Ritva Saarinen

Wellbeing of African villagers within their community empowered by sustainable energy services

School of Electrical Engineering

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Thesis supervisor:

Prof. Liisa Halonen

Thesis advisors:

D.Sc. (Tech.) Pramod Bhusal
D.Sc. (Tech.) Leena Tähkämö

Aalto University
School of Electrical Engineering

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SCHOOL OF ELECTRICAL ENGINEERING Abstract of the Licentiate Thesis

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Advisors: Pramod Bhusal, Leena Tähkämö

One percent of a world population earns over 20 000 USD per year, while the others, 99 percent struggle to survive. Although acknowledging the valuable development work which several non-governmental organizations have accomplished this licentiate thesis demonstrates how to bridge these two separate worlds and build sustainable flourishing learning Village Community. The face-to-face interview study, literature review, and reference studies highlight the needs of villagers and the role of sustainable energy services, which are capable of empowering African villagers and their wellbeing.

Collaborative change processes utilized the power of critical realism in complex system and participatory action research in multidisciplinary learning organizations. This study found that concrete prosocial goals are able to catalyze sustainable social changes and are recommended for development co-operation work. The generated change processes are the service creation process and technology transfer process, which made it possible to create new sustainable services—Safe and Healthy Lighting, Clean Water, and Drip Irrigation to Food Markets—based on solar socio-technical systems. This thesis adopted these building blocks to construct the MOYO concept, which this study found to be agile in empowering not only villagers but partners as well. This concept could act as a change engine to develop viable business environment around sustainable new services and take advantage of promising food markets in Africa, as exemplified by exports of organic products.

This MOYO concept is scalable and it can be leveraged to extend agricultural businesses as exemplified by a juice factory. This future process-based factory is recommended for integration with waste gasification to produce heat and electricity and overcome the pollution problem in larger communities and cities around villages—the management of municipal waste, agricultural and forest residues.

Keywords: Africa, agricultural, behavior, business, clean, creation, collaborative, community, customer, export, flourishing, organic food, healthy, irrigation, learning, lighting, livelihood, markets, need, organization, prosocial, service, socio-technical, solar, sustainable, system, viable, villager, water, wellbeing

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Yksi prosentti maailman ihmisistä ansaitsee yli $20 000 vuodessa, kun taas 99 prosenttia kamppailee toimeentulostaan. Tämä lisenttiasttityö osoittaa kuinka nämä kaksi erilaista maailmaa voidaan yhdistää ja rakentaa kestävä kukoistava ja oppiva kyläyhteisö, vaikkakin tämä tutkimus tunnustaa useiden kansalaisjärjestöjen tekemän arvokkaan työn. Kasvoikkain tapahtuva haastattelututkimus, kirjallisuus, ja vertailututkimukset tuovat esiin kyläläisten tarpeet ja kestävien energiapalveluiden merkityksen. Nämä palvelut tarjoavat mahdollisuuden voimaannuttaa afrikkalaisia kyläyhteisöjä ja asukkaiden hyvinvointia.

Muutosprosessi yhteistyönä hyödyntää kriittistä realismia monimutkaisissa järjestelmissä sekä osallistavaa toimintatutkimusta monitieteellisessä oppivassa organisaatiossa. Tämä lisenssiaattityö löysi konkreettiset prososiaaliset tavoitteet katalysaattoriksi kestävään sosiaaliseen muutokseen ja suosittelee niitä kehitysyhteistyöhön. Muutosprosessit, jotka tässä työssä kehitettiin, ovat palveluiden kehitysprosessi sekä teknologian adaptointiprosessi, jotka mahdollistivat uusien aurinkojärjestelmiin perustuvien palveluiden kehityksen: Turvallinen ja Terveellinen Valaistus, Puhdas Vesi, ja Tihkukastelu Ruokamarkkinoita Varten. Tämä työ käyttää näitä palveluita rakennuspalikoina MOYO konseptin luomiseen ja löysi MOYOn ketteräksi voimaannuttamaan ei ainoastaan kyläläisiä, mutta myös yhteistyökumppaneita. Tämä konsepti voi toimia muutosmoottorina elinkelpoisen liiketoimintaympäristön luomiseen kestävien uusien palveluiden ympärille sekä lupaavien ruokamarkkinoiden hyödyntämiseen Afrikassa, kuten esimerkiksi luomutuotteiden viennissä.

Tämä MOYO konsepti on skaalautuva ja se voi toimia vipuna laajentumiseen maatalousliiketoimintaan kuten mehutehtaaseen. Tämä tulevaisuuden pohjainen tehdas on suositeltavaa integroida jätteiden kaasuttamisella ja näin tuottaa lämpöä ja sähköä sekä samalla hoitaa isompien kyläyhteisöjen ja kylän ympärillä olevien kaupunkien jäteongelmat — kunnallinen jätteenkäsittely, sekä maatalous- ja metsätähteet.

Avainsanat: Afrikka, maatalous, käyttäytyminen, liiketoiminta, puhdas, luominen, yhteistyö, yhteisö, asiakas, vienti, kukoistava, luomu ruoka, terveys, kastelu, oppiminen, valaistus, toimeentulo, markkinat, tarve, organisaatio, prososiaalinen, palvelu, sosio-tekninen, aurinko, ympäristöystävällinen, järjestelmä, elinvoimainen, kyläläinen, vesi, hyvinvointi

Preface

There can be no words without images." Aristoteles

I have taken the heart of my thinking, my research focus, a human being within his or her community, and I would promote that our view of the world, including explicit and implicit understanding, is revealed when we interact.

First of all, I would cordially like to thank my husband Vesa and my children Anna, Ville, Suvi and Tiina: they have been my foundation to explore both new and experienced views in our beautiful but challenging world.

I would like to express my deep gratitude to my supervisor professor Liisa Halonen as a promoter and to professor Esa Saarinen about his inspiring lectures.

My warm thanks go to D.Sc. Leena Tähkämö for her reviewing the manuscript and her time to challenge my ideas during our discussions. I would like to thank D.Sc. Bramod Bhusal for his authentic views of electrifications in the developing countries and his contribution to the interview study; his support and fresh ideas to this thesis gain my cordial thanks.

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Last I thank my sister Piipe, Mom Varpu and Dad Urho for believing in me and my work and their guidance to my Lord Almighty.

Espoo 05.06.2015

Ritva Saarinen

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List of symbols and abbreviations

ARC	Anti-reflective Coating
BC	Black Carbon
BOP	the Bottom of the Pyramid
CFL	Compact Fluorescent Light
CSR	Corporate Social Responsibility
CVD	Chemical Vapor Deposition
DALY	Disability-adjusted life year
DC	Direct Current
EPOPA	Export Promotion of Organic Products of Africa
ERF	Effective Radiative Forcing
EUR, €	euro
FBO	Faith Based Organization
FBR	Fluidized Bed Reactor
GaAs	Gallium Arsenide
GNI	Gross National Income
GINI Index	standard economic measure of income inequality
ICT	Information and Communication Technology
IEA	International Energy Agency
IS	Information System
LCA	Life-cycle Assessment
LCD	Least Developing Country
LED	Light-Emitted Diode
MDG	Millennium Development Goal
MOYO	in Swahili; Heart, Sympathy in English
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
Nogamu	National Organic Agricultural Movement of Uganda
NGO	Non-Governmental Organization
O&M	Operation & Maintenance
PAR	Participatory Action Research
PM	Particulate Matter
PV	Photovoltaic
RF	Radiative Forcing
Si	Silicon
SIDA	Swedish International Development Cooperation Agency
SWB	Subjective Wellbeing
SSL	Solid-state Lighting
TAMAA	in Swahili; Hope in English
UMG	Upgraded Metallurgical Silicon
The UN	The United Nations
USD, $	US dollar
WASH	Water, Sanitation, Hygiene
WCED	World Commission on Environment and Development
WMGHG	Well-mixed Greenhouse Gas
E_g	Energy band gap
eV	Photon or electron energy as electron-volt
lm	luminous flux in units of lumen
lx	illuminance, luminous flux per unit area
η_v	luminous efficacy, luminous flux per power, lm/W

1 Introduction

1.1 Background

Notwithstanding the Millennium Development Goals (MDG) program, wide gaps still remain in reaching the basic needs and wellbeing of rural people in Africa. In fact, one percent of a world population earns over 20 000 USD per year, while the others, 99 percent, just try to survive as the next chapter reveals. However, the licentiate thesis makes the evident that sustainable energy services are reliable rural solutions in Africa, especially solar energy, beside solar energy is nowadays particularly mature and the need for maintenance is almost nil. For this thesis, the in-depth interview study, TAMAA Case (Saarinen, R., 2015a) was conducted. This TAMAA (Hope) Case, among other methodologies and methods, plays a vital role in exploring how to build a sustainable flourishing learning village community even though the poverty is widespread, agriculture practices are ineffective without irrigation systems, and lack of energy prevents from making the most of the African enormous resources. Africans' wellbeing within a flourishing village community, where they can gratify their needs, this might be a vision. However, the vision to be realized, this thesis investigates those change levers which can foster and generate a difference in villagers' quality of life. Majok Kariom, one of the interviewees in TAMAA Case, summarized: "Your mindset will change", this phrase crystallizes the social change and innovation leveraged by new technologies.

This cross-functional multidisciplinary thesis focuses on integrating human needs, new energy services, and new technologies into an open complex dynamic socio-technical system, where concrete prosocial goals and happiness economics can boost the social change. Villagers, the representatives of non-governmental organizations (NGOs) and companies, as well as researchers at universities co-create shared knowledge and meaning of the pphenomena, and collaborate on affordable local solutions for rural people. The ultimate target of this is to export opportunities based on these new sustainable services in equal partnership.

1.2 Research phenomenon

George Pindua, one of the interviewees (the TAMAA case, Saarinen, R., 2015a), stated, 'The basic needs of people in Africa include food, shelter, clean water, electricity, education, hospital and infrastructure'. After all, the universal needs are based on the Universal Declaration of Human Rights, which states that all people regardless of race, gender, birth, poverty or other status are equal and free (UN Human Rights) and need a quality of life, happiness and wellbeing, as well as a society to live with other people (Antonides, 1996; Frankl, 2010; Frey, 2008; Järvinen, 2007; Maslow, 2000; Rudd et al., 2014). Thus, this licentiate thesis starts by inquiring a village community and villagers' wellbeing by first placing their needs, identified from the TAMAA case (Saarinen, R., 2015a), according to Maslow's hierarchy of needs. Figure 1 illustrates how Water, Food and Sanitation belong to survival needs, whereas Health, Income, Lighting and Jobs to safety needs. On the other hand, human desires for participation and being a member of a community are considered social needs, while Education correlates to self-esteem needs. Within the flourishing learning community villagers have opportunities to achieve their full potential, self-actualization, they can search for meaning that makes their life worthwhile, they can even empower others. In this research, the identified needs are expressed with capital first letters, such as Water and Food.

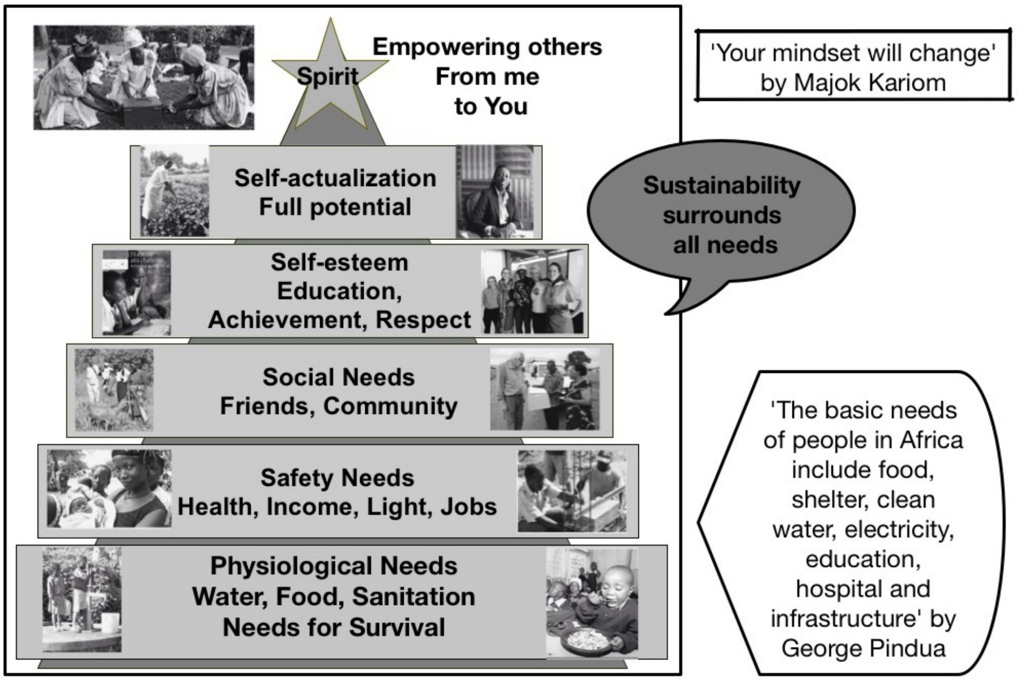


Figure 1. Summary of Basic Customer Needs as Maslow's hierarchy, Saarinen, R., (2015b). Source: Maslow (2000), Spirit based on Frankl (2010), Photos (Photo Ref.)

This licentiate thesis addresses the question: how can villagers fulfill their wellbeing and flourish in the community, where they are living in poverty without access to clean water, nutritious food, healthcare, education, lighting, or jobs? Moreover, there exist neither micro to medium sized business opportunities nor electricity to operate machines and other equipment. Instead, villagers are struggling just trying to survive at the physiological needs level as described in Figure 1. Indeed, the gap to meet the African needs in rural areas is substantially wide when compared with the needs in Maslow's hierarchy above as shown in Figure 2.

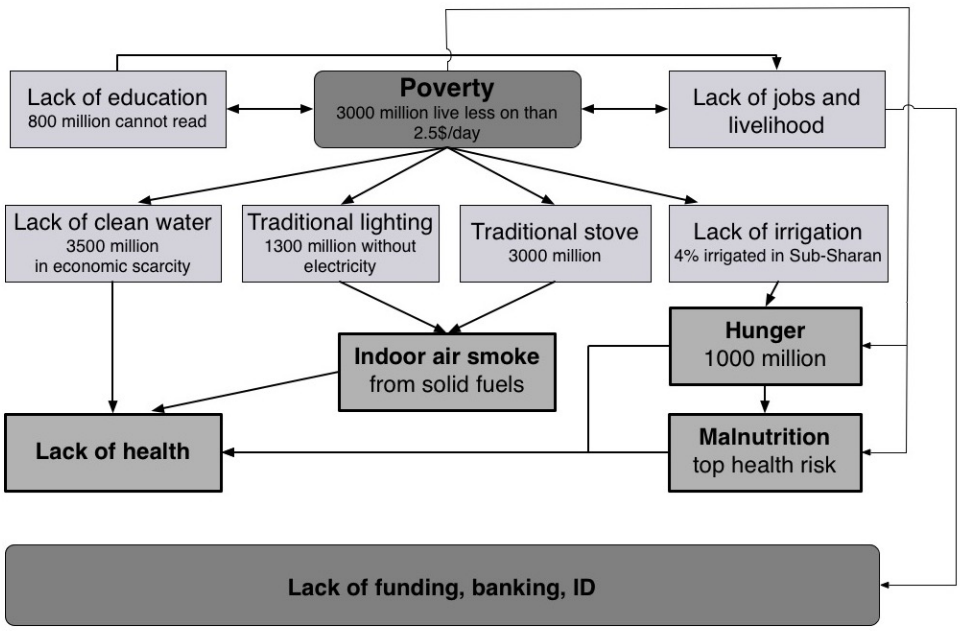


Figure 2. Problem areas to be studied, Saarinen, R., (2015b). Chapter 2 reviews these.

1.3 Research objectives and questions

By acknowledging the valuable and long-lasting development work, which several NGOs have established and performed, this thesis utilizes the results from these studies in the baseline literature review in Chapter 2. General basic customer needs, as a starting point, enable the creation of a sustainable flourishing learning village community, but how to create opportunities for exceeding the basic needs and enter market sectors in sustainable products and services produced by villagers (Beltz et al., 2009; Cooper, 2001; Grönroos, 2000; Urban & Hauser, 1993). First, Chapter 2 analyzes the market perspective in developing countries, especially in Africa and among the so-called BOP (the bottom of the pyramid in Prahalad, 2010) markets (AGI BOP, 2012; Berman, 2013; Bowman et al., 2009; Hammond et al., 2007; IEA, 2014, 2011; World Bank, 2013). Second, Chapters 3 and 4 demonstrate, how to bridge the gap in building flourishing Village Community, while there exist widespread poverty and lack of diverse basic needs, Figure 3 illustrating the bridge. Chapter 4 discusses how to create new sustainable services—Safe and Healthy Lighting, Clean Water and Drip Irrigation to Food Markets—as well as those processes that are needed for creations. On the other hand, Chapter 3 explains those theories and involved methods as well as describes the socio-technical solar system.

Figure 3. Bridging the gap from poverty and lack of basic needs to flourishing Village Community, Saarinen, R., (2015b).

According to many scholars, deciding research questions is a cornerstone for the successful study to solve the problem (phenomenon) and drives research methods. In starting to formulate research questions and objectives, this thesis follows the strategic goal settings approach (Grönroos, 2000; Grönroos, 2007; Hyppänen, 2013; Novick et al., 2002; Tevis, 2009; Urban & Hauser 1993). Gustavsen (2008), and Elden and Levin (1991) emphasize democratic dialogue, co-operation of actors from different organizations, local commitment and involvement, and trust when triggering change happen in collaborative learning. In addition, Elden and Levin discuss socio-technical system thinking, co-learners, and shared knowledge in action research. Furthermore, Novick, Kress and Elias (2002) demonstrate how important it is to establish specific, highly focused, and attainable goals, which are well-formulated, realistic, and preeminently important, and which catalyze actions to achieve the desired outcome. Indeed, the key success factors of EPOPA program (The Export Promotion of Organic Products from Africa) were the clear focus and goals as well as local commitment and learning together in the partnership of local farmers, companies and exports. This EPOPA program brought improvements in the livelihoods of rural communities through exports of organic products (SIDA, 2008), see Chapter 4.1.6.

The main focus of this licentiate work is at community level although the problem areas at state level in Africa will frame interviews (Ellis & von Kessel, 2009). Figure 4 illuminates the research environment in an open complex community system in order to acquire shared knowledge and meaning in the addressed question: 'how to build a sustainable flourishing learning Village Community' (Isaacs, 1999; Isaacs, 2002; Sayer, 2002). The cornerstones of this licentiate thesis are the theory and methodology of prosocial behavior and its economic consequences, critical realism, complex and socio-technical systems, learning organizations, participatory action research, interviews, case studies, service creations, sustainable services, and new energy technologies. The TAMAA interview case study, conducted for this licentiate thesis, is documented in the separate report (Saarinen, R., 2015a), although some parts are embedded in this licentiate thesis document. In this way, both documents can be delivered separately and this licentiate thesis is more coherent to read.

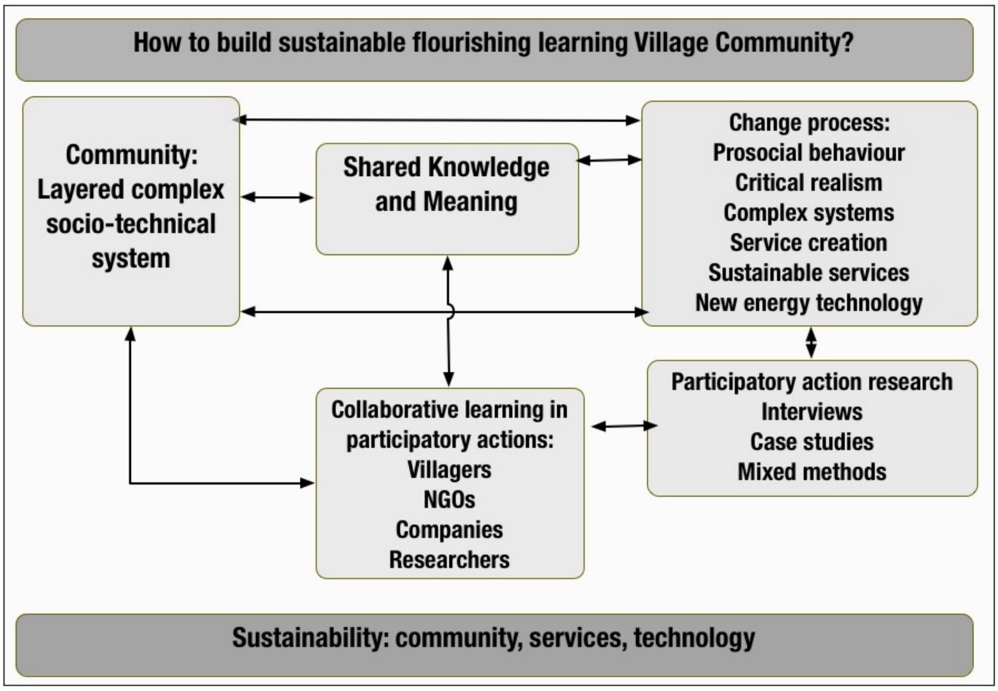


Figure 4. The relationships of the research philosophy, the open complex socio-technical community system, and collaborative learning, Saarinen, R., (2015b)

This licentiate thesis shares the TAMAA vision, which is—sustainable flourishing learning Village Community. The aim of this licentiate thesis is to examine which and how new sustainable energy services can empower the wellbeing of African villagers and how flourishing learning Village Community can offer opportunities to gratify their needs and create businesses in a collaborative learning context. Furthermore, this study intends to create these new discovered sustainable energy services.

The research consists of five strategic steps and four research questions, the research map shown in Figure 5. This licentiate thesis addresses the major research question—how to build sustainable flourishing learning Village Community? This question is divided into the four more specific research questions as following:

1. Which basic customer needs of rural people in Africa can be met by providing sustainable energy services, and how villagers' wellbeing is empowered by these services?
2. How is it possible to build a shared knowledge of villagers, NGOs, companies and researchers in order to enable social changes in the villagers' environment and behavior?
3. What kind of socio-technical system, learning community and partnership model may produce wellbeing of rural villagers?
4. Which concrete-framed prosocial goals will catalyze these changes in participatory organizations and produce wellbeing of rural villagers (customers)?

In starting to answer the research questions, this thesis aims to meet the following strategic steps:

1. Review General Basic Customer Needs of rural people in developing countries, acts as the baseline, documented in TAMAA Case study report (Saarinen, R. 2015a) and recapitulated in this thesis
2. Discover New Customer Needs, driving Change Levers (elaborated and enlarged in this thesis) and Prosocial Goals (in this thesis)
3. Create New Sustainable Energy Services, Concepts and Processes
4. Discover Constraints and Obstacles to these new energy services
5. Conceptualize learning Village Community for generating change to happen in a collaborative social context

The research data discovered to general basic customer needs are analysed and reviewed in Chapter 2.1, and gathered during the years 2009-2014. Similarly, new energy technology data were reviewed in Chapter 3.4. Furthermore, Chapter 3 analyzes and reviews prosocial behavior, case study research, learning organizations, participatory action research, interviews as well as qualitative and mixed methods research, content analyses and conceptualization. Terms are found in Appendix 2.

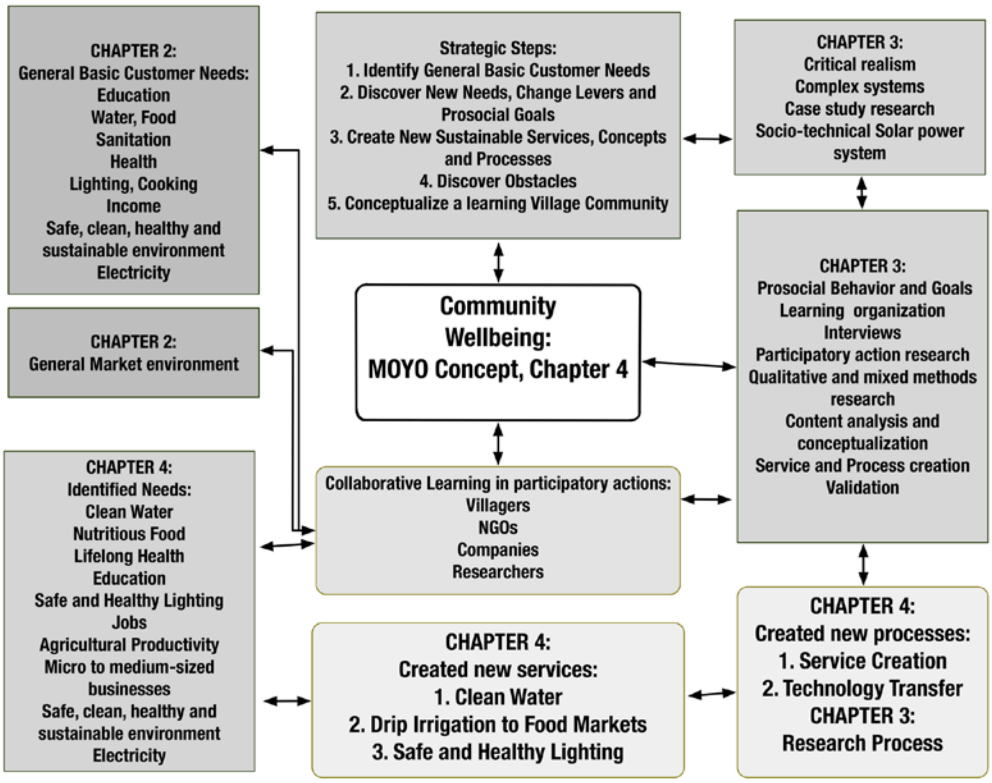


Figure 5. Research Map for licentiate thesis, Saarinen, R., (2015b)

2 Baseline review

2.1 General basic customer needs

2.1.1 Identified basic needs

Applying Figures 1 and 2 as well as the TAMAA Case study report (Chapter 2 in Saarinen, R., 2015a), the status of general basic needs is covered in the next analysis, these needs qualified as general basic customer needs.

2.1.2 Education

Approximately 800 million adults (aged 15 years and over) were considered functionally illiterate, and 123 million youth (aged 15 to 24) did not know how to read and write. It is also estimated that especially in developing countries 250 million children of primary school age lack basic reading, writing and numeracy skills. However, access to education has improved worldwide (approximately 60 million children of primary school age were out of school). But at the same time, we all have the universal right to education: Article 26 of the Universal Declaration of Human Rights. (CIA, 2014; UN Human Rights; UN MDG, 2013; UNESCO EFA, 2014; UNESCO, 2000). Studies indicate that helping women is one of the best ways to support whole families and reduce poverty at the grass-roots level. The role of educated women is crucial in achieving healthy, wealthy, and safe village communities (UNESCO EFA, 2014). The education status in some Sub-Saharan African countries showed positive progress, e.g., in Tanzania and Zambia, where primary school enrollments were 90% or more (UNESCO, 2010; Appendix A in TAMAA Case study report, Saarinen, R., 2015a). On the other hand, in most African countries the differences were discovered in gender parity (ratio of girls/boys) at secondary school level, where enrollments of girls were smaller than in boys and these differences even grow after secondary school level (UN Africa MDG, 2013).

Because the increasing number of poor households are headed or maintained by women, a focus on poor women is therefore essential for poverty reduction. Similarly, investments on girls, which help them to complete good quality secondary education and support their transition from education to work, will improve the livelihood opportunities of these girls. To eliminate malnutrition in the long term, education—especially education that empowers women—is vital. Training and education enable to promote opportunities for women's own small businesses related to their everyday life, to manage their savings and to learn to market their products, thus gender equality matters also as an instrument for co-operation development to create new sustainable services for their society and community, where women and men have equal chances to become socially and politically active. (BMZ, 2012e; DFID, 2005; Grown et al., 2005; Misana & Karlsson, 2001; UNESCO EFA, 2014).

2.1.3 Food, water, and sanitation

By the end of 2011, globally 768 million people relied on unimproved drinking-water sources although by some estimates, the number of people whose right to water is not satisfied could be as high as 3500 million. In Sub-Saharan Africa, only 61% of rural population had clean water for drinking, but noteworthy, the 66% of the rural poorest 20% got their water from such unimproved sources as rivers in 2010 (see Figure 6, UN MDG, 2012, p.53). (UN MDG, 2012; UN Water WWDR, 2014). Moreover, 2500 million people lacked access to clean sanitation, and as a consequence, globally 2 million people die and 4000 million get sick every year due to WASH related diseases, (WASH=Water, Sanitation, Hygiene). Today agriculture exploits more than 70% of water withdrawals but in the least development countries (LCDs, UNCTAD, 2011) even up-to 90%, access to water being a constraint to produce food for hundreds of millions of people. Fresh water, on the other hand, is needed for drinking and might need long distances to fetch. (UN MDG, 2005; UN Water WWDR4, 2012)

Worldwide, there are approximately 1000 million hungry people, the majority in the LCDs. Moreover, the international prices of food are volatile, as a result high prices cause undernourishment and food crises, especially to those who spend 70-80% of their daily income on food and are food net importers. Regarding this issue, 50% of world's hungry people were smallholder farmers, 76% of the world’s extreme poor people were rural, and over 60% of Africans depended directly on agriculture for their livelihoods. On the other hand, increased prices provide better incomes for those who can sell their products to food markets. (FAO et al., 2014; FAO, 2011; Grebmer et al., 2013; IAASTD, 2009; UNCTAD, 2011; World Bank, 2012; World Bank, 2013 GMR).

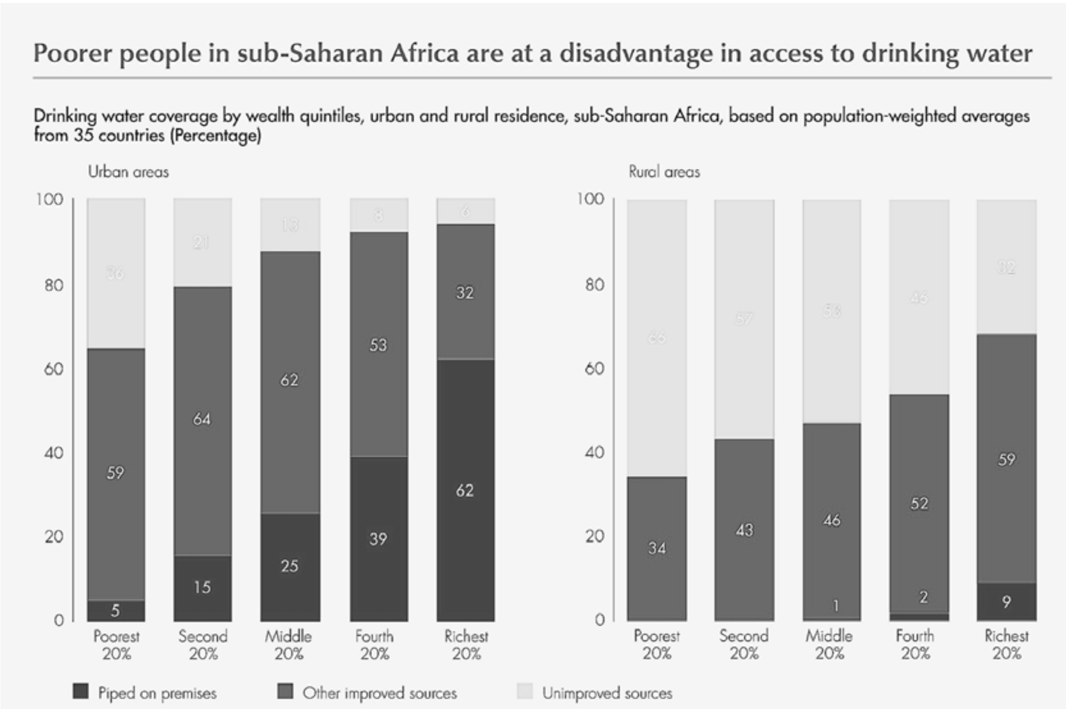


Figure 6. Drinking Water status in urban and rural areas in sub-Saharan area. In rural areas, the 66% of the poorest 20% got their water from unimproved sources like rivers. (UN MDG, 2012, p.53)

2.1.4 Health, lighting, and cooking

Even today, approximately 3000 million people cook and heat their homes using open fires and stoves and approximately 1300 million people lack electricity traditional kerosene lamps being most common. In most Sub-Saharan countries, the use of solid fuels is widespread (WHO Maps, 2012; Appendix G in Saarinen, R., 2015a). Indoor smoke from biofuels, charcoal and kerosene lamps consists of high levels of harmful combustion products, of which the small particle matters (PM) and direct black carbon (BC) cause such diseases as lung cancer, pneumonia and other acute infections, indoor air pollution resulting in 3.5 million deaths every year. (Apple et al., 2010; IEA Energy, 2014; Jacobson et al., 2013; Poppendieck et al., 2010; Smith, 2006; 2000; Torres-Duque et al., 2008; UNDP, 2013; WHO, 2012; WHO Indoor, 2010; WHO PM, 2011).

Undernourishment, indoor air pollution, unsafe contaminated water, these are all related, malnutrition being the top health risk both worldwide and in low income countries measured as DALYs (Appendix I in Saarinen, R., 2015a). In low-income countries, unsafe water, sanitation and hygiene are the second biggest risks, unsafe sex the third biggest risk, and indoor smoke from solid fuels is the fifth biggest risk. The fourth largest risk is related to breastfeeding, and this problem area needs information and education, where the role of educated mother for healthy children is crucial (Appendix B in Saarinen R., 2015a). Noteworthy, approximately 1700 million people lacked access to essential medicines and basic health services: 3300 million were at risk of malaria and neglected tropical diseases affected approximately 1200 million. (AGI BOP, 2012; Haupt & Krämer, 2012; WHO, 2009; the term, DALY, defined in Appendix 2 and WHO 2009, p.v, 5).

