per kWh and higher generation capacity, but are also more susceptible to breakdown. within smaller communities further away from grid connections solar home systems (SHS) offer greater flexibility and limit the effect of breakdowns to single households. (Scott et al., 2017).

In the following section, example literature pertaining to Improved cook stoves (ICS), biogas production from waste materials and small scale solar PV 'solar home systems' will be reviewed as, in the context of rural SSA they currently represent the most achievable and flexible energy interventions.

4.2.1 Solar energy systems

Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? (Baurzhan og Jenkins, 2016)

P-Problem

In SSA in general and in particular in difficult environments such as the Sahel, centralized grid connections are limited to major population centres and their suburbs and even here access is unreliable. Utility companies lack the generation capacity to deal with significant increases in demand and lack the capital and infrastructure to expand grid connections in rural areas, particularly given the diffuse nature of settlements with low population density in the region, as a result half of the worlds non electrified population currently lives in SSA where only 15% of the rural population is connected to a national grid. Within this context, off grid solar PV arrays are often sited as a potential solution to the problem of rural electrification in SSA. Advancements in PV cells, the surrounding technologies (inverters and storage capacity) and the simplification of installation has resulted in significant reductions in the installed and operational costs of solar generation in the last two decades, which when coupled with the steady increase of lifespans has increased the viability of solar PV as an electricity generation technology. In addition High solar radiance levels throughout Africa and in particular in the Sahel (5.5-6 kWh/M^2) suggests PV as the decentralized electricity generation technology with the highest potential in the region.

Solar home systems(SHS) are considered to be the most cost effective, renewable electricity generation technology capable of electrifying rural SSA populations and providing the associated benefits to the populations and environment there, However, despite the significant drops in the cost of small scale SHS, financial barriers still play a large role in preventing the dissemination of the technology to the poorest rural sections of the SSA population. This paper aims to assess the potential for SHS in rural SSA by evaluating their cost effectiveness, affordability, potential financing and it's proven effects on environmental impacts and poverty alleviation compared to improved cook stoves and existing diesel generators respectively.

I-Intervention

The viability of off grid PV SHS is assessed based on five criteria. Firstly, the cost effectiveness of electricity generation in a single year using SHS are. The estimated levelized cost per kWh for each technology, this calculation includes the initial investment cost, fixed operating costs (FOC) (e.g fuel), variable operational costs (VOC) (repair and maintenance), the quantity of electricity produced in a year, the operating lifetime and the available discount rate of the two systems.

The affordability of initial investment is considered using the levelized cost of energy calculated for the SHS during initial comparisons. when combined they give an insight into the initial affordability and the potential operational benefits of SHS.

Available methods of financing initial SHS installation are examined from the viewpoint of the 'average' SSA rural household

Environmental impacts of SHS are estimated based on the avoidance of CO^2 emissions. Additionally the cost per tonne of co^2 avoided is also estimated as a means to determine the cost efficiency of eliminating GHG emissions through the use of SHS.

The potential of SHS to alleviate poverty is also estimated. This is done by looking at the activities enabled by the introduction of SHS, initially estimating the effect of those activities on alleviating the primary impacts of poverty; malnutrition, poor health and lack of education. This is followed by an examination of how SHS may fit into poverty alleviation mechanisms.

A scenario analysis is carried out to to estimate the years taken for the levelized cost of energy provide by SHS in SSA to coverge with that of business as usual rural electricity generation technologies. This takes into account the initial investment cost of the SHS.

Data used for the estimation of cost effectiveness and as such affordability and pay off time for SHS is gathered from 5 sources which include; the world bank, world health organization, journal articles from 'Renewable Sustainable Energy Reviews' and web sources.

The origin of data concerning household budgets is collected from the world bank.

C-Control

The cost effectiveness of SSA is compared to that of small diesel generators, which represents the current, business as usual approach for rural electrification in SSA as with SHS the levelized cost of annual energy production is calculated for this technology.

The affordability of SHS is considered utilizing the levilized cost of energy previously calculated, which is then compared to the average annual household expenditure on kerosene lamps.

The environmental impact assessment is carried out based the avoidance of CO^2 emissions in comparison to kerosene lamps. A comparison is also made with improved cookstoves, which provide a different form of energy to SHS but are given as an example of a technology with a high potential to reduce CO^2 emissions, cost effectively in rural SSA.

The poverty alleviation potential of SHS is compared to that of several alternative technologies, many of which do not generate electricity; improved cook stoves and solar stoves.

The business as usual comparison used to determine the pay off period of SHS is small diesel generators.

O-Outcome

Firstly the paper determines SHS to be a cost inefficient method of rural electrification when compared to small diesel generators, the authors further state that whilst the fall in the installed cost of SHS has dropped dramatically in developed societies the same cannot be said for SSA in which the total installed cost remains much higher as such making it a less viable alternative to current technologies for rural electrification. Typically the installed cost of solar PV reduces within a country as the market matures and the skills, materials and infrastructure required for efficient installation become more prevalent. The African PV market is still underdeveloped, 4 countries (South Africa, Egypt,) make up a total of 88% of the large installed generation capacity and the uptake of small SHS is low (IRENA, 2016). The time taken for price reduction following introduction is falling as can be seen by the increase in uptake. Between 2013 and 2015 total installed capacity quadrupled, however, 95% of this addition was within south Africa and Algeria. (IRENA, 2016)

Cost per kWh is estimated as 0.8USD and 0.42kWh for SHS and diesel generators respectively, however this is refuted by data from IRENE which shows a range of between 0.26 and 0.56 USD/kWh for small scale solar generation in non OECD countries although this data is compared to centralized diesel fired generation rather than decentralized, which is potentially more costly and inefficient. In addition the authors note that the cost of a 100Wpeak SHS one could alternatively purchase a 1.2kWpeak diesel generator, representing a significant increase in potential power generation, increasing the potential for productive electricity use (i.e pumping, milling etc) The authors note that electricity generated form thermal generators is more reliable that that of SHS, however whilst the higher running costs of these generators is incorporated into this conclusion the additional time cost, cost and availability fluctuation of fuel are not mentioned, the elimination of these benefits reduces the consistency of the cost benefit analysis. Operations and maintenance costs for decentralized SHS are shown to be high enough to increase the cost of energy above that of centralized energy tariffs. However, this does not take into account the additional cost of connection for either the consumer or provider. In Kenya the consumer cost of grid connection is 150 USD whilst the cost to the provider is ten times this, it has been shown that rural populations in Kenya are either unwilling or unable to pay this cost, even when discounted by 50% (Lee et al., 2016)

Micro grids are also suggested in this article as an alternative however they are still suggested to be ill equipped to provide energy for productive purposes thus grid connection is seen as the most cost effective method of electrification. However, given the rural context within which the paper is written and the lack of will to currently extend grid connections to rural communities in SSA this comparison seems disingenuous. Whilst is is true that most small scale SHS have a generation capacity of less than 1kw, studies on energy demand show that average household energy demands are easily met by these systems (Grimm et al., 2017).

The high initial install price of SHS shows that the technology is currently out of reach for the majority of SSA household, more than 50% of which live under the international poverty line.(United Nations, 2017) Whilst GDP per captia in SSA has risen dramatically in the last decade(World Bank Data Base, 2017), Macro economic figures of development are less accurate at determining the available wealth of smallholder considering the high level of inter and intranational income inequality in Africa(United Nations, 2017). As a result poverty alleviation is proceeding at a much slower rate than in the rest of the world(United Nations, 2017). This issue is compounded by the rarity of households with regular incomes which prevents regular saving and limits the capacity to make regular repayments should the capital for the upfront cost be borrowed. Using the estimated cost of 0.83USD/kWh the authors calculate that this cost totals 2.3% of the average SSA household income. A comparison is made to the annual cost of kerosene lamps as an alternative source of lighting. The calculated cost of kerosene lamps is given as 2.6% of the average household income. however, the authors later state that the levilized cost of energy for SHS is based on the idea that initial investment costs would be paid off over the course of the systems lifetime (estimated at 20yrs) which is rarely the case as 'pay as you go' systems in which ownership of SHS is transferred to individuals following a limited repayment period generally of 1-2 years(Harrison et al., 2016).

Considering the budget constraints prevalent throughout rural SSA households, financing systems that allow households to gather the capital to cover initial investment are important. The authors suggest that the available financing solutions typical to SSA however, require a short payback period of around 5 years of regular payments. Whilst alternatives for electrification allow a household to tailor the energy cost day to day, depending on budget constraints, important, considering the rarity of regular monthly incomes in most rural households. Financing for Solar PV systems often require the 'productive use' of the generated electricity as a means of ensuring payback.

The ability of SHS to alleviate poverty and generate income is suggested to be low to non existent. due to the high initial cost and cost of energy, potentially economically damaging lending policies, and the limited ability of lighting to alleviate poverty the article suggests that whilst electrification can provide economic growth, the benefits of SHS are greater in ares which are already experiencing economic development as these contain households with the capital to take advantage of the additional energy without being hampered by the initial costs. When coupled with the scenario exercise which estimate that is will take between 9 and 17 years for SHS energy prices to compete with the cost of energy provided by thermal generators the authors suggest that energy policies on a national and international level should focus on meeting the requirements of rural households in SSA rather than meeting SHS dissemination targets at least until the technology becomes as or more cost effective as readily available alternatives.

The final suggestions of the authors is that given the potential socio-economical benefits of electrification for rural communities and the current cost inefficiency of SHS that the focus instead be on the extension of centralized grids to the fringes of rural society. Considering the high cost of grid extension, the low existing energy demand of poor rural populations and the additional cost of connection which often close to that of a SHS which can meet rural energy requirements, this conclusion is disagreeable. However, given the current state of poverty and income inequality, the additional conclusion that investment by rural households into solar PV technology be postponed until the levelized cost of energy for this technology reaches parity with thermal generators is more reasonable. This is supported by several alternative sources of literature which state that without significant subsidies, SHS are currently out of the read of the poorest strata of rural African populations despite growing demand.(Harrison et al., 2016)(United Nations, 2017)(Grimm et al., 2017)(Grimm et al., 2016).

R-Requirements

Requirements for electrification using SHS are predominantly financial, the high initial cost requires either significant savings or a stable income to meet loan payment schedules from microfinance institutions.

The Authors of this paper suggest that these requirements currently represent insurmountable hurdles for the rural inhabitants of SSA to whom they are targeted. Without They further suggest that this situation is unlikely to change without first overhauling the approach to the political and financial institutions surrounding the technologies.

Summary

- SHS provide electricity at a higher cost (0.81USD/kWh) than grid connection with centralized generation (0.08-0.16USD/kWh) or even diesel generators (0.42USD/kWh) and also have a higher installed cost.
- The benefits provided by electrification do little to reduce poverty or increase resilience within communities which adopt them.
- SHS are an expensive way to mitigate GHG emissions from rural communities (150-626USD/tCO^2). Technologies replaced by SHS (lighting) contribute relatively little and greater savings could be achieved through ICS dissemination
- Postponing investment into solar home systems until there is greater balance in the cost and benefit reduces the risk of pushing rural adopters further into poverty.

The output of this paper suggests not only that SHS are not an affordable method of rural electrification in SSA but also that their ability to combat poverty and environmental degradation. The paper suggests that for the purposes of poverty alleviation simpler technologies which focus more on the core needs of communities such as improved cook stoves. Cook stoves are additionally represented as a more effective method of limiting GHG emissions and primary health problems found in rural SSA. However, the benefits of electrification through SHS are often under evaluated throughout the article. The main comparison for the affordability of SHS is that of kerosene lights, this comparison fails to take into the account other benefits provided by electrification such as the increased access to and reliability of telecommunications following electrification, something thought to have an effect on the climate resilience of at risk rural communities. Additionally, the potential GHG emissions linked to thermal generator use are not considered when comparing the environmental benefits of SHS.

Considering the cost-benefit analysis carried out in this paper and the robust nature of the sources linked to SHS data. It is difficult to refute the final arguments of the paper which highlight that SHS have yet to reach grid parity in SSA and as such adoption at this point may be a burden rather than a benefit to the poorest rural households for whom this initial investment is self funded. As such energy interventions carried out in SSA should focus on the needs of communities, enabling sustainable economic development, rather than meeting solar dissemination targets and that action on a local, governmental and extra governmental level is required to increase the viability of solar PV as a source of electricity in SSA. However the suggestion that grid extension by SSA utility companies is unlikely to be heeded and seems to be based on an undervaluation of the potential and impact of solar PV for rural electrification in SSA.

4.2.2 Improved cook stoves

A review of improved Cookstove technologies and programs (Urmee og Gyamfi, 2014)

P - Problem

2.6 billion people worldwide rely on 'traditional biomass' meaning fuel wood, charcoal, crop residues or animal dung cakes for energy production. The vast majority of these individuals live in developing countries where electrification is rare. This is particularly obvious in rural areas where up to 90% of the population may rely on such materials for household energy supply. These fuels in many areas are burned in the '3 stone fires' which serve as cook stoves or other open fire equivalents. These cook stoves are inefficient at converting fuel to heat resulting in a myriad of health and environmental impacts. In Rural Africa, Women and children predominantly oversee the collection of firewood, the inefficiency of existing cook stoves, which inflates fuel requirements makes this an arduous task which takes hours. Additionally this requirement encourages deforestation, leading to the degradation of the environment and the loss of ecosystem services. These effects are particularly disastrous in areas where vegetation is already scarce, such as the harsh dry land environments of the Sahel. Whilst the environmental impact of deforestation affects anyone relying directly on an areas ecosystem services (predominantly rural populations), the personal health impacts of 3 stone cook stoves disproportionately affects women and children. Inefficient use of fuel increases cooking time, cooking is carried out indoors and the fuels used produce high levels of carbon monoxide, hydrocarbons and small particulate matter which according to WHO results as many as 1.6 million premature deaths per year, 600.000 of which are in SSA. In addition as many as 99million disability adjusted life years are lost per year globally due to these practices. ICS use holds the potential to limit these effects, however, globally the reported success of ICS dissemination programs is 'mixed'.

I - Interest

After outlining the problems related to the use of traditional cook stoves in developing countries this article outlines the potential of improved cook stoves to mitigate these impacts. The focus of this paper is twofold. Firstly it gives an overview of and compares designs of ICS disseminated on a global scale. The design specifications for each stove type are described, the key characteristic of each stove are then made explicit and comparable. The categories for this characterization are; Usable fuel types, efficiency compared to traditional cook stoves, Construction material and region of primary dissemination. Additional columns show authors comments and the source of stove characteristics

Secondly the paper considers the ICS programs which are responsible for the dissemination of these ICS examples outlined in the first section of the paper. The article focuses on outlining the various ICS dissemination projects throughout the world, separating them geographically in programs in; Africa, Asia and South America / the Caribbean. The focus of each overview is to outline the context (including the backing; national, NGO, international aid) and the cost, dissemination and use data for each program when available. Thought is then given to an exploration of the approach taken by each program and how these factors either increase or decrease success rate of ICS cook stoves in each region.

Co - context

The key characteristic of this article is to utilize the historical and existing ICS programs and designs to determine the factors which play a part in their success or failure and to distill these into 'lessons' which can be used to increase the success rate of ICS dissemination programs and inform ICS design in the future. The authors determine that '*No program can achieve it's goals unless people adopt it (ICS) and continue to use it in the long term*'. The papers initial focus on design couples with the later analysis of program success in which the authors find that a key indicator of failure is a lack of understanding relating to the reasons for ICS adoption and cultural or practical requirements relating to the existing context surrounding cooking. The authors show that context is key. ICS programs have higher success rates in areas where fuelwood is already scarce and as such the benefits of ICS are easier to appreciate.

During the design process of both ICS and their dissemination programs it is shown that a 'top down' approach generally leads to higher failure rates. The given example is that stoves designed in a participatory manner with communities met the users requirements outside of fuel efficiency to a higher degree than those designed and disseminated through a top down 'lab and donor approach'. However it is also made clear that a focus on training and knowledge sharing is key to overall success as programs which used available funds to kick start self sustaining stove industries showed higher dissemination and use rates than those which focused on direct, prefabricated ICS prevision. This is also supported by their observation that community members suggest that cost is a significant barrier to ICS dissemination, whilst subsidizing ICS purchase can alleviate this, there seems to be no correlation between heavy subsidies and ICS program success. Instead success was most often achieved through investment in building knowledge and capacity for manufacture which both brings down the cost through the use of readily available materials and local labour, increasing success rates.

The authors also highlight that whilst efficiency is important for reducing the impacts associated with traditional cook stoves that alone is not sufficient to ensure continued use. Community factors such as ease of use, aesthetics, improved safety and improved cooking times all provide more immediately obvious benefits and as such are important factors in determining success whilst a lack of understanding concerning the existing context surrounding cooking a fuel use is associated with a higher likelihood of failure following the initial investment period.

R - Requirements

The article only highlights the community requirement of the initial capital to invest in ICS. However it also highlights many more requirements for the design of cook stoves and projects aiming to increase their reach and use. These requirements initially focus on the key impacts and design factors. ICS must reduce indoor air pollution, have a proven and substantial increase in fuel economy, be easy to use and be durable and easy to maintain or repair. Additionally the authors highlight that projects focusing on ICS dissemination should market ICS to households within their given context, meaning that a more intimate knowledge of community requirements and culture must be taken into account, this can be achieved by developing programs using a bottom up approach and focusing on training communities in ICS use, repair and manufacture, utilizing easy to gather, cheap materials and simple methods. This has the additional benefit of reducing the complexity of use and the initial investment cost significantly. Finally, ICS programs should be initially targeted at deforestation hot spots or areas in which fuel wood is scarce, here they have the greatest opportunity to reduce environmental impacts whilst making the benefit of increased efficiency immediately clear.

Summary

- Biomass and charcoal are the primary energy source for 85% of rural SSA, the increased fuel efficiency provided by ICS (50%) can potentially reduce fuel demand and as such deforestation.
- To maximize use, ICS designs should take into account; increased efficiency, reduced indoor pollution, ease of use, safety, durability, price, household requirements and form
- A top down technology transfer approach was linked to a high rate of long term project failure. Bottom up capacity building approaches prioritizing training and local infrastructure saw increased success rates.

This Article focuses on the meeting point between society, ICS engineering and project design. The paper focuses on how the design of both the ICS and their dissemination programs can enable or hinder project success based on lessons learned from historical projects dating from 1980-2010. Quantitative data is gathered from a variety of sources to compare the characteristics of cook stoves, to highlight the dissemination of cook stoves throughout households in the 3 regions present and to show the overall success of individual programs. However, no quantitative data is collected or analyzed by the authors. Instead they focus on synthesizing the project data and insights in the hopes of producing general principles which may inform the design of ICS and ICS related projects in the future. Key factors leading to project failure are shown, followed by four key questions; '(a) Under what situations are improved biomass stove programs more successful? (b) What is the most effective process of choosing the best design for a particular program? (c) What is the role of subsidy in stove programs? (d) Which benefits does the improved stove need to produce?' which are in turn answered through the previously mentioned synthesis of project data and insights. The concluding remarks of this paper, suggest that the inclusion of cultural factors in ICS design and a bottom up approach to dissemination which focuses on capacity building and knowledge sharing rather than direct provision of ICS. This is largely in line with the expected results from such qualitative analysis and is in agreement with much of the supporting literature.

4.2.3 Biogas production

Broadening the potential of biogas in Sub-Saharan Africa: An assessment of feasible technologies and feedstocks (Rupf et al., 2016)

P-Problem

Fuel availability is a key factor for maintaining a minimum level of well-being in sub-saharan countries. Biogas is one of the main options that the literature provides to the ensure this availability, although it is not focused on all of the possible feedstocks for generating biogas that are available. There is a potential for the implementation of biogas technology in SSA, although these differ between urban centers and rural areas.

There are different feedstocks available to produce biogas depending on the area or the country. The article takes that into account, and outlines that the potential of biogas in urban areas is heavily influenced by the better sewage systems which could redirect feces and urine to biodigesters, although there are several cultural and infrastructural barriers, for example sewage system expansion, renewal or redirection is costly and can out weight the potential benefits of biogas provision. In rural sub-sahara, the main feedstocks for producing biogas are livestock manure and crop residues which are abundant materials for farmers, however there are other highly competitive uses for these materials such as fertilization and fodder.

I-Intervention

The article can be divided into the assessment of potential energy generation coming from biogas and the assessment of the biogas technologies, which are divided into households, communities and institutional and commercial levels.

Households

Fixed dome digesters: The needed materials are affordable, although material dependent life spans are typically long and once constructed models are low maintenance. There have been several adaptations on this model accordingly to the conditions of the site, for example introducing an expansion channel rather than output tank ,enabling more gas storage and improved fertilizer output from the digester. Although relatively cheap, some of the materials needed for the fixed dome may be difficult to obtain in remote developing regions. The required materials are somewhat flexible opening the potential to reduce costs, for example using bricks crafted from compressed local soil or clay.

Low cost tubular digesters: They are more economic and popular than the former due to the simple construction, easy maintenance and low cost of the materials. The systems can be made of PVC, polyethylene, neoprene coated nylon fabric, UV resistant bags, industrial grade tarpaulin, or plastic silo bags. These are easier to transport and obtain than the other digesters, making them more appropriate for rural remote locations. Moreover, the installation costs are half of the fixed dome digester. Despite these advantages, the expected pay of time of five years is long, particularly considering the estimated lifespan of a unit is around five years.

Floating cover digesters These have a flexible cover which regulates gas pressure by its weight. When gas production increases, the top rises, but still maintains a regular pressure with its weight. These digesters are more expensive than the ones mentioned above, making them less accessible for people with low income. Although redesigns have reduced costs, the reduction is not thought to be significant enough to limit the financial barrier in rural SSA at the moment.

Communities and institutional In these cases large biodigesters of approximately $20m^3$ are installed either in communities, prisons or schools. The large investment required, according to studies made in Ghana, reduces the economical viability for small communities. Nonetheless, they provide some co-benefits to the people. Modification to sewage systems, to feed the biodigesters, significantly improves sanitation. Resulting in reduced pollution and disease risk for beneficiaries.

Some large digesters have proven able to cover the entire electricity demand in schools and colleges. However, as previously mentioned, the costs of installing these are often prohibitively high. Additionally large amounts of water are required for the creation of bio gas and the improvement of the sewage with flushable latrines. This again reduces the viability of large community or institutional biodigesters, considering the constrained nature of water availability in much of SSA.

Co-Context

The article remarks the potential of sub-saharan countries on generating biogas according to the feedstock records they could obtain. They affirm that based on the average biogas consumption of rural households, a digester can achieve to meet all of the energy and gas demands with the feedstocks that they already have. Additionally much from biodigesters can act as an organic fertilizer in rural settings.

R-Requirements

In order to implement biogas technology to either level, some considerations have to be taken into account of the possible constraints derived from the socio-economic context of sub-saharan africa. Such considerations are to take into account which feedstocks are available and which are the required, what level of energy demand does the community or household require, which local materials are available for the construction of the dome, the water availability and affordability.

Water availability and affordability are specially important in the sub-saharan context. Water is not an abundant resource in drylands, and quite a lot is needed for the good production and well functioning of the digester. If locals have to constantly travel to get water for the dome, it would not be a suitable technology for them. Moreover, affordability can also be a determining factor, as if no funding is aported to the communities or households, the price of one of these technologies can be beyond reach for them.

Lastly, there needs to be a level of commitment from the people in order to maintain the biodigester effectively. In some of the cases analyzed by the article, a lack of community commitment lead to neglected biodigesters, which had leakages that polluted the land and water around (due to the bacteria *Escherichia coli*. Also, these leakage caused the technology to become useless.

Summary

- Feedstocks that are free and available in Sub-Saharan communities can be used for feeding a digester and producing electricity. If infrastructure for the areas is build, these feedstocks can be further optimized.
- There is a great potential of biodigesters for creating energy in households and communities, depending on the necessities, there are several options to build. Moreover, the production of natural fertilizer would reduce the need for artificial fertilizers, and would improve the soil quality when used.
- There are several considerations to be taken before a digester is introduced, like water availability, affordability and community commitment

Although material costs are thoroughly evaluated in this article, the availability of those retain quite underestimated. Specially for poorer regions such as SSA, materials such as the UV resistant bags mentioned above may not be easy to come by in isolated regions. The article also mentions that the construction of these would eventually provide job opportunities for locals to maintain and construct more of these. But, regions that are in need of biodigesters usually have a low level of education, therefore becoming knowledgeable in how biodigesters work is not an easy task that can create employment so easily. Lastly, the article emphasizes that feedstocks proposed are available and free to use from locals, but some of these may be already used in other tasks. For example, animal manure, which is one of the main feedstocks for rural communities, is usually used to fertilize fields for cropping. Therefore, there is a need for identifying non-competing feedstocks to provide material to make the biodigesters function properly.

4.3 Water provision

Water is an essential resource for rural communities in sub-Saharan Africa, and water resources are often scarce. Its availability is a direct factor for climate change resilience, as a constant supply would reduce the impact of drought, one of the most harmful natural disasters endemic to the region, which causes has severe economic and ecological losses (UNCCD, 2018). Most of rural communities in Senegal do not have any type of irrigation systems as a result, the majority of agriculture is rain-fed. However, reliable water supplies are essential for health, the implementation of year round CA introduction an landscape remediation.

The main water sources in which rural communities have access to are water tower reservoirs and wells. Water towers and reservoirs are unlikely to have the capacity to support year round cultivation and are prone to evaporative losses. The water supply of wells is area dependent but can support year round growth with sufficient access to aquifers. Due to being a mostly sandy/loose soil, water tends to be found in deeper depths than on other regions of the world. Therefore, wells tend to be unsustainable to use without energy, as they require a lot of effort to collect. In a lot of cases, the water rural populations use comes from water towers that collect rainwater, and due to bad storage it is usually unfit for cultivating due to the high content of salts. Moreover, it can also cause some health issues. Therefore, the need to increase access to water resources in rural SSA is large. Solar pumps, wind pumps and diesel powered pumps enable the collection of significant amounts of water, the decentralized nature of the energy source is important considering the rarity of grid connections in rural SSA. The following section and article assessing solar pumps in comparison to these alternatives is reviewed.

Solar powered pumps to supply water for rural or isolated zones: A case study (Ramos og Ramos, 2009)

P-Problem

Extension of the electric grid to isolated communities has proven to be highly expensive, and other articles have outlined the difficulty of it (Toman, 2017), rural towns in developing countries are generally found scattered rather than clustered together (Linard et al., 2012). Therefore, this article intends to assess the feasibility of solar powered pumps against other options for water provision in these areas, in order to provide a sustainable solution that can allow people to have access to water and at the same time being beneficial to the environment. In order to achieve a good assessment, the article analyzes several experiences with solar pumps in different developing countries and calculates the cost of a case study through a model.

I-Intervention

The article analyzes a case study in Zambia, focused on the outcome of a solar PV pump that provides water to 10 small families. The costs were calculated on two levels, equipment and loan. Equipment refers to the module cost, pump and accessories, regulator cost, transport and total investment. The loan level included annuities, maintenance cost, total yearly cost and water cost. With the provision of 100 liters per day for each family, and a well depth of 100 meters.

C-Control

Diesel fueled pumps were analyzed with other case studies for the analysis and comparison with the solar powered. Initial investments on the generator were considered, as well as maintenance cost throughout several years and fuel costs. These can fluctuate between different countries and time, as diesel fuel price tends to be quite flexible.

O-Outcome

Solar PV technologies can be very beneficial in countries where solar irradiation is very abundant. Some other technologies, such as wind powered pumps have been used in the past, but the big initial investment and irregularity of winds makes them not viable in most cases. Maintenance needed for the solar cells is very little, but pumps usually require more thorough and regular check-ups.

On the experiences analyzed, these pumps tend to be more viable in the long term than diesel generators. This is due mainly to the high maintenance needed for the generators, which tend to break often, and the constant fuel need. Life cycle studies estimate that the PV are considered to have a 20-year life-cycle period, which is the estimated minimum life expectancy. Moreover, the breackeven point, which is the point in which a technology becomes cheaper than other, is fairly low in most cases, usually on the range of 7 years. This point can be very different depending on the size of the pump, as the smaller the pump required, the smaller the breackeven point is. Therefore, if there is a need for bigger pumps, the investment would be bigger, which would take more time to become cheaper than the diesel generator pumps.

R-Requirements

Water provision with solar PV is possible and most viable in the long term than Diesel generator based. But, the payback time may be dependant to some factors such as available wells and sun exposure. The method did not take into account the differences in water demand during a year, and therefore PV may have a weakness there. A combined PV with wind energy would be the ideal solution to this case, in order to provide energy more equally throughout the year.

Summary

- Solar powered pumps are a viable solution in the long term to substitute/provide rural isolated communities with water
- Diesel generators tend to be more expensive than solar pumps in 7 years due to high maintenance costs and fuel, which at the same time might be troublesome to obtain regularly
- A mixed system between wind powered and solar powered pump would be ideal for compensating when there is less sun, but usually this system is not viable due to the high costs associated to it.

Although providing knowledge and data regarding PV water pumping technology, the article does not emphasize that initial investments for these technology is quite high, and without funding or external partnerships, the technology may not be reachable or appropriate to isolated rural communities. Moreover, the maintenance of the systems could be an issue, as on rural isolated communities, in addition to being poorer in developing countries, do not have people with knowledge regarding its processes. These would mean additional investments for people to come and maintain the pumps and solar panels. Although training could be provided, the great majority of SSA isolated rural communities do not have a profound education, therefore making this training more difficult.

4.4 Synthesis - The nexus of land use, energy and water Interventions

In this section the potential for for the combination of the technological and social interventions reviewed above will be explored. The focus will be on the interactions between the three broad categories provided including example interventions from; increasing water availability, sustainable energy provision and land management. Sustainable development is inclusive, requiring effective stewardship of all resources. Within natural ecosystems land and water resources are inextricably linked. Human development is currently heavily tied to resource depletion. The nexus to sustainable development is implemented in developing countries as a means to increase the availability of resources and limit poverty whilst also maximizing the efficiency of resource use to decouple development from environmental degradation and resource depletion.