2.1.5 Income

Figure 7 (World Bank, 2013 GMR), p.60) shows global income as Gross Domestic Product (GDP) per capita in USD indicating low income in Sub-Saharan Africa expect for South Africa, Botswana and Gabon (World Bank, 2013 GMR). Still, 1200 million people lived in extreme poverty (less than $1.25 a day), of whom 76% living in rural areas (UN MDG, 2013). In 2010, 48.5% of Sub-Saharan Africa’s population lived on less than $1.25 a day (413.8 million people), and this number of people has increased. (IEA, 2014; World Bank, 2013 GMR; World Bank, 2014). Moreover, approximately 3000 million people lived on less than $2.5 per day globally (Chen et al., 2008, p.41; UN Water WWDR, 2014, p.2).

On the other hand, Figure 8 illustrates global income as a pyramid, where the earnings more than $20 000 per year form the upper income group (1% of all people in the world), the middle income group earns $3 000 - 20 000 per year (33% of the world's population), and the bottom of the pyramid (BOP) earns less than €5 per day (4000 million people in the world) (AGI BOP, 2012; Prahalad, 2010).

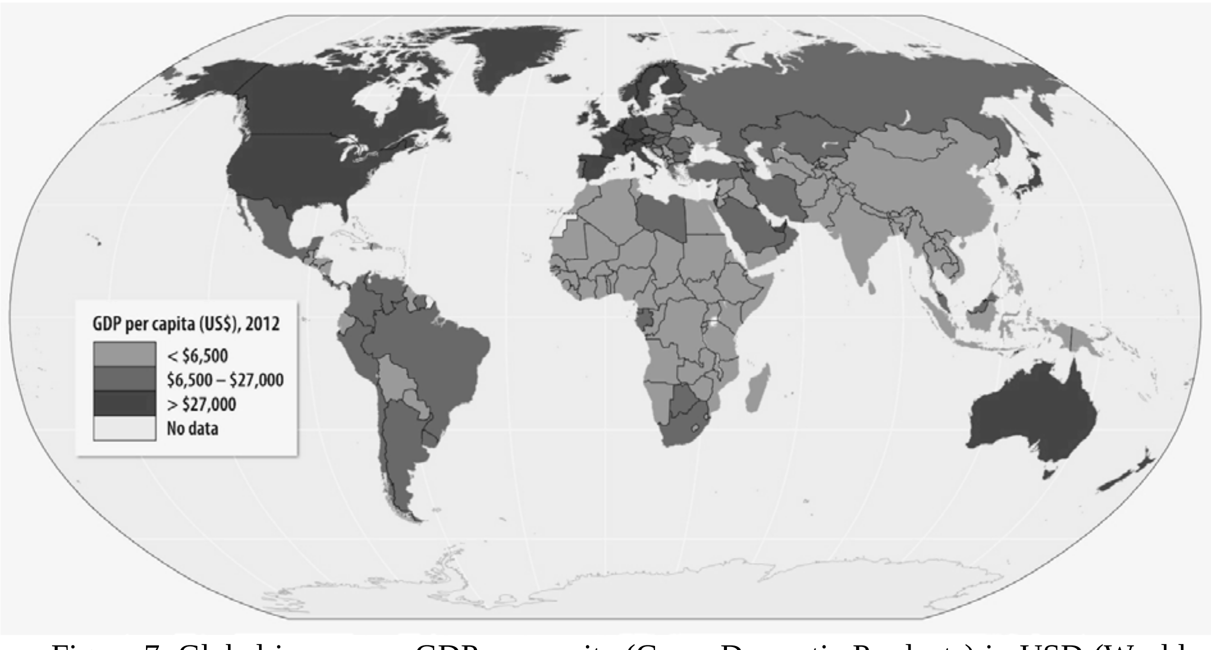


Figure 7. Global income as GDP per capita (Gross Domestic Products) in USD (World Bank, 2013 GMR, p.60)

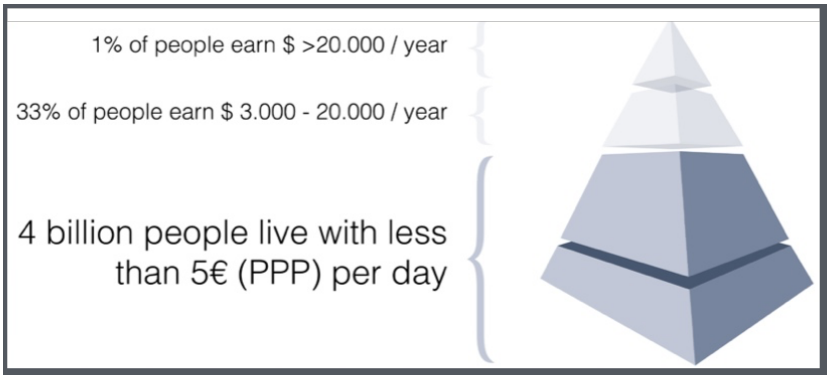


Figure 8. Our world as income groups (AGI BOP, 2012)

2.1.6 Safe, clean, healthy, and sustainable environment

Safe, clean, healthy and sustainable environment could be accounted to Human Rights (UN Human Rights; UN HR Env., 2015) in a similar way than rights to clean water, nutritious food, lifelong health and other basic needs reviewed in Chapter 2. Figure 1 (Maslow's hierarchy of needs) illustrates how sustainability surrounds all needs, and healthy and sustainable environment is a vital condition for agricultural productivity. Deforestation, draughts and erosion are results in the combustion of solid fuels as previous discussed, on the other hand, climate change even exacerbates situation. As a consequence, these issues cause serious troubles in food security, in access to clean drinking water and health of rural people. Nowadays, one third of Africans live in drought-prone areas, mainly in the Sahel, around the Horn of Africa and in southern Africa. It is time consuming to gather wood and straw, and because of deforestation, women and children have to go even further to get their fuel. Forests and woodlands occupy approximately 650 million ha or 21.8 % of the land area in Africa (UNEP, 2006; Appendix K in TAMAA Appendices, Saarinen R., 2014a). (Bizzarri, 2009; Clements, 2009; Corvalan et al., 2005; McCoy & Watts, 2014; Nellemann et al., 2009; Perlis, 2006; Srilata, 2011; UN Water WWDR3, 2009; UNCCD; World Bank Water, 2010).

Climate change is highly related to the agro-forest development and carbon sinks. A carbon sink is a natural or manmade reservoir that accumulates and stores carbon for an indefinite period. Natural sinks are oceans and photosynthesis by plants and algae. Anthropogenic increases in the well-mixed greenhouse gases (WMGHGs) have substantially enhanced the greenhouse effect. With very high confidence, the estimation of the total radiative forcing (RF) of these gases was 2.83 W/m^2 in 2011 (+/- 0.28; 2.54 to 3.12), of this 2.63 W/m^2 during the years 1975-2005, the major components of these WMGHGs producing 80 % of this RF; such greenhouse gases as carbon dioxide CO_2 (1.82; 1.63 to 2.01 W/m^2), methane CH_4 (0.48 ± 0.05 W/m^2), nitrous oxide N_2O (0.17 ± 0.03 W/m^2), and halocarbons (total RF 0.360 W/m^2) were the most abundant WMGHGs. On the other hand, aerosols have cooling effect on RF, but black carbon (BC) is a strong global warmer. Since 2011, nitrous oxide N_2O has become the third largest contributor to RF. Moreover, emissions of CO_2 have made the largest contribution to the increased anthropogenic effective radiative forcing (ERF) 2.3 (1.1 to 3.3) W/m^2. (Abdi et al., 2013; Ciais, 2013; IPCC, 2013; Kulmala et al. 2014; Myhre et al. 2013).

Climate change contributes to the extreme appearances of heavy rains, and draughts in Africa and erosion has caused substantially smaller crop yields resulting in serious hunger and malnutrition of people, as occurred in the fourth consecutive years in

Uganda (Bizzari, 2009). As a consequence, approximately 1000 million people are worldwide affected by land degradation. Drip irrigation in arid and semi-arid regions (see Appendix M in Saarinen, R., 2015a) reduces water use, because this practice delivers water and fertilizers directly to the roots of plants, thereby improving soil moisture conditions. On the hand, irrigation leads to local cooling effect. Thus solar-powered irrigation decreases CO_2 emissions, cools locally, increases plant covers and the impacts of photosynthesis, and mitigates desertification. The forest as secondary organic aerosols has cooling effect and feedback mechanism. Mitigating deforestation and sustainable forest management improve soil conditions, decrease erosion and alleviate climate change. (Burney et al., 2009; FAO, 1987; IPCC, 2013; Kimaro et al., 2007; Kulmala et al., 2014; Trenberth, 2005; Trenberth, 2009; You et al., 2010).

As identified above (Chapter 2.1.4), approximately 3000 million people cook and heat their homes using traditional fuel wood and other solid fuels, in Sub-Saharan Africa approximately 730 million people (IEA, 2014). As a consequence, in developing countries, about 730 million tons of biomass are burned each year, which amount to more than 1000 million tons of carbon dioxide (CO_2) emitted into the atmosphere. (World Bank Cook, 2011). Worldwide, due to deforestation, the net change in forest area was estimated for -5.2 million hectares per year in the period 2000–2010. This means forest losses with an area about the size of Costa Rica, and over half of this change in Sub-Saharan Africa amounting to 3.37 million hectares (in 2010) (FAO Forest, 2011). Sustainability of burning biomass is also much related to carbon sinks. Africa contributed 21 % of the global total carbon stock in forest biomass, and these forest losses, no doubt, have decreased carbon sequestration in forest ecosystems and hindered climate change mitigation (Kellomäki et al., 2013).

2.1.7 Electricity

Approximately 1300 million people worldwide lack access to electricity, and regarding Sub-Saharan Africa 290 million out of 915 million people have access to electricity (IEA, 2014). Rural electrification rates have remained particularly low in Sub-Saharan Africa over the past 30 years at less than 10 %, while they reached 50 % per cent for developing countries as a whole (Bernard, 2010), the total number of people without access rising due to population growths. More than 75% of the population living in large areas in East- and Central Africa lacks access to electricity, such countries as South-Sudan, Tanzania, Ethiopia, Somalia, Kenya, Uganda, Central Africa, and Congo. Moreover, in Sub-Saharan Africa nearly 80% of those lacking access to electricity lives in rural area (Appendix N in Saarinen, R., 2015b; IEA, 2014). Regarding Sub-Saharan rural households, even less than 10 % has access to electricity, with an overall access rate below 25 % (World Bank AFREA, 2012). However, people in developing countries spend about EUR 28 000 million annually for poor quality energy supply, which causes high levels of such pollution as greenhouse gases and black carbon (EU se4all; Chapters 2.1.4 and 2.1.6). In most countries in Sub-Saharan Africa, small diesel generators are presumably the default option for off-grid electrification resulting in an average carbon dioxide emission baseline 1.7 tCO_2/MWh (UNDP Sub-Saharan, 2013). Lack of electricity hinders villagers run their micro-small business. Similarly, lack of a reliable energy access will prevent investors from bridging the infrastructure-financing gap (african monitor, 2012; Saarinen, R., 2015a). Figure 9 shows how solar PV with diesel generators has been estimated to provide both for mini-grid and off-grid electrification solutions in rural areas in Sub-Saharan Africa (IEA Energy, 2014).

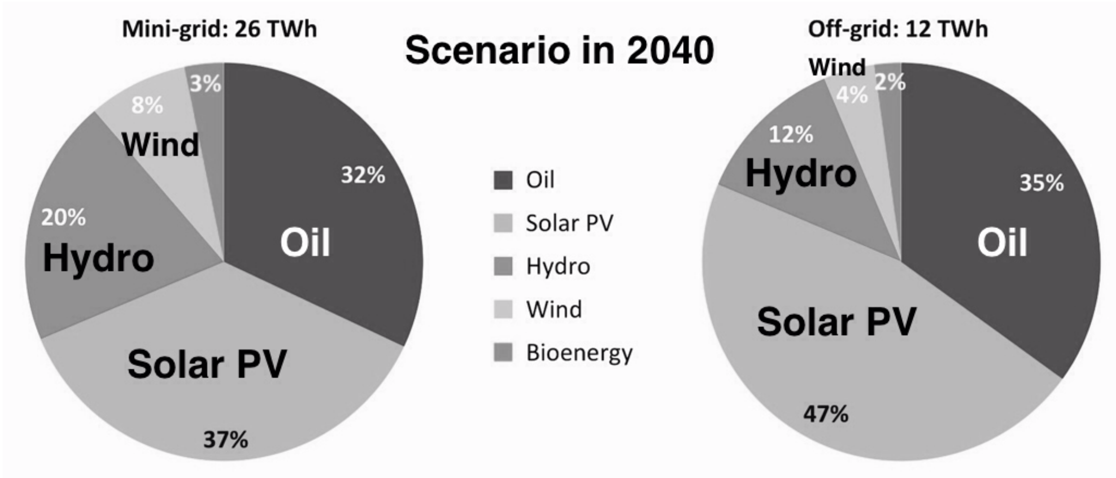


Figure 9. Technology mix for mini-grid and off-grid power generation in Sub-Saharan Africa in the New Policies Scenario in 2040 (IEA Energy, 2014, p.543)

2.1.8 Life-cycle assessment and sustainability

As discussed previously, health and environment are strongly related to almost every sector of our society, and thus, a more holistic perspective on health is needed to address the sustainability of economics, ecology, culture, and politics angles. (Corvalán et al., 1999; Corvalán et al., 2005; Oxfam, 2014; UNEP, 2009). Belz and Peattie (2009, p.18) introduce the concept of sustainability marketing, which seeks to take account of both social and environmental issues, therefore their definition is the starting point for discussing the question of sustainability and sustainable development: ‘Sustainability marketing is marketing that endures forEVER, in that it delivers solutions to our needs that are: ecologically oriented, viable, ethical, and relationship-based’. In the first place, the sustainable development was defined by Brundtland, ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (UN WCED, 1987, the article 49).

Life-cycle assessment (LCA) provides another view to sustainability, this tool (LCA) defined as ‘a concept and methodology to evaluate the environmental effects of a product or activity holistically, by analyzing the whole life cycle of a particular product, process, or activity’ (Johnson U, 2003) and the concept, “cradle-to-grave” begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth (EPA, 2001). (ISO 14040, 2006; ISO 14040, 2006). Sustainability assessment of a product (goods and services, Crawford, 1994, p.23; ISO 14040, 2006) contains three pillars: environmental, economic and social sustainability, and the system boundaries of these three pillars should preferably be consistent. The system is described with a process diagram, which shows the unit processes and their inter-relationships, when assessing the environmental aspects and potential impacts throughout a product's life cycle (e.g., cradle-to-grave) from raw material acquisition through production, use, recycle, and disposal. (ISO 14040, 2006; ISO 14044, 2006; Klöpffer, 2008; Tähkämö, 2013).

The social aspect of sustainability was introduced in Chapter 2.1.6 by creating a relationship to Human Rights, however official social LCA is considered at its early stages (Klöpffer, 2008; Petersen E., 2013), although the licentiate thesis values the work of the UN in ‘he Guidelines for Social Life Cycle Assessment of Products’ (UNEP, 2009; 2013). This thesis draws attention to some key basic needs, discussed above—health and income versus poverty—by bringing forward one interesting study in the social LCA field: anticipating impacts on health based on changes in income inequality caused by life cycles (Bocoum et al., 2015), which study was considered a step forward towards social life cycle assessment utilizing the impact pathways method (here the Wilkinson pathway). This pathway allows a comparison of different change scenarios in the life cycle of a product or a service. Therefore, Bocoum, Macombe and Revéret applied the Wilkinson pathway as a comparative method for anticipating the change in the infant mortality rate caused by a change in income distribution in the population of a country. Figure 10 shows the functional diagram of Wilkinson Pathway (Wilkinson et al., 2010), which brings the discussion to the methods how Bocoum, Macombe and Revéret re-examined, with the most up-to-date time series data, the hypothesis that the increases in inequality have negative consequences to health. For estimating the impact of income on health and the relationship between income inequality and infant mortality, they used an empirical regression model based on the generalized method of moments (GMM). The sample of 46 countries covered the data from the time series 1960 to 2006 in member (29) countries and non-member OECD countries.

Bocoum, Macombe and Revéret (2015) took advantage of the inequality indicator, the GINI Index (also named GINI coefficient, a standard economic measure of income inequality based on Lorenz curve). This indicator is found most frequently in international databases, and it is a measure of the degree of income concentration within a population (OECD, 2014; UNDP GINI/HDI, 2013; World Bank, GINI). Similarly, for the health indicator, they chose the infant mortality (mortality of children under 1 year old) due to the availability in international databases in most countries and in the Millennium Development Goals (the Goal number 4). Thus these two indicators provide the regular visibility and follow-up (UN MDG, 2013; 2012; 2010; 2005). The results of regression analysis based on the model GMM showed a relationship between a variation in income inequality and a variation in infant mortality. Thus, this relationship made it possible to anticipate the potential impacts of a change in income distribution (through the GINI coefficient) and a delayed change in infant mortality. In OECD countries, this delay, lag time, was on average 14 years, and 16 years for non-OECD member countries.

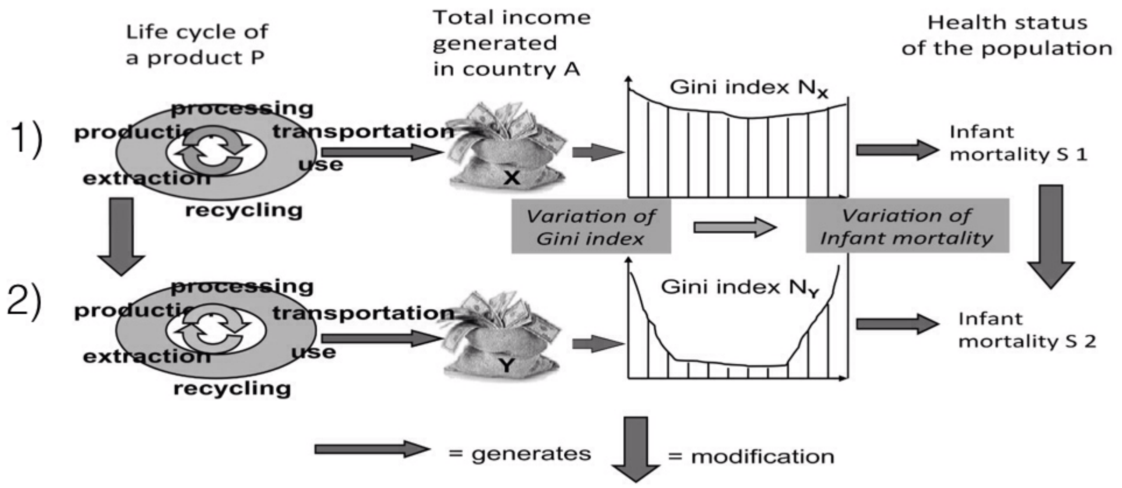


Figure 10. Functional diagram of the Wilkinson pathway (Bocoum et al., 2015, p.407)

Having defined and confirmed the relationship between income inequality and infant mortality, these scholars demonstrated how to calculate the change in income distribution (in the GINI coefficient) as a result from a change in the life cycle of the product (expressed in variation in turnover). A case study in country C exemplified how imported wine is replaced with the wine production in country C, see the functional diagram in Figure 10. In country C, table wine is 1) imported entirely from abroad in the baseline situation (the upper process in Figure 10) and 2) produced within the country after the change. The variations in infant mortality caused by this change in a life cycle were calculated through the steps: a) the number of jobs created for the direct suppliers, b) the variation of income inequality represented by that of the GINI coefficient, and c) the link between the variation of the GINI coefficient and the variation of infant mortality within the population. The cropland was initially covered with natural grassland and sown pasture used to feed animals, the grapevines were cultivated by intercropping with maize (Federer W.T., 1999), the area of 500 000 ha for each crop, and the quantity of wine produced replaced the same quantity that previously was imported (40 million hectoliters). The findings of this case provide valuable insights into social LCA and the methods how it is possible to anticipate the impacts on health caused by an important change in the life cycle of a product. The readers are referred to this study in order to get the exact calculations. The results indicated that in OECD countries, a 1 % variation in the GINI coefficient leads to a variation of about 1 % in infant mortality at the end of 14 years, all other things being equal. For other countries, the results showed that a 1 % variation of the GINI coefficient leads to a 0.5 % variation in infant mortality at the end of 16 years.

The social LCA study utilizing the Wilkinson pathway (Figure 10) concentrated on a social change caused by the change in the LCA, when the import of the product was substitute for the production in country C. Analyzing the potential impacts and describing the system with a process flow diagram throughout a product's life cycle (e.g., cradle-to-grave) provide a system perspective (Chapter 3.3.3 discusses complex systems), which will prevent sub-optimizations in LCA studies. Then, within a system, the sub-processes can be investigated and find out the best potential solutions.

Even though there is much research needed for establishing social LCA, the developed tool, called Wilkinson Pathway, is very promising for governments and big companies and helps them assess the global impacts of their activities on the entire population of a country and make decisions (e.g., sustainable purchasing) against these assessments. These purchasing behaviors and prosocial behavior are related and discussed in Chapter 3.1. This customer-oriented approach in this licentiate thesis frames the understanding of the corporate social responsibility (CSR) related to the customer satisfaction (Beltz & Peattie, 2009; Grönroos, 2000; 2007; Halme, 2014; ISO 26 000, 2010; Lozano R., 2015; Petersen, 2013; TriplePundit, 2015; Urban & Hauser, 1993).

2.2 Market perspective

The bottom of pyramid income (BOP) group was defined in Chapter 1.5. These 4 000 million people are estimated to be a potential market sector of 5000 billion USD. Analysis of the data from household surveys in 110 countries showed that even though Africa has a slightly smaller BOP market, at $429 billion, it is by far Africa's dominant consumer market, with 71% of purchasing power and 486 million people equal to 95% of the surveyed population (Hammond et al., 2007). Globally, this $5 trillion consumer market falls into categories BOP500 to BOP3000, BOP500 representing individuals living less than $500 a year and BOP3000 individuals between $2500 and $3000 as illustrated in Figure 11. The categories in BOP markets in Africa show a different pattern, BOP1000 being distinctly the largest market compared with other categories.

Table 1 illuminates how markets of Food, Energy, Housing, Health, transportation, ICT, and Water are disruptive fields for new innovations in wellbeing and smart living environment. Global Food markets of approximately 3 000 billion USD are the largest segment in BOP 5 000 billion total markets potential (Table 1, Chevrollier, 2011; Hammond et al., 2007). Furthermore, according to future estimates in 2030 by World Bank (World Bank, 2013), Africa's total agriculture and agribusiness could create opportunities for an industry sector of 1 000 billion USD, which is half of Africa's total economy of 2000 billion today (Leke et al., 2014). Regarding potential Food markets development, Africa has most of uncultivated land in the world (Deininger et al., 2011, p.xxxiv), approximately 6 % of land is irrigated and in Sub-Saharan Africa only 4% (You et al. 2010). (Berman, 2013; Mukherji & Facon, 2009; Sasson, 2012). (Chevrollier, 2011; Hammond et al., 2007).

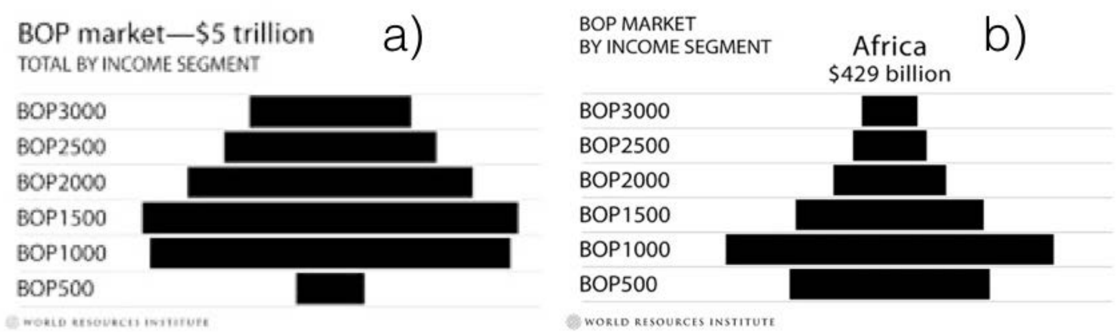


Figure 11. a) Categories of Global BOP markets and b) in Africa (p.19) (Hammond et al., 2007, p.13, p.19)

Table 1. Market opportunity by sectors in global BOP markets, Saarinen, R., (2015b), Sources: Chevrollier (2011); Hammond et al., (2007)

Estimated BOP Market $5 trillion	
Market Sector	**Value in $1000 million**
Food	2 895
Energy	433
Housing	332
Transportation	179
Health	158
ICT	51
Water	20

According to the latest IEA scenario, 950 million Africans will gain access to electricity by 2040, but 530 million people will remain without electricity in Sub-Saharan Africa (IEA, 2014, pp.13, 79). On the other hand, electricity is a basic need as was reviewed in Chapter 2.1.7. The largest potential in BOP markets in the energy sector exists in Sub-Saharan Africa: more than 620 million people in Sub-Saharan Africa remained without access to electricity in 2012 (IEA, 2014, pp.19, 30), Appendix N illustrating access to electricity in Africa (in TAMAA Saarinen, R., 2015a). Thus this IEA projection ties the research questions and the opportunity: What basic customer needs of rural people in Africa can be met by providing sustainable energy services and how villagers' wellbeing is empowered by these services?

3 Socio-technical complex system and methods

3.1 Wellbeing in a process of social change

The addressed research question was how to build sustainable flourishing Village Community, and which kind of socio-technical system, learning community and partnership model might produce the wellbeing of rural villagers. For this purpose, the licentiate thesis took a view of prosocial behavior as an action and mechanism to bridge the gap between customer (villager) needs and the reality (see Figure 3). Prosocial is defined by Oxford Dictionary Online as ‘Relating to or denoting behavior which is positive, helpful, and intended to promote social acceptance and friendship’. This multilevel, multidisciplinary, and cross-functional social change process applied critical realism (see Chapter 3.3.1), which can promote a social learning process for livelihood and wellbeing. This is about education, technology transfer, competence development, or personal development but also about villagers, who in collaboration will need economic and social development in their environment (UN WCED, 1987). First, this licentiate thesis discusses what are prosocial behavior and its consequences to the change in villagers’ quality of life and in the wellbeing of partners in Chapter 3.2. Second, Chapter 3.3 explores critical realism, complex systems, research process and case study research, whereas Chapter 3.4 the socio-technical solar-powered system. Finally, Chapter 3.5 elaborates learning organization and participant action research, interviews and sampling, as well as covers qualitative and mixed methods research. This kind of social change process is illustrated in Figure 12.

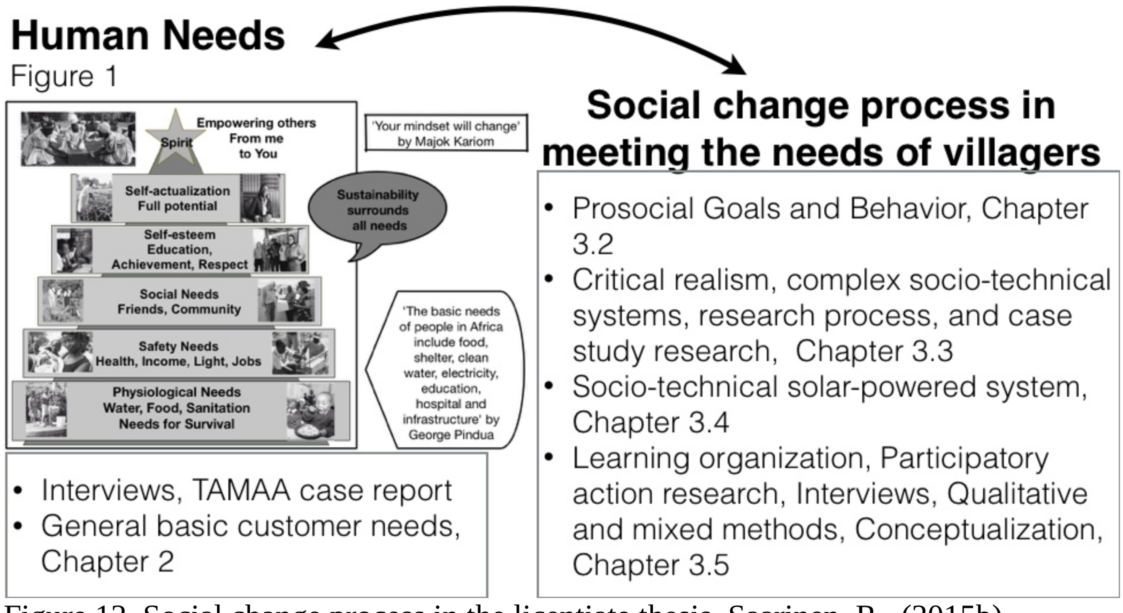


Figure 12. Social change process in the licentiate thesis, Saarinen, R., (2015b)

3.2 Prosocial goals and behavior

3.2.1 Happiness and wellbeing

Several distinguished scholars offer their explanations to this question what is happiness and wellbeing. Frey (2008, p.5) defined “Happiness is a by-product of ‘good life’”, and he continues that according to the eudaimonic (Greek eudaimonia Happiness) view of happiness, people should live according to their true self (daimon); this kind of value-based attitude towards life has potential for lifelong satisfaction. As Maslow (2000), Frankl (2010) and Järvinen (2007) introduced (Chapter 1.2), empowered people have capabilities to develop their full potential, they can search for meaning that makes their life worthwhile, they can even empower others. The empowerment of others and learning organizations (Järvinen 2007) led this discussion to flourishing organizations, and to the positive leadership studies of Cameron (2008). He discoursed about flourishing, honoring, benevolent, excellent, and flow, and continued with enablers as compassion, forgiveness, and gratitude to create a positive climate for the wellbeing of organizations. Furthermore, he showed how positive relationships, which are generative sources of enrichment, vitality, and learning, influence on our whole physical systems, and how persons called positive energizers, benefit their organizations by enabling others to perform better. As Jay (1996, p.180) crystallized, 'true happiness went well beyond its equation with economic well-being'. Having generally introduced happiness and wellbeing, the next chapter now shows through case studies how concrete prosocial goals are able to catalyze sustainable social changes and are thus recommended for development co-operation work in order to build sustainable flourishing Village Community.

3.2.2 Prosocial behavior case studies

First, this licentiate thesis investigates through a case study (Rudd et al., 2014) how specific expressed prosocial goals and actions with these goals in your mind, indeed, make people happier after these actions. Second, after familiarized the concept prosocial goals, this thesis continues with case studies how spending money on others promotes happiness (Dunn et al., 2008), and then, how active decisions elicit latent willingness to donate (Stutzer et al., 2007). Next, the universal study addressed the question, whether these prosocial behaviors in spending money on others are universal (Aknin et al., 2014). By applying the experiences of these cases, Chapter 4.2.3 analyzes and discusses business opportunities, wellbeing and prosocial goals in the results part of the licentiate thesis.

1) Concrete Prosocial Goals

This Concrete Prosocial Goals case showed how and why persons who accomplished prosocial acts with specific goals in their minds, felt themselves afterwards happier than those ones who had more abstract goals (Table 2). Rudd, Aaker, and Norton (2014) conducted experiments both in fields (4) and in the laboratory (2). They addressed the question of 'would a more concretely-framed prosocial goal (e.g., making someone smile or increasing recycle) make people happier than those people who assigned a more abstractly-framed prosocial goal even though with similar functionality (e.g., making someone happy or saving the environment)'. Unlike most studies regarding happiness and wellbeing, this case extended beyond people's individual goals and have leveraged to broader group of people.

First, the results revealed that specific goals in mind reduced the gap between expectations and reality. Then, the crucial thing was that the goals were concretely expressed (Novick et al., 2002) and had a real power in them to make a change in a receiver (e.g., made a person smile), or to influence on a target society (e.g., increasing the amount of materials or resources to be recycled or reused), or to give even chances to multiple people or a group (e.g., gave a person who needed a bone marrow transplants a better chance in finding a donor). Equally important, the results of these 6 experiments were valid at individual, society and community (a group of people or multiple people) levels. Certainly, concrete specific prosocial goals promote happiness and benefit the receivers of benevolences. The final test result showed that people were not able concretely to predict the correlation between the concrete prosocial goals and happiness.