Supporting financial infrastructure can be used to support farmers in their adoption of new agricultural practices such as those found within the CA umbrella by lessening the initial cost of tools for no-till seeding, herbicide or labour cost for initial de-weeding of no till plots (this may be required until the weed root and seed stock is depleted), additional labour if required or provide safety nets in the case of crop failure. Post harvest systems are also important in order to provide crop producers with supporting infrastructure such as food storage and processing systems and increased market linkages to increase resilience of post-harvested food networks.

The provision of loans with extended payback periods, funding of local training and knowledge sharing can increase the dissemination, usability and lifespan of renewable energy technologies. This could be applied on two scales, household or community. Investment in community wide renewable energy technologies decreases the kWh cost of electricity but increases the complexity of installation and maintenance again increasing the importance of capacity building with rural communities through extension programs. Such social and financial tools reduce down time and result in greater efficiency and productive use of energy, such as the provision of water which can increase health of communities and the efficiency of agriculture. Electrification implies a myriad of livelihood improvements for rural African populations and is thought to be highly correlated with economic development. Considering the nature of poverty as a driver for environmental degradation, electrification may indirectly benefit climate resilience. However, it also directly affects climate resilience. Rural electrification markedly increases the populations access to telecommunications technology. Increased reliability of long term communication increases the potential for knowledge sharing and enables more effective disaster preparation and recovery.

Sustainably increasing access to energy plays a vital role in reducing environmental degradation in rural SSA and in the development of rural African communities. Fuel efficiency increases reduce biomass and charcoal requirements in cooking, which in turn allows for the redistribution of human capital for productive purposes and reduces deforestation. These factors greatly effect the efficacy of reforestation and sustainable agriculture programs, increasing food security, reducing forest depletion and environmental degradation. At the same time, greater tree density increases the availability of biomass as a resource, and numerous indicators of soil quality. This combination of increased availability and efficiency of use creates a positive feedback loop, increasing the efficacy of both interventions over time.

Sustainable agricultural techniques such as intercropping with woody species provides fuel through coppicing and has been shown to increase useful organic material which can support income diversification by providing more cattle fodder or can be used in composting or to achieve permanent soil cover, both important steps in climate resilient agriculture.

Water availability is yet another necessity closely linked to the other categories. For communities to have a water source at their disposal is essential for other practices analyzed to occur. Land management is closely linked to it, specially within Conservation Agriculture. For the three principles to be implemented, water is needed for the crops. Mostly, current agriculture is limited in Africa to the rainy season, but to shift to a long term CA irrigated based crops, water needs to be provided throughout the year. In addition, in rural populations where there is not a stable water supply to sustain the population, CA becomes very difficult to implement completely with a functional long term perspective. Not only availability is important, but also CA increases the efficiency resources, in order to maintain the supply of water and avoid over exploitation. For example, cover crops are aid in soil water retention, therefore increasing plant water use efficiency and reducing evaporative losses. Other land management techniques are also linked to water availability. Reforestation requires water for the trees to grow, but when completed it creates a positive feedback loop, as trees increase water use efficiency on the land in which they are planted through peculation and water cycling.

Chapter 5

Case study analysis: Creating community resilience in rural Senegal

A number of common barriers cited to reduce the efficacy of international development projects in SSA are circumvented through the application of an approach based on the idea of appropriate technology. Any technological intervention has to be used in order to achieve it's impact. In order to maximize the impact of technology based interventions it becomes necessary to increase the capacity of the affected communities to assimilate the new techniques and technologies. The ability of capacity building to increase the efficacy of interventions within the fields of land, water and energy are well documented (Urmee og Gyamfi, 2014), as is the supportive effect interventions in these areas can have between on another (1.4.1) and the damaging effect of the unsuccessful development strategies of the mid 20th century (AGRA, 2017). Therefore a rural based, holistic approach to development projects in which the abilities of capacity building and the land, water, energy nexus are utilized with the aim of creating resilient, sustainable and self sufficient communities may be key to increasing climate resilience through the reduction of poverty and environmental degradation.

In the previous section nine preeminent interventions for sustainable development in SSA were reviewed. The aim of this section is to generate a framework by which the suitability of potential interventions may be determined. Based on their ability to integrate with other activities, interventions and with the communities in which they are carried out. This framework will be created using the knowledge and experience gained through the literature review and field work in the Fatick and Diourbel regions of Senegal. This will begin with an exploration of the location, activities and ethos of the 'Center for Renewable Energy and Appropriate Technology for the Environment' (CREATE). This is followed by an inventory of the interventions they carry out in sponsored communities. An exploration of the factors which determine the success rate of these practices will be performed utilizing the data obtained through the observations and interviews with CREATE technicians and participating community members. These principles and other key criteria for appropriate technology and capacity building will then be used to assess the sustainability of the interventions reviewed in the previous chapter on the field of the area studied.

Finally, an action net will be developed to illustrate potentially successful combinations of activities to build resilience against desertification in rural Senegal and to highlight the ways in which the applied nexus approach may increase the impact of the chosen interventions.

5.1 Senegal case study

Data collection is carried out in The Senegalese regions of Fatick and Diourbel. During this week long process visits were made to 9 villages sponsored by the collaborating NGO CREATE! (Center for Renewable Energy and Appropriate Technology for the Environment). During these visits, structured interviews were held with available community members on the site whilst unstructured interviews were held with site technicians. In addition, CREATE strategy meetings were attended and a formal conversation was done with the CREATE founder. The data gathered, in combination with a review of existing literature provides the in situ data and information required to perform this analysis.

5.1.1 Introduction to CREATE!

CREATE! had the initial goal of re-greening the African country by tree planting and other activities to create better environments for rural populations enabling the sustainable extraction of resources, reducing poverty and environmental degradation. They started their actions by re-planting. However, their methods shifted following the realization that a holistic solution is required to tackle the interconnected issues pertaining to environmental degradation and poverty. After several years of experience, the NGO is now dividing its actions into four categories for improvement: Water, community gardens, income generation and renewable energy, all which support each other, and when combined they increase the efficiency of each category.

CREATE! action plan works with communities throughout a period of 5 years. They provide training for the creation of community gardens, solar water pumps and ICS. These communities are usually located in rural areas suffering from low soil quality and poverty. The process starts with CREATE! reaching to a community and providing an initial cookstove training for the villagers. After a period of approximately two months, the staff come back to check on the process. This initial intervention is carried out as a test of dedication and commitment for improving their condition. Because they are made from freely available materials, and a simple design, villagers should have been able to build several in homes throughout the community. High ICS saturation is considered a success, at which point CREATE moves ahead to the next stage of implementation. Community motivation is considered a great asset and a requirement for program success. When the project starts, the first step done by CREATE is to rehabilitate water sources, old abandoned wells, with local manpower, followed by a joint CREATE and community investment in solar water pumps. Once water is provided, the community garden initiative is started. This action consists of training the beneficiaries in sustainable agricultural practices, based on the methods inclusive to conservation agriculture. Training is supplemented by practical application which in turn forms the community garden sites. The land for the gardens was usually used for rain-fed crops, and is freely given to the community. Usually by individuals, often village chiefs, who see the potential benefit of CREATE intervention in their communities.

Gardens are planted with vegetables, fruits herbs and spices commonly used in households. Local growth drastically increases the availability of these foods, which previously were only available one or two days per week. This confers several health benefits and increases food security. Small scale industrial poultry rearing training and infrastructure is also provided. Increased access to poultry represents both a highly nutritious food source and a diversified income source. Training is maintained for a 5 year period in which the role of technicians slowly switches from trainer to supervisor as the self sufficiency of communities increase. This increases uptake of the provided knowledge and greatly increases the likely hood of long term impacts. these practices will be explained in detail on the following section. Water is then provided through renewable solar pumps.

Gardens provide with food and income, as the products not consumed by the gardeners or their families are sold to the larger community or at markets. This creates an income generation opportunity and increased food security, which are two factors much needed on the region.

CREATE's philosophy is not only to provide with resources to the people who need it, but also to encourage self sufficiency. It tries to work outside of 'the existing paradigm of rural development aid in SSA', in which NGO's and development programs provide resources or transfer technology, paying little mind to the capacity for integration or self sufficiency. Based on large economical investments and dissemination targets, this approach creates dependency within communities which then rely on the continuing function of the provided technology (Chambers, 1995). With a limited focus on capacity building when transferred technology fails, replacement or repair is impossible and any positive impact is lost. Create aims to build self sustaining communities, limiting dependency on donation through capacity building. Only then can an NGO create long lasting solutions in a context typified by a severe lack of economic, material educational and natural resources.

The following section will explore the practices introduced throughout CREATE training in an attempt to highlight the importance of this holistic approach.

5.1.2 CREATE Activities - The Nexus in Practice

The following section highlights the practices carried out by CREATE, their impacts and inter-linkages. These are determined through observations collected throughout fieldwork, unstructured interviews with CREATE technicians and structured interviews with on site community members which are analyzed utilizing nexus theory.

Energy

One of the primary actions of CREATE is reforestation. Woody biomass provides the majority of the rural energy mix in Senegal, predominantly for cooking and heating. Fire wood collection takes hours each day and is mostly carried out by women and children. As populations grow and without a viable, affordable alternative the cutting of trees and shrubs results in a significant amount of environmental degradation and the already limited resources are over exploited. This reduces the climate resilience of the environment which in turn reduces the resilience of the rural poor that rely direct upon these ecosystem services for food and fuel provision(Keeble, 1988).

Understanding the importance of tree density for environmental health and the drivers for deforestation in rural Senegal has lead to the improved cook stove becoming the first intervention introduced to new communities.

Built using local materials which are freely available, these cook stoves are able to reduce the use of firewood by between 50-70%, reduce cooking times, reduce health risks related to particle inhalation and reduce the risk of errant sparks immolating grass houses and people. Cook stove manufacture is carried out at a community level 5.1. The reliance on local materials reduces the capital investment to almost nothing and instead utilizes the readily available human capital instead. The stove building method is simple requiring no measuring tools. Additionally these cook stoves build upon the existing culture of cooking over three stone fires with large metal pots. Training programs carried out in each village kick start a small scale ICS manufacturing whilst the limited technical requirements and ease of building ensure that replacement and repair is possible without additional financial input.

(a) **(b)**

Figure 5.1: ICS training process in a community(a) and finnished product (b)

The reduction in fuel wood usage enables more effective reforestation increasing the availability of materials and the positive effects of increased tree density on the local environment and potentially agricultural yields forming a positive feedback loop as long as both practices are maintained. Additionally, the reduced cooking times and the ease gathering the required fuel allows for the redistribution of human capital from cooking and gathering to productive or income generating activities. In a general sense, these would lead to poverty reduction and as such are likely to reduce environmental degradation. Within CREATE communities, this human capital is most often utilized in community gardens which allow for the production of vegetables, the regeneration of the soil, reforestation and income generation.

Water

Water is a primary constraining resource in much of SSA. The region is typified by low rates of irrigation, low rainfall and high average temperatures. Most agriculture is rain-fed, taking place only in the three to 4 month rainy season. Wells and water towers provide water to rural inhabitants. However both methods are unable to support agriculture either due to the difficulty of gathering or the constrained nature of the resource.

Prior to CREATE! Interventions, wells within many communities had fallen into disrepair, in favour of easier to use water towers. This was due to the lack of mechanization, as wells have a significant depth, which taking water from was very effort intensive. The water provided by these towers often proved unusable in agriculture. CREATE's water based interventions thus often begin with the refurbishment of existing wells when necessary, followed by the installation of photo-voltaic panels at all sites. These provide power to a flexible screw pump which in turn fills the 5000L reservoir, water is accessible by a tap at the base of the reservoir. These solar pumping systems also directly feed into a number of basins (2-6, site dependant) at each site enabling easy access to water and irrigation for communities and community gardens. An example can be seen on figure 5.8

Pv panels cleaned bi-weekly and are aligned seasonally by create staff to ensure maximum efficiency. They use a flexible screw pump which can take a multitude of inputs, this simplifies the system and as such it's maintenance. This reduction in complexity reduces the required capacity building to ensure maximum impact.

Three to four 250W photovoltaic cells are used per site. The determining factor for the number of cells used is the height and refresh rate of water in the well. As the pump speed is determined by the power input, if the refresh rate is too slow to provide efficient pumping, then one panel is removed to slow the pump rate. This reduces the likelihood of the pump touching the base of the well and in taking sand. Despite these efforts to simplify the integration of the solar pumps into communities their maintenance and replacement still represents the most fragile aspect of the self sufficiency communities CREATE aims to instill within communities. However, CREATE maintains contact with all communities, even following the completion of the 5 year training period, primarily to act as a point of contact in case of total pump or PV failure. This represents an important stewardship step which increases the 'appropriateness' of the solar pumping system within rural Senegalese communities.

Figure 5.2: Water system in the Walo community

Increased availability and ease of access to clean 'sweet' water provides health benefits which were not seen in communities relying on the 'salty' water from water towers. Additionally with no limits on water availability communities are able to irrigate crops regularly and overcome the excessive drainage and evaporation inherent to the sandy soil, allowing year round vegetable cultivation. The connection between water and agriculture requires little explanation. However, considering the general scarcity of water resources in the region conservation agriculture methods are taught to community members and used on all sites to minimize water loss, preventing resource depletion by maximizing water use efficiency. This concept will be more thoroughly explore in the section below.

Ecology and Agriculture

Community Gardens Provide the ability to produce vegetables throughout the dry season, smallholder, dry season agriculture is almost unheard of outside of this. Plot size for these gardens is between 0.4 and 1.8 hectare with the most common area being 1 hectare. The small size of these sites allows for close maintenance, whilst overall yield may be higher on larger plots, the use of several sustainable and conservation agriculture techniques enables the year round provision of enough vegetables to ensure food security and provide additional income in areas in which conventional agriculture during dry seasons is impossible.

Agricultural techniques taught to beneficiaries by technicians and used on the sites allow for the maximum retention of water and nutrients whilst minimizing soil disturbance and ensuring specific species are grown in a manner that maximizes their productivity. Water is a precious resource and whilst in most senses it is abundant, the use of efficiency maximizing CA techniques in tandem with additional water availability safeguards against future resource depletion.

Primarily these practices include aspects of;

- Agroforestry - utilizing a mixture of trees and crops
- Mixed cropping - growing multiple species of crop on a single field
- Minimum soil disturbance (through the use of Zai planting and strip bedding)
- Crop rotation - utilizing different crop nutrient requirements allow nutrient cycles to balance over time
- Organic composting
- Transplanting.

Agroforestry - *The principle of growing woody vegetation around of within a plot of agricultural land for the ecological benefits imparted.*

Reduced deforestation is coupled with tree planting drives once per year, just before the onset of the rainy season, each CREATE! sponsored community plants an average of one thousand trees per year in their local environment, on and off site.

Trees are used for shade, to act as windbreaks and for their positive effect on soil structure, nutrient balance (as many affix nitrogen and all sequester carbon). In addition, existing trees are not cleared from the site, should they be present. for example: community site in Keur Dauda Contains a single large White Acacia whilst the Walo site contains a cluster of smaller trees. These trees are preserved as they provide protection from sun and wind to seedling nurseries and site workers during the hottest points of the day.