Table 2. Prosocial Goals case, Saarinen, R., (2015b)

Prosocial Goals Case Study (Rudd et al. 2014)						
Experiment	1 Initial test	2	3 Laboratory	4	5 Laboratory	6 Final test
Sample	50 persons: 62% female, 38% male	127 persons: 71% female, 29% male	60 pairs of university friends: 49% female, 52% male	70 persons: 70% female, 30% male	92 University students: 64% female, 36% male	84 persons: 62% female, 38% male
	Individual persons experiments			Society experiments	Multiple people or group experiments	Individual experiment
Concrete prosocial goal versus more abstract goal	make someone smile (more concrete goal) versus make someone happy (more abstract goal)			increasing the amount of materials or resources that are recycled or reused (more concrete goal) versus supporting environmental sustainability (more abstract goal)	give those who need bone marrow transplants a better chance of finding a donor (more concrete goal) versus give those who need bone marrow transplants greater hope	make someone smile versus make someone happy
Greater personal happiness	Yes	Yes	Yes	Yes	Yes	
Reduced the gap between expectations and real outcome	N/A	Yes	Yes	Yes	Yes	
More specific goal in mind when performing	N/A	Yes	Yes	Yes specific goal in mind	Yes specific goal in mind	
More concrete goal	N/A	N/A	Yes	Yes more concrete goal	Yes more concrete goal	
Specific goal in mind correlates with better match with outcome	N/A	N/A	Yes	Yes, Specific goal in mind matches better with outcome	Yes, Specific goal in mind matches better with outcome	
Predicted more personal happiness with more concrete goal	N/A	N/A	N/A	N/A	N/A	Persons with the concrete goal did not predicted their happier conditions

2) **Prosocial Spending Money Promotes Happiness:**

Scholars Dunn, Aknin, and Norton (2008) demonstrated in their studies that spending money on others promotes happiness, and how people spend their money is at least as important as how much they earn, particularly once person's basic needs are met. First, these scholars conducted the baseline study, and asked people (632 Americans) to map their spending habits in their typical month to categories, and the answers were then classified to the prosocial and the personal spending group. Simultaneous regression showed that those who spent more on others felt more personal happiness than those who spent on themselves. Furthermore, the results showed that prosocial spending and incomes were independent and similar in magnitude, and personal spending was not related to happiness (see Table 3). Second, these scholars tested how an economic bonus and its spending will influence on employees' personal happiness. As in the baseline test, those who spent their bonus on others felt happier than those who spent it on themselves, and the impact of prosocial spending remained significant when testing pure income effect. Therefore, they continued with the personal gifts in order to demonstrate the causal impact of prosocial spending (cause and effect). After receiving an envelope with a gift, people were randomly asked to spend the money by 5pm that day either on himself or herself or on someone else as a gift or as a charitable donation. As in previous tests, those who spent their gifts on others felt happier than those who spent on themselves and the size of the gift did not influenced on the happiness.

Table 3. Prosocial Spending promotes happiness, Saarinen, R., (2015b)

Prosocial spending promotes happiness (Dunn et al. 2008)			
Prosocial spending versus personal spending	**Samples**		
	632 American (55% female)	**16 employees received a bonus**	**causal impact, the received gift, N=46**
higher prosocial spending	significantly greater happiness	significantly greater happiness	greater happiness
personal spending	unrelated to happiness	unrelated to happiness	unrelated to happiness
pure effects on income	independent of prosocial spending	independent of prosocial spending	
spending your bonus/gift on others		significantly greater happiness	greater happiness
additional effects of income		prosocial spending remained significant	
additional effects of the amount of the bonus/gift		prosocial spending remained significant	prosocial spending remained significant
spending your bonus/gift on yourself		unrelated to happiness	unrelated to happiness

3) Active decision increases donates:

Stutzer, Goette, and Zehnder (2010, 2007) made evident that active decisions increase donations and uncover latent social preferences; active decisions understood as an elicitation mechanism (by A Marshall as cited by Stutzer et al., 2010, p.2), which ‘is potentially capable of transform latent willingness to donate, contribute, or share into actual pro-social behaviour’. Their experiment was incorporated in a Red Cross at the University of Zurich, and more than 1 800 students participated, who were separated in three groups according to commitment levels in active decision questions. All groups received an information sheet and the schedule for donation dates. The student in Strong Active Decision (AD) group had the active question in the information sheet, whether they want to donate blood with the available answers a YES and a NO, and a schedule when they will donate (the option YES) (see Table 4). The second group named Weak Active Decision has the same YES and NO options and the option to delay the decision.

Table 4. Active decision (AD) increases donations, Saarinen, R., (2015b)

Active decision increases donations, Stutzer et al., (2010): uncover latent social preferences			
Sample: > 1800 students participated at Zurich University, response rate over 95%			
Levels in active decisions	**Questions in willingness to donate: however all participants got an info sheet and dates for donations**	**Awareness of the importance of this prosocial action: NOT Aware**	**Awareness of the importance of this prosocial action: NOT Aware**
		The effect on people's actual blood donation	**The effect on people’s stated willingness to donate**
Strong active decision	Active question 'yes' or 'no': willingness to donate at the scheduled choosable dates	Latent donors became active: Probability to donate increased 8.2-8.7% compared to no AD (reference)	Latent donors became active: Probability increased 7.2% in participation compared to weak AD (reference)
Weak active decision	as above 'yes', 'no', but also 'no decision at the moment'	Probability to donate increased 3.8-4.5%* compared to no AD (reference)	Reference
No active decision	No question in willingness to donate	reference	NA

Confronting students with strong active decision questions increased 8.2-8.7% of students' actual effect to donate compared with reference group, who had no question regarding willingness to donate. When comparing students' answers regarding their willingness to donate, strong active decision question increased willingness to donate by 7.2 %. These results were valid among the students, who were not sufficiently aware of the social significance of blood donations, and the awareness was elicited by a question 'Do you feel sufficiently informed about the importance of donating blood?' and had to be answered with a "YES" or a "NO". Thus, strong active decision unlocked students' latent willingness to donate and latent prosocial behavior came visible and increased actual participation in this prosocial action.

4) **Prosocial Spending and Wellbeing: Cross-Cultural Evidence for a Psychological Universal**

The global study provides the first support for a possible psychological universal: human beings around the world derive emotional benefits from using their financial resources to help others (prosocial spending). Scholars Aknin et al. (2014) tested in their cross-cultural study whether the results of other studies were valid universally, these other studies of prosocial behavior and of spending money on other people promotes happiness. The sample represented over 95% of the world's adult population (aged 15 and older), the survey data from 136 countries between 2006-2008. They applied the Cantril ladder, (the Cantril Self-Anchoring Striving Scale, Cantril, 1965 as cited in Aknin et al., 2014) for measuring subjective wellbeing (SWB). They controlled household income and checked whether respondents had lacked enough money to buy food in the past twelve months. The causal impact was tested in Canada and Uganda by randomly selecting participants, and these results were consistent with their hypothesis that the link between prosocial spending and emotional SWB is both positive and consistent across countries, even though spending practices were different in Canada and Uganda.

3.2.3 Prosocial investments and economics

Meier S. (2006) conducted a survey of economic theories on prosocial behavior, and tested these theories by confronting each specific theory with existing empirical evidence, his study mainly based on field and survey evidence. Furthermore, this survey emphasizes that institutional environment might significantly interact with pro-social preferences. Standard economic theories claim that public goods are often under provided, because people free-ride on the contributions of others, as they cannot be excluded from using the public good. Meier claims, however, that in reality, people free-ride less often than is predicted by standard economic theory, the choices people take are not always based on their self-interested, 'material payoff maximizing' motives. Similarly, such other scholars as Offer (2012) agree and argue that choices are not always intended to maximize economic advantages, but they are also intrinsic ones; individual wellbeing depends on interpersonal acceptance such as obligation, compassion, and public spirit as well as what is just and proper.

Interestingly, Meier surveyed not only individual happiness and prosocial behavior but also happiness in the institutional environment, thus he extended his research work far beyond the studies of the traditional wellbeing and happiness. In his studies, this institutional environment where people contribute and behave pro-socially is crucial and he concludes and claims: 'Pro-social behavior is widespread and quantitatively important for economic and societal outcomes. When designing institutions, pro-social behavior has to be taken into account. If it is not, the institutions may not reach their intended goals'. This emphasizing on the wellbeing of institutions is related to studies by Cameron (2008) in wellbeing and flourishing organizations. Similarly, Järvinen (2007) investigated not only instruct aspects of empowerment but organizational aspects of empowerment as well. The reviewed study of the prosocial goals (Rudd et al., 2014) was also extended beyond people's individual goals and leveraged to broader group of people who were interested in environmental sustainability. Taken together, all these effective findings are analyzed in Chapter 4 and showed how prosocial goals and happiness economics (Frey, 2008) benefit the villagers and those who co-operate in achieving flourishing learning Village Community and which kind of partnership model might empower participants. To summarize with the voice of Vuokko Alanne, one of the interviewees: 'Our values influence our society' (Saarinen, R., 2015a).

3.3 Social change in complex systems

3.3.1 Critical realism philosophy for social change

Because this is a research in open dynamic complex socio-technical systems and applies participatory action research for social change, this licentiate addressed the choice of the research philosophy in terms of positivism, post-positivism, relativism, constructivism, or critical realism (Easterbrook, 2007; Easton, 2009; Kemmis, 2008; Outhwaite & Turner, 2007; Robson, 2002; Sayer, 2002). Both *Critical realism* and *positivism*—positivism based on the work carried out by August Compte (Martineau 2000)—study natural and human sciences, but their capability to apply participatory action research and empower social change is the cornerstone for choosing one or other of two as the research philosophy in this licentiate thesis. Kemmis (2008) analyzes how critical realism associates with action research and how these together are capable to make a social change, likewise Robson (2002) shows how action research and initiating social change is possible in real-life research as in critical realism. Furthermore, Reason and Bradbury (2008) emphasize the engagement of interviewees or other recipients of research, the aim not trying change people 'out there' rather change with people, which view is consistent with socio-technical system thinking (Chapter 3.2.3). Regarding positivism, Robson (2002) asks: 'Should you, as a researcher, get involved in these processes?' and means action research and influential approaches to generate change. Finally, Sayer (2000) sees that the phenomena are often identified in open *complex systems* (Chapter 3.3.3) and *critical realism* endorses or is compatible with a relatively wide range of methods. Summing up, basis research philosophy for this licentiate thesis is *critical realism* in open dynamic *complex systems*, and research strategy participatory action research in learning organizations.

Because human beings are crucial parts of socio-technical systems, critical realism offers the choice to investigate both technology and human sciences in collaboration (Chapter 3.3.3) and find out change levers, which can generate the desired output. Critical realistic research happens in a context, which provides ideal conditions to trigger a mechanism, and the outcome is caused by the action to the input by triggering this mechanism (Bennett et al. 1997), the process shown in Figure 13. The mechanism could also block the effect of the action and interfere with the operation. (Robson, 2002; Sayer, 2002). Critical realism describes casual processes in complex systems, where cause and effect are not linear and due to rich ontology this critical realism process has different layers (strata) making it possible to describe causes and outcomes at versatile levels. This approach makes it also possible to create concepts and models, and to study processes and systems rather than variances. (Easton, 2009; Maxwell, 1996, 2009; Oman, 2004; Sayer, 2002; Zachariadis et al., 2010).

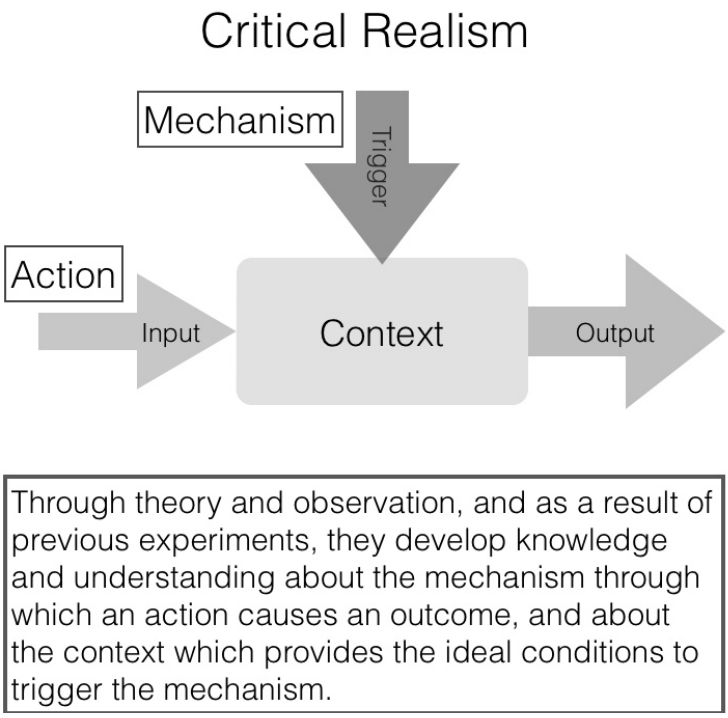


Figure 13. Critical Realism Process, Saarinen, R., (2015b), the definition Robson (2002), p.30

People have the capacity to learn and change, they have potential capabilities to make change happen, because they have powers to act even though in the current situation these powers were neither visible nor observable, thus people need to be empowered (Figure 1). Regarding this social change process (Figure 13), the same mechanism can produce the different outcome according to contexts in open systems, where there are many interacting structures and mechanisms, and vice versa, versatile mechanisms can cause the same outcome. (Aaltonen, 2007; Antonides, 1996; Cameron, 2008; Collier, 1994; Frankl, 2010; Järvinen, 2007; Maslow, 2000; McKenzie & Myers, 2008; Novick, et al. 2002; Saarinen & Hämäläinen, 2004; Whyte, 1991). Acquiring knowledge and meaning (Figure 4) of phenomena is not only a change but also a learning process, and this licentiate thesis, likewise several scholars, considers critical realism a philosophical perspective, which manifests that there is a world existing independently of our knowledge of it, the laws of the world exit, even though our views of this world will change across time according to our knowledge and observations. Thus, critical realism recognizes that fallible humans in particular social contexts construct knowledge, and our research of the phenomena reflects our experiences. (Collier, 1999; Easton, 2009; Jay, 1996; Kemmis, 2008; Keränen, 2010; McKenzie & Myers, 2008; Mingers, 2011; Robson, 2002; Sayer, 2000; Zachariadis et al., 2010). This brings the discussion to the learning organization and participatory action research (Chapter 3.5).

All in all, this licentiate thesis creates shared knowledge and meaning about the context, the conditions and mechanisms, which can trigger the actions on input and make a change happen (see Figures 4, 12, and 13) towards sustainable flourishing Village Community, where villagers can gratify their needs (Figure 1). For this, the licentiate research utilizes prosocial goals and behaviour studies (Chapter 3.2 above) to create a learning community in participatory action research in a complex socio-technical system. Before proceeding to examine complex socio-technical systems, it is necessary to discuss the research process.

3.3.2 Research process

The research process, Saarinen R. (2015b), associates and co-operates with the social change process (Figure 13) and is depicted in Figure 14. This final version served TAMAA Case and the research process of licentiate thesis for driving new applied processes based on this general process:

1. Input: Current Knowledge and Hypothesis
    - What we know about the phenomenon
2. Identify, React
    - Analyse Current Sate: what is wrong with the current theory and explanations?
3. Theorize, Design
    - Research Plan: better/refined theory, research strategy, goals, research questions, sampling, case studies
4. Observe, Test, Experiment
    - Monitor, Measure, Experience, Explore, Find, Field work, Document
5. Evaluate
    a. Evaluate, Analyze, Explanations, Implications, Report, Modify for a new cycle if necessary
6. Output: Fulfilled requirements , if not
    - Start again, if the requirements have not been met

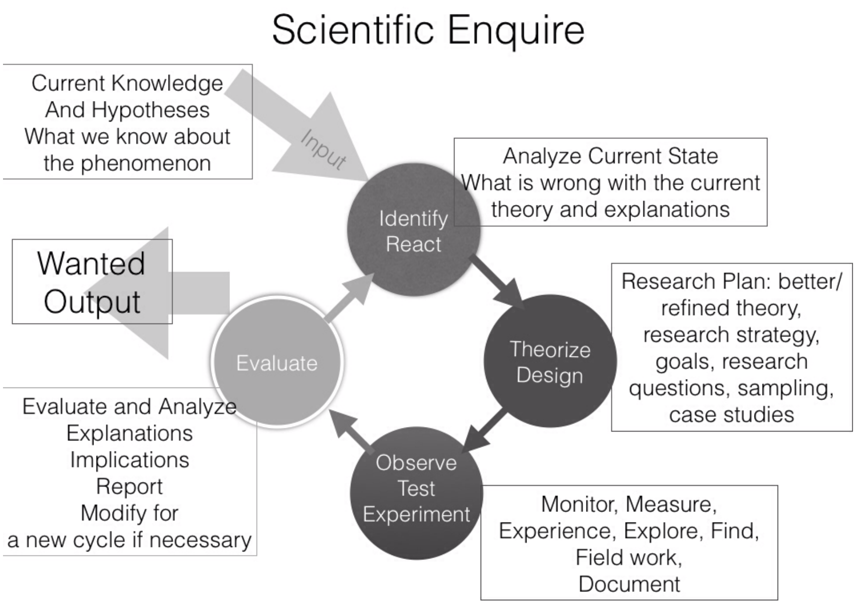


Figure 14. Research Process, Saarinen, R., (2015b)

3.3.3 Complex socio-technical systems

According to (Oman, 2004, p.13) the *system* is defined: ‘a system is constituted by the set X of its elements and their characteristics and by the set R of relations between the elements and the system’s environment. These relations manifest themselves as an exchange of matter, information and/or energy and they determine the structure of the system.’ This definition is general and consistent (Appendix 2 Terms and definitions). The critical realism process (Figure 13) is dynamic and active or proactive instead of reactive and static; it describes interactive open real-life *complex systems*, which are holistic rather than reductionist.

This process has such different layers (strata) as individual, group, community, institutional, or social levels. Real-life complex systems have feedback; humans are capable of looking backwards and learning from experiences. The needs of human beings in complex systems might be obvious, but they are, in many cases, latent (hidden) and can only be captured in multiple methods. Complex systems include non-linearity and chaos, and it is not possible to describe these systems solely with linear methods. On the contrary, they are more like networks and maps rather than linear and hierarchical but have rich ontologies. They do not always produce the same output when presented with the same input, and the system behavior is partly dependent on human operations. (Aaltonen, 2007; Castellani & Hafferty, 2009; Chesbrough, 2003; Doumpos & Grigoroudis, 2013; Hepp et al.2008; Hyppänen 2013; Hyötyniemi 2005; Kane & Trochim, 2009; Kaneko & Tsuda, 2001; Mingers, 2011; Oman, 2004; Saarinen & Hämäläinen, 2004; Sayer, 2000; Senge, 2006). There are ontological diversity and various complex systems in our reality, as shown in the TAMAA system concept map (Kane & Tochim, 2009, 2007) in Figure 15, which are the results of the assessment in TAMAA Case (Chapter 4.2 in TAMAA Case study report, Saarinen, R., 2015a). Furthermore, in this licentiate thesis, Chapter 3.5.5 discusses conceptualization.

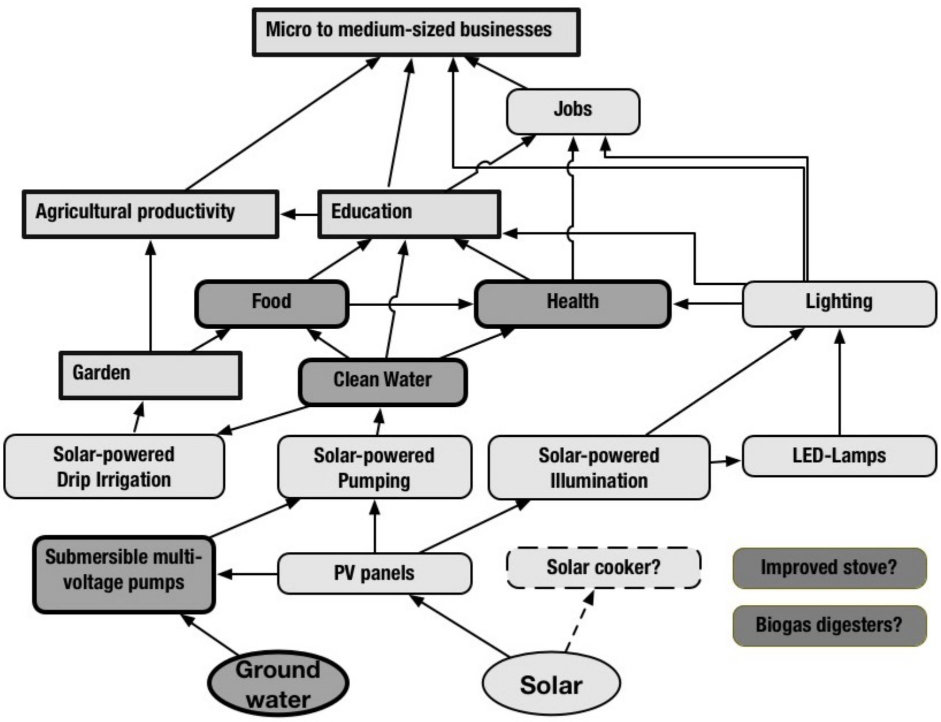


Figure 15. Complex system and rich ontology. System concept map consists of a) Needs: Food, Water, Health, Education, Lighting, Agricultural Productivity, Jobs, and Micro to medium-sized businesses with Energy Services, b) Energy Services: Solar-powered Pumping, Solar-powered Drip Irrigation, and Solar-powered Illumination with technologies, and c) Technologies: submersible multi-voltage pumps, PV Panels, LED-lamps, and with Resources: Solar and Water. TAMAA Case study report (Saarinen, R., 2015a)

Turning now to socio-technical systems, the systems, which comprise both social (sociology) and technical (technology) aspects, in other words, technology and human values. Weck, Roos, and Magee (2011) crystallize these interrelationships: “Meeting Human Needs in a Complex Technological World”. Furthermore, MIT Engineering Systems Division (ESD) has defined Engineering systems as “A class of systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions in society" (MIT ESD, 2008, Weck et al., 2011, p.31; Appendix 2).

The aim is to bridge the human need domain (Figure 1; Chapter 2) and the domain of the complex system and technology (Figure 15) and form the complex socio-technical system, where villagers and other actors can meet their needs, as illustrated in Figures 16 below and 20 (later in Chapter 3.4.1). In this complex causality (see critical realism and Figure 13 above), human nature plays a key role in technological changes (discussed in Chapter 4.1.7) and in the life cycle of products and services (Chapter 2.1.8, and discussed in Chapter 3.4.3.). The complexity of these kind of systems brings the discussion to the service creation process (Chapter 4.1.2) and its capabilities for producing new energy services for villagers, as well as which kind of solar-powered socio-technical system is required for these services (discussed in Chapter 3.4). Furthermore, this licentiate thesis explores how organizational and individual behaviors in learning organizations (discussed in Chapter 3.5.1) and in participatory actions are capable of empowering and creating social changes (discussed in Chapter 3.5.3). (Whyte, 1999). Before proceeding to the concrete solar-based system, the next chapter explains how real-life experiences can be captured through case studies.

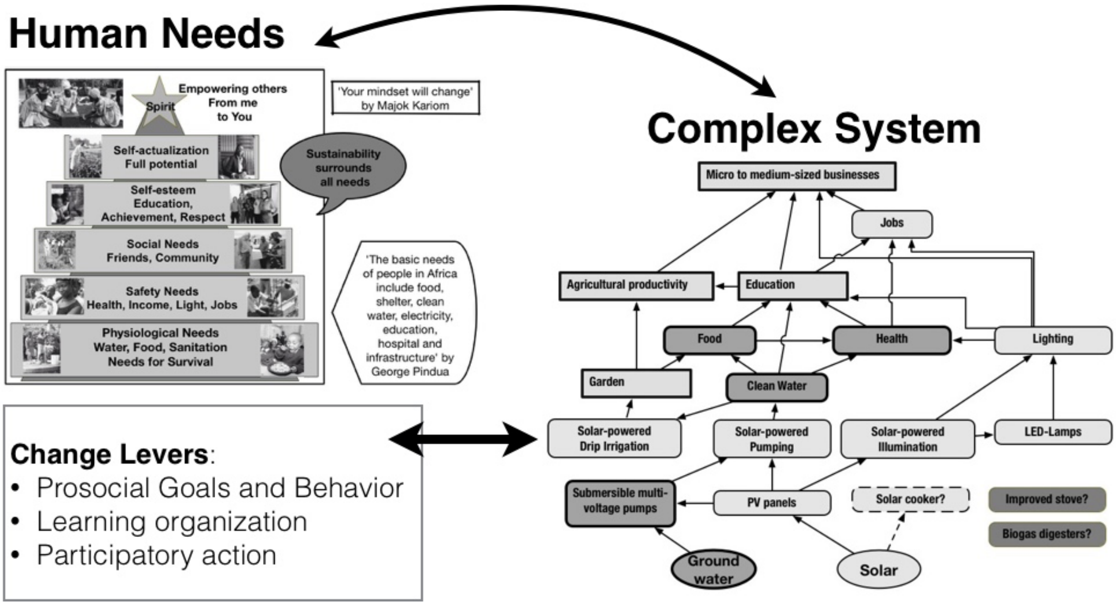


Figure 16. Complex socio-technical system, Saarinen, R., (2015b)

3.3.4 Case study research

The research through case studies focuses on in-depth analyses of one case or multiple cases, they can apply qualitative, quantitative and mixed methods research (Chapter 3.5.4), and usually case studies characterizes complexity (Chapter 3.3.3) and causality (Chapter 3.3.1). The definition of case study research should be defined (Gerring 2007). Yin (2004, p.xiv) defined, "'case' to be 'the real-life set of events from which data will be driven' and the 'case study' is 'the substance of your inquiry'" (see Appendix 2). Yin suggests making a case study significant by embedding it in larger research literature, as this licentiate thesis has accomplished. As discussed in Chapter 3.5.2, TAMAA Case utilized the sample of the representatives of non-governmental organizations (NGOs) and companies, as well as researchers at universities (Table 6), in order to bring the voice of the professionals worked within people in the developing countries and especially in Sub-Saharan Africa. Thus, a case study approach specially fit this licentiate research work; as Patton (2002) put it, when a comprehend understanding is needed in 'some special people, a particular problem, or unique situation in great depth, and where one can identify the cases rich in information - rich in the sense that a great deal can be learned from a few exemplars of the phenomenon in question.'

Similarly, Gerring (2007) highlights this in-depth knowledge of an individual example, and gaining a better understanding of the whole by focusing on a key part. Byrne and Ragin (2009) continue by emphasizing this instance character of a case study, a particular situation or set of circumstances. Whereas, Easton (2009) discusses critical realism and case study research in industrial marketing, and he demonstrated how one or a small number of instances can provide the opportunity to unravel and disentangle phenomena in the research environment of a complex set of factors and relationships, as this licentiate thesis has applied. This is a process of iterative–parallel research (compare with the research process in this licentiate thesis in Chapter 3.3.2 and in Figure 14), which as Easton (2009) cited'..."implies a continuous moving back and forth between the diverse stages of the research project" (Verschuren, 2003)'. To summarize, Yin (2009) crystallizes, '… reality provides important insights into the case…even further value if the interviewees are key persons in the organizations, communities, or small groups being studied'.

In-depth analysis of multiple cases offers, as Miles and Huberman (1994) express, 'an even deeper understanding of processes and outcomes of cases, the chance to test (not just develop) hypothesis, and a good picture of locally grounded causality'. Multiple cases as a part of the same case study strengthen the validity of the selected cases and offer the possibility of responding to questions and feedbacks of the first case, i.e., the data from the second case might fill a gap left by the first case or respond better to some obvious shortcoming or criticism of the first case. Furthermore, multiple cases offer the replication of cases or modification of general processes or concepts to local conditions. On the other hand, negative case analysis improves validity and reduces researcher bias as well as brings forward lessons to learn and improve or avoid. Whereas, within cross-case analysis, the first case (like SMILE Case) builds a conceptual framework and the successive cases (like TAMAA Case) investigate whether new patterns matched to the one found earlier. Even more can be learned by exploiting the concept of embedded units of analysis, where a main case is integrated and the data for a case study come from more than a single layer, and the embedded units (sub-cases) are embedded within the larger, main unit of the case study (like SMILE Case) (Yin, 2009; Olsen, 2009). Triangulation (Chapter 3.6) applying multiple methods, qualitative, quantitative, and mixed methods research strategies, will strengthen even further case studies. (Ragin, 2009; Robson, 2002; Yin, 2009).

Regarding structures of case studies, Harvey (2009) brings forward the three level ontology: 1) philosophical ontology, 2) scientific ontology, and 3) social ontology in case studies. Ragin (2009) explains how to conduct cases by outcomes, which is related to the critical realism process (Figure 13) and the research process (Figure 14). Case studies may rely on real-time cases or archival records of case studies, and they can effectively utilize open ended-interviews (Miles & Huberman, 1994; Yin, 2009). One profitable form of case study is a pilot study, which is a small-scale version of the real thing and demonstrates the creation of the real case. Pilot cases have been utilized in ICT systems, manufacturing systems, and energy systems, among others (Larman, 2001; Robson, 2002; Yin, 2009).

Case studies enable people to apply the lessons derived from one situation to other cases (Whyte, 1991; Yin, 2004), and, as Yin (2004) suggests, this licentiate thesis embedded case studies to the larger literature reviews in Chapters 2 and 3. On the other hand, exploiting the concept of the embedded case, Figure 17 illuminates how SMILE Case is constructed from the base case 'Ilunda Water Project' (Stricklin, 2006) and from four other cases embedded in the SMILE case, thus complementing, strengthening and acknowledging the phenomena and the analysis of case study evidence. For the research work of this licentiate thesis, data was gathered during the years 2009-2014, and this work applied case study methodology. These complementary cases (sub-cases) are A1 'Solar-powered drip irrigation in Benin' (Burney et al., 2009, 2013; NDF, 2014), A2 'Energy Delivery and Utilization for Rural Development: Lessons from Northern Ghana' (Kankam & Boon, 2009), A3 'O&M and Training of PV system' (Greasen, 2010), A4 'Solar-Wind Home System' (Kahiu, 2009), and A5 'Solar-Wind Pumping and Irrigation system (Shivrath et al., 2012). The aim of SMILE Case was to evaluate why and how basic needs have been met, and those reference cases offered documented knowledge to be applied in this licentiate thesis, Figure 17 including those cases and their references.

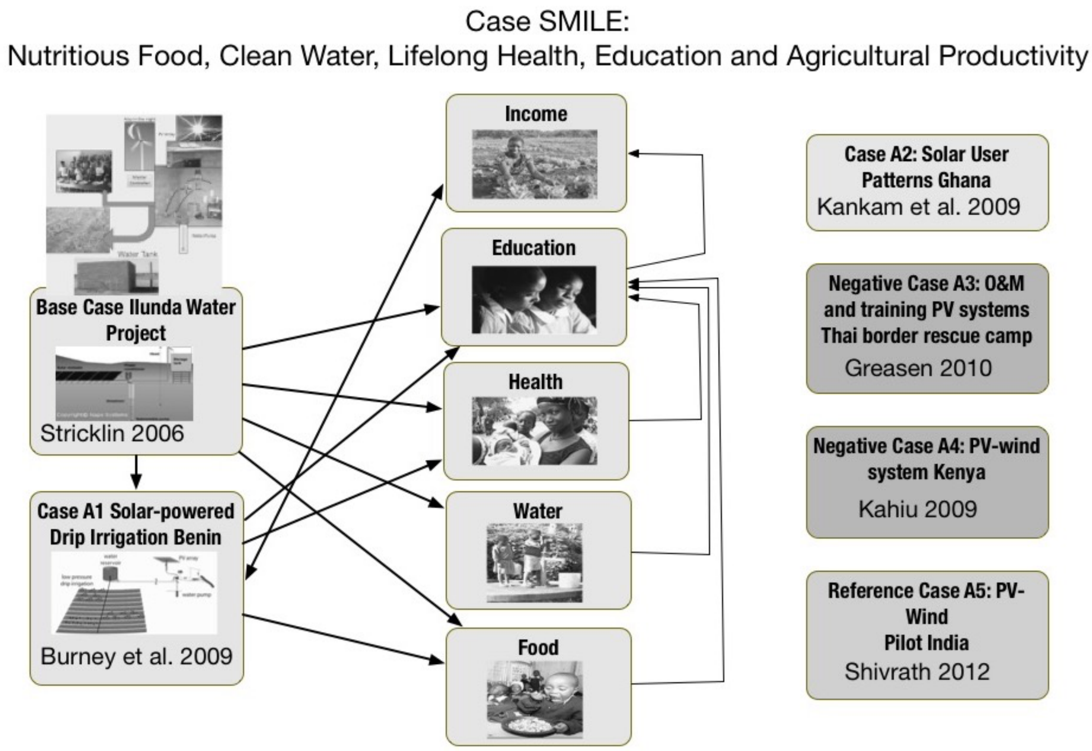


Figure 17. Case SMILE: Base case Ilunda Water Project; A1 Solar-powered Drip irrigation Benin; A2 Solar User Patterns Ghana; A3 O&M and Training PV systems Thai Border rescue camp; A4 PV-wind system Kenya; A5 PV-Wind Pilot India. Saarinen, R., (2015b). Photos (Photo Ref.).

The base case, Ilunda Water Project built a solar-wind hybrid system to produce clean water and irrigate school garden, the readers are referred to TAMAA Case study report (SMILE Base Case in Saarinen, R., 2015a). The embedded case A1, solar-powered drip irrigation, built gardens led by Benin women and this project is broadened to eight gardens and has been successful and sustainable. The negative embedded cases, A3 and A4, provided lessons to learn regarding maintenance, operations, spare parts, warranties, contracts, project management, and community involvements. These aspects and experiences are discussed in Chapter 4.

TAMAA Case continued to exploit findings from SMILE Case and used in-depth face-to-face interviews, reference interviews and cases as well as content analysis, literature reviews and participatory action research to identify needs, concepts, and services, which can empower participants to build a flourishing learning village community. The TAMAA Case process is depicted in Figure 18, and the TAMAA Case study report is documented in the reference (Saarinen, R., 2015a). Furthermore, Chapter 4 discusses the ABC Water project (4.1.4), and the Nepal Light case (4.1.3). SMILE Case provided input to TAMAA face-to-face interviews for formulating some interview questions, which were reviewed and enlarged in TAMAA Case. Based on the interviews and the literature reviews (Chapter 2), TAMAA Case identified Needs and discovered Energy Services, whereas the licentiate thesis widened, created and demonstrated these services. Similarly, TAMAA Case described Village Community and the licentiate thesis widened, demonstrated and created Village Community as a solar-based socio-technical system. According to participant action research (Chapter 3.5.3) the participants provided the feedback for TAMAA Case study report.

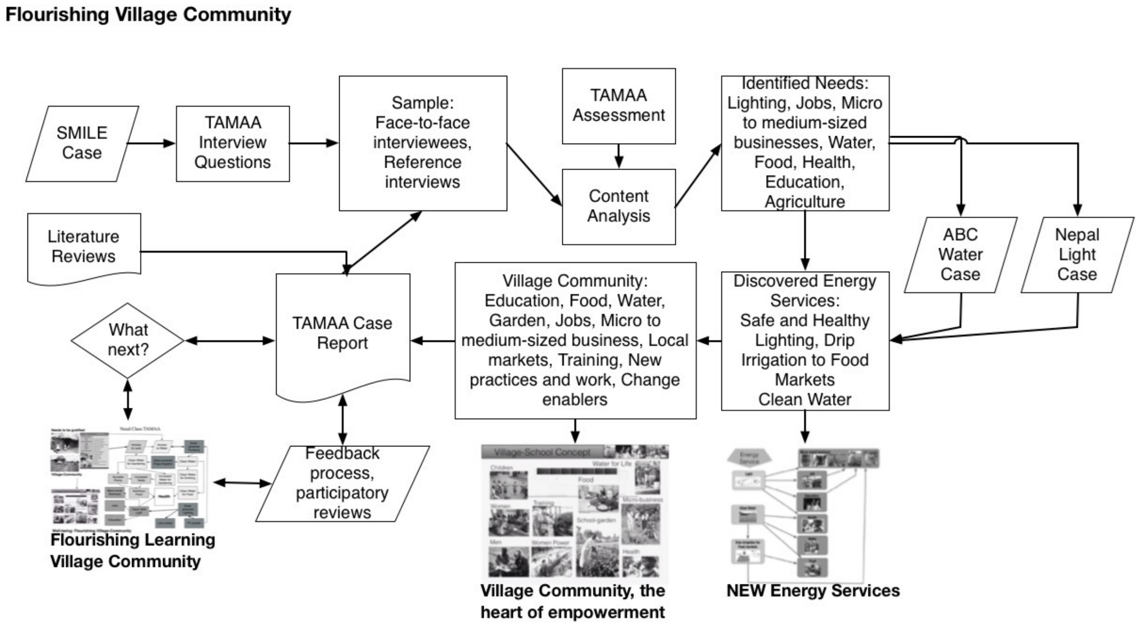


Figure 18. TAMAA Case: TAMAA interviews, the input from SMILE Case, literature reviews (Chapter 2). TAMAA Case identified Needs and described Energy Services whereas the licentiate thesis created these services. TAMAA Case described Village Community and the licentiate thesis demonstrated and created Village Community as a solar-based socio-technical system. The participants provided feedback for TAMAA Case study report, Saarinen, R., (2015a)

This licentiate thesis elaborated TAMAA Case with the EPOPA case study (SIDA, 2008). Moreover, case studies in prosocial goals and happiness were added, named 1) Prosocial Goals (Rudd et al., 2014), 2) Prosocial spending promotes happiness (Dunn et al., 2008), 3) Active decision increase donates (Stutzer et al., 2007, 2010), and 4) Prosocial spending and wellbeing: cross-cultural evidence for a psychological universal (Akin et al., 2014) as described in Chapter 3.1.2. The creation of new services produced the outcome, the new services, which are capable of meeting the needs of villagers, the service creation demonstrated in Chapter 4.

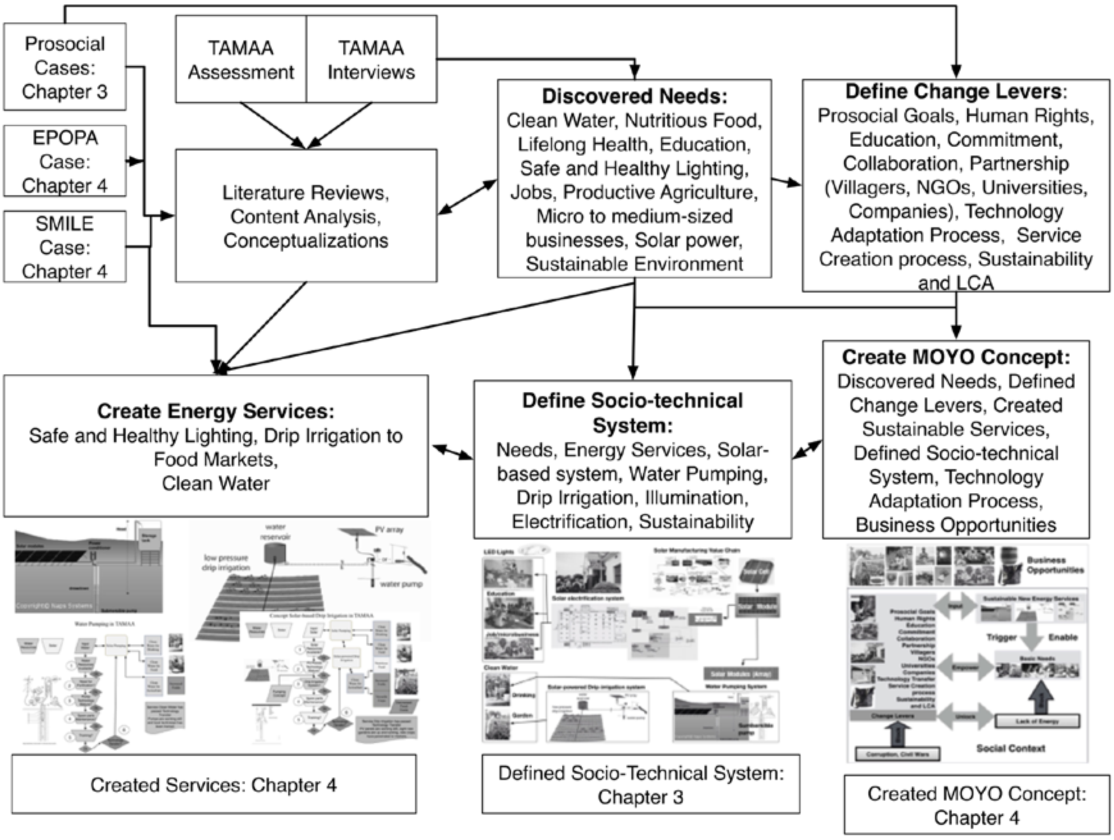


Figure 19. Licentiate thesis: TAMAA interviews and assessment, Prosocial cases, EPOPA Case, SMILE Case. Discovered Needs and defined change levers. Defined socio-technical solar-powered system. Created energy services. Created MOYO concept, Saarinen, R., (2015b)

3.3.5 Review socio-technical complex systems in critical realism philosophy

Whyte (1991) has applied the concept “socio-technical system thinking regarding organizational behavior” and underlined that organizations are integrations of social systems and technical systems. Similarly, Weck, Roos, and Magee (2011) demonstrate how the social sciences are integrated into complex engineering systems. On the other hand, socio-technical systems have largely been applied in IS and ICT systems (e.g., Hyppänen, 2013; Ruotsalo, 2010; Zachariadis et al., 2010). Regarding socio-technical systems, Whyte has applied this kind of research ’Participatory Action Research (PAR)’ in his studies, and likewise Elden and Levin (Whyte 1991) have introduced so called Scandinavian PAR, which is based on co-generative learning. In addition, Kemmis (2008) analyzes and synthesizes critical realism and participatory action research. One question that needs to be asked, however, is whether complex systems and critical realism correlate.

Sayer (2000, p.13) discusses the problems by identifying causal responsibility in open dynamic complex systems, cited ‘Social systems commonly involve ”dependencies or combinations [which] causally affects the elements or aspects, and the form and structure of the elements causality influence each other and so also the whole’ (Lawson 1997, p.64)”. Moreover, causation (cause and effect) is not linear, but depends on the relationships of structure, mechanism, conditions, and effect/event (see Figure 1.2 in Sayer, 2000, p.15; and Figure 13 above), and the same input can cause different outcomes and vice versa versatile inputs can cause the same output (Robson 2000; Sayer 2000, p.15). These complexities in social open systems, unlike in some of natural sciences, make it practically impossible to isolate out the various components and examine them under controlled conditions. On the other hand, this kind open complex environment offers opportunities to enter new markets and to find partnerships of a new kind disruptive innovations for social change, named catalytic innovations, as is discussed in Chapter 4.2.2. (Christensen et al., 2006; Christensen, 2003; Sayer, 2000).

Mingers (2011) considers the relation of system thinking and critical realisms and their long history. Similarly, Easton (2009) and Sayer (2000) discuss structures and internally related objects or practices in a system. In addition, Easton (2009), in his critical realism case study research in industrial marketing, describes how an organization comprises a series of other entities (departments, people, processes, resources), all of which can affect one another and structures can be nested within structures. Zacharias, Scott, and Barres (2010) have researched critical realism as a theoretical foundation of mixed-method research in IS systems, which consist of both natural sciences (due to their technological characteristics) and social sciences (due to their applications in deeply human contexts such as organizations). They have presented evidences from a study of innovation adoption in financial services and highlight the value of multiple methods in order to inspire and inform the research process and to link research questions in multi-level analysis. The design and use of multiple research methods, each with their own philosophical nuances and practical challenges, can offer new insights to research work by encouraging creativity. (Zacharias et al., 2010).

3.4 Sustainable socio-technical solar-powered system

3.4.1 Layered community system model

Africa has abundant solar resources (Appendix O in Saarinen, R. 2015a), and indeed, TAMAA interviewees (in Chapter 4.1.1; TAMAA Case study report, Saarinen, R. 2015a) preferred solar energy to other energy sources and suggested small-scale village systems. Furthermore, the latest estimations of International Energy Agency (IEA) emphasize that the solar PV systems with diesel generators are suitable for mini-grid and off-grid solutions in rural areas in Sub-Saharan Africa (IEA Energy 2014; Figure 9 and Chapter 2.1.7). For these reasons, this licentiate thesis considered solar power as a baseline for sustainable energy services in African rural village communities. On the other hand, like Chapter 3.3.3 suggested, both human layers and technology layers need to be integrated into a socio-technical system. Therefore, Figure 20 illuminates a holistic view for the basic layered structure of this sustainable solar-powered socio-technical system comprising of people, technology, environment, and community.

System modeling follows the rich ontology illustrated in Figures 15, 16, and Figure 1. Figure 20 has two system parts: a solar-powered system layer and a human system layer. The top level in the human system layer starts from the spirit level and prosocial goals (Chapter 3.2; Aknin et al., 2014; Dunn et al., 2008; Frankl, 2010; Frey, 2008; Meier, S., 2006; Myslinski, 2014; Rudd et al., 2014; Stutzer et al., 2010), which boost empowered people to collaborate as Henry Ford summarizes: ‘Coming together is a beginning, keeping together is a progress, working together is a success’. In fact, prosocial goals (Figures 12 and 16) act as catalysts for social changes as discussed in Chapter 4.2.2. This system provides a communication center named”'Visual Meeting Place” (Figure 21), a collaboration portal, for villagers to be a part of shared knowledge and village community. Education levels provide knowledge of versatile education opportunities and material, which also villagers can upload to the portal. Furthermore, villagers can get knowledge of technologies (here solar systems) and business opportunities, new practices for gardening and agriculture, and opportunities for the collaboration of universities and institutes. Within this flourishing learning community villagers can develop capabilities to achieve their full potential, be self-actualized, be full members of their community, and they can even empower others (Figures 1, 20). (Berthold, 2012; Novick et al., 2002; SGT Studio Programme, 2014).

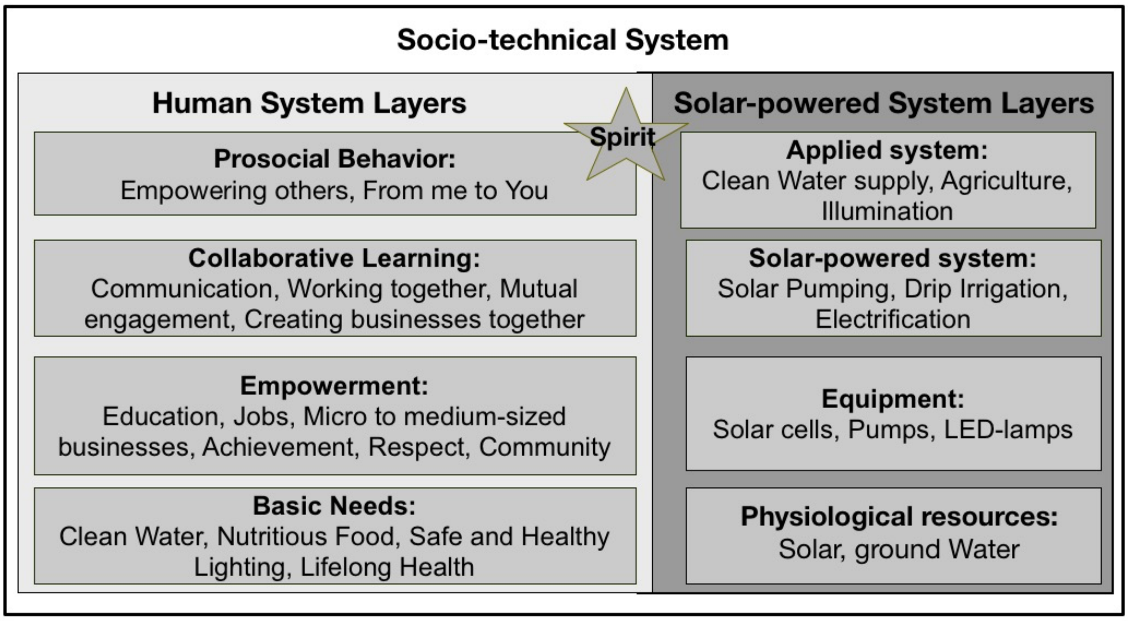


Figure 20. Layered solar-powered socio-technical system. Solar system layers and Human system layers. Top layer Spirit: Prosocial behavior boosts to empower others. Saarinen, R., (2015b)

Figure 21. Visual meeting place, a communication center. Needs at all levels: e.g., Water provides information on Clean Water (as in this licentiate thesis), and Garden provides information on productive gardening, etc. Education at all levels gives information on education opportunities and education material. Building solar systems offers practical and technical knowledge. Saarinen, R., (2015b). Photos (Photo Ref.)

Although this is an illuminated opportunity (discussed in Chapter 4.2), the first step might be like in Figure 22, which emphasizes the communication within villagers, who are discussing about the opportunities, which solar power might provide to their village.

Figure 22. Village meeting place, a communication center, Saarinen, R., (2015b). Photo: Irja Aro-Heinilä. Home solar system: NAPS (2014).

For implementing basic needs, a solar-powered system for a village community is designed (Figure 23) based on solar modules (Chapter 3.4.2), which power submersible pump(s) and get clean soft water for drinking, cooking and gardening, thus decreasing water-based diseases (Chapter 2.1.3). This pumping system (Chapter 3.4.4) provides irrigation and makes soil more prolific and productive as well as balances rainwater irrigation and draught times, resulting in increased yields. Because of productive and prolific drip irrigation, the garden provides more yields than is needed and the surplus can be sold to food markets especially at local market places (Chapter 4.1.5).

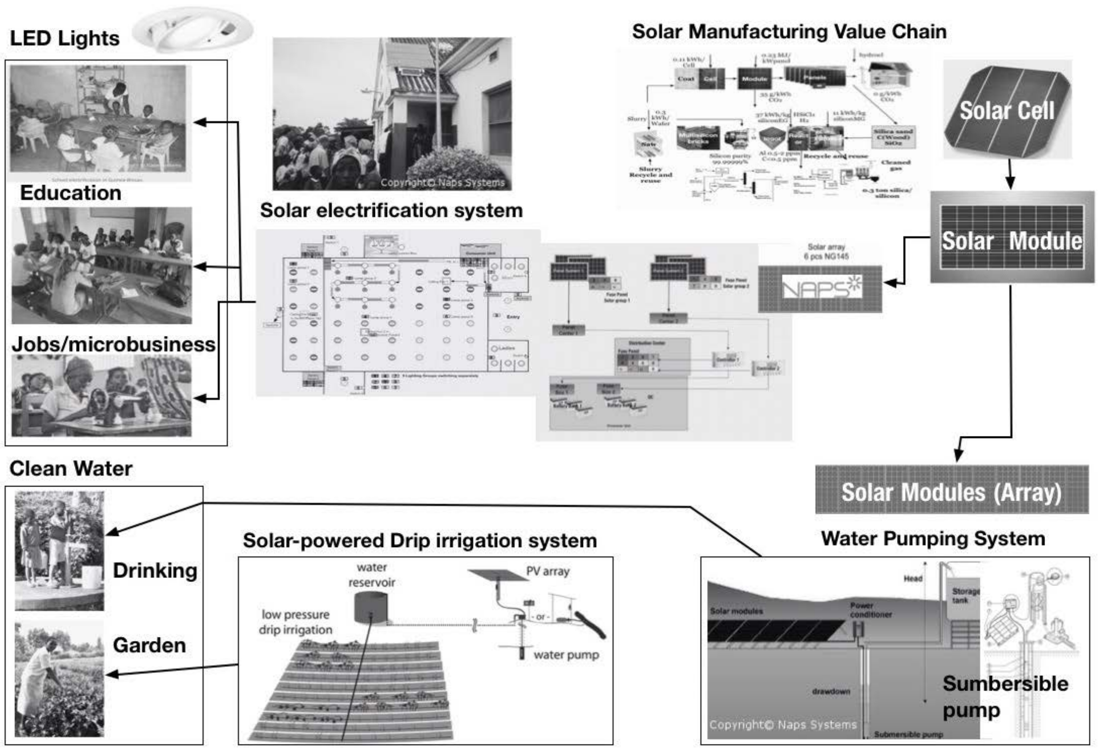


Figure 23. Solar-powered system for a village community, Saarinen, R., (2015b), photos NAPS, SLEF, and Women's Bank, drip-irrigation Stanford (2011), pumps Grundfos (2014). Photos (Photo Ref.), Figure 23 Saarinen, R., (2015b)

The service, Safe and Healthy Lighting, is based on PV modules and comprised of solar-powered illumination with LED-lights at homes, in schools and other buildings. LEDs offer long lasting sustainable solutions with high efficiency, and their replacement cycle is longer compared with, e.g., Compact Fluorescent Light (CFL) bulbs (25 000h or 40 000h versus 8500h, Bland et al., 2012 p.iv), in that regard they are environmental friendly lamps, which are suitable for solar-powered electrifications. Furthermore, significant improvements in health of villagers are caused by decreases in the deceases due to indoor harmful smoke and black carbon from traditional light sources like kerosene lamps. The avoidance of greenhouse gases cools global warming, not to mention the benefits of near nil maintenance and fewer spare parts due to fewer replacements. (Chapters 2.1.4, 2.1.6, 2.1.8 and 4.1.7). Figure 24 illuminates a drawing plan for LED lighting in a large village hall, and the PV system is shown in Figure 25.

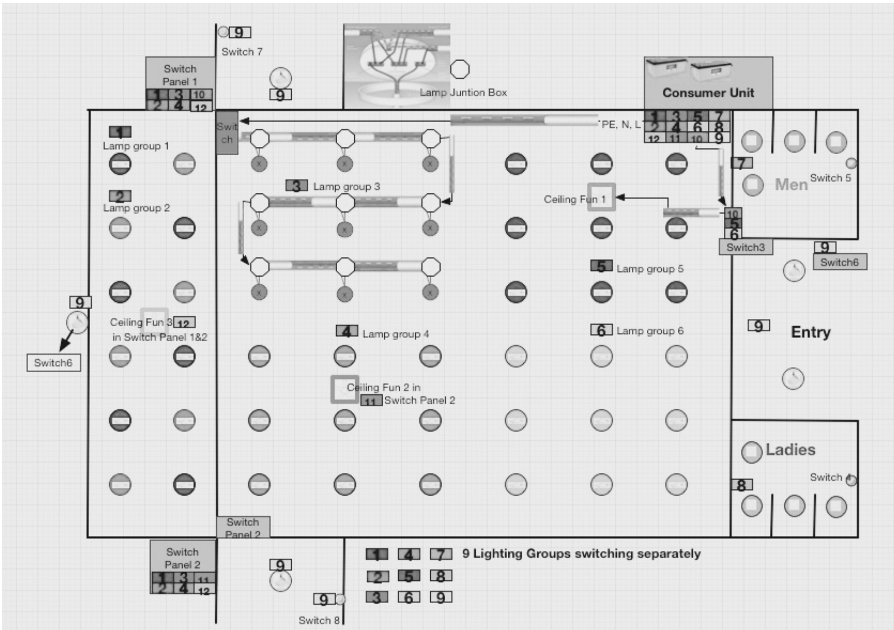


Figure 24. LED illumination drawing plan (see Chapter 3.4.2), Saarinen, R., (2015b)

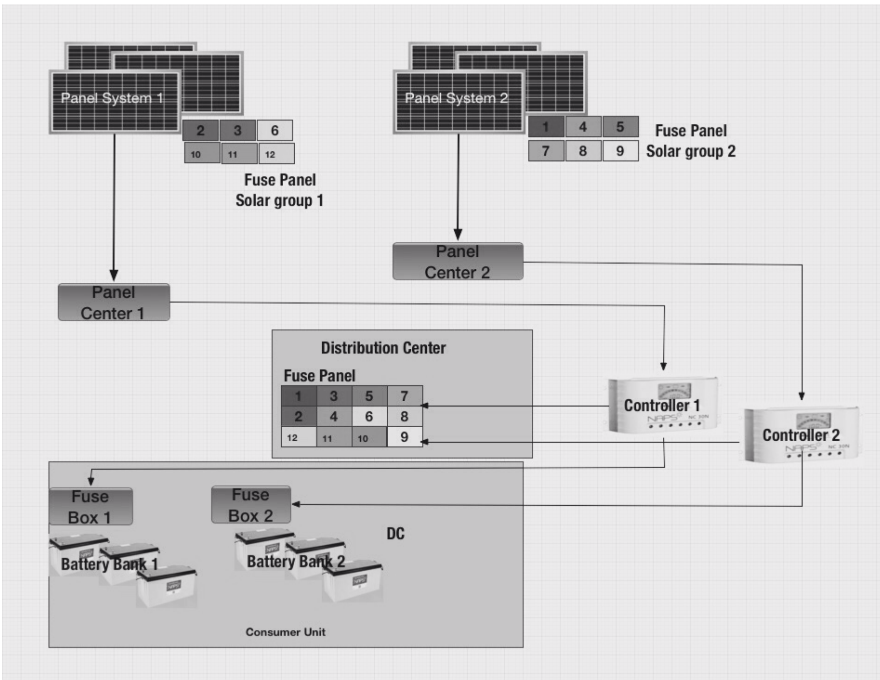


Figure 25. PV Solar-powered system for lighting and other direct current (DC)-equipment (see Chapter 3.4.2), Saarinen, R., (2015b)

Services, Safe and Healthy Lighting, Clean Water and Drip Irrigation to Food Markets, are demonstrated in Chapter 4.1. This discussion turns now to LED and solar cell semiconductors, which form the basic components of solar-powered electrifications.

3.4.2 LED and solar cell semiconductors

In starting to review LED and solar cell semiconductors, the village electrification system (Figure 23) exemplifies theoretical studies and forms the demonstrated concept based on photovoltaic (PV) panels. LEDs and solar cells belong to solid-state physics, which makes it possible to study large-scale solid material systems based on their atomic-scale properties. Thus, these systems are possible to construct from these smaller parts, modules, which are based on semiconductor photonics (light) devices and materials, which absorb and emit photons (Battachary, 2008; Saleh & Teich, 2007; Wenham et al., 2007; Žukauskas et al., 2002). LEDs and solar cells typically have a crystal structure, LEDs converting electrical energy to optical energy while solar cells directly converting optical energy into electrical energy (Kalogirou, 2014; Wenham et al., 2007; Sze, 2002). The key component of LEDs and solar cells is formed from a p-n junction, the p- and n-type doped semiconductors joined together. This junction rectifies, that is, it allows current to flow smoothly in only one direction, and behaves as a diode. (Sze, 2002).

A PV array system (as shown in Figures 23 and 25) consists of PV modules in strings and these strings connected in parallel, the required power output (W) defining how many modules are needed. This kind of system has no moving parts nor noises as well as the emissions are zero during the use phase, as a result they require minimal maintenance and have a long life cycle. Regarding profitability, the changes in the market prices of PV modules have fallen to less than $0.80 per Watt in 2012, compared with approximately $2 in 2010 and $5 in 2000 (Kalogirou, 2014, p.481), and alongside of PV modules the costs of PV systems have decreased (Feldman et al., 2014; Viitanen, 2015); current market prices are available, for instance, in (SolarServer portal) and in (Photon Solar portal), whereas the production costs of silicon are discussed in Chapter 3.4.3. (Kalogirou, 2014; Lobera, 2010; Luque & & Hegedus, 2003; McEvoy et al., 2012; Morales D.S., 2010; NAPS Products, 2015; Wenham et al., 2007).

The required power output of PV devices is dependent on many factors, such as temperature, incident irradiance and spectral irradiance distribution. Thus, PV modules are rated at Standard Test Conditions (STC) with a solar radiation level of 1000 W/m^2 at module temperature of 25°C, with the Maximum Power Point (MPP) of the module output power in W. Despite the inevitable changes in the environment, the solar panels have to operate at their MPP, therefore the controllers of all solar power electronic converters employ some method for maximum power point tracking (MPPT). (Esram et al., 2008; Kalogirou, 2014; Kotti & Shireen, 2015; Lobera, 2010; Morales D.S, 2010; Schmid & Schmidt, 2003; Theocharis et al. 2012; Wenham et al., 2007; Xakalashe & Tangstad, 2011).

PV power generation is caused by the absorption of solar light (photons) in p-n junctions, light generating an electron-hole pair (Figures 26 and 27). The electric contacts are formed from a metallic grid on the front of the cell (negative conductor) and a metal contact on the back (positive conductor). In this p-n junction, electrons move to the negative terminal and holes to the positive terminals, and if an external electric field is present, these charges can produce a current for use in an external circuit. Although new technologies are emerging like thin films (Haller et al, 2013; Hyoungseok et al., 2014; IRENA, 2013; Li & Liu, 2015; Poortmans & Arkhipov, 2006;

Soga, 2006), the typical cell today is crystalline silicon. Silicon (Si) belongs to IV-type in the periodic table and has an indirect energy band gap (Figures 27b and 28a), four valence electrons each Si-atom associated to eight covalent electrons (Figure 27a), Si-properties shown in Figures 28 and 30. Antireflection coating reduces the reflection of light from the front surface of the cell by affecting the angle of light as discussed in a silicon production process in Chapter 3.4.3. (Ceccaroli & Lohne, 2003; Green M.A, 2012, 1982; Kalogirou, 2014; Luque & Hegedus, 2003; McEvoy et al., 2012; Saleh & Teich, 2007; Schmid & Schmidt, 2003; Wenham, et al., 2007; Xakalashe & Tangstad, 2011).

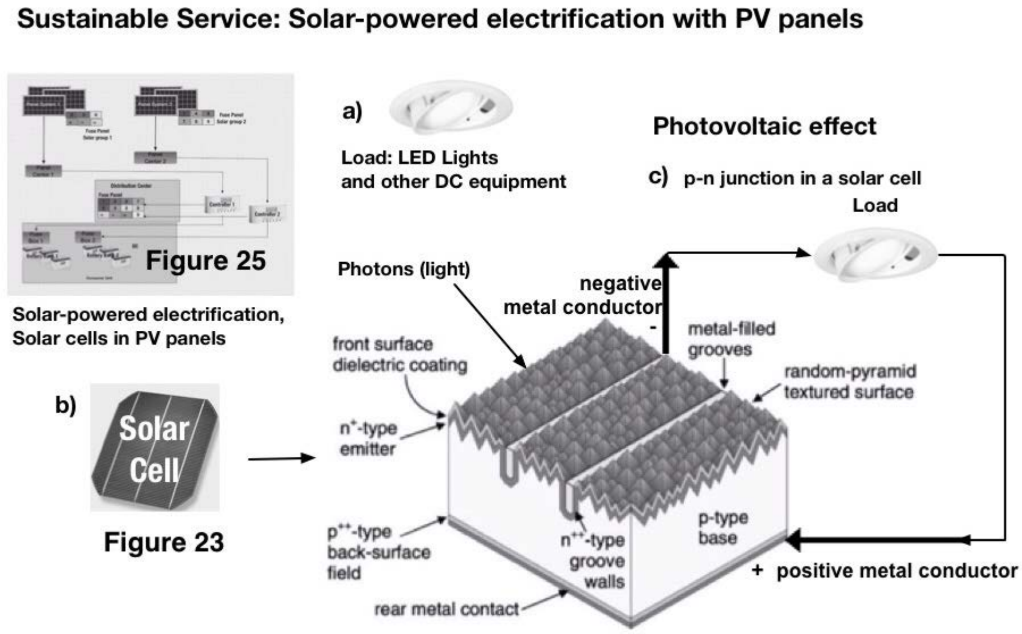


Figure 26. Solar cell semiconductor: a) a load consists of LED lights and other DC equipment, b) a solar cell, c) a photovoltaic effect on a p-n junction and exemplified antireflection coating (Cheung, 2010; Wenham, et al., 2007, pp.70-71). LED-photo Airam

The p-n junction and the concept of energy bands characterize semiconductors. The energy gap or band gap energy (E_g), is the potential difference between the conduction band (E_c) and valence band (E_v) as expressed in Equation (1) (Sze, 2002, p.29) and in Figures 27, 28, and 29, these band structures depending on temperature. As exemplified, Figure 28 shows band gaps at room temperature for Si (1.12 eV) and Gallium Arsenide (GaAs, 1.42 eV, used for the first LEDs). In order to increase conductivity by larger numbers of electrons and narrow the gap between the p-type valence band and n-type conduction band, doping is utilized in solar cells by introducing impurities into the junction (Figures 27 and 29a), p-type (positive, typically boron B, three electrons, III-type in the periodic table) and n-type (negative, typically phosphorus P, five electrons, V-type). This kind of doping moves the Fermi level (E_F) closer to the conduction band for n-type material and closer to the valence band for the p-type material, Fermi energy (E_F) defined in (Sze, 2002, p.34, Appendix 3). Figures 27b and 29a show the Fermi levels of the valence band and the conduction band in thermal equilibrium (total positive and negative charge must be equal) without any external excitations (without an external applied voltage). This doping physically happens in the silicon production process as described in Chapter 3.4.3. (Ceccaroli & Lohne, 2003; Markvart & Castañer, 2012; Saleh & Teich, 2007; Schubert, 2008; Silberberg, 2003; Sze, 2002).

$E_g = E_c - E_v$ (1)

where

E_g = energy band gap

E_c = covalent energy

E_v = valence energy

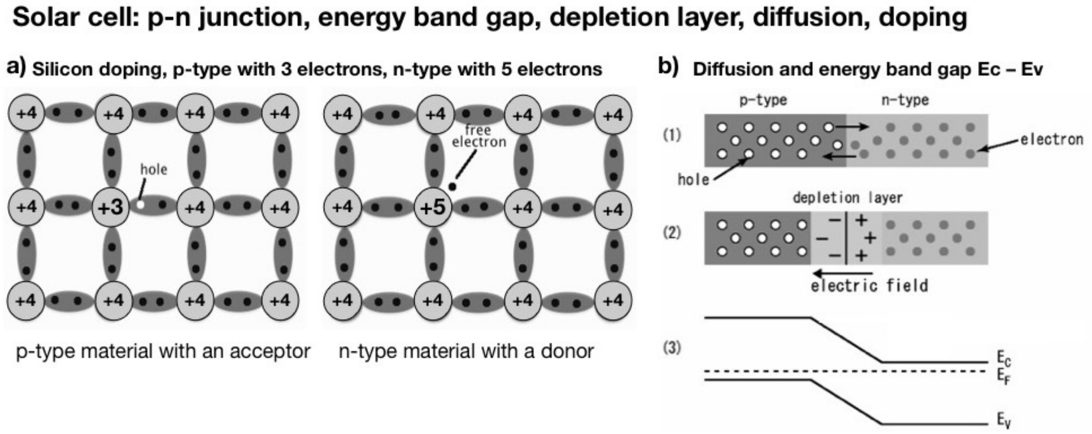


Figure 27. P-n junction: a) Silicon doping, (Bhattachary, 2008; Sze, 2002), Figure Saarinen, R., (2015b) modified from (Pinho, 2013); b) Diffusion and energy band gap, (3) a p-n junction in thermal equilibrium, (McGehee, 2011; Visser & Rolinski and Sze 2002, p.89)

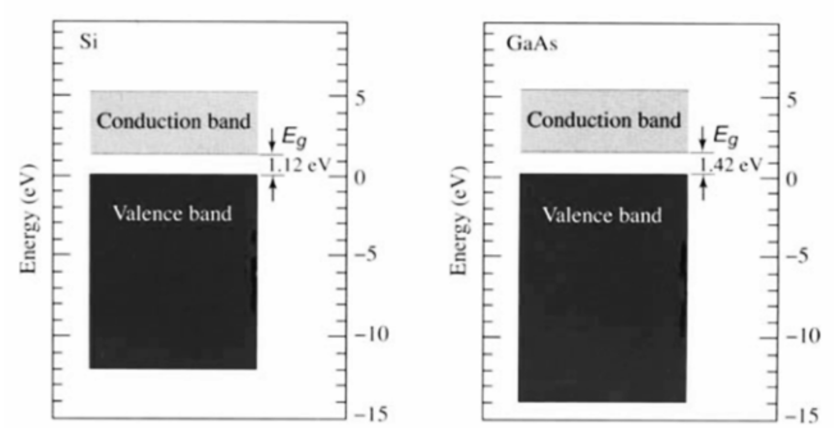


Figure 28. Band gaps at room temperature: a) Silicon, b) Gallium Arsenide, (Saleh & Teich, 2007, p.629)

The power generation was caused by the absorption of solar light (photons) in p-n junctions in solar cells as explained previously. By the absorption of a photon (E_{photon}) in solar cells, Equation (2) (Silberberg, 2003, p.261), electrons can be excited from the valence band into the conduction band and leave behind electron holes in the valence band if the energy of the photon is greater than the band gab of the semiconductor. In the conduction band, the electrons have no atomic bonding and therefore are able to move through the crystal (electrons being charge carriers) and the electrons from the n-type material diffuse into the p-type material swept by the built-in electric field (Figure 29a) and recombine with holes. Similarly, the holes from the p-type material diffuse into the n-side. The electric field forms between positive and negative ions in the depletion region and opposes the directions of photons diffusion as shown in Figure 27b. (Battachary, 2008; Markvart & Castañer, 2012; Saleh & Teich, 2007; Schubert, 2008; Silberberg, 2003; Sze, 2002).