Cutting of the planted windbreak trees which surround agricultural sites is forbidden, technicians build knowledge of the importance of trees for maintaining soil health and agricultural yield to ensure this behaviour persists.

Tree Planting outside the CREATE! Sponsored garden sites are important both for the ecological benefit of increased tree density, but also as wood is a primary material for energy and building. On figure 5.3 the tree seedling ready for planting are shown. Improved cookstoves reduce this need, but cannot eliminate it. Tree cutting is thought to have been reduced by as much as 70% on some mature sites, resulting in an increase in the tree density in the local area and an increase in the associated benefits to soil quality, water storage capacity and agricultural yields.

Figure 5.3: Tree seedlings being prepared for the tree planting campaign

The protection of seedlings from wind, heat and pests is difficult, windbreaks, once mature reduce wind speed and after many years reduce the ambient temperature to create a micro climate, in addition nurseries are placed under trees when possible providing protection from the sun and wind. Old mosquito nets are also used, they provided the above benefits whilst also protecting from common pests such as ground squirrels which forage in gardens during the dry season when green biomass is a rarity.

The more complex ecological benefits provided by high tree densities may not be well understood, however there are visible benefits such as the provision of wood, shade and potentially fruits which beneficiaries understand very well.

Mixed cropping - *The practice of growing multiple Edible crop species on the the same field, site or area.*

Regular irrigation allows year round cultivation, the products are primarily used to feed beneficiaries and their families, resulting in improved health, the additional is sold.

When water is removed as a constraining resource and year round growth becomes possible, soil nutrient balance becomes a primary determining factor of vegetative productivity. Ecological principles are poorly understood in many rural Senegalese communities, part of the CREATE! Mandate is to increase the knowledge of how community actions and CREATE! Interventions affect the immediate environment and how these effects benefit the community. Part of this knowledge transfer involves training in mixed cropping, crop rotation and utilization of fallow periods.

Mixed cropping increases resilience to pests, disease and diversifies community vegetable intake and income sources. Additionally, mixed cropping with woody species, for example cashew trees confers the additional benefits to soil structure, water retention and crop yield. Benefits which reduce environmental degradation through economic development and increase WUE.

Crop rotation is used throughout sites to maintain nutrient cycles. Plants with differing requirements, or legumes crops which affix nitrogen to the soil are rotated, when combined

(a) (b)

Figure 5.4: Mixed cropping examples in Walo (a) and Fass Kane (b)

with organic fertilizers this practice eliminates the need for inorganic fertilizer inputs which represent a costly, potentially damaging input to conventional agriculture in the region. Additional benefits from crop rotation include the mitigation of persistent pests or suppression of weeds and the increase of soil quality through the cycling of shallow and deep rooted plants.

Edible species to be planted in community gardens include; African eggplant, tomato, green pepper, sweet potato, beets, onions, carrots, chili peppers, okra, hibiscus, cashew, papaya, banana, Jujube, various varieties of mint and mainga. The selection of specific species is carried out before planting based on a number of factors such as; expected climate, previous crop and community requirements.

On sites large enough to justify the loss of productivity (those above 1Ha) fallow periods are used in tandem with crop rotation and mixed cropping to ensure the nutrient cycle is preserved. During these fallow periods.

In order to simplify the implementation of these methodologies, gardens are split into sections, The community of Darou Diaji for example is split into three distinct sections, each separated by lines of cashew trees. These sections make working groups easier to organize as well as facilitating the easier managing of crop rotation cycles and fallowing specific strips.

Organic composting: Even though soil quality is increased by the practices mentioned above, the crops still need a constant input of nutrients to fully grow. Commercial fertilizers would mean an economic constraint, therefore, CREATE teaches the beneficiaries to create organic compost through plant residues, animal dung (mainly coming from the poultry sheds) and water. Piles of organic fertilizer are scattered through the garden, and are watered regularly for the microorganisms within to start the decomposition and release the nutrients better. Then, these piles are used to fertilize the plants.

Transplanting: In order to increase the survival rate of plant seedlings, these are cultivated in separate nurseries. The nurseries are usually better protected against wind erosion and pests, usually by providing small walls or net cover (figure 5.5). It also allows for fallow soil to restore for when the seedlings are changed. It also allows for a good redistribution of crops when needed.

Minimum Soil Disturbance *To avoid, insofar as possible, mechanical soil disturbance for the development of agricultural activity.* In conventional agriculture, minimum soil disturbance (MSD) is carried out through eliminating tillage. However on CREATE sites,

Figure 5.5: Seedling nurseries getting ready to be transplanted in Fass Koffe

MSD is achieved through three methods. Initially, plants are grown to seedlings in nurseries they are then transplanted into Zai. Zai planting is a method in which small 'pockets are dug into the soil and filled with compost. Zai planting conserves water and the addition of compost increases the water storage capacity of the zai. The soil around the zai is not disturbed, this has the effect of lowering water loss through evaporation (figure 5.6).

Figure 5.6: An example of Zai planting

The use of Zai planting therefore increases WUE on CREATE sites. The only crops not grown in zai on site are those for which this method is detrimental to growth such as lettuce and mint. All planting beds regardless of planting method are arranged in strips. Each strip is bridged by a channel of undisturbed earth. These channels act as walkways, preventing the compression of planted soil, increasing water infiltration and reducing surface run-off. These undisturbed channels also reduce evaporation losses of the site as a whole.

Income generation

The main goal of the community gardens is beneficiary subsistence, however, surplus produce is sold either to the larger attached community or at local markets, providing a stable income stream throughout the year. Poultry sheds erected on the majority of sites provide significantly increased access to chicken. Chickens produced take 40 days to mature. Similarly to the community garden the primary use for chicken is to meet the needs of beneficiaries who work the site. Additional supplies are then sold to the community at large or at local market, diversifying the communities income generation methods.

The income generation process is supported by the VSLA (Voluntary services and lending association) program called AVEC!. It is self managed by the beneficiaries themselves, and it is adapted to a simple way of keeping track with the money, as most of the villagers do not know how to read or calculate.

Each week, the members could choose to save a certain amount of money, with a maximum determined, on a box called the ”charity box”. For these, if one of the families are struggling economically during some period, they can ask for a loan from the so called charity box. The interest of this loan is then paid back to the same box, and once a year, the contents of it are divided equally through the participants. This makes a very reliable and honest lending system, as it allows the interests to benefit the whole community, and provides a safety net for people within it that has more economic struggle.

With the loaning system and the direct income, poverty is reduced, and therefore so is land degradation. Allowing people to use alternative choices to degrading activities, as now they have the means to invest on them. Income generation is closely related to the other categories, it provides a supporting blanket in which the activities can be further promoted and carried out within the population, gives the option for the repair of technologies (such as the water pump, if needed), opens more options for electrification in housing (therefore also increasing climate resilience) and gives the possibility to expand the agricultural practices that are carried out to maximize even more the benefits through creating a positive feedback loop.

5.2 Principles of Appropriateness

In this section, the principles of appropriateness will be connected to the practices implemented by CREATE! using the data gathered through interviews with technicians, community members and our own observations. Below the primary characteristic of AT are outlined, within each category the ways in which existing CREATE practices embody these characteristics. Furthermore, with the data obtained, more factors which are not described as characteristics of appropriate technology will be identified and described.

The definition of appropriate technology is flexible. The criteria shown below have been gathered from Murphy et al 2009, *Appropriate technology - A comprehensive approach for water and sanitation in the developing world.* They represent a more socially orientated definition of AT and cover technical, social and cultural factors. Additionally these criteria were selected due to the high reliance on capacity building that they encourage.

Decentralized

Making technologies decentralized is an important characteristic for appropriateness. Reducing the dependency on external sources in a poor rural context increases the reliability and long term prospects of interventions. It is especially important for isolated communities, where external resources are limited.

- Agriculture: The conservation agriculture practices carried out by CREATE! have the aim of using no external input. The only external resource needed are the seeds and tools, both of which can be locally sourced. The use of common autochthonous species simplifies this criteria. Also, this need is reduced if the seeds are stored once the first cultivation is done. There is no need for complex machinery or tools that could not be locally fabricated, such as water pots or pickaxes.
- ICS: The ICS production method is taught to the villagers at the beginning of the implementation, and it is the only external source needed. The production is very simple, with measurements by hand which are easy to learn and do not require measurement tools. Only local and common materials are used, to simplify its design, and repair techniques are also shown for the future damages that use can have. This characteristics makes it dissemination simple but very effective, and once the locals are taught how to build it, they can easily do so whenever the need is a need to.
- AVEC: This program is entirely autonomous, run by women from the community. Several people of the village are designated specific tasks for a month, like keeping the key, the box with the money or the accounting notes. Every week there is a meeting for the VSLA, in which the members are the only ones participating. The only outside source required is people form outside the community to buy the products which the garden and poultry produce. However, interview data suggestes that this is rarely difficult produce are even be sold within the village, which makes transactions much easier.
- Reforestation: Similar to agriculture, these are methods which are entirely run by the community without the need of external sources. Every year trees are planted by the locals, with the only materials being the seedlings and bags. These are easily to come by and the program has no need for outside sources to be used in order to complete it.

Other practices that are done on the communities require external sources, and are not entirely decentralized. Nonetheless, these resources are easy to come by in rural villages, such as supply for poultry, and therefore reduce the negative effect of not being done without external sources.

Meeting Basic Needs

In developing countries, meeting the basic needs of locals, such as water, sanitation, food or energy, is the important part that organizations should take into account. Inappropriate technology would provide interventions for satisfying wants, instead of first tackling the needs. A participatory approach to technology or project design can ensure basic needs are met.

- Agriculture: Self sustenance of food is crucial for people in rural Senegal, and the agricultural practices provide the villagers with several vegetables and fruits that would not be available otherwise. This fact was emphatically remarked by one of the interviewees, as food resources are not abundant to them. Specially it was mentioned that the provision of fruit such as mangos or bananas are important. Fruit is difficult to come by, as they require a lot of water to grow and the conditions of the Senegalese context are not the ideal for growing. Therefore, fruit price on the market is usually prohibitively high. Fruit provides an essential source of nutrients, especially in children. This fact is acknowledged by the beneficiaries, and it gives a good nutritional value which increases the health of those participating in the project and their families.
- Poultry: It also provides with great nutritional value. A constant supply of a meat is valuable for the rural inhabitants in developing countries such as Senegal, and substantially increases the health of those who benefit from it. Moreover, the monetary income from selling the poultry not eaten covers the basic need for economic revenue.
- AVEC: It provides villagers with a safety net, so when a family struggles economically, they can borrow from charity destined savings from all comunity. This ensures a basic economic stability for all inhabitants, which is needed in such poor regions. This safety can provide people with more food, medicines and other basic necessities that may not be covered with the other practices that CREATE! is involved
- Water pumps: Water provision is an essential need for villagers. A constant supply of water in a country with an unpredictable and arid climate ensures hydration for people and the ability to cultivate throughout the year. Therefore, ensuring the provision of other needs. Some of the interviewees also acknowledged the importance of water, as water has the most direct and visible effect to the land and lifestyle of the villagers, who suddenly are provided with safe water to drink and cultivate. sufficient water supplies also ensures the provision of additional basic needs such as food security, hygiene and health.
- ICS: Improved cookstoves reduce health issues related to smoke inhalation, derived from traditional methods of cooking which are based on an open fire inside the houses. Moreover, it reduces fire risk, as the fire is much more controlled (figure 5.7), therefore providing people with safety measures against these hazards, which are very common. Additionally, it reduces by half the amount of time needed for cooking, which lets the women dedicate their hours into other activities, which if it is agricultural for example, can provide with more basic needs.
- Reforestation: The provision of more fuel wood is another basic need that is covered with the action plan. The fact that these are also planted by the beneficiaries adds consciousness within the community, which prevents the over use, increasing the local availability of wood. If the trees are planted close to the villages, they also provide basic services, such as reduced time to collect wood and shelter form the sun.

Almost all of the communities acknowledge the importance of having all activities in action, as they are interlinked between each other. The fact that this has been inculcated into locals knowledge is important, as when they are not supervised anymore on the future, they can continue with the same activities and being provided with the basic needs.

Figure 5.7: Community members preparing coffee on a ICS, despite the poor state of repair of this ICS, the flames are easily contained, reducing the risk of immolation

Contextually Effective

The technologies have to be design or adapted to provide the associate benefits to the environment in which they are introduced to, avoiding that technologies designed outside of the context in which they are applied in may not be effective on the area.

- Agriculture: The agricultural techniques taught to the beneficiaries are adapted to the context by the technicians, who are educated to a degree level in various agricultural fields, and can put expert knowledge into the local adaptation of the practices. This ensures that they will be adapted not only to the national context, but also to the regional one, as activities can vary between villages in order to maximize the benefits provided. Moreover, the fact that these are derived from CA context makes them more efficient that conventional practices utilized. One of the interviewees remarked the fact, stating that before, crops were only planted during the rainy season, but now they can be cultivated all year long. If they were to grow a single hectare of millet or peanut during the rainy season, it would have the same benefits of half an hectare of the garden. This proves that the benefits are also perceived by the locals.
- Solar Pumps: PV technologies are specially effective on the Senegalese context, as Senegal has one of the highest rate of solar irradiance on earth, which makes the PV function more effectively throughout the year than it would on other regions. Moreover, the pumps used are designed with a tubular screw system inside, which

makes them more effective against sandy soils, like the Senegalese, and less likely to be obstructed by it, therefore reducing maintenance and repair costs because its increased durability in the context.

- ICS: These were designed taking into account the context in which they were going to be developed. The initial design was based on other countries approach to improved cook stoves, but then later it was modified so it would fit more the Senegalese context and would increase its efficiency.

Flexibility

The adaptation of practices in a local context is important when introducing a technology, as if it is of a rigid nature, and no modifications can be done, then the suitability for locality will be reduced and the chances of failure in implementation would be increased.

- Agriculture: A determining factor is the tools used for carrying these activities. During the field research it could be seen how these tools differed between communities depending on the materials that they had available at the moment. For example, watering cans were modified buckets in some of the sites, but in others they were tin based and built specifically for the purpose, as they had access and economic resources to buy them. Therefore, the materials are very flexible to its application or to the available materials.
- ICS: The materials used for their construction are very basic, but also can be varied depending on the needs or conditions of the locals. The material that can be the most troublesome would be the millet husks, as there may be the possibility of some communities that they do not grow millet. But, as an alternative, other crop residues can be used for the same purpose, like for example rice husks, which are very available on the region, as rice is one of the main food consumed in the region.
- AVEC: It is a flexible method, as community member have the decision power to regulate how much money they want to put into the saving scheme. If the financial situation is not ideal, they can even decide not to put any money. This allows a great amount of flexibility when dealing with monetary issues.

Environmental Sustainability

Innovations and techniques applied to the areas should not be harmful to the environment, as a solution that pretends to be long-lasting should not harm the development of future generations.