$E_{photon} = h\nu = \Delta E_{atom} = hc/\lambda$ (2)
where
E = energy
h = Planck's constant = 6.626x10-34 Js
ν = frequency (Greek)
λ = wavelength (lambda Greek)
c = speed of light

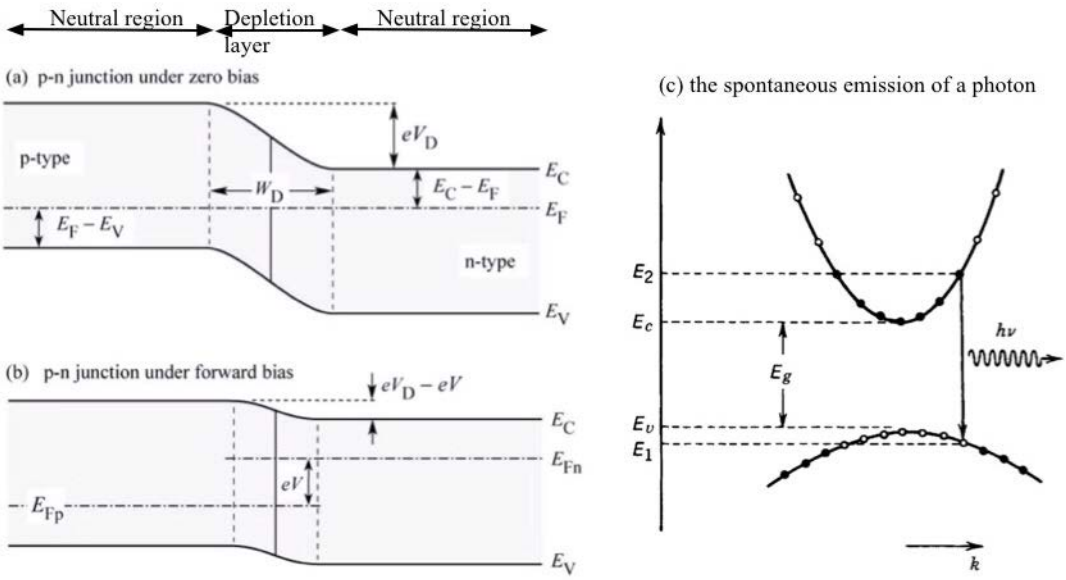


Figure 29. P-n junction under a) zero bias (or at equilibrium), WD = the depletion region width, VD = the diffusion voltage (Schubert, 2008, p.60) (or built-in potential, Sze, 2002, p.91) which represents the barrier that free carriers must overcome in order to research the neutral region of opposite conductive type; b) forward bias. (Schubert, 2008, p.59); c) The spontaneous emission of a photon resulting from the recombination of an electron of energy E_2 with a hole of energy $E_1 = E_2 - h\nu$, see Equation (2) (Saleh & Teich, 2007, p.685)

Unlike solar cells, semiconductors emit photons in LEDs, but before proceeding to examine LED p-n junctions, it is necessary to discuss the nature of light. Visible light is one type of electromagnetic radiation (or electromagnetic energy or radiant energy), which was described by a vector wave theory by James Clerk Maxwell (1831-1879). The optical part of the electromagnetic spectrum is depicted in Figure 30, and the whole spectrum can be found in (Silberberg p.257, Figure 7.2) or in (Saleh & Teich, 2007, p.151, Figure 5.0-1). Modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, the wavelength and the color of emitted light depending on the band-gap energy E_g of the semiconductor as shown in Figure 30. (Schubert, 2008; Sze, 2002; Žukauskas et al., 2002). Regarding the color of LEDs, the introduction of white high-brightness LEDs has changed the lighting, resulting in the replacements of incandescent lamps to solid-state lamps (SSLs) for better energy efficiency (Morkoc, 2009; Narukawa et al., 2010; Poikonen, 2012; Schubert, 2008).

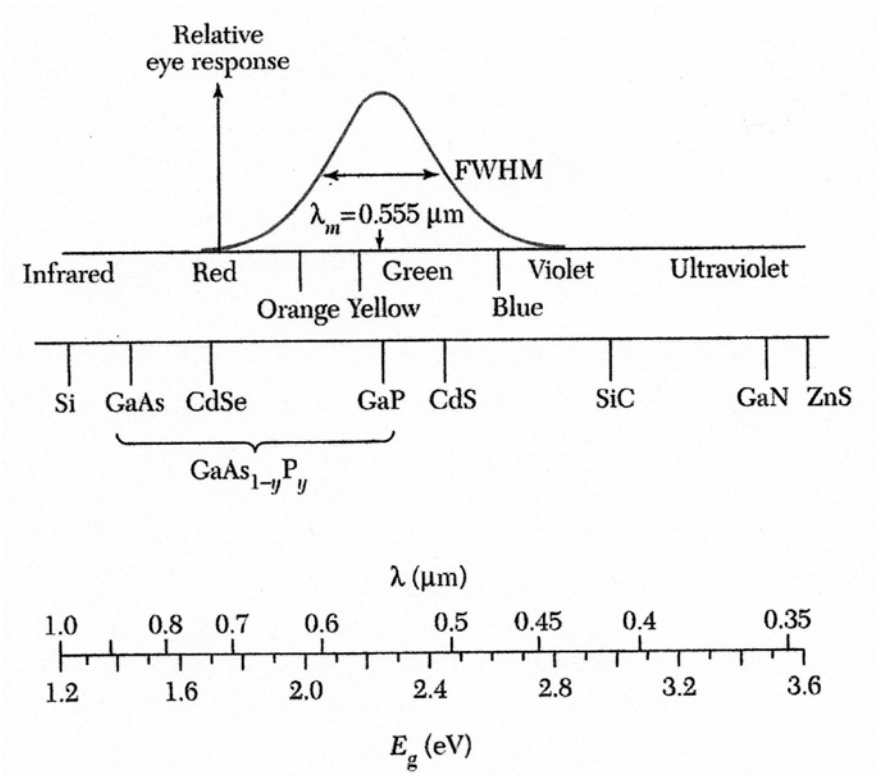


Figure 30. The electrical and optical properties of a silicon and compound semiconductor material in photonic devices. Figure includes semiconductors of interest as visible LEDs and relative response of human eye, the maximum sensitivity at 0.555 µm. Wavelength λ (Greek lambda). FWHM=Full width at half maximum in (Sze, 2002 p.293) and (Schubert, 2008, p.90). (Sze 2002, p.288)

The previous section has described the p-n junction of doped solar cells; similarly most of the commercial LEDs are realized using doped n- and p-junctions. When the p-n junction behaves as a forward bias—an external power applied to its terminals, this semiconductor spontaneously emits (Figures 29b,c and 31b,c). In other words, excess electrons from the conduction band recombine radiatively with excess holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single color) light (Equation 2) according to the electroluminescence effect discovered by H.J Round in 1907 (Round, 1907 as cited by Schubert, 2008, p.2, Sze, 2002, p.3 and Žukauskas et al., 2002, p.38). Furthermore, it should be emphasized that these photons should be allowed to escape from the device without being reabsorbed as shown in Figure 31b, the p-side facing upward. The electric field formed in the depletion region and the external electric field due the DC voltage source opposite each other, the direction of current flowing from p-region to n-region (Figure 31c). (Saleh & Teich, 2007; Schubert, 2008; Sze, 2002; Silberberg, 2003; Žukauskas et al., 2002).

Silicon is a poor light emitter and unsuitable for LEDs because of the low energy barrier and the indirect band gap, therefore the first LEDs were made of gallium arsenide (GaAs in Figures 28 and 30) and produced infrared light (Saleh & Teich, 2007; Schubert, 2006; Sze, 2002; Žukauskas, 2002). Today they are often constructed from III-V semiconductors, and Gallium Nitride (GaN) is considered one of the most important semiconductor materials since silicon (Figure 31b). One essential property of GaN is its direct band gap of 3.44 eV at the temperature of 25°C (Figure 30), which is considerably larger than that of silicon. (Amano et al., 1986; Kauppinen, 2014; Morkoc, 2009; Nakamura et al., 1992; Narukawa et. al., 2010; Poikonen, 2012; Suihkonen, 2008; Törmä, 2011).

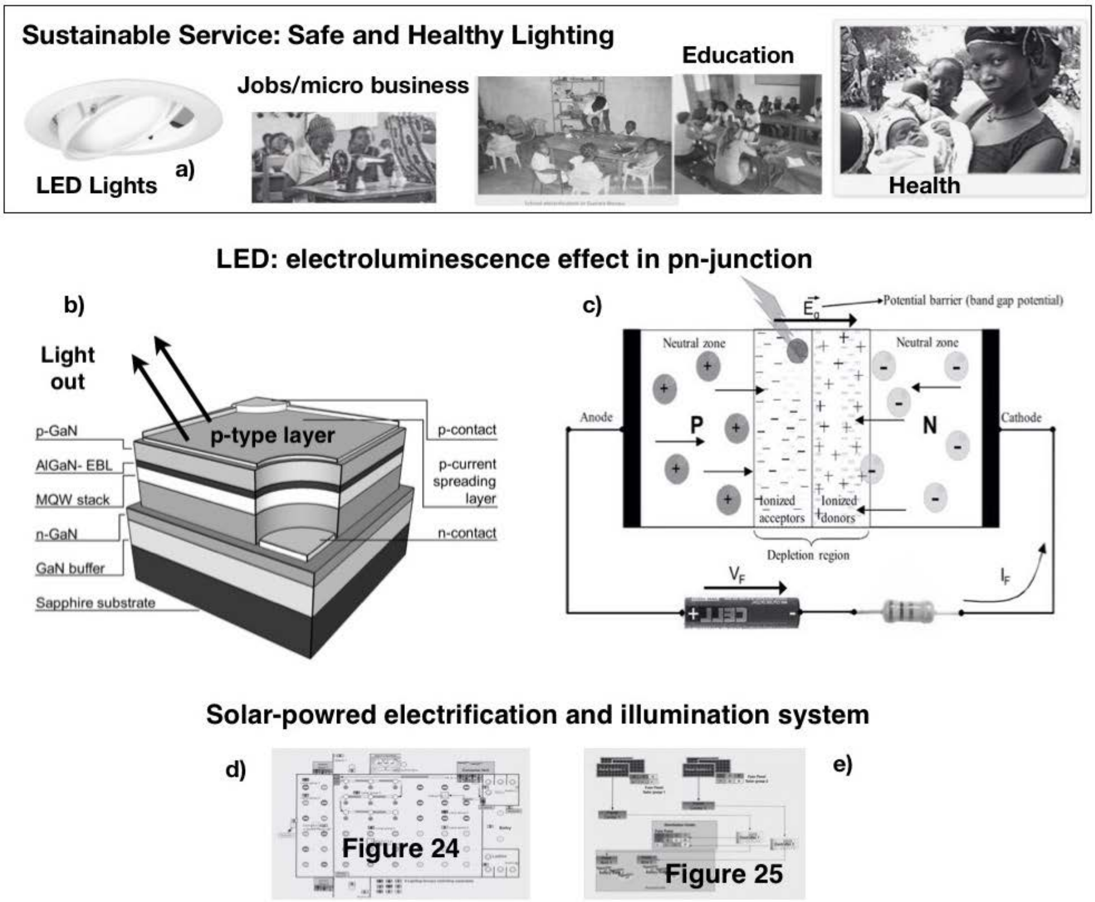


Figure 31. Safe and Healthy Lighting (see Chapter 4.1.2). a) LED lights; b) Gallium Nitride (GaN) LED structure exemplified in the p-n LED junction, Suihkonen 2008, p.32; c) p-n junction, the photoelectric effect of LED, Aalto University School of Electrical Engineering Illumination Engineering (Pinho, 2013), (Schubert, 2008, Žukauskas et al., 2002); d) LED illumination drawing plan in Figure 24; e) Solar-powered electrification in Figure 25. Photos (Photo Ref.). Figure 31 Saarinen, R., (2015b)

This chapter has reviewed LED and solar cell semiconductors as building blocks for LED illumination systems and electrification based on PV modules as illustrated in Figures 23, 24, 25, and 31. The key focus has been on the modular system structure to meet the needs of required outputs in electrification and illumination. This modularity offers tangible advantages to implement these systems step by step and learn by doing (Chapter 3.5). The other advantage to emphasize has been the basic technology of both LEDs and solar cells as photonics devices, which can be applied to versatile systems. Before proceeding to solar-powered water pumping, the life cycle assessment and sustainability are discussed next.

3.4.3 Life cycle assessment and sustainability of solar cells

Chapters 2.1.4 and 2.1.8 reviewed the concept of the sustainability of products and services, whereas this chapter investigates how sustainable is the life-cycle of a silicon PV module from the cradle-to-grave, and what is the sustainable life-cycle of the electricity produced by PV modules. The research scope is a wafer-based crystalline silicon solar cell and module, and the purpose of the life-cycle analysis is to find out a small-scale solution, which neither causes noxious health impacts, unprocessed wastes nor CO_2-emissions. Target audience is NGOs, partner companies and other stakeholders, who together provide new sustainable energy services for households and their village communities. This LCA follows the life cycle stages defined in Figure 32 as the LCA of the product chain, and the primary steps of the supply chain of the wafer-based crystalline Si-module are presented in Figure 33. The functional unit used in this study is 1 kWh of electricity per a PV module. (Fthenakis et al., 2011: Gløckner et al. 2008).

This LCA is reviewed at the stages, 1) raw material extraction, 2) manufacture, 3) use, and 4) waste management (ISO 14040, 2006) (see Figures 32 and 33), and the distribution is discussed afterwards. In comparison to most other energy technologies, the GHG emissions of PV system occur almost entirely during system manufacturing and not during system operation, that is, the use phase of PV panels produces no GHG emissions neither the small particle matters (PMs) nor direct black carbon (BC). This licentiate thesis investigated an exemplified LCA for a solar cell through the supply chain shown in Figure 33, and the results suggested that the net CO_2-equivalent per kWh (g CO_2-eq per kWh) is 13-14 mg/kWh for a crystalline silicon cell module of ESS®-silicon and 16-17 mg/kWh for Siemens-polysilicon powered by hydropower and co-generation. This indicates that the product chain (Figure 33) is noticeably dependent on the energy-mix used. Next is expressed how these results were achieved, for a more detailed breakdown of a solar cell production process and LCA calculations the reader is referred to the references in this chapter and Appendix 1. This LCA study emphasizes the production phase of silicon, turning now to discuss this energy intensive process.

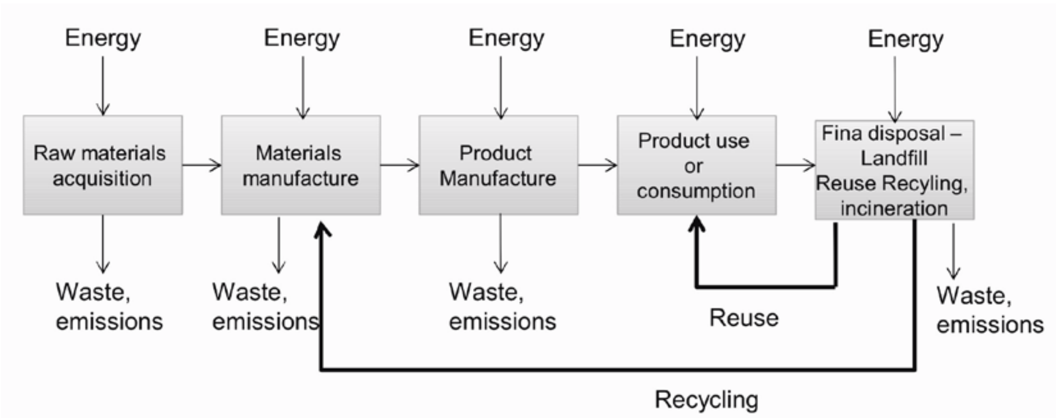


Figure 32. The LCA (cradle-to-grave) of a product expressed as a supply chain process, based on ISO 14040 (2006) and Johnson, U., (2003). (Maria Törn Aalto University)

The method was first to analyze the production process and to review literature, by addressing the question whether a crystalline silicon solar cell is today most environmentally friendly and healthy way to produce solar energy. As reviewed in Chapters 2.1.4-2.1.8, energy consumption generally has significant environmental impacts. According to Alsema (2012) and Filtvedt (2013) as cited by Aselma et al. (2006) approximately half of the energy requirement of the modules comes from the raw material acquisition and pure silicon feedstock production. Considering these studies, the energy analysis was at first reviewed and thereafter a more comprehensive environmental LCA was interpreted. These results of energy analysis provided a good indication of the CO_2-emissions and CO_2-mitigation potential of the considered energy technology. The sustainability of any energy system depends on the net energy yield, which is calculated as a difference of the output and input energy during the lifetime of this energy system. Moreover, the comparison of payback times of the new energy systems benefits this comprehensive approach. (Alsema, 2012; Filtvedt 2013; Jungbluth, 2005; Chapter 2.1.6). Finally, health impacts were investigated. (Alsema & de Wild-Scholten, 2005; Frischknecht et al., 2014; Fthenakis et al., 2011; Fthenakis et al., 2005; Gløckner et al., 2008).

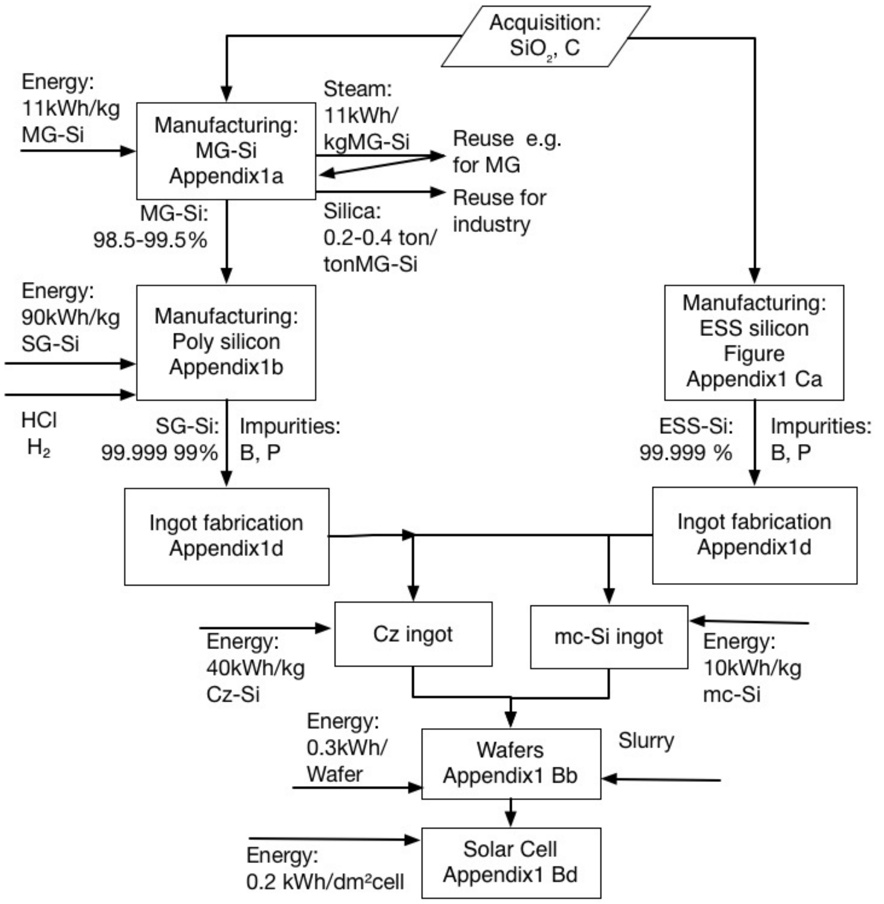


Figure 33. The primary steps of the typical supply chain of a wafer-based crystalline Si-module. Saarinen, R., (2015b)

While exploring the supply chain of a Si-module, this LCA study mind deeper the references and created a draft product-chain process, which was completed during iterative assessment (Figure 33). The reviewed silicon production process consists of Arc-Furnace, a Fluidized Bed Reactor (FBR) process and a Chemical Vapor Deposition (CVD) reactor, the process illustrated in Appendix 1. Silicon is first produced from quartz in large electric arc furnaces, which yield metallurgical-grade silicon (MG-Si) as illustrated in Figure 1a in Appendix 1, (in Figure 35 named as metallurgic silicon). Then MG-Si has to be further purified to polycrystalline silicon before silicon is suitable for the manufacturing of electronic components such as integrated circuits or solar cells. For producing polysilicon there are three alternative routes: Siemens reactor, Fluidized Bed reactor, or Free Space reactor as shown in Figure 35. The Free Space reactor has not been used industrially on a large scale and is not covered in this licentiate thesis (Ydstie & Du, 2011, p.128). The traditional Siemens process dominates markets through a chemical route shown in Figure 1b in Appendix 1. (Alsema, 2012; Ceccaroli & Lohne, 2003; Pizzini, 2010; Tangstad, 2013; Woditsch & Koch, 2002; Xakalashe & Tangstad, 2011; Ydstie & Du, 2011). The alternative route to produce solar grade silicon through a metallurgical route is expressed in Figure 34.

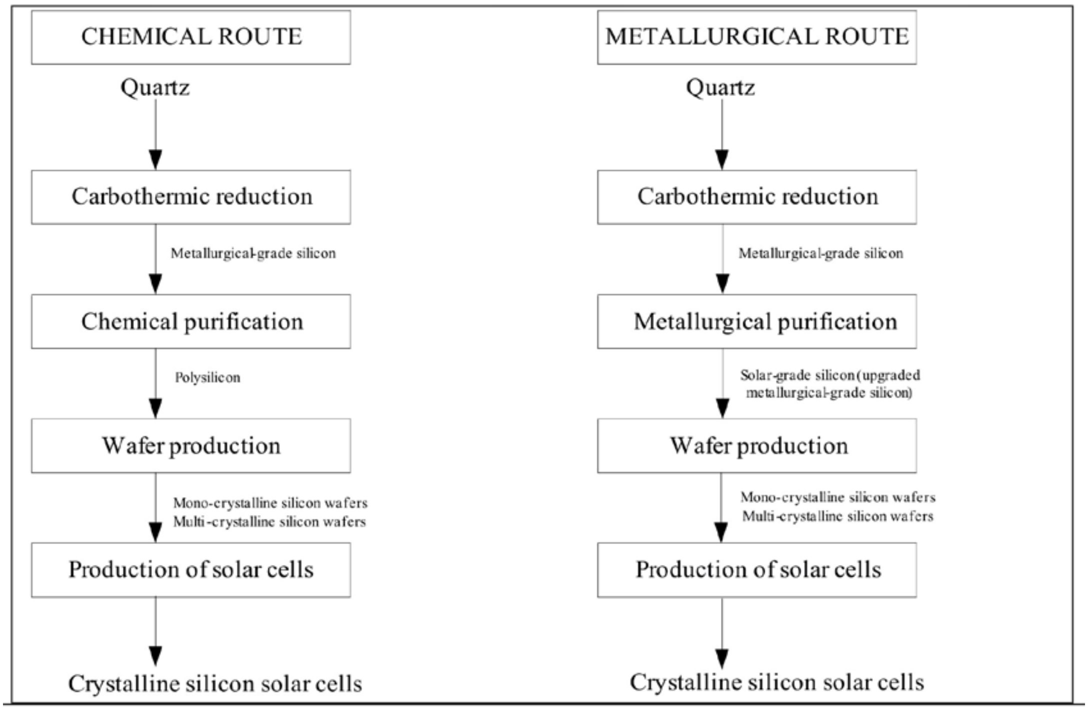


Figure 34. Stages for the production of crystalline silicon solar cells from quartz (Xakalashe & Tangstad, 2011, p.84)

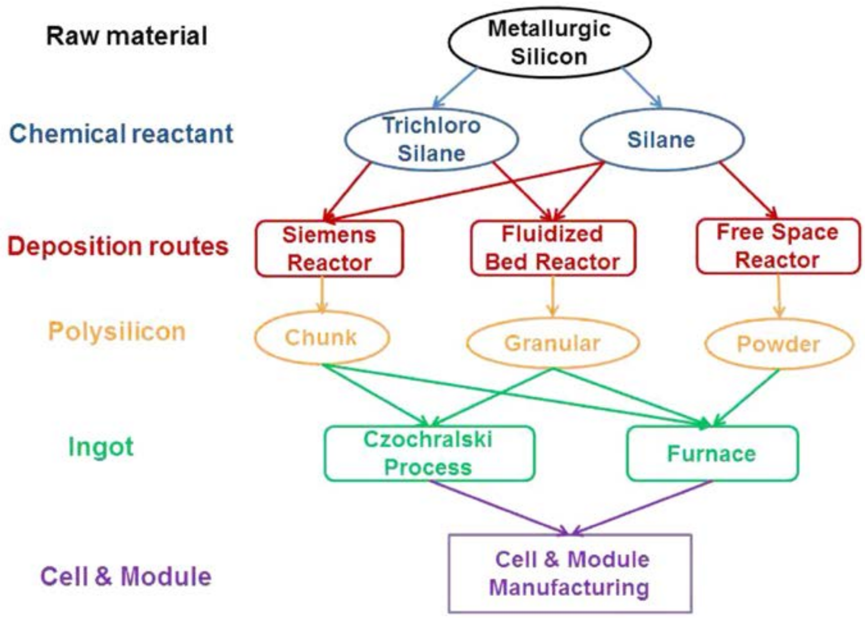


Figure 35. Polysilicon processes of a solar cell (Ydstie & Du, 2011, p.127)

The MG silicon needs to be produced at the high process temperature and needs electricity, Appendix 1 (Chapter A) explaining this MG-process. Among reviewed versatile electricity demands, the demand of 11 kWh/kgMG-silicon was selected for the LCA of the typical supply chain exemplified in Figure 33. This MG-Si process produces by-products as steam and silica, which can be recycled and reused (Figure 33). With the typical specification of 98.5-99.5% MG-Si has impurities such as C, B, and P, of which boron and phosphorus are needed for a p-n junction as discussed in the previous chapter. Some impurities required for the production of a solar cell should be reduced as low as ppb (part per billion) levels, which levels are obtainable by going through the CVD, the traditional Siemens CVD process shown in Figure 1b and a new FBR CVD in

Figures 1ca and 1cb in Appendix 1. The alternative route producing solar-grade silicon named upgraded metallurgical silicon (UMG) (Figure 37) is discussed after the FBR and Siemens approaches.

The increased use of pure semiconductor silicon (SG-Si) limits the PV market expansion and has recently boosted the research work for low-cost FBR processes, which at the present covered less than 10% of all solar grade silicon (SoG-Si) manufactured (Buy & Ceccaroli, 2014, p.635). This FBR approach suggests the energy demand as low as 5-10-12-20-30 kWh/kg (Buy & Ceccaroli, 2014, p.641; Goodrich et al., 2013, p.114; Jungbluth et al., 2012, p.40). Furthermore, Goodrich et al. (2013) have investigated opportunities to reduce manufacturing costs for the PV module supply chain of the wafer-based monocrystalline silicon. This study indicates the significant reduction in direct manufacturing costs of U.S. solar grade polysilicon in the silicon production process based on a FBR process compared with a traditional Siemens process, the difference of energy demand in the Siemens-based process (90 kWh/kg) versus the FBR approach (12 kWh/kg) shown in Figure 36. Similarly, Frischknecht et al., (2014) indicates the share of the FBR process will increase in Europe in long-term.

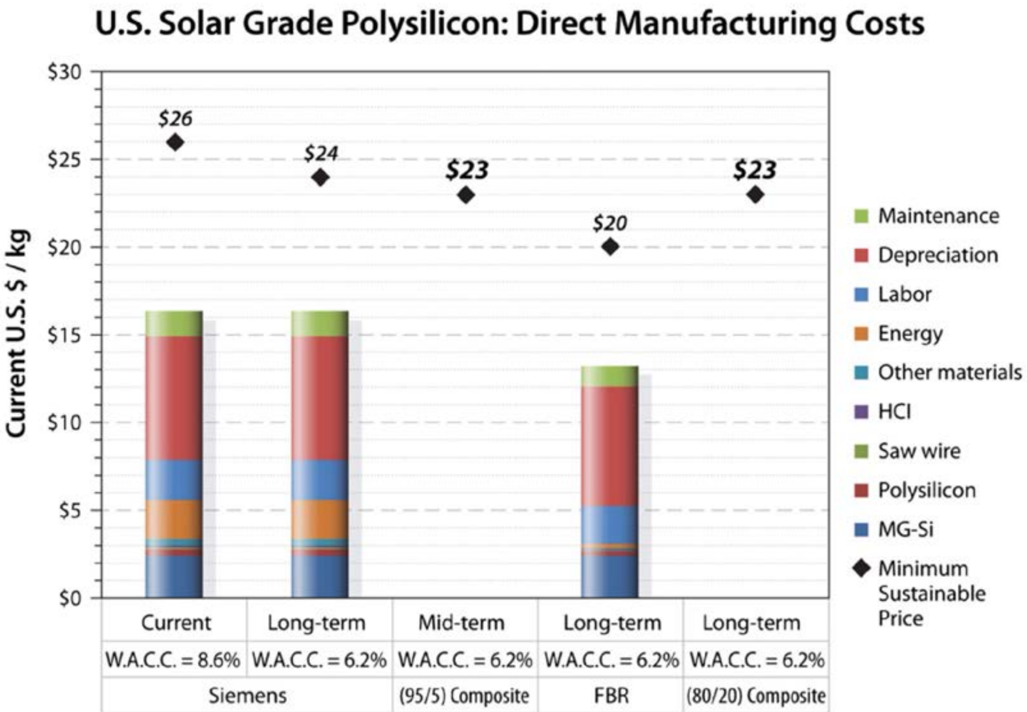


Figure 36. Model results for polysilicon production costs and minimum sustainable prices, for a U.S.-based 15 000 MTPA production facility (15 000 metric tonnes per year for polysilicon production, p.112) with onsite TCS production. The two most commonly employed methods within the U.S. are shown where the minimum sustainable prices were derived using the specified WACC (weighted average cost of capital, p.112) and Siemens chunk/FBR material ratios. The ‘polysilicon’ and ‘saw wire’ components correspond to the Cz pulling of ingots and the shaping of filaments. (Goodrich et al., 2013, p.114)

This licentiate thesis presents the Siemens process shown in Figure 1b in Appendix 1 for producing polysilicon (Woditsch & Koch, 2002; Xakalashe & Tangstad, 2011). The purification of MG-silicon happens first in the FBR, which process produces trichlorosilane (TCS). After further purification, TCS is then reduced by hydrogen in the Siemens reactor containing heated silicon rods and the semiconductor silicon is produced in this CVD-reactor. Although at present the energy demand for this Siemens-based process could be as high as 200 kWh/kgSG-Si (the review of energy demands expressed in Appendix 1 Chapter A Section Ab), the energy demand for this fluidized-bed/Siemens based process could be 90 kWh/kg (Goodrich et al., 2013, p.114), which is utilized for this licentiate thesis in the exemplified LCA. Readers are referred to Appendix 1 (Chapter A) and references for further details.

Because the polysilicon process is energy intensive, the source of energy plays a significant role in this production chain. Regarding the countries producing silicon (Statista portal), from the sustainability point of view Norwegian hydropower can first be selected for the exemplified LCA in Figure 33 and afterwards re-checked. After reviewing whether there exist LCA studies (ISO 14040, 2006; ISO 14044, 2006) of solar grade silicon (SoG-Si) production powered by Norwegian hydropower, the studies from Gløckner and de Wild-Scholten (Gløckner & de Wild-Scholten, 2012; de Wild-Scholten & Gløckner, 2012) revealed that the GHG emissions for ESS®-silicon (Elkem portal) are estimated to approximately 10 kg CO_2-eq/kgESS®. Their LCA study on the environmental footprint of Elkem Solar Silicon® (ESS®) is based on full-scale commercial operation plant in Norway. For the calculations, an average module efficiency of 14.3% and an expected lifetime of 30 years for a module have been used. ESS® is a solar grade silicon block, which is produced in the five steps utilizing the metallurgical route shown in Figure 37. ESS® was approved as a registered Carbon Footprint Product (CFP) in Japan (2013) (CFP Japan portal). The energy consumption and GHG emissions of this ESS® metallurgical route is significantly lower than that of the Siemens process powered by hydropower as illustrated in Figure 38, the Siemens process operating in effective co-generation in this comparison.

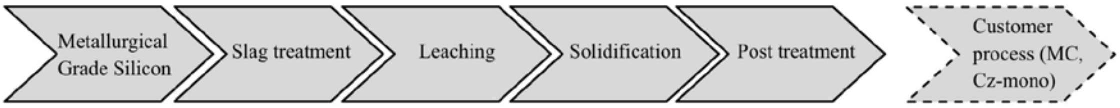


Figure 37. Current Elkem® Solar Silicon - ESS® process (Søiland et al., 2014, p.662)

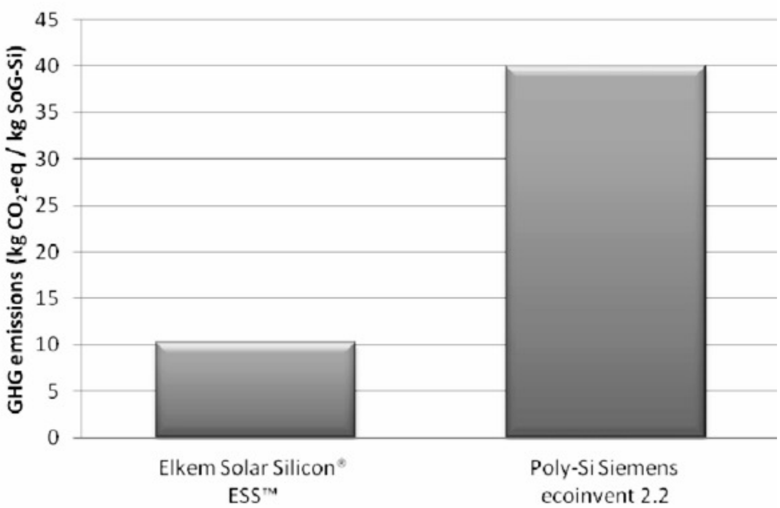


Figure 38. GHG emissions in kg CO_2-eq per kg SoG-Si for production of solar grade silicon in Elkem® Solar Silicon - ESS® process compared with Poly-Si from a Siemens type process (Gløckner & de Wild-Scholten, 2012, p.4663)

The next step involves, after the polysilicon process, converting solar-grade silicon into thin sheets (wafers) for use as solar cells, the majority of silicon wafers being

Czochralski (CZ) single crystalline or multicrystalline (mc) ingot material. For ingot casting or crystallization, the common two crystallization techniques are applied, the Czochralski growth process for Cz-ingots and the Bridgman process for mc-ingots. During ingot casting or crystallization, the impurities such as phosphorus (P) or boron (B) are added. Although the energy demand for the Czochralski process could be as high as 127 kWh/kgCzingot, this licentiate thesis applies the modest energy demand of 40 kWh/kg for the modern Cz-process. Regarding multi-crystalline silicon, most of the mc-silicon for the photovoltaic industry is produced by the multi-crystalline ingot block casting process, which melts silicon material in a crucible, as shown in Figure 1db in Appendix 1. Alternatively to the Bridgeman process, the block-casting can be employed for the crystallization process, where a second crucible (block casting) is used. The typical energy demand for producing the mc-ingot is 10 kWh/kgmcingot (Ferrazza, 2012, p.89). The readers are referred to references in Appendix 1, which describes this Cz-process and mc-silicon ingot process in more details.

The process from an ingot to a PV module is illustrated in Appendix 1, whereas the typical plant layout for the industrial production of crystalline silicon in (Cheung 2010; Xakalashe & Tangstad, 2011, p.94). The Cz-ingots are first sawed into squared blocks with a cross section defined with the final wafer size, while the mc-silicon ingots already have a proper square or rectangular shape and they are only cut to blocks. The lost materials (approximately 25% of Cz and 15% of mc ingots) are recycled back to the ingot production processes. Wafers are produced from blocks by the automated multi-wire splicing saw process. The slurry is typically a mixture of polyethylene glycol (PEG) and abrasive silicon carbide (SiC) particles, which is recycled back to the slurry tank until it is pumped again on the wires. Regarding sustainability, this slurry can be based on fluids that are water washable instead of oil-based procedures. Because this sawing process has high material losses and results in high costs, new techniques avoiding this wafer production have been developed such as ribbon growth techniques or the thin film technology. Improving the process for producing thinner and stronger wafers can also reduce the electricity costs. Energy needed to produce one wafer is 0.3 kWh/wafer.

New wafers go through cleaning, etching and texturing processes in the manufacturing of a solar cell as shown in Appendix 1 and in Figure 26 in Chapter 3.4.2, which chapter investigates a solar cell. Anti-reflective coating (ARC) and the surface texture reduce the reflection of light from the front surface of the cell by affecting the angle of light. After the wafers are etched to remove the damaged layer near the surface, this etching step creates a surface texture on the top of the cell for reducing the primary reflections, this chemical multilayered texture shown in Figure 26 (distributed upside pyramids). This light-trapping mechanism allows the fabrication of a thinner solar cell, as the light can travel distance larger than the actual cell thickness. The energy requirements to process a crystalline silicon cell are 0.2 kWh/dm^{2}cell. The reader is referred to references in Appendix 1 for further details.

Solar cells are constructed in modules as discussed in the previous chapter, and modules without the frame are called laminates, which can be installed directly into the building. The energy consumption for the production of PV panels might be 4.7 kWh/m^2 for electricity and 5.4 MJ/m^2 for heat (Jungbluth et al., 2012, p.70), these figures varies according to the suppliers and assessment estimates. After the 25-30 years operation the metals and silicon of solar panels are recycled and the remaining parts of panels are incinerated or landfilled.

Regarding GHG emissions the energy mix at every stages of the supply chain up to final disposal and landfill fundamentally influence on the assessment results. The goal for this LCA study was to find out a small-scale solution, which neither causes noxious health impacts, unprocessed wastes nor CO_2-emissions. Therefore, as the baseline in this licentiate thesis is the ESS®-silicon from Elkem® Solar Silicon-process and compared with p-Si from the Siemens type process, the energy mix mainly based on hydropower for the ESS®-silicon (Norwegian energy mix) and for Siemens p-silicon also on co-generation of heat and power (Gløckner & de Wild-Scholten, 2012; Gløckner et al., 2008; Ostfold Research 2015; de Wild-Scholten & Gløckner, 2012). Life Cycle Inventory information on raw material production, transport, etc. was taken from the Ecoinvent 2.2 database. Elkem sells parts of by-products from the production process. The results of the LCA study conducted by Gløckner & de Wild-Scholten are illustrated in Figure 39. The GHG emissions from the wafer fabrication indicate the need to develop solar cell production processes, which are not dependent on wafers but will avoid this phase such as ribbon growth techniques or the thin film technology. Another interesting finding was that the Siemens-type p-silicon production based on hydropower and co-generation noticeably resulted in lower GHG emissions than with (Frischknecht et al., 2014) the different energy mix and without co-generation.

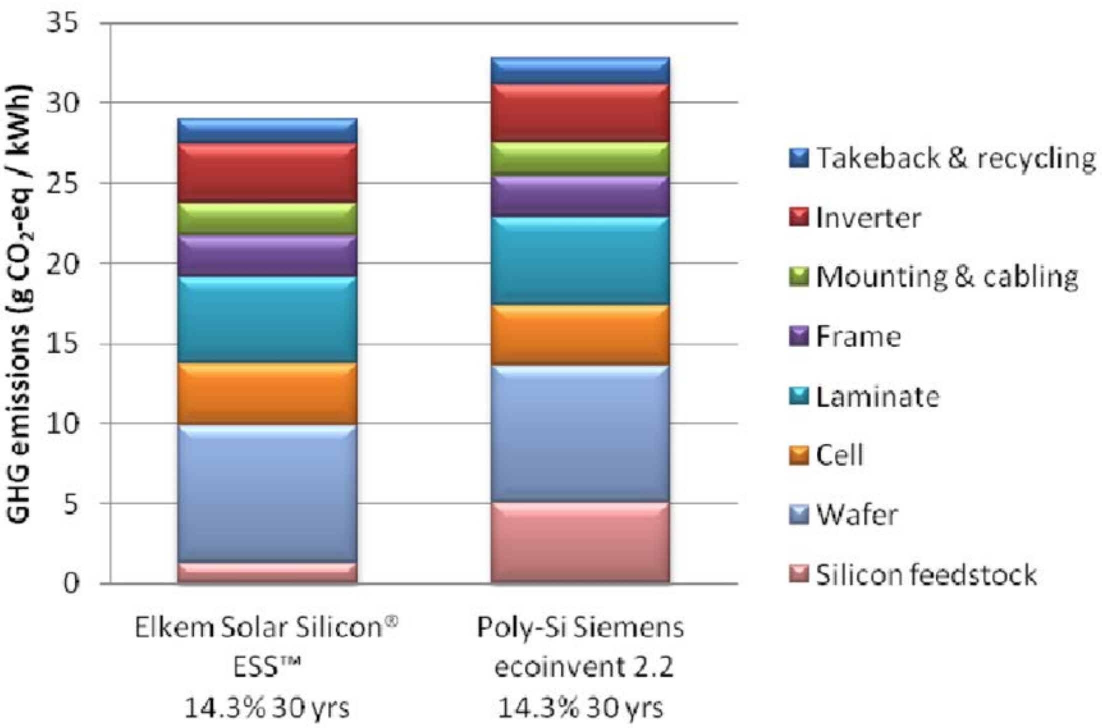


Figure 39. GHG emissions in grams of CO_2-eq per kWh for the entire PV energy system value chain for ESS®-silicon from Elkem® Solar Silicon-process compared with Poly-Si from Siemens based process at an in-plane irradiation of 1700 kWh/m²year (Gløckner & de Wild-Scholten, 2012, p.4663)

One unanticipated finding was that the lamination of PV panels caused distinguishable GHGs (Gløckner & de Wild-Scholten, 2012; Gløckner et al., 2008; de Wild-Scholten & Gløckner, 2012). Comparing these studies with LCA studies by Frischknecht et al. (2014, pp.58, 68) showed that Aluminum (Al) process needs considerations and improvements of the production phase of the PV panel, as above exemplified the thin film technology (Haller et al, 2013; Hyoungseok et al., 2014; IRENA, 2013; Li & Liu, 2015; Poortmans & Arkhipov, 2006; Soga, 2006). Copper might replace the silver used for the metallization paste, due to cost reasons (Frischknecht et al., 2014, p.20). For acidification potential (kg SO_2-eq), readers are referred to the LCA study by Frischknecht et al., (2014) for the latter part of the solar cell production chain starting from the wafer fabrications. For the polysilicon and UMG (ESS®-silicon) this LCA study is not valid due to the difference energy mix used, the Norwegian mix versus European mix. Regarding solar power and hydropower, there are no SO_2 and NO_x emissions in the use phase, and the production phases of ESS®-silicon and Siemens p-silicon indicate mostly the acidification potential (g SO_2-eq/kWh) of hydropower from cradle-to-grade. Ostfold Research (2015) has conducted an updated LCA status of Norwegian hydropower, and the results further support hydropower as a sustainable energy, even including emissions from inundation of land. According to these data, the acidification potential of Norwegian hydropower is estimates for 0.0067 g SO_2-eq/kWh and global warming potential for 2.39 g CO_2-eq/kWh, as well as others such as eutrophication potential, photochemical ozone creation potential (POCP), and ozone depletion potential (ODP) are inconsequential (Ostfold Research, 2015, p.6).

Chapter 4.1.5 discusses the avoidance of GHG for the solar-powered drip irrigation system. Regarding sustainable and productive agriculture, climate change decreases cereal output in Africa (Nellemann et al., 2009) and is a serious threat to food security as discussed in Chapters 2.1.3 and 2.1.6. However, the CO_2 emissions produced are least in the world in Sub-Saharan Africa (Appendix P in Saarinen, R., 2014a).

3.4.4 Solar-powered Pumping

The hydraulic power required to lift or pump water is a function of both the apparent vertical height lifted and the flow rate at which water is lifted. Two typical submersible pumps are shown in Figure 41 and a PV-Pumping clean water system (see Chapter 4.1.4) and irrigation system with water storages in Figures 23 and 40. The irrigation system also consists of a water conveyance system to carry the water directly to the field or plots in a controlled manner according to the crop water requirements (see Chapter 4.1.5). Although the pumping technology is well known and mature, the operation and maintenance of pumping systems are the key success factors for a new energy service of rural people as well as the availability of spare parts and training (Chapter 4.1.7). (Barrlow et al., 1993; Fraenkel, 1986; Grundfos, 2014; Wenham et. al., 2007).

To express shortly, the LCA for pumping energy delivered from PV panels (Figures 40 and 41) has reviewed and analyzed in the previous chapter, but the question is whether any LCA studies from cradle-to-grave might be available in the production of the water pump. It seems that available studies such as in the solar cell production supply chain might not be available, even though Grundfors provides information on their environmental management and Life Cycle Thinking (Thrane & Myrdal, 2008). This licentiate thesis acknowledges these approaches towards greener products, but more comprehensive LCA studies would serve the purpose trying to define the sustainability of the solar-powered system for a village community (Figure 23.)

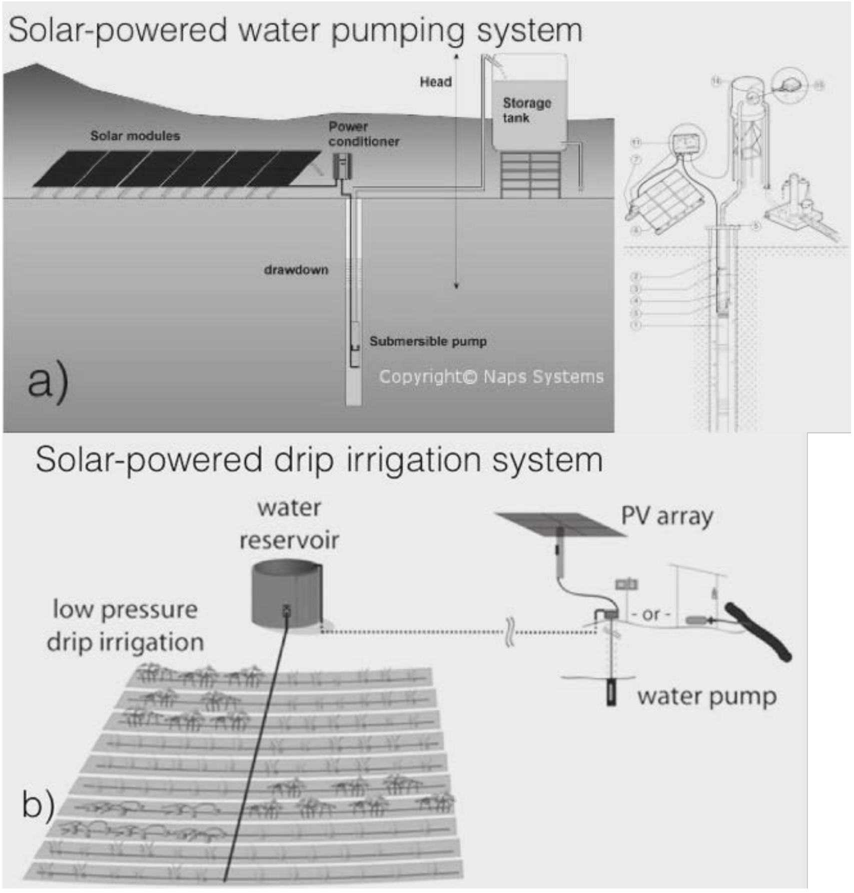


Figure 40. a) Solar-powered water pumping system, NAPS Water (2015), b) Solar-powered drip irrigation system, Standford Benin (2011)

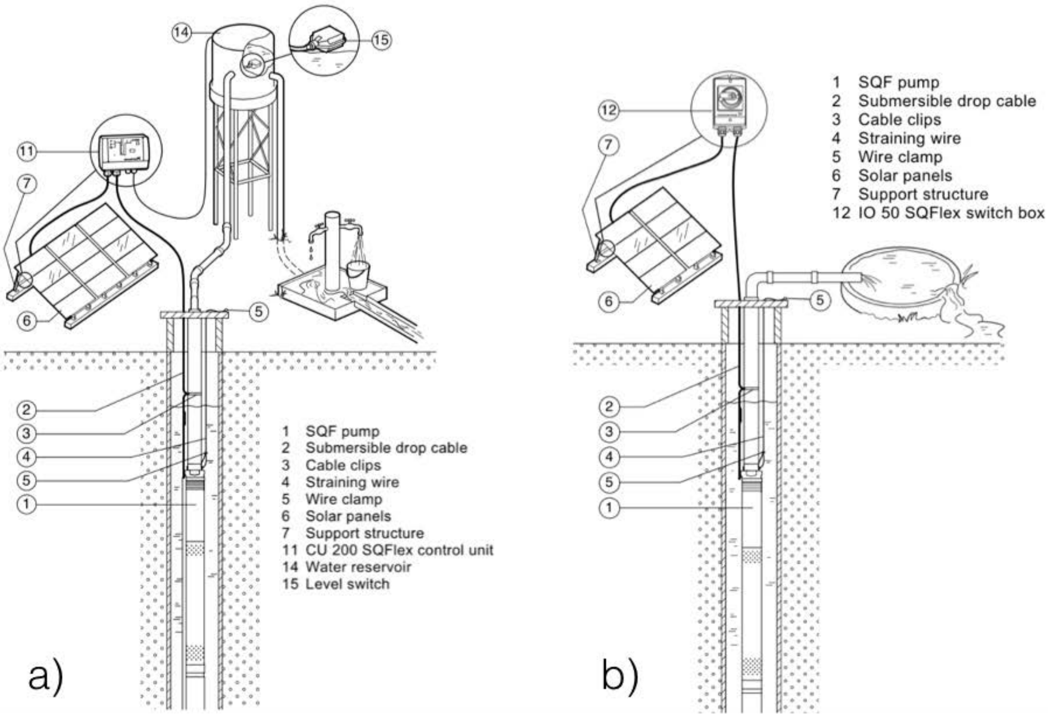


Figure 41. Solar-powered submersible pumps: a) solar energy stored as water in a reservoir (14) at a higher elevation, b) the simplest pump system with a storage tank at ground level, Grundfos, (2014).

3.5 Learning organization and participatory action research

3.5.1 Collaborative learning organization

Chapter 3.4 discussed the layered solar socio-technical system, and to convey the meaning of this kind of system will need words. Words, like TAMAA in Swahili, are related to their culture and context and thus the aspect of interpretation, in this sense words need communication media and social acceptability of communities (Kaplan, 2002; Meier, S., 2006; Vakunta, P.W., 2011). As written in 1997, 'our view of the world, including explicit and implicit understanding, is revealed when we interact. We have different mental models and beliefs, which guide our behavior. The terms Learning Organization or Knowledge Management and Organizational Learning are not only new words but also the philosophy behind them is the knowledge of a human being and how she or he acts on one another and on his or her environment. The networked multimedia is a good expedient to interact between a customer and a supplier, between colleagues, between teaches and students. We can get experiences and create visions together and deepen our mutual understanding'. (Saarinen, R., 1997). This might today be more valid than ever (Fidelman M. 2013; Isaacs 2002; Krippendorff 2004; Lehtonen 2014; Lewis et al. 2010; Nonaka et al. 2003; Roschelle et Al.; Senge 2006; Their 1994). Indeed, individuals communicate, interact, and learn within and outside versatile socio-technical systems, where they are trying to satisfy their needs according to their need hierarchies (Figure 1) (Antonides 1996; Maslow 2000; Whyte 1991). Furthermore, our world in high technology fields like energy and information and communication technology (ICT) is strongly related to high education and text-based materials (Lehtonen 2014). However, 3000 million people live on less than 2.5 USD per day (Chen et al., 2008; UN Water WWDR, 2014), most of whom do not have capabilities to read complicated texts (UN Africa MDG 2013; UNESCO EFA, 2014).

The main research question was how to build a flourishing learning village community, communities to empower people's ability to manage and organize their life in a positive, goal-directed manner and to apply the problem-solving approach (Novick et al. 2002; Paulus et al.2003; Roschelle et al.; Senge 2006). That is, laying down the foundation for the co-creating communities, and an environment where people can learn, create and work together. Therefore, for emphasizing and providing voices for co-learners in TAMAA Case (Saarinen, R., 2015a), some citations are set forth: 'Obstacles and barriers are there, very much related to low education and lack of training how to use technical devices, try to show that the whole community is profiting from a system, planting a we-spirit, bringing knowledge to common people, not only to experts, is part of the solution to integrate new energy systems into a daily life of rural people in Africa' told Brita Jern. 'The input of every member of the community matters. Every one tries to reach the self-actualizing level, one's full potential, and tries to empower others. Co-learning, working together, applying local resources with local methods, small-scale solutions suitable for local environment, scaling-up, modularity, local people have ownership to their solutions, adapting our western new technology to local needs', discussed Mika Vehnämäki. 'Solar power is new technology to people who live in the countryside. If I am not wrong, it is about five or ten years since the technology introduced to us', shared George Pinhua.

Then, how to create a learning organization and come together to learn, 'Dialogue is a special way of thinking and talking that invites people open a space of learning together: Its purpose is to bring out change at the source of people's thoughts and feelings rather than at the level of results their ways of thinking produce' (Isaacs 2002). When people learn together, they also get ownership to their knowledge and become an active part of their community. Furthermore, 'Sharing tacit knowledge requires interaction and informal learning processes such as storytelling, conversation, coaching, and apprenticeship of the kind that communities of practice provide' (Wenger 2002; Snyder 1996). An organization, which can be called a learning community, has a shared vision, individual and collective learning practices, collective intelligence, a common language, and interdisciplinary teams and projects. They encourage the growth of their people, foster democratic decision-making, enable positive deviance and create positive climate, create a new level of creativity. The learning organization has feedback processes, which could be reinforcing or balancing. Reinforcing or amplifying feedback processes enable the growth as the organization foster positive relationships and thus positive-energy network. On the other hand, balancing or stabilizing feedback operates whenever there is a goal-oriented behavior and try to control the organization towards the goal. Reinforcing and balancing feedback processes involve a delay, meaning the feedback might happen after a certain time and the relation between the change and the result might not be obvious (see Change process Figure 12). (Cameron 2008; Castellani et al. 2009; Christakis et al. 2002; Isaacs 2002; Lehtonen 2014; Nonaka et al.2003; Novick et al. 2002; Sayer 2000; Senge 2006; Whyte 1991). The next chapter discusses how to face-to-face interviews serve knowledge creation, and Chapter 3.5.3, on the other hand, participants action research, whereas Chapter 3.5.4 qualitative and mixed methods research.

3.5.2 Interviews and sampling

TAMAA Case explored in-depth knowledge for the problem area defined in Chapters 1 and 2, and set the purpose on mining with interviews multidisciplinary participatory co-learning knowledge of African villagers within their community and how their wellbeing can be empowered by new and sustainable energy services. Aligned to numerous scholars (Gubrioum & Holstein, 2002; Holstein & Gubrium, 2005; Holstein & Gubrium, 1995; Keränen, 2010; Langvik, 2004; Maxwell, 2009; Patton, 1990; Robson, 2002; Silverman, 2004, 2005, 2006; Urban & Hauser, 1993), the design of interviews started from the research questions, the research strategy, and objectives. The focus was to explore and find out experienced real-life views of the phenomena, and the meaning of this particular phenomenon to the participant, who was a part of social units to be studied, and who had a personal commitment on the subjects, which covered several interview segments or even all segments. The approaches to collect qualitative data through open-ended interviews can be divided into three tactics as (Patton, 1990):

1. the informal conversational interview
2. the general interview guide approach
3. the standardized open-ended interview

TAMAA Case applied mainly the standardized open-ended interview, which consists of a set of questions with the intention of taking each interviewee through the same questions for minimizing variations in the questions (Table 5). 'This reduces the possibility of bias that comes from having different interviews for different people.' (Patton, 1990). On the other hand, based on previous experiences of the researcher, the semi-structured interview was applied when well grounded (Robson 2002). A series of interviews, where participants' historical accounts are required in order to acquire how a particular phenomenon developed—change happened, acted as an input as well as a feedback for the creation of new sustainable energy services and new concepts. These active interviews sought a deeper understanding of the phenomena (Chapters 1 and 2) and explored, reviewed and validated concepts and processes developed in SMILE Case as well as brought out further issues to research in-depth. These interviews involved a greater expression of the interviewee's self than do other types of interviews and took an account of their (the interviewees) experience. These kinds of interviews act as organizers of the meaning, when they are conveyed, obtaining the practical knowledge and authentic insights from people's experiences.

Table 5. Interview questions for the first interview round, Saarinen, R. (2015a)

N	Individual	Community	Social
1	What basic Needs of people do you think there are, people who are living in Africa? And do you think, there are differences between rural and urban areas?	How do you think nutritious Food and clean Cooking could be arranged in African countries?	How do you think new Energy Services can provide Security for people and what these new Energy Services could be ? Security meaning Health, Food, Water etc.. and costs of living?
2	In your opinion, what are the biggest obstacles and barriers for people for getting these basic Needs?	What about clean and fresh Water How do you think this is possible to arrange in Africa?	What about Access to these new Energy Services? How do you think this is possible to arrange? And What do you think is the biggest obstacles and barriers for getting new Energy Services?
3	What about new Energy Services? How they are connected to basic Needs? What do you think are the most important new Energy Services for people living in Africa?	How about Education, Training and Working environments? What do think is the connection to the energy and what kind of energy?	How about Healthy Environment for people? What is your opinion, what kind of new Energy Services can contribute this?
4	What do you think, what are obstacles and barriers for new Energy Services for people living in Africa?	How these new Energy Services could provide Livelihood opportunities and exporting possibilities? What kind of business models there could be?	What do think, what are the most important things to create and transfer new Technologies for people living in Africa? What are obstacles and barriers?
5	What do you think, what kind of possibilities there is for people to be a part of a community-based energy system, a larger ecosystem of energy services, for instance for villagers ?	How these Energy Services might decrease deceases and provide healthy environment?	What do you think, how these new Energy Services and basic needs like Food, Water, Health, Education can be a part of people's life? How all these Needs could be integrated and combined to new Energy Services ?
	What basic needs of rural people in Africa can be met by providing sustainable energy services and how?		

Each person was interviewed individually face-to-face using active thematic in-depth open-ended interviews. The face-to-face interviews were recorded leaving thus time for the interviewees just to relax and feel as comfortable as possible while telling their stories what they think and know and what they have experienced during their working life in developing countries or being a part of a sending organization. The preconceived categories derived from SMILE Case were confronted with the perspectives of the persons being interviewed. Active interviews provide an active decision environment mentioned in prosocial behavior and active decision in Chapter 3.1.2. The key interview research question was 'what basic needs of rural people in Africa can be met by providing sustainable energy services and how?' This question was categorized into interview questions (Maxwell 2009, p.230) as expressed in Table 5.

Sampling procedures in the social and behavioral sciences can be categorized into (Teddlie & Yu, 2007):

1. Probability sampling
2. Purposive sampling
3. Convenience sampling

4. Mixed methods sampling

Purposive sampling:
TAMAA Case utilized purposive sampling selecting information-rich representatives from target organizations and gradually increased the selection that would yield the most valuable information, knowledge, ideas, experience, and insights for the research and the further refinement of the theory. Utilizing snowball sampling, the sample expanded to new contact persons until the representatives shown in Table 6 made the sample. Purposeful sampling can be used to achieve representativeness or typicality of the settings, individuals, or activities selected (Maxwell, 1996). Readers are referred to the TAMAA case study report for more details (Saarinen R., 2015a). (Hardon et al., 2004; Holstein & Gubrium, 1995; Holstein & Gubrium, 2005; Maxwell, 2009; Patton, 1990, 2002; Zachariadis, 2010).

Table 6. Purposive sample, Saarinen, R., (2015a)

Interviewee position	Representative Organisation	Interviewee name	Experince
CTO, D.Sc.	International solar-power company	Mikko Juntunen	CERN, Nokia, medical imaging, solar systems, over 20 years
Controller	Church Mission Organisation	Solveig Nylund	Africa clean water projects, solar pumping, 17 years
Scientist, D.Sc.	Aalto university	Pramod Bhusal	Nepal, Thailand, Vietnam, Philippines, Ethiopia, EU countries, several years
Director of International Co-operation, PhD	Finn Church Aid	Tomi Järvinen	Several years experience in development cooperation
Mission coordinating secretary	Evangelical Lutheran Church	Vuokko Alanne	Several mission and development aid coordinations for target developing countries, 28 years
Senior Economic Adviser, D.Sc. Econ., L.Sc. Social	Department for Development Policy Ministry of Foreign Affairs	Mika Vehnämäki	Several years for co-operation development with foreign countries
Senior consultant	International sustainability consultant company	Paula Tommila	In development co-operation in Ministry of Foreign Affairs of Finland, sustainability consulting, several years.
International Learning Space Coordinator, M.Sc.	Finn Church Aid	Pasi Aaltonen	Constructions work, education concepts, school-concepts in developing countries
Mission coordinating secretary	Evangelical Lutheran Church	Helene Taal	Several mission and development aid coordinations 12 years, before as assistant in business environment
D.Sc., Scientist, Lecture	Aalto University	Paulo Pinho	Multinational experience, Lighting technology, Finnish and Portuguese nationality, born in Angola
Master thesis student in Business	Aalto University	Majok Kariom	at School of Business, Business management, from South-Sudan, worked in Kenya
Multicultural diacon	Evangelical Lutheran Church	Jyrki Myllärniemi	Church international work practices in deacon multicultural work, young people teams, over 30 years
M.Sc. Electrical	Church Mission Organisation	Seppo Vehko	Several years experience in Ethiopia
D.Sc, energy professional	International power company	Tapio Keränen	30-years, several positions
Rev, Dean reference interview	Evangelical Lutheran Church in Tanzania	Rev, Dean George Pindua	assistant to the Bishop of the Evangelical Lutheran Church in Tanzania, Morogoro
PhD, theology reference interview	Evangelical Lutheran Church	Irja Aro-Heinilä	Experience over 20 years in East-Africa
Mission Director reference interview	Church Mission Organisation	Brita Jern	Several years experience in Kenya

The selection of the interviewees (Table 6) was based on their mature, deep knowledge and experience of research aspects, which was able to reveal valuable data to research. The purposive sample was combined with reference interviews, instead of face-to-face interviews the interview questions were sent by e-mail to the interviewees and the answers were received as written versions by e-mail (Appendix IA in the TAMAA Interviews Saarinen, R., 2014b). The interviewer was Ritva Saarinen.

3.5.3 Participatory action research

The village community system addressed ill-structured problems and multiple and conflicting criteria in the environment (Doumpos et al., 2013; Sasson, 2012; Vincke, 1992), where complex social groups participate at versatile levels to learn together, which kind of sustainable new services and technologies are needed to empower rural villagers to achieve their wellbeing (Järvinen 2007; Hammond et al. 2007; Iosifides 2011; Jones et al. 2013; London et al. 2011; Novick et al. 2002; Swantz et al. 2008). The co-operative development starts from the customers, the villagers within their communities in rural areas in Africa, and proceeds so that both givers and receivers are in the same change process and both are beneficiaries, givers being individuals, faith-based organizations (FBOs), and social entrepreneurs (Cameron, 2008; Grönroos, 2007, 2000; Rudd et al., 2014; thisisFinland). Those who develop new technologies and services, and marketing them as companies belong to this socio-technical complex system as service providers (Beltz et al., 2009; Bowman et al., 2009; Hyppänen, 2013; SIDA, 2008).

Participatory action research (PAR) investigates the phenomena both from the theoretical and practical view in order to make the strength of collaboration of villagers, researchers, NGOs, universities, and companies. It is scientific and practical research, education and action to gather information, to explore and experiment complex socio-technical systems and communities. Furthermore, participatory action research involves people who are concerned about or affected by an issue and they take a leading role in producing and using knowledge about it. The aim is to make change happen and take actions to meet the needs and requirements of customers (villagers) and communities in the context, which provides the ideal conditions for the desired output by involving participators to work together for prosocial, social, technical, and economic goals in equal mutual partnership. Additionally, it advantages from learning organization and socio-technical system thinking as Saarinen E. and Hämäläinen (2004) describe, ‘Systems Intelligence: Connecting Engineering Thinking with Human Sensitivity: Its emphasis is on interactive participation in systems with feedback and subtle interrelations.’ The target is to find out creative solutions to the phenomena and make change happen through co-generative learning in socio-technology system thinking, when a strong technology turning point occurs and participators see themselves as actors in a change process. Similarly, participatory action research tries to develop new or improved scientific findings and theory, case studies being an essential source of research data, and PAR reduces bias of researcher and scientific community allowing non-isolated research environment (Kemmis et al., 2008, 2005; Reason & Bradbury, 2008; Swantz et al., 2008; Whyte, 1991).