- Agriculture: Conservation agriculture's principles are to increase production but at the same time preserving the environment. Minimum soil disturbance, for instance, preserves the soil as much as possible, because if damaging the soil, the productivity is reduced. The main idea of the practices used by CREATE are to increase productivity, but at the same time increasing environmental resilience.
- Reforestation: The tree planting campaign carried out is responsible for planting a thousand trees in each site every year. The provision of services related to trees are drastically increased with this campaign, for example carbon sequestration, improved soil quality, biodiversity increase among others. These services mean an increase in

resilience in a social, economic and environmental level. The social level relies on the creation of fertile soil for food harvesting and then selling, making it socially and economically beneficial. The environmental level relies on increasing the overall resilience of the ecosystems in which they are being planted.

- Solar pumps: This technology relies on renewable energy. Solar PV eliminate the need for using fossil fuels, which degrade the environment, and provides a method of using the clean resource of sunlight.
- ICS: Improved cookstoves are a sustainable method due to reducing the wood needed for cooking. As stated before, it can reduce by 50% to 70% the wood used for cooking. Although it still uses a limited natural resource, combined with the tree planting campaign it ensures that the trees have time to regrow before being cut again, therefore providing renewable capacities to the resource. Moreover, the local materials used for its construction do not suppose a harmful effect to the environment.

Community sustainability

Community sustainability refers to the ability of an intervention to integrate into communities, thus securing long term use and provision of benefits. A large part of ensuring community sustainability comes from matching the complexity of interventions to local absorptive capacities to ensure the ability of the community to understand, operate, maintain and ideally replicate interventions.

- **Capacity Building** - The CREATE technology and technique transfer method relies heavily on capacity building to increase the absorptive capacity. The focus of this capacity building is threefold. Firstly understanding of the operation and enaction of solar pumping technology, improved cook stove manufacture, use, maintenance and repair, sustainable agricultural activities. Secondly an understanding of the impacts and importance of the above mentioned technologies and thirdly, building and understanding of the underlying ecological principles that result in those impacts. This is shown by community members responses regarding soil quality in which they mention 'correction' of previously degraded land now used for community gardens. Capacity building is carried out over a 5 year period during which CREATE technicians teach towards supervisory roles. The length of this training and the high level of community participation in making the technologies and techniques work aims to create resilient self sustaining communities. Community members see the fruits of their labors and as such the value of the training. 67% of communities visited stated that the difficulty of training was reduced due to the efforts of the technicians showing that their innate contextual and cultural knowledge simplifies knowledge transfer.
- **Agriculture** - Agricultural interventions carried out by CREATE community members are aimed at maximizing plant water use efficiency and protecting the nutrient balance through Methods such as zai planting and crop rotation, which results in a completely self sufficient, small scale, organic vegetable farm. In the rural Senegalese communities CREATE operates in, illiteracy rates are high and experience in vegetable growth is limited. These techniques are predominantly simple, with interviewed community members stating that there was little difficulty in the training, any difficulty stemmed instead from behavioural change due to lack of experience,

suggesting that the complexity is well suited to the absorptive capacity of the visited communities. When asked about their future plans for the existing site, 89% of communities (including graduate communities) stated that their plans included expansion of their existing site and 100% stated they would continue to use the create introduced techniques. Additionally, many community members stated that the knowledge they had gained is actively being spread to younger generations showing that the sustainable methods of agriculture are being successfully integrated into these communities.

- **ICS** - High rates of ICS saturation are required in order to move forward with the process. This practice ensures that the majority of the community are capable of replicating the initial technology, increasing community sustainability. The simpleness of the method eliminated the need for outside input and increases the ease of knowledge dissemination. During Field visits, we were not able to visit homes to confirm the continued use of ICS, however community members and technicians continually mentioned their use. Additionally each site contains at least one ICS which is regularly used to prepare coffee.
- **Poultry** - Whilst no community members specifically stated that they intended to continue poultry rearing on site, the majority of sites (including graduate sites) do continue to carry out the practice. Poultry's positive effects on the community prosperity were mentioned by several community members during site visits.
- **Reforestation** - Reforestation is considered a prime CREATE directive. The combination of additional knowledge, tangible benefits and the reduced fuel wood need resulting from ICS dissemination result in reforestation practices becoming sustainable within CREATE communities. Tree planting drives are carried out once a year by all participating communities, this practice was observed during field visits in both graduate and non graduate communities.
- **AVEC** - Once running, AVEC reduces the reliance on outside financial inputs in the case of disaster through the generation of a community 'solidarity fund' to which each community member pays 15CFA (0.17DKK) a week. This fund is used to support households in financial difficulty or to support community projects such as practice expansion or technology repair, making it very appropriate in the community sustainability aspect.

Affordable

Financial constraints are often apparent in poor rural SSA contexts. Interventions must be affordable for the majority of the population, or made affordable through supportive activities, in order to effectively disseminate. Failure to address financial constraints limits the appropriateness and heightens the likelihood of project failure.

- **Capacity Building** - Capacity building is an inexpensive tool use to impart the knowledge previously mentioned. All rural community sites of 1Ha or larger contain a small training centre in which to carry out these activities, as no other facility is available. This represents the only cost to communities. As with all CREATE interventions, this construction is subsidized by CREATE and paid off over a period of 5 years through the profits generated by produce sale.

- **Agriculture** - Agricultural practices on CREATE sites are labour rather than capital intensive. Several considerations are made to make cultivation possible on the lowest possible budget whilst maintaining maximum benefits. Whilst seeds are purchased from local markets, plant species are selected for their climatic resilience depending on season to minimize loss. Easily reparable and replaceable hand tools are used in all practices. Initially these tools are provided by CREATE, subsidized in the same manner as other costs and paid back over the entire training period using a percentage of agricultural profits. In several cases at graduated sites (5-7 years after initiation) modified or improvised tools are used following breakage. These include flattened steel re-bar over hand held hoes and buckets over watering cans. These tools are effective and almost eliminate the cost of replacement.
- **ICS** - The affordability of ICS has been cited as a major factor affecting dissemination and use of the technology (Urmee og Gyamfi, 2014). All materials and tools used are freely available within existing community limits. Clay forms in depressions following the rainy season and is already utilized to make bricks and ceramics. Sandy soil is suitable and is everywhere, millet husks are readily available as a bi-product of traditional agricultural activities and the three stone foundation and machete are existing tools used daily in rural Senegalese villages.
- **AVEC** - AVEC requires very few materials (notebooks, ink and a safe storage box) to function. Additionally AVEC eliminates the need for outside loans, and all interest on local loans are paid into a central pot which is divided equally at the end of the year. The low material requirement and the avoidance of external interest payments makes AVEC incredibly affordable and cost effective means of increasing financial security in fragile rural Senegalese communities. AVEC also increases the ability of these communities to pay for the potential expansion or required maintenance of existing activities and technologies whilst increasing their capacity to integrate new development strategies or technologies in the future.
- **Solar Pump** - The affordability of this technology would ordinarily act as a substantial constraint, potentially limiting the implementation. CREATE subsidizes this technology in order to overcome this constraint. Initially, community input is set to an affordable level, the remainder is loaned to the community with the understanding that a portion of the profits made possible by irrigation and produce sale is used to make repayments. Repayment levels are balanced with profits, with community affordability in mind. This is done to limit the growth of the 'donor' mentality which CREATE feels is detrimental to the development of self sustaining communities.

Local Participation, materials and skills

Encouraging the input of actors affected by or with the ability to affect the implementation of a technology or intervention, including key local decision makers when possible, increases the likelihood that the action will be contextually effective and meet basic needs whilst also boosting community integration and the likelihood of long term use. The use of local skills and materials reduces the cost and increases the community sustainability of interventions.

- **Capacity Building** - The CREATE training is mandatory for all those who wish to reap the benefits of the community garden. This enforced community participation results in the development of skills throughout the entire community. CREATE technicians are all Senegalese nationals, this simplifies training due to contextual knowledge however it also results in a far more participatory approach to knowledge transfer in which existing indigenous knowledge is combined with scientific knowledge. Five years of training begin in a technician led manner, however as the skills and knowledge of community members grow, technicians take on a supervisory role, allowing community members to carry out tasks and disseminate knowledge. 50% of communities members asked indicated either the willingness and ability or the existing practice of knowledge sharing with surrounding communities, showing that community engagement and participation can be effectively used to increase knowledge, awareness and potentially dissemination of sustainable agriculture, energy and water saving techniques and technologies. Following 'graduation' technicians still visit communities to engage in community led problem solving, acting as occasional consulatants when required.

- **Agriculture** - Agricultural methods introduced rely solely on community input to function, local skills are generated and utilized to increase food security and income generation. Additionally all materials used are local and when possible generated on site. This keeps costs and required outside inputs to a minimum whilst encouraging the use of local skills and materials to solve problems.
- ICS - Improved cook stoves as previously mentioned utilize exclusively local materials in their construction and local skills in their dissemination. Additionally the construction of community cook stoves builds the required skills to continually maintain them without additional inputs.

Cultural/Social Integration

Cultural aspects which may limit the applicability of an intervention in a rural SSA context are not always apparent. They may range from gender issues to grazing or land rights. integration of these aspects reduces the likelihood of rejection and can be attempted through community integration and a participatory approach to innovation. A culturally appropriate technology will fit within and build upon existing cultural elements. If not taken into account, large projects may fail to integrate or in the worst cases destroy indigenous ways of life.

- ICS - ICS training as with most CREATE interventions are predominantly aimed at the female population. Women are largely responsible for the gathering fire wood and cooking meals. As a consequence they are also disproportionately affected by the negative impacts of the traditional method of cooking over three stone fires, predominantly loss of health and time. By targeting those most able to benefit from the implementation of ICS, CREATE increases the chances of a high level of ICS saturation. Additionally, the implemented ICS design mimics the traditional method of cooking over three stone fires. These three stones are used as the foundation of constructed ICS, this understanding of the importance of cooking culture ensures that the ICS is easy to integrate into community live by minimizing the required behavioural changes.
- **Capacity building** - As previously mentioned the CREATE technicians are all Senegalese nationals, giving them a deep knowledge and understanding of local culture, social norms and requirements. This allows for the integration of scientific

knowledge with indigenous knowledge and methods increasing the absorptive capacity and eliminating the potential for cultural clashes resulting in project failure. Capacity building is also largely aimed at the female population. In Senegal and much of rural SSA it is common for the majority of the young male population to migrate to urban centres in a search of lucrative work. Interviewed female community members all stated that prior to CREATE intervention the majority of their day was taken up by gathering fuel, water cooking or caring for the elderly. No income generating activities were performed. The Implementation of ICS reduced the time required for these activities allowing women to take part in the capacity building exercises, gaining knowledge and acting for the benefit of their families and entire communities.

- **Agriculture** - Despite traditional methods of agriculture, there seems to be little to no existing cultural barrier to the implementation of sustainable, vegetable based agriculture in rural communities. The land used for these community gardens is freely donated, in most cases by either the village chief or a farmer. This donation model shows that there are no cultural barriers to women taking on additional income generating activities and responsibilities. Additionally as the land then becomes the property of the community and all actions are carried out by the community, there is no chance that activities performed there will have a detrimental effect on the local culture or way of life.
- **AVEC** - Once per year the proceeds of local loans provided through the AVEC system are shared out between the participating community members. This occurs two weeks before Senegal's biggest traditional holiday known as Tabaski. The provision of these additional funds at this time has seemingly had a very positive effect on the holiday season. This encourages the maintenance of the practices.

Appropriate Transfer Methods

Whilst the appropriateness of an intervention is important, equally so is the method with which it is introduced to communities. Appropriate transfer methods can ensure contextual effectiveness through participatory approaches and may involve increasing the base absorptive capacity or limiting the complexity of imported technologies or techniques to allow for more effective integration.

- **ICS** - Training involves gathering all potential community garden workers (as well as many curious on lookers). The training approach is highly participatory. The method for correctly measuring the foundation is shown by the practicing technician who then asks questions, then disassembles the foundation and asks a participant to rebuild it. This method uses different numbers finger and hand widths dependant on the size of the pot to be used. As the training session progresses methodologies for preparing and mixing materials, testing the material texture and ICS construction are transferred in the same participatory manner. This is then followed by a question and answer session where both the technicians and participants ask questions.
- **Agriculture** - Similarly to ICS construction training, CREATE agriculture training takes a participatory approach to teaching. Techniques are not difficult to understand, however some of the underlying principles surrounding the effect of tree density, reason for crop rotation of zai planting are more difficult to grasp. However once again the cultural and contextual knowledge of the local technicians helps to reduce

difficultly. The length of the CREATE program also increases the 'appropriateness' of the approach. Technicians believe that the length of training is the key to their success in an environment where existing international aide has made little impact. The technicians transfer to a supervisory role throughout the five years aides the building of community competence, self sufficiency and a capacity to innovate.

- **Solar Pumps** - Solar pumping technology has proved to be the most difficult aspect of the CREATE program to integrate into community competences. Training focuses on understanding the principles of how the system works. Whilst the system is streamlined to simplify operation. Pumps used are Grundfos flexible screw pumps, they contain relatively few moving parts which aides durability and limits the need for maintenance. Additionally they are able to utilize a variable range of energy inputs with higher inputs resulting in higher pump RPM. This simplification allows for a streamlined pumping system which is in turn easy to operate. This reduction in complexity aids in the integration of the technology.

5.2.1 Additional Criteria

Whilst attributing characteristics of AT to the above CREATE practices it became apparent that some factors linked to the success of CREATE in central Senegal could not be directly linked to the aforementioned criteria. Presented below are additional 'success criteria' identified either by CREATE technicians, leadership or by community members. AT should be human focused. However, little thought is given to the existing state of communities selected for interventions. During field work. CREATE emphasized the importance of a strongly bonded and motivated community with an effective decision making process along with the motivation of community members to work for their own benefit in determining the success of intervention. This knowledge comes from their experience of project failure in central Senegal and is explored below.

Community Cohesion

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- **Strongly bonded community** - When asked, all community members at active CREATE sites stated that whilst the on site agricultural activities bring them into contact each day their sense of community pre-dates CREATE intervention. CREATE staff highlighted this as an important factor in determining communities in which the potential of their interventions can be maximized. Communities can be divided along many lines, interfering directly can be difficult and is often not helpful. However, considering the significance of the changes to daily life this factor plays an important role, particularly in the case of labour intensive practices.

- **Strong leadership** - Whilst a bonded community is determinant for success, this bonding is usually related to its leadership. According to CREATE, the leadership capabilities play an equal role to the development of new activities. A quick decision maker, with a strong commitment to the cause may influence the beneficiaries in a positive way. Moreover, a strong head of the village usually leads to a bonded community because of his or hers actions. If the leader is motivated to commit to the new changes brought by CREATE, he or she will influence people on following the lead, and will prevent scattered who do not seek the same goal. An example was provided during one of the interviews, in which members from community stole the PV panels to sell them, and expected CREATE to reimburse the costs. But, according to the interviewee, this kind of situations are avoided when a strong leader is in play, as he would be able to identify the guilty and recover the panels. Even more, this situation may have not arisen with a strong leader, as preventing criminal actions or bad behaviour from the village is one of the main qualities of a capable chief.

Community Motivation

Whilst 'labour intensive' is a divisive criteria for appropriate technology generally speaking as labour intensity (particularly for agricultural interventions) rise costs (not including labour costs) are reduced. CREATE agricultural practices provide a potential to alleviate food security and poverty issues but require a dedicated group of community workers to be effective. Additionally, CREATE staff have expressed the view that recent aid activities in Senegal and SSA in general have created a paradigm of dependency in which rural communities rely on and expect donations from incoming NGOs or intervention programs. This paradigm is seen to be damaging to the formation of self sufficient communities and sustainable development.

- **ICS training** - The first stage of intervention, community ICS training, serves as a method of assessing the motivation of communities prior to pump installation. High rates of ICS dissemination in the weeks following training is an indicator of community motivation. Communities seen to be highly motivated are given high priority for full intervention.
- **Subsidies/loans over donation** - CREATE interventions in Senegal are partially funded by the communities which host them. The remaining required capital is loaned to communities with the understanding that a portion of agricultural profits will be used to pay back the remaining debt. This practices is carried out; to ensure dedication to project success, to provide a feeling of community ownership over technologies such as solar pumps, to break any existing dependence and encourage self sufficiency. CREATE has found that rates of solar panel damage or theft have reduced significantly since the implementation of this practice.

5.2.2 Assessment of Appropriateness

In the following section we will explore the ability of the reviewed technologies and interventions to conform to the characteristics outlines above. Their appropriateness, chance of achieving success and factor or adaptations which may increase or limit their capacity for successful integration. This is done in order to determine if these interventions are suitable for integration into Senegalese communities such as those sponsored by CREATE. The purpose of this is to provide an example of how aid interventions can be scrutinized and adapted in early phases of project planning to maximize assimilation and positive impacts whilst limiting the potential for negative impacts and project failure.

Conservation Agriculture

The appropriateness of CA as a method has been seen during the data gathering and is outlined in the previous section. Nonetheless, the fact that worked into the CREATE action plan, does not mean that if implemented in other sites it would be appropriate. There are several factors to consider beforehand. Specially, these are determining when institutional support for conservation agricultural methods is limited, such as in Senegal.

The principles of CA must not be implemented literally as defined by FAO. These have to be adapted to the context beforehand. For instance, there was a lack of cover crops in some of the sites visited in Senegal, but other principles where implemented instead, like inter cropping or the use of manure made from plant residues to counteract this factor. This is mainly done because of the lack of tools for cover cropping and the insufficient land to produce a functioning system. This situation exemplifies that if there hadn't been an adaptation, the practice may have not been appropriate due to the lack of materials to undertake the task, but CREATE sustainably intensified the garden to compensate from these effects.

Moreover, the transfer method was also determining for the successful implementation. By taking into account the context in which the villagers were, a proper transference of knowledge should be designed. In cases such as seen in Senegal, in which villagers were uneducated and had no previous knowledge of full year cropping, a more inclusive method is needed, in which continuous teaching is undertaken by locals to locals. This may be one of the main causes for unsuccessful implementations on the past, as context has also to be applied on the transference mechanisms used.

Farmer Managed Natural Regeneration (FMNR)

In a rural Senegalese context reforestation encompasses many aspects of the AT ans success criteria mentioned above. FMNR forms small scale agroforestry systems by supporting and protecting the growth of the existing root stock and emerging woody vegetation, selectively pruning and pollarding shoots to encourage growth. Links have been made to the increase in soil quality, greater carbon sequestration, nitrogen affixation and water storage capacity, which in turn translates to higher agricultural yields and increased climate resilience(Haglund et al., 2011), some of this is connected to the increased availability of wild foods and fodder which are less susceptible to drought and make livestock more drought resilient. Thus FMNR is determined to provide basic needs for households. The supporting research highlighting these effects is based on case studies in SSA and Senegal suggests that it is effective in Senegalese drylands, where these impacts are needed. FMNR requires no additional inputs, the requirements are knowledge of the potential benefits. Tools and skills required are already available in most smallholder and rural household(Haglund et al., 2011) this, this eliminates additional costs and the need for outside inputs increasing the affordability and potential community resilience of FMNR as a form of reforestation. Moreover, continuing with slash and burn techniques can act as a barrier due to its damaging nature. Haglund et al (2011) determined that a primary factors affecting the integration of FMNR in rural Niger was the education level of the head of house. The methodologies used are simple and expand upon existing skills common with in agricultural communities. Therefore, implementation is possible with appropriate capacity building and local practitioners to help disseminate the practice.

P.Reticulartum Intercropping

The study shows that even with no additional fertilizer inputs Intercropping with *P. reticulartum* increased millet yields up to 100% throughout the course of the experiment, through increased SOC, carbon sequestration, the concentration of five macro nutrients and 2 micro nutrient improving soil quality shows environmental sustainability. Additionally the levels of above ground biomass increased while coppicing of shrubs provided additional materials for ground cover, construction, fuel or fodder showing that the intervention is contextually effective. Overall the benefits gained largely relate to long term soil quality and food security improvements which are basic needs across the Sahel. Given that *P. reticulartum* is a native, fast growing shrub, very little in the way of additional inputs is required for it's cultivation making it an affordable solution to combat low fertility soil. Tools and skills required are available locally, the outside input here is knowledge, assuming appropriate transfer mechanisms and capacity building are utilized there is little to prevent the practice effectively integrating into smallholder communities. However, the experiment takes place over 11 years, with significant rises in millet yield becoming apparent 5-7 years. These increases may be linked to an increase in climate resilience imparted by the intercropping. in cases of drought the additional nutrient availability reduces the likelihood of crop failure. Additionally the traditionally agricultural methods involve clearing smaller shrubs from farm land before the wet season. This may pose a barrier to implementation unless it can be overcome by capacity building efforts.

Improved cook stoves

The potential impacts of ICS implementation has been covered in section 5.2. As a singular technology the improved cook stoves designed and disseminated by CREATE directly encompass all of the AT considerations explored here. However, ICS come in many forms. Reviewing the literature reiterates that a lack of contextual effectiveness is a significant driver for project failure as lab designed ICS are not adequately adapted to the receiving environment or economic realities. They also highlight the importance and potential of involving capacity building activities with appropriate ICS designs to greatly improve the long term use and dissemination. ICS are intensely flexible, when appropriately designed, introduced and integrated into communities they have the potential to achieve incredibly high saturation levels. ICS are deemed to be highly appropriate technology for remote rural communities.

Solar Home Systems

Solar home systems have the potential to provide decentralized electrification to rural population in Senegal, which is important considering the difficulty of grid extension and the high cost of grid connections (150USD assuming extension has occurred). The primary uses of electricity in rural areas of SSA including Senegal are lighting, entertainment and phone charging(Grimm et al., 2017). These may be considered to be wants or desires rather than base needs. However, the demand for meeting these needs is high, represented by a high willingness of rural populations in Rwanda to spend a substantial amount of their income on SHS(Grimm et al., 2016). The social and resilience related benefits of lighting and increased access to communication technology are plain to see (capacity building through additional study and resilience through access to forecasts)(Peters og Sievert, 2016), they do not however constitute basic needs themselves, whilst the primary health benefits shown to be alleviated in south America and Asia through the replacement of kerosene lamps does not transfer to Senegal in which LED lamps have largely replaced kerosene (Peters og Sievert, 2016) . Whilst the cost and difficulty of acquiring the units and maintenance skills reduce the affordability, community sustainability and all but eliminate the input of local materials, local skills however, when available are immensely valuable and should be utilized.

Logically the potential for social and cultural integration for such an alien technology should be low. However, in many parts of SSA the demand for electrification far outstrips the ability to obtain it, showing that communities are willing to integrate these technologies(Grimm et al., 2016), they may act as a symbol of status or populations may simply value the potential of the technology. This increases the likelihood of long term effective use. However, without the use of appropriate capacity building and technology transfer techniques this may prove difficult. Simplifying systems to fit the absorptive capacity in cases where existing skills are limited, followed by capacity building to increase the benefits seen within communities should be used to maximize impact. Encouraging the formation of robust SHS markets within regions through capacity building activity is likely, as with other technologies, to improve integration, impact and affordability of these systems. This, however is likely to be difficult given the existing dearth of solar markets in the majority of SSA and the difficulties faced by the poorest stratum of the rural population in acquiring units(Bensch et al., 2017).

The appropriateness of SHS is deemed to be highly context dependent, specially between larger population centers with more opportunities. Basic needs must first be met to build absorptive capacity. It is possible in the shorter term to circumvent the barriers of SHS implementation through alternative, more affordable technologies which meet many of the same needs as SHS would, until the point where integration into SHS markets becomes viable either through subsidization or sufficient capacity building.

Biogas Generation

The primary benefit of the biogas technologies studied on the article is that they are designed to be very adaptable to the context in which they are built in. That benefits its potential application making it more appropriate. Moreover, the use of local material as feedstocks makes it even more adaptable. Nonetheless, the availability of these has to be assessed beforehand, as they may be currently used for other means, such as animal fodder, therefore even if it is very context adaptable, it is also context dependant.

Water availability is also another dependency that these technology has, as to be able to use it, there is a need for constant supply. The feedstocks must be mixed with water in order for the digestion to start. Nonetheless, as it has been seen in other technologies, the success of biogas depends with community commitment to be successful. Though, training needs to be provided, and may be more complicated than other technologies such as the improved cook stoves. The materials used for the construction of the domes are generally available, and the ones that are more difficult to find (like solar resistant bags) can be substituted with more available materials but with regular and more maintenance.

It is a sound and flexible technology, but the learning on how to use it and maintenance may be intricate for rural villagers to undertake flawlessly without proper training, and because of the domes characteristics, a malfunctioning can cause contamination of land.

Therefore, to make the technology appropriate, there is a need for ensuring the proper maintenance (either by providing it or teaching it to the locals), and water and feedstocks availability should be assessed beforehand. Taking this into account, there are other technologies to achieve similar results, such as ICS, which need a lot less of supporting investments, and therefore would be more appropriate for the Senegalese context.

Solar Pumps

Solar pumps posses mostly all of the appropriate characteristics that a technology should have, but it fails to be affordable. Even though PV prices are currently decreasing, it is still inaccessible for most of the rural population in developing countries, as their economical resources sometimes barely suffice to provide basic needs such as food. Even though, the payback period tends to be relatively short, the initial investment is still too great. Moreover, the PV panels and solar pumps may not be easy to acquire in some parts of the rural Africa. Therefore villagers have focused more with more affordable methods like water towers

Nonetheless, a solar water pump provides with a continuous supply of water throughout the year, which other methods can not provide. And it is an essential resource to have to develop other activities such as agriculture asa result the willingness to pay for this technology is high within the senegalese context studied. Financial help has to be given to the villagers for the initial investment. Also within the continuous training scheme, so they can take care and maintain the technology by themselves (turning and cleaning of PV panels for instance). But, the provision of such technology is still an issue, as the ones that want to provide with it have to search for the market in order to find it, as it is not common locally. Therefore, for the technology to be appropriate, financing has to be provided, along with market linkages and training for the maintenance. Instead of training, also continuous monitoring could be applied to the technology to check if it is working within the levels it should.

5.3 Action Net: A holistic Nexus Based Methodology

In the following section Actions deemed to be appropriate in either their base or modified state will be mapped out in an action net. The purpose of this action net is to highlight the potential for an interconnected web of actions to increase climate resilience and reduce the risk of desertification in the central region of Senegal. The action net will highlight how individual actions and interventions link to the goal of increased climate resilience and how the interconnected nature of these actions can be utilized to produce an enhanced effect. Following the creation of the action net these interconnections will be described and explored. The aim of action net is to highlight the importance of understanding and incorporating the wider ramifications and interactions of interventions in local level for development aid.

The development of an action net is an important step in the early stages of development project planning. Considering the tendency of national decision making processes in SSA to neglect rural development and the lack of contextualization, the inefficiency of existing development aid programs in the region and the aid dependency they often create. The ability of action nets which include the provision of appropriate capacity building activities and appropriate technology will be explored below. The aim of the action net is to enable the development of self sufficient, climate resilient and sustainable rural communities and form the foundation of sustainable development.

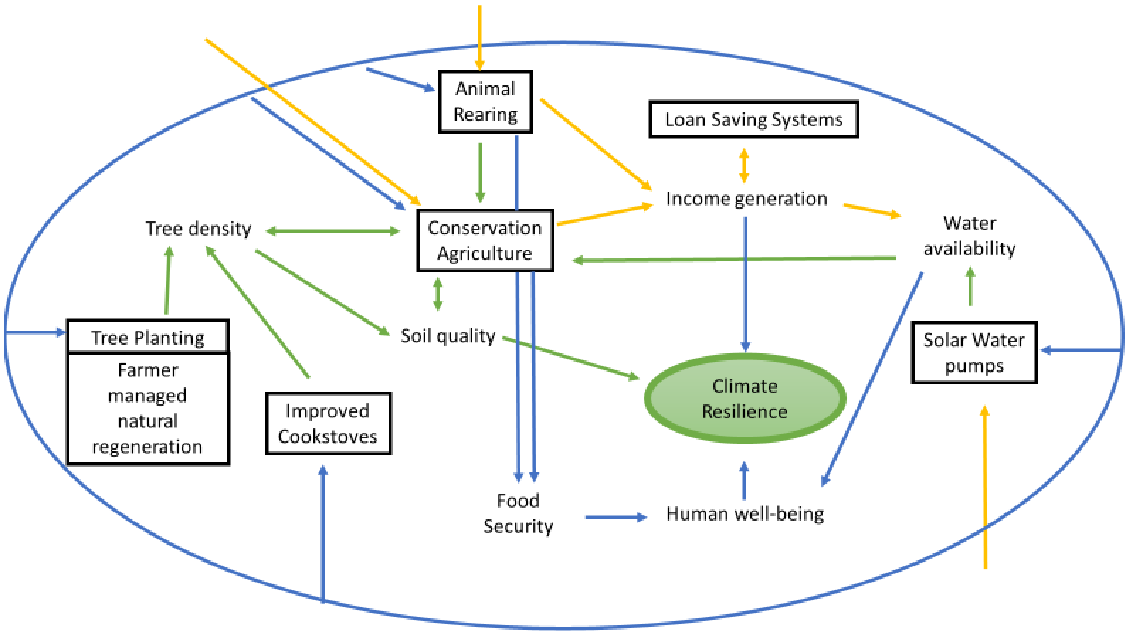

Figure 5.8: Suggested network of actions and their interrelations between each other. Green arrows represent ecological influences, yellow arrows represent the economical, and blue arrows social.

Interrelations between actions have different natures according to the effects they generate. In order to create a fully comprehensive action net, these were defined in social, environmental and economic effects. Knowledge of the nature of these is very important, as they cover different aspects of the action net, and as said on section (), a wicked problem such as climate resilience for desertification needs to have solutions developed which involve the various issues.

The blue circle represents capacity building activities. Capacity building is intrinsic to all selected interventions, as its effect on each of them provides with the basis for sustaining the new practice or technologies, and thus is essential for the proper function of the action net. It is not a supplementary characteristic, but the basis in which all of the practices should be built on.