To place a flourishing learning village community to a wider perspective of action research, the characteristics and dimensions in research work can be subdivided into 1) Human flourishing, 2) Participation and democracy, 3) Knowledge-action, 4) Practical issues, and 5) Emergent development form as described in Figure 42 (Reason et al., 2008). In these kind change processes researchers are not outsides but useful parts of actions. Whyte, Greenwood and Lazes (1991) summarize participatory action research

(PAR): ”Through practice to science in social research” and ”continuous mutual learning”. Swantz (2008) shares her knowledge and over several decades’ experiences of practices in PAR in Africa, particularly in Tanzania, and declares that PAR means doing research with people, participation means identification, grassroots knowledge to science, involving rural people, and sharing work. She continues that people work as actors and not as objects in research, and researchers try to understand people’s problems in mutual co-operative development. Furthermore, work should continue afterwards and not only in written documents.

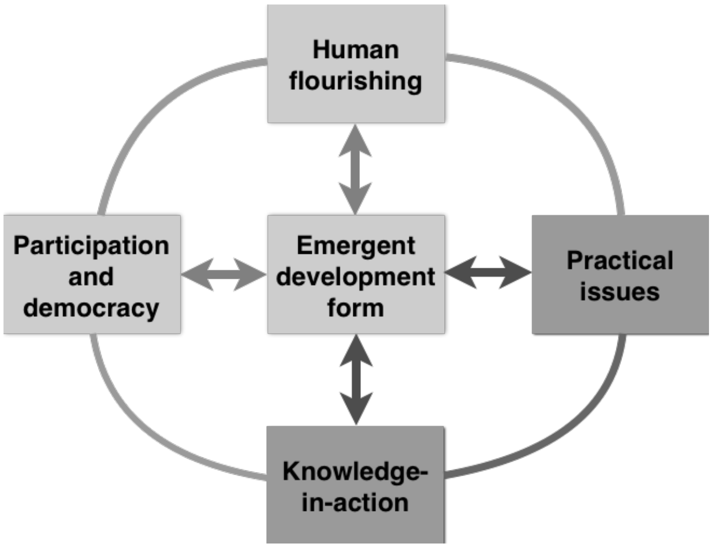


Figure 42. Characteristics of action research, source Reason & Bradbury, 2008, p.5. Re-drawn and modified by Saarinen, R., (2015b)

3.5.4 Qualitative and mixed method research

Qualitative research has a long tradition in the business fields, where acquiring the needs of potential and current customers of products and services is crucial for business: a service or product should match with customer needs (Figures 1, 13, 16, and 20). Designing and marketing new products and services has applied such methods as field tests, field work, focus group discussions, in-depth interviews, lead user analysis, observing people, analytic dialogue, analyses of 'documentary' societies and cultures, technology analyses, creative group methods, brainstorming, matched groups, narratives, discourse analyses, use-case stories, visual data, requirement management, conceptualization, case studies, among others. The heart of all these methods is to capture early opinions and corrective actions for developing and creating services and products for users. (Belz & Peattie, 2009; Cooper, 2001; Easterbrook, 2007; Grönroos, 2000; Hyppänen, 2013; Larman, 2001; Maxwell, 2009; Patton, 1990, 2002; Robson, 2002; Silverman, 2006, 2005, 2004; Urban & Hauser, 1993; Yin, 2009).

The social studies in the context of real-life complex systems have applied much the same methods as named above, the methods, which could provide qualitative data to understand social processes. A good design of qualitative research is addressed, so that it would be effective in describing processes, understanding real-life phenomena, and the critical role of the context where the phenomena existed. (Denzin & Lincoln, 2011, 2005; Silverman, 2006, 2005, 2004). Maxwell (2009, 1996) has provided the research design model, which includes phases: goals, conceptual framework, research questions, methods, and validity. Robson (2002) has named the importance of a good design as flexible design, and Yin (2009) has illustrated how to make successful case studies. Keränen (2010), on the other hand, points out the dialectical on organizations (communities), one key worth to mention here is that people are continuously contracting the social world through their interactions with each other.

Applying quantitative, qualitative methods and mixed methods, improves and complements the research with the most appropriate approaches to data gathering, analysis, interpretation, and presentation. This kind of research tries to answer one or more questions from different perspectives, in order to seek new insights into existing knowledge or phenomena, for the purposes of breadth and depth of understanding and corroboration, data collection, analysis, and inference techniques. (Creswell & Plano, 2011; Creswell, 2010; Cresswell & Tashakkori, 2007; Fakis et al., 2014; Green & Hall, 2010; Green, 2008; Johnson et al., 2007; Nastasi et al., 2010; O'Cathain, 2010; Tashakkori & Teddlie, 2010, 2009; Tashakkori & Creswell, 2008; Teddlie & Yu, 2007).

3.5.5 Content analysis, conceptualization and visualization

As introduced previously, our words have their meaning in cultural contexts in versatile forms as oral, written, images, and other visuals, and the context defines which kind of combination for communication and interpretation is most applicable for presenting, illuminating, and framing the research work. (Kane et al., 2007, 2009; Lehtonen, 2014; Rosas et al., 2012; Wheeldon et al., 2012). A common language to share our knowledge, thoughts, ideas, even our feelings and inner heart in high technology fields and knowledge-intensive organizations is strongly associated with text-based materials, whereas we have much overlooked the visual dimension of knowing and knowledge creation although this approach will leave outside most of those 3000 million people living on less than 2.5 USD per day, who do not have capabilities to read complicated texts. (Lehtonen, 2014; Nastasi et al., 2010; Nonaka et al., 2008; Their, 1994; Wenger, 2002). To change the way to communicate, collaborative learning in social communities ('socius=friend') can be embodied and make these communities and their needs visible by multimedia means (Bradley G., 2006; Fidelman M., 2013; Marvasti, 2008; Saarinen, R., 1997).

The research questions drive content analysis, which explore the functions and effects of symbols, meanings, and messages, and they cross-validate other measures of research, extract the meaning in order to understand what they mean to people, enable or prevent, and what the information conveyed by them does. The purpose is to find out patterns or themes for the mechanisms, which trigger the change in the context, where the change will happen. Though these mechanisms work as the input actions, which are needed to make change to happen, and cause the output that matches with the needs (Figures 12 - 16). A document might be a written research document, documented courses, minutes of meetings, records, newspapers, magazines, speeches, diaries, TV program, videos, photos, or documented texts in the Internet. Constructing categories and forming groups of themes help to look for patterns, observing through documents. (Krippendorf, 2004; Robson, 2002; Senge, 2006; Tashakkori et al., 2009; Wheeldon et al., 2012; Yin, 2009, 2004).

Conceptualization specifies the words with concepts and tells us what is the meaning of abstracts issues, how concepts are nested within other concepts, constituting a hierarchical, interrelated, and complementary structure of meaning. A word's meaning is related to the concepts to which it is connected, and in this thesis the concept name was expressed with the capital letter like Safe Light, Clean Water. This kind of the conceptual model of causual systems provided deeper understanding of the phenomenon researched. Conceptualizing abstract issues, give a shared understanding of the complex problem area, which would otherwise have been difficult to study, sharing a defined common language. (Christakis et al., 2002; Kane & Trochim, 2007, 2009; Saarinen E. et al., 2004; Sayer 2002).

Matrix analysis and visualization have traditionally shown their power in market and new product development fields, likewise they have been used for describing complex systems. Visualizing in analysis describes and categorizes research data by matrices, flow charts, maps, diagrams, and organizational charts in visualized, systematic, way for comparing and contrasting data. The matrix collects and arranges data in a clear format in order to create one place for further analysis with research data and provides the coherent view for drawing flowcharts and maps of complex phenomena. Establishing categories provide pictures how research data falls into categories, which help to analyze behaviors and patterns of information. (Hyötyniemi, 2005; Kane et. al., 2007; Lehtonen, 2014; Novick et al., 2002; Maxell, 1996; Miles et al., 2014; Patton, 1996, 2002; Urban et al., 1993; Wheeldon et al., 2012).

3.6 Validation

This licentiate thesis was the cross-functional, multidisciplinary and multi-criteria study, and the validity and reliability of research data have been improved by using multiple methods and mixed methods research. Participatory action research reduces the bias of a researcher and scientific community allowing non-isolated research environment (Kemmis et al., 2008, 2005; Patton, 2002; Reason et al., 2008; Swantz et al., 2008; Whyte, 1991). Moreover, peer reviews not only reduce the bias of a researcher but also provide a support and a research team. The triangulation compensates the weaknesses in one method with the strengths in other methods and thus abates threats to the validity of research work, because it tests and checks data and information with multiple sources and methods, and with parallel mixed methods. It can take advantages of more than one observer or analyst, member checking and peer groups in the study with mixed methods, and multiple theories or perspectives. (Bickman et al., 2009; Johnson et al., 2007; Maxwell, 2009; Robson, 2002; Tashakkori et al., 2010, 2009, 2008).

The validity, quality and perspective of this thesis were enhanced by the baseline literature review study (Chapter 2), this data gathered during the years 2009-2014. The data analysis started before conducting the interviews by categorizing the key research questions into the sub-research questions (Chapter 1.3) and by creating the categorized interview questions into Table 5. The research data analysis was categorized into these sub-research questions as well. Furthermore, the licentiate thesis followed the previous defined research process (Figure 14) and modified this in order to create new sustainable services, which will meet the identified needs of villagers (Chapter 4.1). The interviews were videotaped and documented in Appendices IE and IF as well as the written reference interviews in Appendix IA in TAMAA Interviews (Saarinen, R., 2015a). The sampling method was purposive sampling, which involved international professionals co-worked with Africans, 14 face-to-face interviewees and three reference interviewees. This sample was a selection of information-rich representatives from target organizations. The first impression of the data was taken as quick notes during interviews and collected into Appendix ID in TAMAA Interviews (Saarinen, R., 2015a).

4 Results

4.1 Created New Services

4.1.1 Weighted discovered Needs

The research and interview questions were categorized into individual, community, and social interview questions (Table 5). Similarly, the written stories (Appendix IE, Saarinen R. 2015a) were categorized according to individual, community, and social perspectives. The notes of the recorded interviews were placed in Table 7 as a raw data for analysis. In the first phase, data were grouped into the Need and Energy Service sub-tables, both groups including several items as the summary of the interviews, when every interviewee told freely and openly his or her experiences and insights into interview questions. During the interviews, each interviewee discussed the aspects in Need and Energy Service groups differently according to her or his experiences, thus first analysis started by counting how many times each interviewee weighted each aspects as for instance Food, Water, and Education in the Need group.

Table 7. Categorized preferences as raw data, in A) Need Set (the left sub-table) and in B) Energy Service Set (the right sub-table), Saarinen, R., (2015b)

A) Need Set			
Need	Preferencies	Interviewee Amount of 14	Total Preferences
Food	1;3;5;1;3;4;1;6;7;8;3;2;11	13	55
Water	2;3;9;4;2;5;4;2;6;9;4;9;5	13	64
Health	1;2;1;1;3;2;4;5;4;2;6;5;11	13	47
Sanitation, Hygine	1;3;1;3;1;2;2;1;2;5;3	11	24
Education	1;3;3;2;5;9;10;4;8;15;10;10	12	80
Cooking	1;2;4;1;2;4;2;6;2;5;4;5;1	13	39
Light	1;2;8;1;3;3;6;3;3;3:2;1	12	36
Cooling	2;8;1;1;2;2;1	7	17
Indoor Air, environment	1;1;2;3;1;1;3;3;4;2;4;1;6	13	32
Security, Shelter	1;1;1;1;1;2;2;1;2;3;4;11	12	30
Work	2;1;5;8;3;6;1;1;3;7;3;9	12	49
Agricultural Productivity, Garden	2;3;3;1;1;1;2;5;7;4;4;6;9	13	48
Forest, Deforestation, droughts, pests	1;2;1;1;3;1	6	9
Livestock, farm animals	1;1;1;5;4;2;2;3	8	19
Micro/small business	1;1;1;6;1;1;2;4;3;8;8	11	36
Mutual benefits business, local	1;1;2;2;5;1;5;8;5;3;12	11	45
New Practices	1;3;1;3;3;11;14;2;12;10;11;15;4;16	14	106
Incomes, Money, Investments	1;3;7;9;1;2;4;4;8;6;13;13;5;25	14	101
Assets	1;1;8;2;1;3	6	16
Identity, ID, Tribes, minorities	1;4;3;4	4	12
Banking, Credits	1;1;4;2;1;1	6	9
Mobile phone, charging, Internet	1;1;2;3;2;7	6	16
Infrastructure, taxes	1;1;4;5;2;4;3;6;2;15	10	43
Corruption, Conflicts, Wars	1;1;2;1;4;3;2;1;3	9	18

B) Energy Service Set			
Energy Service	Preferencies	Interviewee Amount of 14	Total Preferences
Improved Stoves, Cooker, Heater	1;2;2;1;1;1;6;6;2;10;2;3	12	37
Pumping, wells, dams	3;1;5;2;1;3;1;2;1;5;6;2	12	32
Irrigation	1;1;1;1;1;3;4;3	8	15
Compost Toilet	1;1;1	3	3
Modern Lamps	1;3;1;1;1;5;1;2;2;2	10	19
Better Lighting	1;2;6;1;1;1;1;4;4;3;2;1;1	13	28
Electricity/ Energy	1;1;1;3;3;4;2;3;8;14;1;12	12	53
Cooling	2;8;1;1;1	6	13
Solar	1;2;4;4;1;1;1;1;5;8;5;18;2;3	14	56
Hydro	2;1;2;2;3;4	6	14
Wind	1;2;2;2	4	7
Machines	1;1;1;1	4	4
Small-scale system	2;3;2;1;3;3;2;3;3;6	10	28
Village system	1;1;2;1;1;2;2;4;16;4;7	11	41
Communal Sharing	1;2;1;1;2;2;2;7;2;3	10	23
Maintenance, Quality	1;1;1;1;1;3;5;1;5;1;6;3	12	29
Ownership	2;1;3;2;3	5	11
coal, straw, dung, fuel wood, waste	2;3;5;5;1;3;2;7;1;2;7	11	38
kerosene (lamps)	3;1;2;1	4	7
oil, gas turbines, diesel	2;4;1;2:3	5	12

The dark grey color in Table 7 means either use of fossil fuels or environmental or health hazards, or a serious threat to social norms like corruption.

The preferences of interviewees were placed in Table 7 according to the frequency the interviewee emphasized the aspect, and these preferences of each interviewee were separated by a semicolon. Table 7 shows two sets of actions, A) Need and B) Energy Service, and the sets A and B are asymmetric, in some items they are related to each other, whereas some items have no relationship (Vincke 1992, pp.5-7). For example, “Food” in the A) Need Set, the left sub-table: 13 interviewees of total 14 interviewees referenced Food as a basic need and the third interviewee 5 times as is shown in the column Preferences, the eighth interviewee preferred Food 6 times, and the 13th interviewee preferred Food 11 times etcetera, total Preferences for Food amounted to 55. Taking an example of the right sub-table, “Solar” in the B) Energy Service Set: all the 14 interviewees preferred Solar, e.g. the third and fourth ones 4 times, and the 12th one 18 times, altogether 56 times.

Next, this analysis grouped needs to the five main broader need groups: a) Safe and Healthy Lighting, b) Clean Water, c) Nutritious Food, d) Education, and e) clean safe cooking. For the creation of services, each service was mapped with relevant items from A) Need set and B) Energy Service set in order to get an integrated service, which comprised all influential aspects. To start with, the preferences were placed in Table 8 to summarize how **a) Need Safe and Healthy Lighting** was comprised of direct and indirect needs. The definition of Class is found in Appendix 2 and Chapter 4.1.2.

Table 8. Need Class: Safe and Healthy Lighting, Saarinen, R., (2015b)

Need: Safe and Healthy Lighting 357 Preferences							
Direct Need	Light(ing)	Better Light	Modern Lamps				Total
Preferences	36	28	19				83
Indirect Need	Education	Health	Indoor Air	Security	Jobs	Business	Total
Preferences	80	47	32	30	49	36	274

Need Light received 36 preferences, but two interviewees did not mention it at all (Table 7). Taking account Better Lighting (illumination) with 28 preferences and Modern Lamps with 19 preferences from Energy Service set B, Lighting was preferred 83 times as shown in Table 8. As a consequence, Lighting was considered an important basic need. In the interviews, Lighting was preferred as a modern electricity light and especially solar-powered illumination in rural areas. Furthermore, Safe and Healthy Lighting affects on Education, Health, Indoor Air, Security, Jobs, and Micro to medium-sized business amounting to the frequency of 357, Lighting thus encompassing villagers' whole wellbeing. Chapter 4.1.3 analyzes Lighting as a created new service.

In the same way, during the interviews **b) Clean Water** was preferred a crucial basic need, which directly influences on such other basics needs as Food, Health, Sanitation & Hygiene, Pumping, wells and dams, Irrigation, and Hydropower, thus Clean Water had the frequency of 251 preferences (Table 9). Furthermore, Clean Water involves in Education, Cooking, Security, Jobs, Agricultural Productivity, and Micro to medium-sized businesses, altogether Clean Water amounted to 533 preferences. In conclusion, Clean Water was considered a cornerstone for all developments of rural areas in developing countries and this service is analyzed in Chapter 4.1.4.

Table 9. Need Class: Clean Water, Saarinen, R., (2015b)

Need: Clean Water 533 Preferences								
Direct Need	Food	Water	Health	Sanitation& Hygiene	Pumping, wells, dams	Irrigation	Hydro	Total
Preferences	55	64	47	24	32	15	14	251
Indirect Need	Education	Cooking	Security	Jobs	Agricultural Productivity	Business		Total
Preferences	80	39	30	49	48	36		282

As Clean Water and Safe and Healthy Lighting, **c) Nutritious Food** was acknowledged a vital basic need, which directly touches Water, Health, Cooking, Agricultural productivity, Livestock, and Stoves and totaled to 309 preferences (Table 10). Considering those indirect correlations with Education, Security, Jobs, Irrigation, Pumping, Compost, and Micro to medium-sized businesses, Nutritious Food summed up to 544 preferences. Chapter 4.1.5 discusses **Agricultural Productivity,** which significantly contributes to Nutritious Food.

Table 10. Need Class: Nutritious Food, Saarinen, R., (2015b)

Need: Nutritious Food 554 Preferences								
Direct Need	Food	Water	Health	Cooking	Agricultural Productivity	Livestock	Stoves	Total
Preferences	55	64	47	39	48	19	37	309
Indirect Need	Education	Security	Jobs	Irrigation	Pumping, wells	Compost	Business	Total
Preferences	80	30	49	15	32	3	36	245

Turning now to the self-esteem need, **d) Education**, which can leverage people to self-actualization level (Figure 1, Maslow's hierarchy of needs). This need was highly preferred and amounted to 80 preferences. Considering the integrated value of Education with the help of Figure 15, this system concept map shows the direct connections to Food, Water, Health, Lighting, Agricultural Productivity, Jobs, and Micro to medium-sized businesses, the frequency of preferences resulting in 415 (Table 11). Indirectly Education correlates with Modern Lamps, Better Lighting, and Electricity/Energy amounting to 100 preferences, altogether 515 preferences. Chapter 4.2.1 analyses Education and school food, which is related to **c) Nutritious Food**.

Table 11. Need Class: Education, Saarinen, R., (2015b)

Need: Education 515 Preferences									
Direct Need	Education	Food	Water	Health	Light	Agricultural Productivity	Jobs	Business	Total
Preferences	80	55	64	47	36	48	49	36	415
Indirect Need	Modern Lamps	Better Lighting	Electricity /Energy						Total
Preferences	19	28	53						100

Finally, interviewees preferred 76 times to cooking, improved stoves and cookers, but when the whole phenomena are accounted with Water, Food, Health, Indoor Air, Agricultural Productivity, Forest & deforestation, the frequency of preferences amounted to 331, which figure indicates how large individual, community and social problem area **e) clean safe cooking** is as was suggested in Chapter 2.1. The TAMAA case study report (Saarinen R., 2015a) discussed clean safe cooking.

By listening again the recorded interviews, data were categorized into Needs and every Need into individual, community, social, and obstacles groups (shown in Table 12). Needs are now placed in the needs-of-pyramid hierarchy (see Figures 1, 8, and 11), Food and Water at the bottom and banking and Micro to medium-sized businesses at the top. The interviews revealed a real-life set of businesses and Job opportunities as well as mutual business partnership models, and these new needs, 'Lighting', 'Jobs', 'Micro to medium-sized businesses' along with their requirements, are placed in Table 13.

Table 12. Needs categorized into Individual, Community, Social, and Obstacle groups, Saarinen, R., (2015b).

Need	Individual	Community	Social	Obstacle
Banking	Bank account, ID, credits, assets	Banks	Banking system, IDs, ownerships	Poverty, social structure
Micro to medium-sized businesses	Improved stoves production Hand-made products Making Cheese	under street light micro business, charging kiosk, selling ice, Improved stove production, hand-made products, making cheese, selling school-garden's vegetables	Women Bank, start-up funding	Poverty, Lack of education, Subsidized fuel, old traditions, ownership model
Mutual partnership	equality, humble mind, local	service charges, not free of charge, local knowledge	Infra	No ownership of systems, goods
Jobs	Getting work	Village Gardens, improved practices, irrigation, selling surplus to markets	local work for migrant workers	lack of education, unemployment marginalization
Agriculture	Improved practices, education	Improved practices, irrigation, education, school-garden	Improved practices, education, land reform	Poverty, Lack of education, investments, financing
Electricity	Light, cooling, equipment	Solar, hydro Village Electrification	National Electricity grid and utility	Poverty, lack of investments, financing, policies at state level
Light	Solar Light	Solar Light, street lights	Indoor Air program	Poverty, costs, Subsidized diesel, Funding, Financing
Equality	Inviolable worth of each human: Gender, race, disabled	Inviolable worth of each human: Gender, race, disabled	Inviolable worth of each human: Gender, race, disabled	No awareness of Human Rights, no education, prejudices, harmful old traditions
Education	Children Solar Light	Solar Light School Food	Enrollment, school food, removal school fares	Poverty, illnesses, costs, old traditions
Health	**Indoor Air, Solar Light**	**Indoor Air, Solar Light Solar cooling**	**Indoor Air program**	**Poverty, costs, lack of education, old traditions**
Water	Solar-based Pumping	Solar-system, 5-10 people in group, access to water near to you	Access to Clean Water, clean water programs	Poverty, lack of education, old traditions, Subsidized diesel, Gas turbine Funding, Financing
Food	**Improved stove Solar cooker**	**Improved stove**	**Improved stove programs**	**Poverty, lack of education, old traditions, Financing**

The dark color indicates the health consequences of traditional cooking and lighting practices and how solar light, improved stove or solar cooker can improve indoor air problems.

4.1.2 Service Creation Process

The service creation process (Figure 43 below) started by the discovered Customer Needs placed on Table 13, which helps to map Needs, Requirements, and Services. The requirements to services are applied from the needs (this is named the requirement management phase in Figure 43), and some requirements are the same for several needs, as exemplar the requirement "2H Decrease in Malnutrition in Health Need", which is the requirement to Food Need and Health Need, 2H means the second requirement in Health Need. The service categories include those requirements, which Service can meet as exemplar Service Clean Water: includes requirements 1W Clean Water for Drinking, 1F Clean Water for Food, 3W Clean Water for Agriculture, and 3E Clean School Water. Service Clean Water has the requirement "1F Clean Water for Wood", which is the first requirement in the Food Need, thus this requirement is the same one to Needs, Water and Food. The licentiate thesis now turns to discuss the service creation process.

Table 13. Need, Requirement, and Service categories, Saarinen, R., (2015b)

Need	Requirement(s)	Service
Food 	1. Clean Water for Food 2. Nutritious Food 3. Food Security 2H. Decrease in Malnutrition	Service Nutritious Food: 1F Clean Water for Food 3W Clean Water for Agriculture 1A Improvements in Crop Yields 2A Improvements in Versatile Crops 4A Increased Food Security 2F Nutritious Food 2H Decrease in Malnutrition
Water 	1. Clean Water for Drinking 2. Access to Clean Water 3. Clean Water for Agriculture	Service Clean Water: 1W Clean Water for Drinking 1F Clean Water for Food 3W Clean Water for Agriculture 3E Clean School Water
Health 	1. Decrease in Water related Diseases 2. Decrease in Malnutrition 3. Healthy Indoor Air	1H Service Clean Water 2H Service Nutritious Food 3H Service Safe and Healthy Lighting
Education 	1. Healthy Pupils 2. Nutritious School Food 3. Clean School Water 4. Healthy Teachers	1H Service Clean Water 2H Service Nutritious Food 3H Service Safe and Healthy Lighting => 1E, 2E, 3E, 4E
Lighting  	1. Safe and Healthy Lighting 2. Healthy Indoor Air, same as 3H, 3J 3. Provides Security 4. Enables Learning and Education 5. Healthy Pupils, same as 1E 6. Healthy Teachers, same as 4E 7. Enables Jobs 8 Healthy Workers, same as 4J 9. Enables Micro to medium-sized businesses	Service Safe and Healthy Lighting: 1L Safe and Healthy Lighting 2L Healthy Indoor Air, same as 3H, 3J 3L Provides Security 4L Enables Learning and Education 5L Healthy Pupils, same as 1E 6L Healthy Teachers, same as 4E 7L Enables Jobs 8L Healthy Workers, same as 4J 9L Enables Micro to medium-sized businesses
Jobs 	1. Income 2. Livelihood 3. Healthy Indoor Air 4. Healthy Workers 5. Enables Food, Water, Health, Education, Banking	1H Service Clean Water 2H Service Nutritious Clean Food 3H Service Safe Healthy Lighting => 3J, 4J, 5J
Agricultural Productivity 	1. Improvements in Crop Yields 2. Improvements in Versatile Crops 3. Increased Water amount to Agriculture 4. Increased Food Security 5. Responses to High Food Prices 6. Access to Arable Land	Service: Dripp-irrigation to Food markets 1A Improvements in Crop Yields 2A Improvements in Versatile Crops 3A Increased Water amount to Agriculture 4A Increased Food Security 2F Nutritious Food 5A Responses to High Food Prices 2H Decrease in Malnutrition 1J Enables Income 2J Enables Livelihood 5J Enables Heath, Education, Banking

The service creation process is applied from the research process (Figure 14). The research process and the critical realism process (Figure 13) enable to create the development process for new energy services, which meet the needs of people living in developing countries. Figure 43 illustrates how to capture needs and requirements for new energy services, and how to verify and validate them. Several iterative, incremental, and agile cycles are needed until the service meets the requirements and needs. This process utilizes scholars (Antonides, 1996; Armour & Miller, 2001; Cooper, 2001; Easterbrook, 2007; Grönroos, 2000; Larman, 2002; Novick et al., 2002; Urban & Hauser, 1993):

1. Qualitative and Quantitative methods to capture needs and requirement
2. Iterative and incremental method
3. Classes
4. Concepts
5. Use cases
6. Processes, sub-processes
7. Milestones and process phases
8. Multi-level ontologies and mapping
9. Verification process
10. Validation and technology transfer process

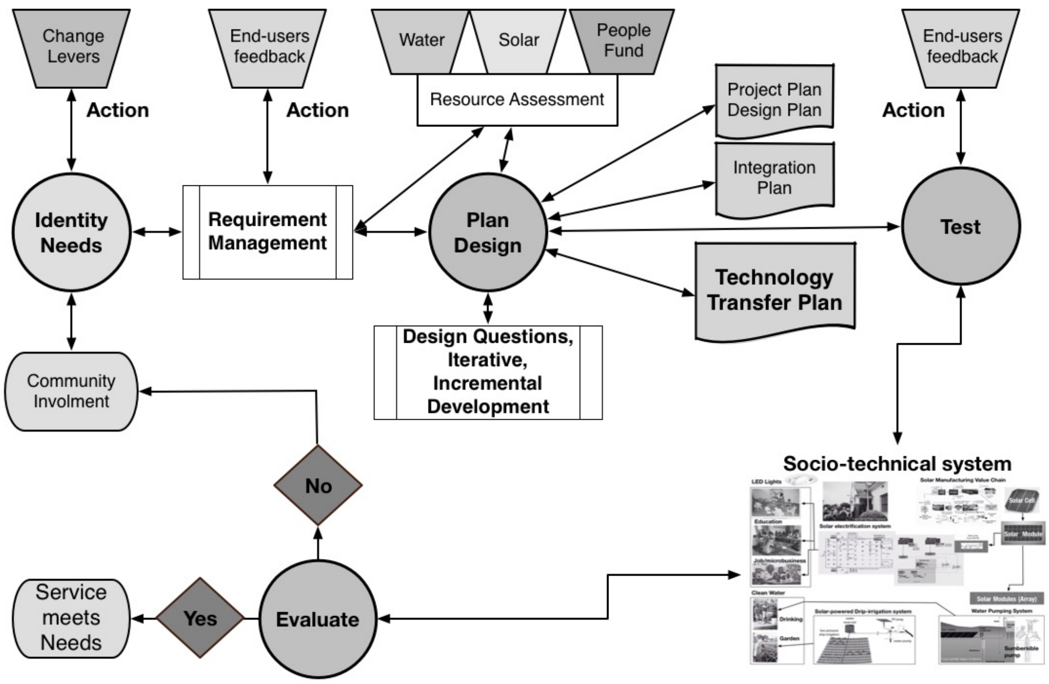


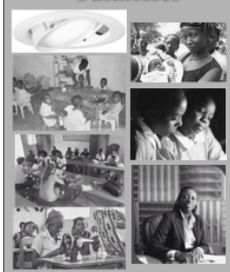
Figure 43. Service creation process. Service creation starts by identifying needs with the community and other actors (Table 13; Chapter 2). The requirement management defines requirements with related needs for services and takes account of users' feedback; this is an iterative process (Table 13). The design and development of services create required services, which meet requirements (Table 13); this is also an iterative and incremental process. The planning phase includes project plan, resource assessment, integration plan and drafting Technology Transfer Plan (Figure 47, Table 16). The testing phase includes the feedback of users and the iterative and incremental process modifies the development of services. The evaluation assesses whether the

created service matches the needs, and if not the modification will start and a new round of the creation. Change levers (Chapter 4.2.3, Figure 49. Saarinen, R., 2015b)

4.1.3 Safe and Healthy Lighting Service

Solar-based Lighting is integrated into Health, reducing the serious indoor air problems caused with the use of traditional kerosene lamps. Lighting makes Education and Jobs possible also in the evening, on the other hand, Micro to medium-sized business opportunities are related to Lighting and Jobs (Figure 14). The Need Class of Lighting (Class, Appendix 3), which comprises the Needs—Lighting, Health, Security, Education, Jobs, and Micro to medium-sized businesses—and which meets the related requirements, was created as illustrated in Table 14 (driven from Tables 12 and 13).

Table 14. Need Class of Lighting, Saarinen, R., (2015b). Photos (Photo Ref.)

Need Class of Lighting	
Comprised Needs	**with Requirements**
Lighting **Health** **Security** **Education** **Jobs** **Micro to medium-sized businesses** 	Service Safe Healthy Lighting: 1L Safe Healthy Lighting 2L Healthy Indoor Air, same as 3H, 3J 3L Provides Security 4L Enables Learning and Education 5L Healthy Pupils, same as 1E 6L Healthy Teachers, same as 4E 7L Enables Jobs 8L Healthy Workers, same as 4J 9L Enables Micro to medium-sized businesses

By applying the service creation process (Figure 43), the creation of Lighting service began first with the phase ”Identify Need”, which in a real-life field case calls for the involvement of local community and users' feedback. This licentiate thesis applied the baseline review, General Basic Customer Needs in Chapter 2.1, as well as the conducted TAMAA interview study for acquiring deeper understanding of the needs of African villagers and their communities (Tables 7-14) (Saarinen, R., 2015a). The most weighted needs of customers, villagers, were analyzed to be Clean Water, Nutritious Food, Lifelong Health, Education at all levels, Safe and Healthy Lighting, Agricultural Productivity, Jobs, and Micro to medium-sized business opportunities. These needs were mapped to Maslow's hierarchy of needs as illustrated in Figure 1, and the results in Tables 8, 9, 10, 11, 12, 13, and 14 associate with the needs, requirements, and services, which can be modified to local needs as George Pindua replied in his feedback to the TAMAA case study report (Appendices IA and IF in TAMAA Interviews, Saarinen, R., 2015a).

The next phase in the research process was to analyze resources; there are abundant solar resources in Africa (Appendix O in TAMAA Appendices, Saarinen. R., 2015a), but the assessment of local conditions is needed to confirm the local conditions, see the technology transfer process in Chapter 4.1.7. The interviewees emphasized such issues as a) the applied technology should match the local practical needs, b) education, training, public education and guidance, and knowledge transfer at all levels, c) applying best practices, visiting the places where successfully implemented, learning by doing, and villagers should be involved, d) the system integration and gradual development, with statements like “integrated into together”, “all should go hand-in-hand”, ”small-scale step-by-step”, e) the maintenance and operations of the installed systems, f) batteries and other spare parts, and g) finally summarizing by Paulo Pinho, one interviewee: ‘perhaps not providing solutions but by sensitively discussing how local people can utilize new technologies, from the point of view their own culture and traditions, how co-operate, how to use these technologies, they have to find their own ways to use and deploy new technologies.’. (Appendix IE in Saarinen, R., 2015a).