External economical input is required for starting actions, as rural populations do not have the necessary resources to sustain them at the beginning. This is represented with the yellow arrows coming from outside the capacity building circle into the actions.

Interventions have been selected for inclusion within this action net based on their ability to adhere the considerations of appropriateness in their base, or a modified form(section 5.2.2) and are intended to be carried out at a community, rather than household level.

The introduction of ICS is included as the technology is seen as highly appropriate and capable of conferring significant time saving, health and environmental benefits to communities that introduce them. ICS introduction should be carried out as early as possible to support effective ecosystem regeneration through reforestation.

Tree planting and Farmer managed natural regeneration are both included as appropriate methods of reforestation. The only requirement for the implementation of FMNR in rural Senegal is the willingness of farmers to become practitioners, the primary barriers to this are educational, biophysical and geographical. With capacity building programs targeted at communities with adequate soil and root stock FMNR has the potential to increase soil quality, food security and woody biomass availability availability. Additional forage for cattle also provide additional incentives for the farmer-herder interactions which already provide organic fertilizer in the region. Tree planting programs require additional knowledge, outside inputs of seeds and planting bags along with willingness. Effective tree planting holds a potential for reforestation on a broader scale than FMNR whilst also enabling the provision of non agricultural benefits such as wind breaks and shade. The additional requirements can be overcome by integrating tree planting with sustainable agricultural overhaul as in CREATE communities, increased tree density improves local soil quality and reduces erosion which benefits agriculture. Linking these two practices through effective training is likely to increase adoption by enabling practitioners to reap tangible benefits to food security, material availability and income generation. The form of conservation agriculture proposed is inclusive and involves all three central practices, minimum soil disturbance, crop rotation and permanent soil cover. Additionally woody species intercropping and crop diversification are included within the sustainable agricultural package termed here as conservation agriculture.

Minimum soil disturbance requires the elimination of the currently used animal drawn ploughs, these are replaced with hand or animal drawn direct seeders. The seeder type can be adapted to labour availability and are simple enough that maintenance, repair and fabrication could be carried out using local materials and skills following capacity building activities.

Permanent soil cover would replace slash and burn as the primary method of weed suppression. Soil cover can be achieved with either available non crop biomass or GMCC if non crop biomass has alternative uses. Crop husk use requires no additional inputs assuming there is no competition for the resource. However, agricultural biomass is often used in Senegal to feed animals, Thus woody species intercropping is suggested for early implementation as in addition to soil remediation and increased millet growth this action is linked to increasing above ground biomass. Small amounts of biomass soil cover are linked to improved water retention, if non is available then the use of legumes GMCC may be planted as a summer cover crop. However this requires additional inputs of seeds and knowledge. The use of herbicides in the first crop cycles following implementation can reduce labour requirements however it increases the financial and training requirements, these can be broken down through capacity building, herbicide use is only advised until weed population can be organically reduced.

Mono cropping is common in Senegal. The introduction of diversified leguminous crops into rotations reduces nutrient depletion and diversifies income. This practices requires few additional inputs as leguminous crops such as cow-pea are viable in the region. However, market based farm operations would require supportive infrastructure to make this diversification a viable income generating tactic. In addition to diversification through, legume-cerael crop rotation it is suggested that farmers diversify into variable vegetable growth on small areas of land. With suitable irrigation, vegetables can be grown all year round, increasing food security, income and biomass provision. Due to the intensity of cropping it is advisable that strip cropping, diversification, crop rotation and composting are used to prevent nutrient depletion, additionally reforestation and woody species intercropping lowers wind speeds, local temperature and increases biomass provision, biomass from this area would be use to cover soil strips and compost. This form of CA has multiple requirements for implementation.

Many resource requirements for these agricultural interventions are met through ecological interactions between the practices. However, additional labour and tool requirements are likely to act as a financial barrier, these can be overcome through cash injections from supportive financial infrastructure or through financial support from aid providers. Outside cash injections should be focused on enabling the set up of self sustaining systems in which future financial demands are met through the increased income generated by sustainable intensification. The introduction of year round growth raises the issue of water availability, Agriculture in Senegal is almost entirely rain fed, year round vegetable growth requires year round irrigation.

Integration between herders and farmers is already prevalent in Senegal. Herds of cattle are used to fertilize fields prior to the rainy season. However, in order to support year round growth a more sustainable method of organic fertilization is necessary. The introduction of small scale animal rearing, for example chicken coops, Provides additional income which out weights the required inputs quickly. Additional availability of chicken also provides a more abundant protein source to meet dietary needs. Animal feces are used in tandem with above ground biomass to form compost which prevents nutrient depletion. As animal rearing is common in rural Senegalese households, this practice is easy to integrate, but may require initial financial stimulation and capacity building to increase productivity.

Solar water pumps are introduced to increase water availability, a core need and to enable year round vegetable growth and increasing the efficacy of tree planting programs, indirectly meeting several other basic needs. Solar water pumps encounter several, barriers to successful implementation and integration. These primarily relate to the cost and complexity of the system. System complexity reduces the ability to utilize local skills to operate, maintain and repair the system whilst the initial cost reduces the potential for initial implementation. However, the additional water provision makes it central to the goal of sustainable intensification and year round vegetable growth. As such these barriers may be circumvented through simultaneous deployment of solar pumps as part of the CA package introduced by aid organizations. Initial financial constraints can be met through cash injection, or with suitable financial support mechanisms, payback times should be as long as feasible. CREATE for example uses a 5 year repayment model in which income generated from agriculture is used to slowly pay off the pump in a manner that still supports community development. Systems installed would be shared through communities Systems can additionally be simplified through the use of appropriate pumps and control mechanisms, whilst capacity building should be used to increase the absorptive capacity of receiving communities.

The proposed action net is seen as a phase one intervention plan for implementation in remote rural communities. In SSA these communities are often made up of households of agricultural workers, often subsisting on less than 1.90USD per day, with high food insecurity and limited access to education. Thus the purpose of this action net is to outline the potential of aid organization develop self sustaining agro-economical communities. It relies on the utilization of initial investments and capacity building activities to increase the availability of and benefits gained from local labour and skills. The basic needs met include increasing food and water security,income generation and availability of woody biomass whilst reducing fuel wood requirements and rehabilitating local environments.

which are all central to increasing climate resilience.

Where possible, economical inputs should be made available through enabling the generation of or supporting existing supportive financial institutions, when this is not currently possible, external economical input should be fully reimbursed, or funneled into further development once practices and markets mature into profitability. Doing so reduces the mentality of reliance on external inputs perpetuated by the existing paradigm of aid provision and technology transfer.

The above action net is seen as a foundation for further community and economic development, as such the focus is on basic needs. Electrification technologies such as solar home systems are absent. Universal electrification is seen as highly desirable for rural communities and can increase the effect of capacity building, resilience and economic development. However electrification is not seen to meet the basic needs prioritized in this phase one action net. If demand is high, then some of the benefits (lighting and increased access to communication technology) of a SHS can be met in rural locations through the provision of solar lamps with built in phone chargers. Other than entertainment, which is desirable but not a basic need, these are the primary uses of SHS(Grimm et al., 2016)(Grimm et al., 2017). Solar lamps are able to meet these needs more affordably and could be used to the point that demand, income and absorptive capacities are able to support the dissemination of SHS.

This action net represents a significant deviation from existing practices in Senegal, where economic investment is higher and not recovered due to the lack of appropriateness of the technologies in which these are invested. Moreover, the income generation derived from the actions can allow room for loan saving systems, that provide with economical security, which affects positively the climate resilience.

Another aspect that differentiates this action net from the current standard is the continuous capacity building embedded into the actions. These are likely to increase the probability of intervention integration and long term community sustainability and resilience.

Chapter 6

Discussion

The key aspects of this report will be discussed this chapter. Firstly the methodologies used to determine the contextual appropriateness of the reviewed technologies will be explored, with the aim of exposing important factors within the appropriate assessment. The focus will be on how each technology was determined to meet the principles of appropriateness or not, and the importance of local inclusion and a holistic approach to intervention design and dissemination in the development process.

Following this the ability of this approach to scale up to a variety of aid providers is explored, with a focus on the how the appropriate technology concept can be utilized by aid providers in order to increase the potential for project success. Additionally, the importance of a bottom up, participatory approach to intervention design and dissemination is discussed

Finally, the potential benefits of effective scaling of this approach to the larger Sahelian region is explored, The effects considered here span multiple levels from household to global.

6.1 Assessment of Appropriateness

This section aims to provide a discussion on the considerations needed to develop the principles of appropriateness treated in this project, to provide rural communities with increased resilience through an assessment previous to the implementation of projects. It will deal with the adaptation of these concepts to other context specific areas and how this adaptation would be more successful .

6.1.1 Meeting of appropriate technology principles

During the assessment of appropriateness, the AT principles described in section 5.2 should be taken into account. However, these principles act as a guideline, because as explored in this project, the context determines the principles, and not the other way around. Thus, these principles provide the basis of the assessment and push decision makers to interact with the receiving context.

Some of these may be redundant to the case. For example, flexibility may not be a defining criteria if the technology or practice is designed to meet a very specific need or objective. As deriving the technology or practice to be more flexible could undermine it's ability to meet specific needs. This example shows that the concept of AT is malleable, and its flexibility should be used to be adapted in any context in which new practices or technologies should be implemented.

Nonetheless, this project serves as an example of an appropriate assessment. Taking into account the experiences and cases analyzed, new principles could be found in other contexts, and these could vary in importance depending on the situation. Thus, an assessment of the principles should be undertaken beforehand, as failure to meet crucial principles may limit the suitability of an intervention to the context, reducing the probability of long term success.

Determining the goal of intervention and utilizing that in combination with the application of contextual knowledge through the principles of AT can increase the likelihood that the applied interventions are appropriate, increasing the probability of community integration and long term use and as such, increasing the chance of achieving the intended goal.

The goal of the interventions proposed in this report are to increase the climate resilience of rural communities. Environmental degradation through human activity was deemed to be a significant driver for desertification, here seen as the ecological terminus of low climate resilience. Poverty, low food security and low levels of education were determined to be the most significant drivers of environmental degradation. As such, meeting basic food, water and income needs affordably and in the long term whilst providing viable alternatives to degrading current practices became the immediate goal. This frames the assessment of appropriateness by highlighting the AT principles linked to those goals. However, the remaining principles are still considered as a means to limit the potential of suggesting inappropriate interventions.

6.1.2 Local inclusion

Local inclusion can become a crucial aspect to adapt new technologies and practices(Ojo, 2015). A participatory approach to determining the primary needs of communities reduces the likelihood that interventions are targeted at secondary needs or wants, perceived as basic by northern aid providers(Dyer et al., 2014).

Working with local managers, decision makers and labour is likely to increase intervention integration(Di Maddaloni og Davis, 2017) due to their intrinsic understanding of contextual realities which may escape outside scrutiny. Moreover, inputs from local managers allow for the inclusion of indigenous knowledge which can be crucial to integration (Di Maddaloni og Davis, 2017). Due to the understanding of the context, local managers can also facilitate the learning and adaptation process.

Local inclusion is facilitated when locals already have a relationship of trust with the managers, and know their interests are shared. Cultural differences are difficult to overcome, specially in SSA countries, where the culture is radically different from those of the generally northern aid providers conducting development and climate resilience research. Thus, building ties between local and international aid providers prior to strategy formation and implementation of interventions can radically improve project outcomes(Di Maddaloni og Davis, 2017).

This factor has proved decisive in the implementation of CREATEs interventions in rural Senegal. According to the interviewees, a good technician with good methods is essential for building their capacity and understanding. This was outlined by 66% of the community members interviewed. Moreover, when asked factors which increased training efficacy and reduced difficulty, CREATE technicians stated that their local and contextual knowledge differentiated them from other NGOs previously engaged in the region. Additionally the use of simple techniques adapted to the absorptive capacity of communities through the integration of cultural knowledge enables all community members to participate, despite the lack of formal education prevalent in the communities.

6.1.3 Integrating Interconnectivity in Interventions

The interconnections between resources and ecological systems has been highlighted in section1.5. Practically, in an agricultural setting, this requires that actions and interventions must share and respect these same connections in order to ensure long term sustainability and avoid breakdown or environmental degradation(Nasiru Idris Medugu et al., 2011).

The action net developed acts as a visual representation of the interrelations between the practices aimed to provide water, food and energy sources. The importance of these considerations is highlighted in appropriate technology theory which states that AT is an environmentally and socially responsible approach to engineering(Keith Schneider, 2008). Additionally Field observations and interviews with technicians revealed that rather focusing on individual practices, CREATE's action was developed and taught to the communities as a holistic package as each intervention reinforced the potential or enabled another in addition to their singular benefits.

This interconectivity is translated to community members through training. The majority of the interviewees admitted when asked that there is no single most important practice, it is the whole that counts. By taking this consideration, the action net avoids committing the error of tackling the issue in a fractured manner, limiting the chance of introducing harmful or inappropriate interventions.

By using the action net approach prior to the implementation, these interconnections can be identified and therefore planning to maximize the benefits of the practices could be done, increasing the overall success in creating resilience.

6.2 Scaling up the approach

In the following section, the ability of the assessment of appropriateness to scale up and affect the strategy of NGOs and international or multilateral aid providers. This is done in order to highlight the potential of utilizing appropriate technology principles to increase climate resilience through the action of these aid providers and will culminate in and exploration of the possible benefits stemming from region wide resilience building based on this approach.

6.2.1 Appropriate Technology Based Strategies for Aid Providers

The ultimate goal of development aid is achieving environmental and community sustainability, but the processes used to may vary and may have different methodologies. For instance, some organizations adopt a more action reactive approach, in which they directly provide communities with resources to meet the basic needs, like food security, potable water or medical care, among others. The success of these are usually measured based on the input, output and short term benefits. This kind of approach is specially useful when disasters occur, as there is a need for a quick response. But, this method is also used to tackle ongoing issues, and may not be suitable for those.

Development aid has to be considered as an ongoing action which is constantly unfolding and adapting in order to be successful (Kopinak, 2013), and appropriate technology through a participatory approach can make a difference for development aid providers. In the past, some projects that just aimed to provide with meeting what they believed to be the basic needs ended up creating a dependence of the community towards continuous input, for instance cash inputs that are aimed to reduce poverty end up creating a negative effect towards the GDP, and therefore increasing infrastructure should be targeted instead of direct inputs (Ovaska, 2003). This does not achieve community resilience, as when left alone, the systems implemented are very likely to collapse and are not able to maintain them, which ultimately causes them to still be vulnerable to future impacts of the same nature (Lensink og White, 1999). This is usually a product of having tight deadlines or goals to meet, as they put pressure on the implementation and seek to achieve results as soon as possible.

Enabling continued application of interventions though empowerment, capacity building and technology transfer creates a self reliant community that can withstand future risks and bounce back to its original state, ensuring long-term benefits (Kopinak, 2013).

For this long-term perspective approach to succeed, an understanding of the root cause of the issues is necessary to formulate the proper actions to be taken. Which is achieved through community stakeholder engagement, local managers and encompassing social, environmental and economical characteristics of the region.

This is a longer term perspective applied in some cases by development aid, but when tackling ongoing and complex issues such as desertification, it is essential (Kopinak, 2013). The AT approach brings the goal of increasing resilience closer when used, because it is an integrated example for systematically using capacity building

6.2.2 Top-down vs bottom-up

When speaking of development aid, we refer to a slow process with long term goals of sustainable improving livelihoods and environments. To achieve this goal it is essential that basic needs are met, the root cause of problems is exposed and targeted and that interventions are able to be continually applied by the population of the receiving community. The consensus from reviewed literature, interview data and field observations is that these requirements are most easily met through a participatory, 'bottom-up' approach to intervention design and implementation.

AT principles state that appropriate interventions should meet basic needs. These needs are best determined through direct organization-community interaction (Murphy et al., 2009). Additionally a bottom up approach holds the potential to increase local participation, this holds the potential to increase understanding and the potential to utilize local skills within interventions increasing long term efficacy. Top down approaches to technology transfer can have detrimental effects on intervention efficacy. For example, in South Asia, in 1978 up to 70% of installed hand pumps were non functional, users were unaware and unable to repair or maintain them as they had not been involved in the strategic process and no capacity building had taken place. The top down approach to technology transfer undertaken here significantly undermined the goals of the project which ultimately failed to meet user needs(Wijik-sijbesma, 1985).

Bottom up approaches, focus on gaining and integrating contextual knowledge increase the likelihood and capacity building, increases the likelihood of communities taking ownership of technologies. Such action can be seen in CREATE sites, where communities take an increasing level or responsibility for the continuation of interventions over the 5 year program, following this period, graduate communities continue to utilize the technologies and skills passed on, they become fully integrated into their way of life.

In developed countries and large aid organizations, there is a tendency towards encouraging top down approaches to development aid. This approach is reinforced through several mechanisms. Targets for development aid often focus on a northern idea of development, represented by income, employment or ecological data as was seen with the millennium development goals or the UN sustainable development goals. When taking a top down approach to poverty alleviation or deforestation, there is a tendency to treat the symptoms through technology or financial transfer without gaining a contextual understanding of the root cause of the problem (Kopinak, 2013). Additionally, top down transfers carried out in this way increase the opportunity for corruption to reduce the community impact of aid (F, 2016). The complexity of problems such as poverty or deforestation belies simple solutions, understanding of the contextual realities and the implementation of appropriate interventions is thus essential to ensure long term sustainable development and poverty alleviation at a community level.

Should broad targets such as the SDGs be met utilizing a top down approach, without the implementation of appropriate interventions which target the root causes then achievements are likely to be short term and in the long term, potentially damaging.

6.2.3 Adaptability to other SSA countries

The appropriate technology concept is centred around contextual adaptation. Appropriate actions differ between villages, regions and countries. Many factors can alter the recieving context in potentially subtle ways, such as cultural differences, differing ecological conditions, or even demographic factors.

With the objective to integrate all of these changes into the contextualization, the nexus approach could serve as a starting point. As identifying the issues and connectivity between the land, water and energy factors will help organizations to better define this context. With help from local managers, the consideration of appropriate technology principles and the nexus approach, a good action plan can be implemented regardless of the difference between our case study in Senegal and the country in which the action plan wants to be implemented.

6.3 The effect of resilience building and sustainable development in SSA

In this section, the potential implications of increasing climate resistance and enabling inclusive and sustainable development in the Sahel will be explored and described. It is easy to imagine that the existing socio-economic, and ecological state of this region is immutable. However, this is not the case. Through effective capacity building and appropriate interventions, we believe that basic needs can be met, and can form the foundation of inclusive sustainable development in the African Sahel.

Africa and it's inhabitants are highly vulnerable to the effects of climate change. 61% of the population of SSA is rural, 57% work in agriculture and almost all are either directly or indirectly reliant on the health of their ecosystem for survival.

Inappropriate actions in rural areas which result in deforestation and soil erosion reduce the absorptive capacity of the environment. The contraction of precipitation patterns in the further environmental arid and semi arid regions of the Sahel are thought to be responsible for limiting agricultural productivity. Thus pushing communities into poverty and driving environmental degradation. The combination of these factors may result in desertification as can be seen in areas of Senegal such as 'the peanut basin'.

However, though the appropriate action and inclusive, holistic strategies of development discussed in this report, increasing the resilience of these communities is possible. Through the integration of a holistic land, water an and energy management strategies, facilitated by international development aid and focused on building absorptive capacities, ecological health, food, water and energy security in a sustainable manner.

Increasing climate resilience and empowering rural communities throughout SSA holds the potential to eradicated rural African poverty and food insecurity through sustainable agricultural intensification and ecosystem remediation. Reducing the climate vulnerability of rural SSA people reduces through the introduction of appropriate techniques and technologies could enable economic growth and allow Africans to take control of their own development, leapfrogging many of the carbon intensive industries which are typical to developed countries. Decentralized energy infrastructures for example have the potential to universally electrify rural Africa whilst minimizing associated CO^2 emissions. Increased nutritional value in diets and a reduction of particle inhalation from cooking can reduce mortality rates, particularly in children. Often following the stabilization of child mortality, populations stabilize, reducing overall demand on materials. Increased tree density is associated with increased crop yields, ecosystem stability, biodiversity and carbon sequestration, which when coupled with reduced fuel wood requirements and the potential for low carbon solar energy can have an overall positive impact on global climate change. Whilst the ability to sustainably intensify agriculture reduces the need to extend existing agricultural lands, reducing the associated biodiversity loss and ecosystem fracturing resulting from this practice.

Empowering the population of the Sahel to take control of their own development through the interventions and strategies explored throughout report may also hold the potential to reduce migration both nationally from rural to urban areas and internationally, preventing thousands of people per year from risking their lives in the hope of improving it and reducing strain on European economies and reducing the overall amount spent in international aid to Sahelian countries in SSA.

The optimism may be high in this section. however, so too is the potential of the African population.

6.4 Methodological Limitations

In the following section, the methodological limitation present within this report will be explored and explained. The focus will be on determining the potential effects of these limitations and the severity of that effect.

The review of state of the art covers a number of relevant technologies and practices which relate to the areas of land, water or energy management. The selection of these intervention was conducted through supplementary reading and reinforced through field operations and interviews. However, only a small number of the potential interventions within specific areas were finally reviewed. This may have limited our ability to integrate goals such as electrification into the action net. In an attempt to increase the validity of the review, sources were limited to the last ten years. However, no repeatable search string was produced limiting the repeatability of the search process.

In total five days were spent in the field. The length of these activities may have undermined our ability to gain contextual knowledge pertaining to Rural Senegal. Field work was conducted in April, at the end of the dry season. As such we were unable to observe typical smallholder agricultural practices. However, in an attempt to circumvent this bias, technicians were questioned repeatedly regarding seasonal activity, climate environmental differences and traditional agricultural techniques.

Wolof and french are the two most spoken languages in central Senegal. As neither interviewer is fluent in either language, and English fluency is rare in rural communities, interviews were carried out via a translator. This allowed interviews to proceed in a semi structured manner. However, the lack of direct communication limited our ability to probe participants and further explore their answers.

Field observations and interviews provided data on the existing practices carried out on CREATE community sites, insights into the training approach and the effects of the interventions. However, verifiable data was not collected concerning the effect of intervention on; Poverty alleviation, soil quality(nutrient balance, SOC etc), resource availability and use. However, quantitative measures of livelihood improvements were collected through the use of interview. Additionally, some qualitative and potentially subjective data was collected concerning biophysical and socioeconomic factors through interviews with technicians and community members. For example, community members were asked what the land now used for growing was like before intervention , with the majority suggesting that there had been improvements in the benefits gained from the land. Given that the purpose of this report was to explore the ability of AT to increase the benefit gained from interventions rather than assessing the efficacy of specific interventions this lack of ecological and socio-economical data is not seen as a large weakness.

Chapter 7

Conclusion

The arid and semi-arid drylands of the African Sahel are considered 'at risk' of desertification. In the Sahel 50-70% of the population live in rural areas whilst the majority of these rural inhabitants rely either directly or indirectly on ecosystem services for food, fiber, energy, building materials and water, in short, for survival. Desertification is driven by two principle factors; human activities which reduce the resilience of the local environment to climatic shocks and climatic factors such as extended periods of drought. The human activities in question largely relate to agricultural activities, ploughing, monocropping, deforestation and excessive grazing or forests and grassland all reduce the resilience of the environment to climatic shocks by depriving the soil of nutrients, water and soil organic matter. As the soil quality lowers, so do yields leading to ecosystem fragmentation which further propagates the issue. Coupled with this are the increasingly erratic weather patterns seen across the Sahel as a result of global climate change. The already low mean annual precipitation (100-200mm/Yr) in the Sahel is becoming unpredictable, resulting in longer periods of drought followed by intense deluges. These climatic events destroy crops, pushing populations further into poverty which in turn drives environmental degradation, lowering the resilience to future shocks and forming a positive feedback loop.

International aid providers, be they non governmental organizations, multilateral or governmental organizations are aware of the problems of environmental degradation, water and food insecurity and poverty in SSA and the Sahel. However, efforts to reduce and reverse these realities have met with limited success. The limited headway made in eliminating poverty and environmental degradation can, in part, be linked to the method of development aid implementation and technology transfer. The selection and implementation of resilience building or poverty reducing interventions is often guided by inappropriate goals or targets which remedy the symptoms of low climate resilience such as low tree density without discovering or eliminating the root cause of the issue. These strategies are too often based on a silo thinking, in which problems are handled in isolation. This leads to the introduction of inappropriate interventions which prove inaccessible to rural Sahelian inhabitants, work inefficiently in the Sahelian environment, or fail to take into account the environmental, technical, cultural or socio-economic ramifications of implementation. The result is often the rejection of interventions in favour of aforementioned traditional alternatives.

In this report the concepts of appropriate technology coupled with that of the land water and energy nexus and a focus on capacity building for long term, sustainable improvement in climate resilience have been explored. With the hopes of determining a strategy, intervention design and implementation which ensures the provision of basic needs for rural Africans and empowers them to take control of their own development.

Which interventions are considered best practice for building climate resilience in rural Sub-Saharan African drylands within the areas of land, energy and water management?

A supplementary literature review revealed some of the most common, interventions carried out in Sub-Saharan Africa, useful in building climate resilience and pertaining to either land, water or energy management are:

- Conservation agriculture, which describes the combination of; minimum soil disturbance, crop rotation and permanent soil cover to minimize water, nutrient loss and organic matter loss
- Woody species intercropping to increase crop yields through SOC provision and nutrient re-balancing.
- Reforestation through farmer managed natural regeneration
- Improved cook stoves to reduce or eliminate fuel wood requirements in cooking
- Electrification through solar home systems to facilitate study, communication and reduce fuel needs
- Biogas generation, generated from local waste to subtitute kerosene and fuel wood in lighting and cooking
- Solar powered pumps to increase availability of water.

The identified interventions are then reviewed in depth in order to answer the next research question.

How viable can existing resilience building interventions be for implementation in small, remote communities in rural Senegal, according to the considerations of an appropriate technology?

Literature pertaining to each identified intervention was analyzed and systematically reviewed using the systematic PICO framework3.1. Following this the viability of each intervention for the rural Senegalese context was assessed through the application of appropriate technology principles. The definition of AT is flexible, as it not only refers to low-tech but to social aspects like adaptation and capacity building. As such criteria were selected that encompassed both the technological requirements and the requirements of appropriate transfer methods and capacity building (sections 5.2 and 3.1.1). Finally the ecological, social and economic interconnections between the interventions are highlighted through the use of the action net concept. Contextual knowledge to reinforce these assessment was gathered through field work in rural Senegal in partnership with CREATE!, an NGO using appropriate technology to increase climate resilience and reduce poverty in Senegal, in addition, field work exposed several additional interventions currently in use in rural Senegal which were also assessed and considered for integration into the action net.

Through these assessments it was discovered that conservation agriculture, FMNR (and more formal forms of reforestation), animal rearing, community level savings and loan associations, solar water pumps, improved cook stoves all supported by capacity building activities carried out when possible by local practitioners, were deemed to be appropriate and were in turn proposed as a holistic package of interventions which could be supported by aid providers.

How can the use of appropriateness assessments by development aid providers increase the efficiency and impact(benefit?) of resilience building interventions, projects and programs in rural Sub-Saharan African dryland communities?

The potential to utilize the principles of appropriate technology exists for aid providers of all levels. As highlighted throughout this report, context is key. AT is especially useful in communities in which there has currently been little development due to it's focus on basic needs. In order to achieve its goals, the interventions introduced by a project must become integrated into a community, whilst the exact method of achieving this will be different from context to context, the application of certain AT principles at an early stage can increase the probability of this occurring.

The best results are seen when projects meet the basic needs of a community. Determining these needs are best determined through a participatory approach involving the receiving communities. Additionally, interventions should be accessible to the majority of the population, this requires that interventions be tailored to the ability and willingness of the population to pay, that they are adapted to fit the available absorptive capacity, that they take into account potential cultural or social barriers and that focus on developing self sustaining markets and infrastructures, driven by the skills of the communities.

Interventions, should respect and take into account the interconnected nature of poverty, environmental degradation and ecosystem services. Doing so increases that chance to avoid overall harmful intervention, but also opens the opportunity to integrate technologies and practices in a holistic network in which they support each other.

How can the efficacy of developmental interventions aimed at increasing climate resilience in rural Sub-Saharan African communities be increased through improved application of sustainable technologies, practices and capacity building?

The purpose of development aid in SSA is not to forcibly develop Africa, but to empower the population of Africa to take control of their own development. The purpose of develop aid providers of all levels is to facilitate and guide. The existing paradigm of aid focuses on technology transfer in order to meet arbitrary targets set by those with a limited understanding of the receiving context.

Focusing instead on building resilience by meeting basic needs to ensure safety and livelihoods sustainably, facilitating income generation and empowering local communities to take control of their own development may hold the potential to do what decades of international development aid under the existing paradigm has not. Eliminate poverty, basic resource constraints and environmental degradation by ensuring that rural Africans are able to face and thrive within the challenges of the future.

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Appendix A

Structure	**Question**
Is there a motivation from people behind the success? how and why to adopt them the state of the land before CREATE! came in	How did you find out about the CREATE!?
	Why did you choose to get involved with CREATE!?
	What were your expectations before starting?
	What was the previous use of the land now used for this graden?
Land was explained to refer to soil texture and moisture content tree density and vegetative productivity	What changes have you noticed in the land since the beginning of CREATE! Interventions?
Previous knowledge and adaptation, what made the training effective, scope other possible projects. The changes the act causes	How difficult was the initial training?
Their previous knowledge situation, is it a difficult barrier to overcome?	What were your activities before starting?
	Are you aware of the effect of their previous actions (deforestation) on the environment?
	Did you have any knowledge of agricultural practices prior to create?
Knowledge obtained through training, do they have the nexus theory embeded?	Which do you believe is the most important activity that you do under Create's project?
Future impact of the practices in the community and other places	What are your future plans for the garden?
	Have you thought about the possibility of expanding the current garden?
	Have you shared the knowledge acquired with other communities?

Table A.1: Interview guide for community members