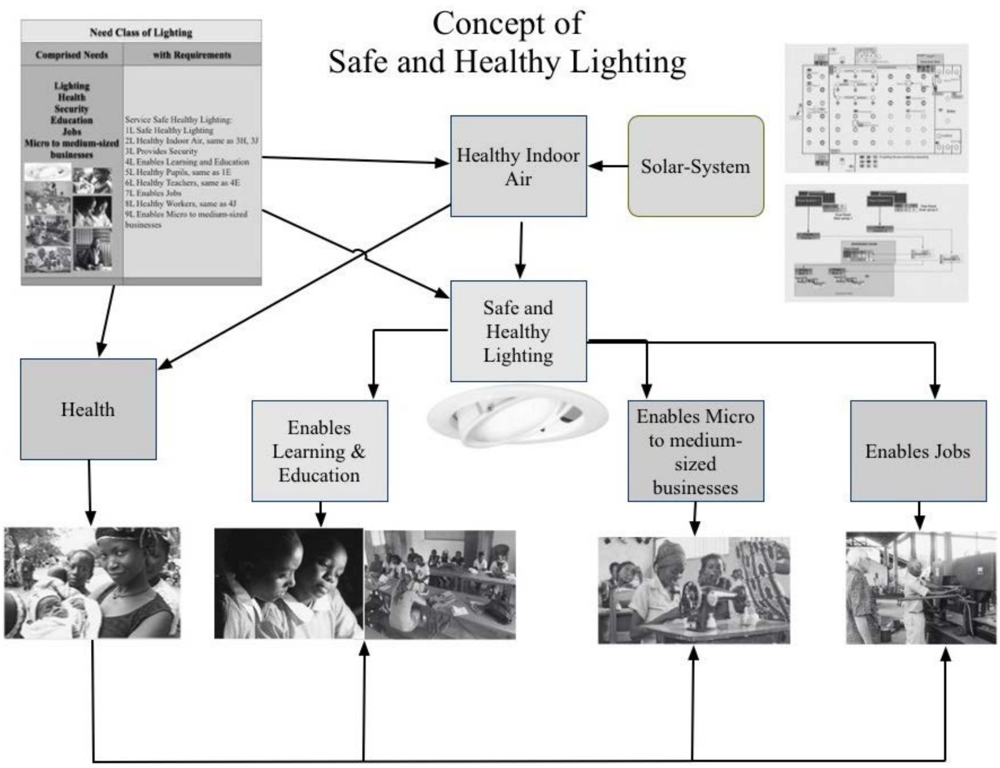


Figure 44. Concept of Safe and Healthy Lighting: Lighting, Health, Security, Education, Jobs, and Micro to medium-sized businesses, Saarinen, R., (2015b). Photos (Photo Ref.)

The socio-technical solar system was reviewed in Chapter 3.3. Furthermore, Bhusal (2009) has researched and tested solar-powered LED lighting in Nepalese rural villages and Amogpai (2011) LED-lighting powered by PV panels in Sudan, whereas Tähkämö (2013) has studied the LCA of fluorescent and LED light sources and compared them with each other. As a consequence, the technologies of solar cells and LED-lights themselves can be considered stable, as Brita Jern, one interviewee, expressed: ’New energy services are splendid solutions for Africa, especially solar energy... solar energy is nowadays highly developed and the need for maintenance is almost nil. As far as I know solar energy services are functioning for decades.’ (Appendix IA Brita in TAMAA Interviews, Saarinen, R., 2015a).

Bhusal (2009) has researched how to replace fuel-based lighting with safe solar-based LED lighting in Nepalese homes, and internationally reported the results with his colleagues (Bhusal et al., 2007a; Bhusal et al., 2007b). Fuel-based lighting in developing countries is based on such versatile resources as candles, oil lamps, kerosene lamps, and biogas lamps, the ordinary wick-based kerosene lamps being the most common. However, even kerosene lighting is too expensive for people living in remote areas faraway from roads, thus villagers use such alternatives as jharro sticks (a resin-soaked pine tree stick). In rural homes, villagers have one room, which serves as a kitchen, a bedroom, a study room, a dining room, and a living room. Therefore, Bhusal defined what would be the lowest but sufficient lighting for defined tasks. He concluded that the illuminance level around 25 lx is sufficient for reading (a text near the light source), and the illuminance of about 5 to 15 lx was recommended for general activities. (Bhusal, 2009, p.34). Lighting is often the first electrification project in the rural community, and usually, rural communities lack the technical skills to install and maintain lighting and energy systems (see Chapter 4.1.8). The measurements results showed that the LED technology can bring necessary light to rural homes with least energy use and it is the potential technology to replace fuel-based lighting in a sustainable way. In a small rural house, even 5 MW small PV panel with its own small battery brings basic lighting to these people (Bhusal et al., 2007b). Lighting improves wellbeing, health, education, and business in village-communities, and LEDs and solar cells, based on semiconductor-based photonics (light) devices, provide sustainable Safe and Healthy Lighting.

4.1.4 Clean Water Service

Clean Water was preferred a crucial basic need influencing on other basics needs as Figure 15 and Table 9 emphasize: Food, Health, Education, Agricultural Productivity, Lighting and Jobs are all related to Water either directly or through Health. Clean Water is a cornerstone for all developments of rural areas in developing countries. Applying SMILE case (Figure 17) and the real-life ABC Water project (SLEF ABC Water portal), Service Clean Water was created as shown in Figure 45. Water pumping and pumps are shown in Figures 40 and 41 in Chapter 3.4.4.

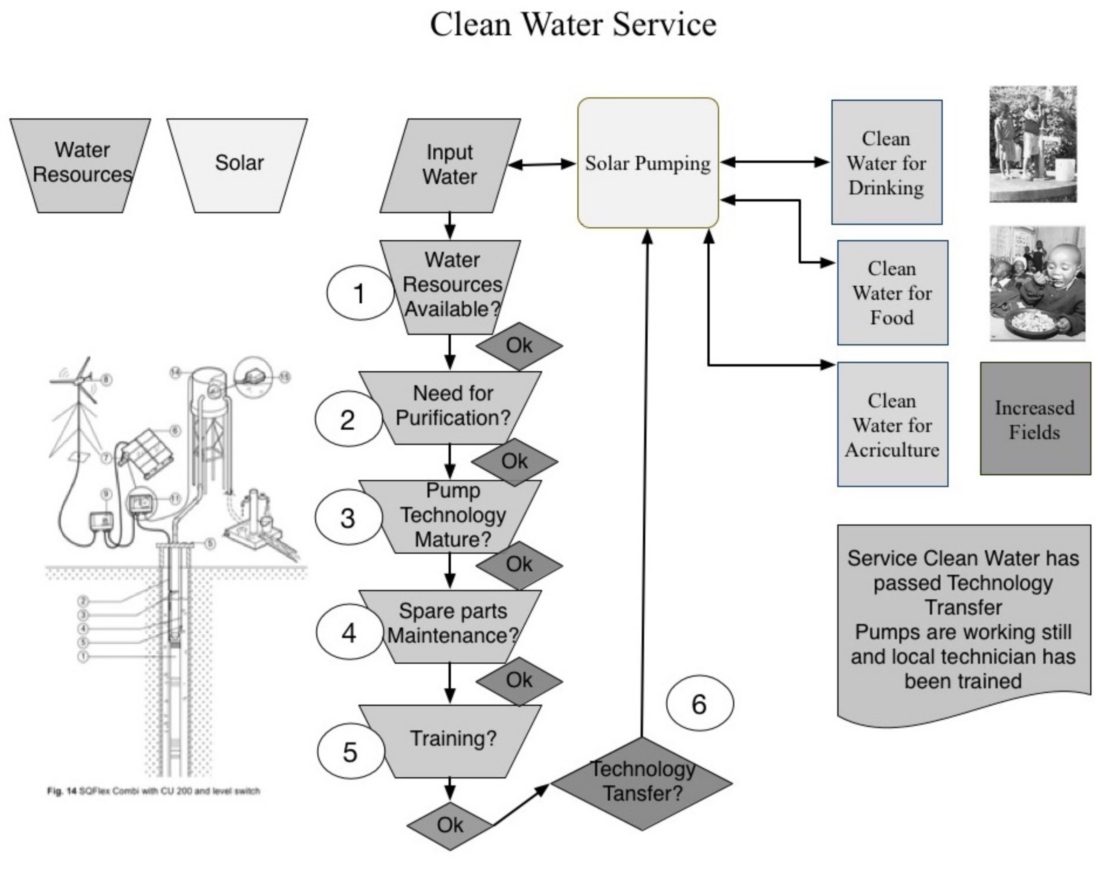


Figure 45. Flowchart for Clean Water Service, Saarinen, R., (2015b)

The real-life case ABC Water project in Abongo Dhoga Community in Kenya serves 1000 villagers at the total cost of 27 448,05€ or 27,45€ per person and this solar-powered system is pumping clean water 200 l/min or 12 m^3/hour, affluent amount of good quality water. The ABC Water project was initiated by SLEF (SLEF ABC Water, 2012, Appendix IB in TAMAA Interviews, Saarinen, R., 2015a), and it was taken over as a development co-operation project in Ministry for Foreign Affairs of Finland. Lake Diocese in Evangelical Lutheran Church in Kenya was a partner church and local Atemo Bible College.

Summarizing from the TAMAA Case study report (Saarinen, R., 2015a), ‘Clean water has enormous meaning for people in developing countries. Water near to you so that you have time for other activities and not just for survival and trying to get water and food fuel from long distances. For pumping water from groundwater wells, solar-energy is absolutely great. For nutritious food, you need irrigation and access to watering system and clean water without need to cook it first. Clean water pumping also provides small-business possibilities, solar-based watering, and gardening, and you can sell surplus for markets, getting incomes, meaning livelihood, ideal condition for rural people. Clean water is the basic need for healthy people, sanitation, and better hygiene.’ (Solveig Nylund, Appendix IE).

4.1.5 Service, Drip Irrigation to Food Market

Jyrki Myllärniemi, one of the interviewees, told the story from the Zimbabwean village (the story 1 in Appendix IE, Saarinen, R., 2015a), where a dam and garden system provided for the whole village work and income. As a consequence, villagers were no more forced to go as migrant workers to capital city or other countries. They learned through this dam project to organize and manage projects, budgets, funds and how to keep meetings, as well as the meaning of networking, and they started many new projects. Furthermore, they understood their rights and ownership issues. Through a banking system, they placed their income on bank accounts and gave those who had no money for their children's schooling.

This Zimbabwean story is related to SMILE Case, which demonstrated how women-groups started to cultivate their vegetables garden plots alongside a communal garden since 2007 in Benin (Case A1: "Solar-powered drip irrigation in Benin" in Figure 17 in Chapter 3.3.4 Case study research; Burney et al., 2009, 2013). The gardens were drip-irrigated by solar-powered submersible pumps, each solar system jointly used by 30-35 women in an agricultural group. As a result, food security increased significantly. During the first year farming, women kept 18% of vegetables production to their households and sold the rest to local markets, and the status of women's gardens and their livelihood opportunities is found in (NDF, 2014). In summary, Figure 46 demonstrates the solar-powered drip irrigation for gardening (the pumps in Figure 41). The other successful case evaluated and assessed in SMILE Case was Ilunda Water project in Tanzania (Base case: "Ilunda Water project" in Figure 17, SMILE Base Case, Water at the end of the TAMAA Case report, Saarinen, R., 2015a). In Gunga school premises, the hybrid system utilizes drip irrigation for the school garden, and the solar-wind hybrid pumping for clean water for drinking and food preparations. The system has submersible pumps able to pump large amount of water for 24 hours per 7 days per week, the solar panels are located on the roof of the well-house, and the chlorination system makes its own chlorine and injects the correct amount directly into the flow line from the pump.

Drip irrigation in arid and semi-arid regions (Appendix M, Saarinen, R., 2015a) reduces water use, because drip irrigation delivers water and fertilizers directly to the roots of plants, thereby improving soil moisture conditions; in some studies, this has resulted in yield gains of up to 100%, water savings of up to 40–80% (Burney et al., 2009; Silungwe et al., 2010). The savings compared with traditional irrigations have been estimated to be 30-70% by Narayanamoorthy (2009), or 40 – 80% by Sivanappan (1994), over 50% by Maisiri (2005), even up to 90% by Tanji (2002). Drip irrigation is also suitable for lands of all kinds, and improvements in yields co-operate with better utilization of fertilizers. Furthermore, irrigation leads to local cooling (IPCC 2013), thus irrigation with renewables like solar decreases CO_2 emissions, cools locally, and increases plants (photosynthesis, land cover change, mitigates desertification) as well as in a smart and sustainable way increases food security (FAO 2011; IPCC 2013).

Considering the sustainability of PV panels in Case A1, solar-based drip-irrigation provided each garden (120 m²) a minimum avoidance of 0.86 ton of carbon emissions per year and 12.9 ton over a 15-year lifetime (Burney et al., 2009). At the moment there are 8 gardens (NDF 2014) amounting approximately 100-ton avoidance of carbon emissions over a 15-years lifetime.

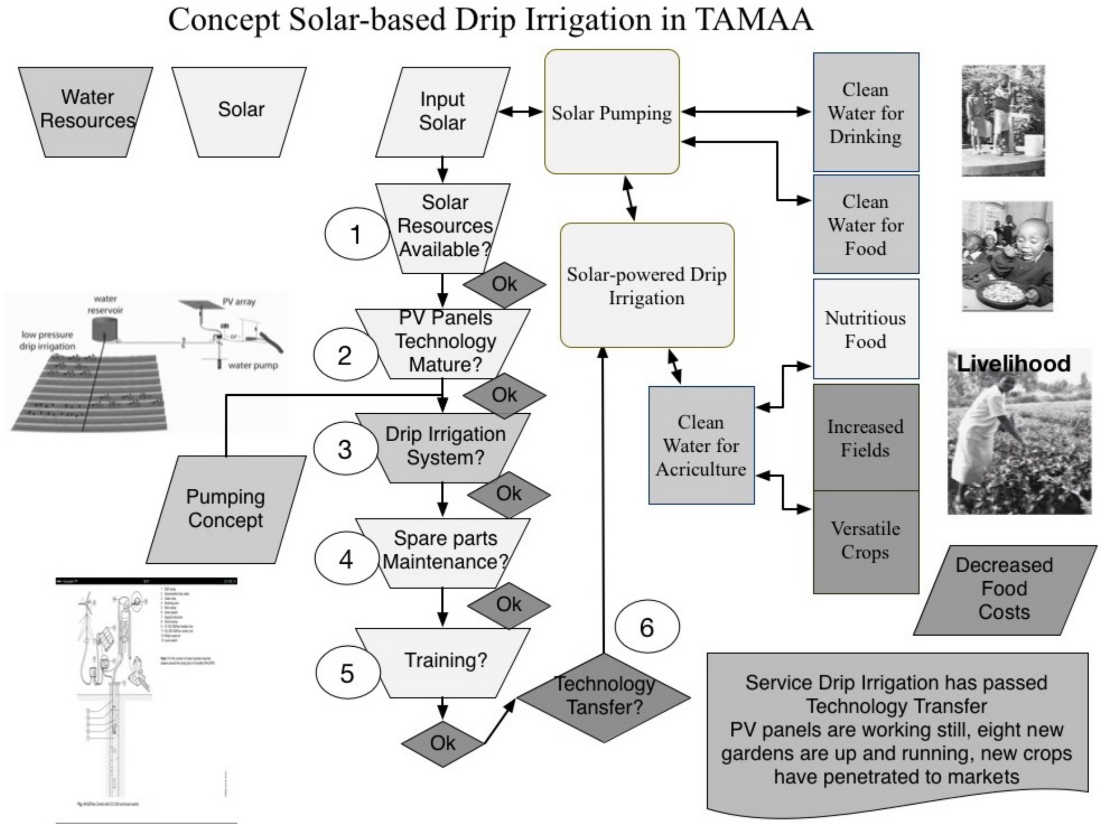


Figure 46. Flowchart for solar-powered Drip irrigation, Saarinen R. (2015b)

As reviewed in Chapter 2.2, global food markets are the largest segment in BOP total markets potential and Africa's total agriculture and agribusiness could create an industry opportunity of 1000 billion USD, which is half of Africa’s total economy of 2 trillion USD today. Service, ”Drip Irrigation to Food Markets”, decreases high food prices, which cause malnutrition and food crises especially to those who are food net importers spending 70-80% of their daily income on food, at the same time, increased prices provide better income for those farmers who can sell their products to food markets. As a result, agricultural productivity provides better livelihood. (SIDA, 2008; World Bank, 2012, 2013). New agricultural development work in participatory action mode will result in opportunities for exporting organic product from Africa, where smallholder farmers—50% of world's hungry people are smallholder farmers and over 60% of Africans depend directly on agriculture for their livelihoods (Chapter 2.1.3)—are actively searching for new and better ways of working as teams with researchers and other stakeholders (Whyte, 1991; SIDA, 2008). This licentiate thesis turns now to the experimental evidence on the EPOPA program (Chapter 4.1.6) and how to enter international food markets (Chapter 2.2).

4.1.6 EPOPA case study for international food markets

The EPOPA case study shows how to enter successfully international food markets. The idea of building export opportunities for rural households of developing countries started based on the farmer's practices in Uganda, who did not use any agrochemicals and were thus by default almost organic farmers. The Export Promotion of Organic Products from Africa (EPOPA) programme was executed in Tanzania and Uganda during 1997–2008 by Swedish International Development Cooperation Agency (SIDA) and implemented by Agro Eco BV and Grolink AB (SIDA, 2008). The basic foundation for the EPOPA concept was the market study and the global organic market demand that has grown from 13 billion USD in 1998 to 33 billion USD in 2005. By 2015, the global organic food and beverage market is expected to reach 104.50 billion USD (UNESCAP FS, 2012, according to Marketsandmarkets, 2011). In the period 2002 to 2007, the EPOPA programme was considerably scaled-up and subsequently phased out in 2008. During the program, farmers sold organic products for approximately 15 million USD per year, the total export value being more than double. A total of 110 000 farmers participated, but only 80 000 have actively delivered products to the exporters, meaning approximately 660 000 rural people benefitted the cost of the program being only one cup of coffee for Swedish tax-players (EPOPA, 2008).

The one of the key success factors of programs was properly executed front-end studies (Cooper, 2001). Indeed, the EPOPA programme assessed first the suitable exporters for the organic products, who were willing and capable of selling the products. These exporters were competent to build a direct profitable mutual relationship with right farmers, who wanted to farm organic products with a competitive quality and price for the markets and in areas and conditions suitable for selected products. The exporter was responsible for creating the markets for the product and arranging and paying the required product certification. Because exporters were selected to create a viable business, hardly any funds were made available for investments. In order to market products as organic in the global markets, organic producers have to undergo the certification process by a recognized certification body. The certification process focuses on how the product is produced and the traceability of the products in the trade from the primary producers to the end outlet. It is very much a targeted process. The needs are led by consumers, who are conscious of the sustainability, quality, and ethics among other important drivers in the organic markets. The organic markets were new to exporters and it took time to learn and adjust to it, but during the program they increased their competencies in several areas as exporters.

Selected farmers were smallholders and most of them were "organic by default", e.g., they used hardly any agrochemical inputs before their participation in the program. Despite the great variety of crops and large number of farmers, there were no insurmountable problems in the production or with pests. Farmers experienced a substantial increase in their income in percentages. For those farming such high-value crops as cashews, fresh fruits and spices, the increases were substantial also in absolute terms. On the other hand, especially those farmers producing basic commodities despite the increases in incomes were not able sufficiently to come out of poverty. Working with the commercial sector to develop agri-business has been successful for many rural farmers. The improved food security among smallholders, who were farming organic products, do not depend on the increased prices of agrochemicals and thus organic farming decreases the costs. Benefits of farmers' increased incomes contributed to local employment in manufacturing, trade and service. During the whole certification process, the whole community became more experienced and was proud of knowledge people achieved.

4.1.7 Collaborative Adaptation of New Technology

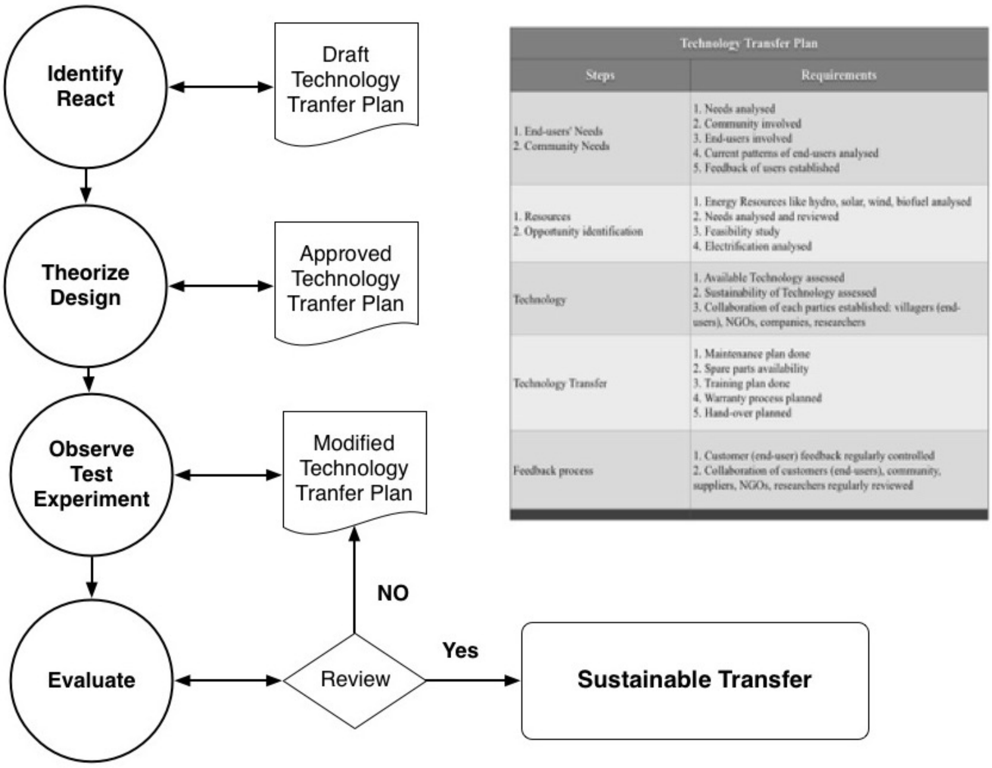
The successful adaptation and implementation of the new energy service mean that it meets the real needs of the user and is suitable and practical locally for the purpose it was created. Some key issues in the adaptation of a new technology are placed in Table 15 based on the interviews (Saarinen, R., 2015a). Tapio Keränen, one interviewee crystallizes: 'Modern complicated technology, a solar-based system, is quite simple to transfer, you acquire them, some people will learn to use them and utilize them in the receiving land. But if we think about a battery system, this will need long time until we have an infra, which will take care of their maintenance, or there is a shop, where you can buy new batteries and charge them.' (the story 2). Another one, Mikko Juntunen, emphasized: 'But when going in places where you cannot read, the preliminary knowledge of how the new system works is quite challenging, and then it is necessary that you can utilize the new system in a practical way and be able to maintain the system. If there is a village community where you have several solar-systems, you already have structures, there can be someone who can be specialized in that system and can have income and livelihood of it.' (the story 5 in Appendix IE, Saarinen R. 2015a).

Table 15. Some key issues in the adaptation of new technology, Saarinen, R., (2015b)

	Family/person	Community	Social
Mothers, women	Women accelerate change New practices save time for, e.g., micro-small business and school work	Women accelerate change New practices save time for, e.g., micro-small business and school work	Women's rights to land and bank accounts Credits Education up-to the university level
Education at all levels	Literacy, preliminary, secondary, tertiary, mathematics, Apprenticeship contracts	Preliminary, secondary, tertiary schools, Apprenticeship contracts	Public education: preliminary, secondary Vocational school, high school University
Long term collaborative equal partnership	Respect, long term collaborative learning, participatory adaptation	Respect, long term collaborative learning, participatory adaptation	Infra
Training Maintenance Warranty Skills	New skills, technology, practices spare parts	New skills, technology, practices spare parts	Universities, trade and technical schools
Infra, shops, banking	Bank accounts	Shops, banks, electricity	Banking system, roads, railways, electricity networks
Visits, excursions	Best practices	Best practices	Best practices
Pilot projcts	Involvement	Involvement	Involvement

Next, the Case A3 “O&M and Training PV systems Thai Border rescue camp” (Greasen, 2010) as a negative case study in SMILE Case (Figure 17) illustrates how the adaptation of new technologies needs long-term collaborative learning (Chapter 3.5.1) in a village community. There was no maintenance and warranty plan for the installed PV home systems in spite of the large amount of users of 203 000. Over 14 000 solar systems were installed under the government program in Thailand, when the Border Green Energy Team (BGET) started in 2005. The facts of the government energy program: 203 000 solar home systems, 200 million USD, no maintenance plan, 23% failure rate within 20 months. When analyzing the reasons why the O&M was not working at all, the BGET team asked: What will a customer normally do when a system component broke down? The customer asks the repair of the component from the supplier or the shop, which have given a warranty. But the warranty process was not arranged in this case.

When starting a new technology project, it is important to build the operations and maintenance capabilities at the same time and trained the local people to take care of the PV systems, and the warranty process should be arranged between the customer and the installation company. To overcome the obstacles in Tables 15 and 17 and based on the research process (Figure 14), this licentiate thesis created Technology Adaptation process (Figure 47). Table 16 presents the corresponding technology transfer plan, which will be modified by a collaborative program team during the service creation process (Figure 43) and technology adaptation.



Technology Transfer Plan	
Steps	Requirements
1. End-users' Needs 2. Community Needs	1. Needs analysed 2. Community involved 3. End-users involved 4. Current patterns of end-users analysed 5. Feedback of users established
1. Resources 2. Opportunity identification	1. Energy Resources like hydro, solar, wind, biofuel analysed 2. Needs analysed and reviewed 3. Feasibility study 4. Electrification analysed
Technology	1. Available Technology assessed 2. Sustainability of Technology assessed 3. Collaboration of each parties established: villagers (end-users), NGOs, companies, researchers
Technology Transfer	1. Maintenance plan done 2. Spare parts availability 3. Training plan done 4. Warranty process planned 5. Hand-over planned
Feedback process	1. Customer (end-user) feedback regularly controlled 2. Collaboration of customers (end-users), community, suppliers, NGOs, researchers regularly reviewed

Figure 47. Technology Adaptation Process, Saarinen, R., (2015b)

As previously pointed out, Table 15 expressed the Needs categorized into Individual, Community, Social, and Obstacle groups, the Obstacles group in that table revealing why the basic needs were not met. On the other hand, after several listening of the recorded interviews, the obstacles were arranged differently only at social and individual level in Table 17, because solely community level answers to the obstacles were few. These two ways broaden the view of barriers, which need to be triumphed in developing new services.

Table 16. Technology Transfer Plan, Saarinen, R., (2015b)

Technology Transfer Plan	
Steps	**Requirements**
1. End-users' Needs 2. Community Needs	1. Needs analysed 2. Community involved 3. End-users involved 4. Current patterns of end-users analysed 5. Feedback of users established
1. Resources 2. Opportunity identification	1. Energy Resources like hydro, solar, wind, biofuel analysed 2. Needs analysed and reviewed 3. Feasibility study 4. Electrification analysed
Technology	1. Available Technology assessed 2. Sustainability of Technology assessed 3. Collaboration of each parties established: villagers (end-users), NGOs, companies, researchers
Technology Transfer	1. Maintenance plan done 2. Spare parts availability 3. Training plan done 4. Warranty process planned 5. Hand-over planned
Feedback process	1. Customer (end-user) feedback regularly controlled 2. Collaboration of customers (end-users), community, suppliers, NGOs, researchers regularly reviewed

Table 17. Obstacles, Saarinen, R., (2015b)

Obstacle	Invidual	Social
Poverty	Yes	Yes
Lack of land reform	No right to land, no farming	In many countries no land reform, no landownership arranged
Lack of banking	No ID-card, no bank account	Banking system, ownerships, ID, need for a stable structure and laws
Lack of money, funding	Yes, need for start investment, one interviewee considered this social	Yes
Lack of jobs	Yes	Yes
Lack of knowledge and public education	Unliterary, school fares, lack of food, household activities, poverty	Lack of public education and qualified teachers, school fares, school books and material
Lack of training, also professional	No knowledge how to use new systems	Access to trade and technical schools
Women and girls do household activities	Women and girls need to be trained to use new services	Old traditions of women and girls, women need to be involved to new systems
Lack of sanitation, clean water, food	Diseases, education suffers	Diseases, healthcare and hospitals needed
Fuel food, straw etc. free in rural areas	Costs for improvement systems, e.g. Improved stoves	Costs as deforestation
Subsides for fossil fuels like petrol, diesel, kerosene	**Costs of new energy systems like solar**	Costs of greenhouse gases
Corruption, conflicts	**Yes**	**Yes**

To summarize, the requirements for the service in the sustainable service creation include such features as this service is 1) easy to use, 2) efficient, and 3) adaptable to local needs as well as 4) modular so that more modules can be easily added to increase the available output, and furthermore, this service 5) requires minimal maintenance and 6) has a long lifetime. Regarding the technology adaptation, Brita Jern, one of the reference interviewees, gave her evidence: 'I think the girls and the women are the target. We need to teach them, they are the ones who are preparing food, fetching water, feeding children and so on. Try to teach the need for maintenance, try to show that the whole community is profiting from a system, thus avoiding thefts, planting a we-spirit, educate people who can maintain devices and supervisors and who can do check-ups. Bringing knowledge to common people, not only to experts, is part of the solution to integrate new energy systems into the daily life of rural people in Africa.' (Appendix IA in TAMAA Appendices, Saarinen R. 2015a).

4.1.8 Summary of Services

Thus far, this licentiate thesis has analyzed the baseline review (Chapter 2) and such new services as Safe and Healthy Lighting, Clean Water, and Drip Irrigation to Food Markets as well as the adaptation of new technology and obstacles. The licentiate thesis reviewed, created, demonstrated and validated how these new services were possible to create based on solar technologies. Furthermore, this research work integrated Needs, Energy Services, and Technology to the socio-technical system with the rich ontology. Taken together, this study suggested a model to frame a sustainable flourishing learning village-community from these service building blocks in a co-generative learning mode. Next, this village community is illustrated.

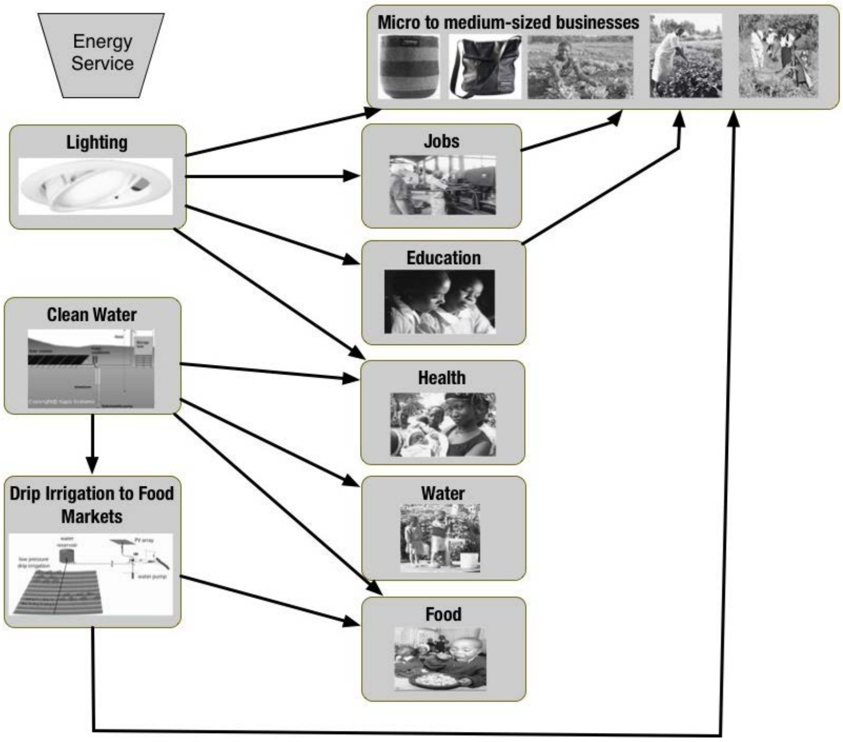


Figure 48. New energy services related to basic needs, Source R. Saarinen 2015a. Photos (Photo Ref.)

4.2 New Concept: MOYO Community

4.2.1 Education and Nutritious Food

SMILE Case examined and validated a solution providing Nutritious school Food and Clean Water for school children and their teachers (Figure 17), this Base case (Stricklin, 2006) indicating how crucial a village school is for children and the whole community.

On the other hand, Chapters 4.1.2, 4.1.3, 4.1.4, and 4.1.5 demonstrated how to produce Safe and Healthy Lighting, Clean Water, and Drip Irrigation for gardening, and thus make it possible to provide nutritious Food and a healthy school environment to school children and their teachers. Indeed, Paula Tommila, one interviewee referred to their projects to improve school children's nutrition and how school food improved not only nutritious intake but enrollment of Education as well (the story 6 in Appendix IE in TAMAA Interviews, Saarinen R. 2015a). Similarly, the nutritious food of school children was preferred in the reference interview (Appendix IA Brita Jern), this reference interview pointing out clean cooking opportunities as a solar cooker.

Pasi Aaltonen, the other interviewee (the story 9), continued this metaphor (Alvesson, 2001) and discussed largely the school-concept with school garden, school kitchen and food. The idea was to create a prototype of a school-concept, where the parents and their children can together cultivate vegetables and other horticulture products and get livelihood possibilities by selling surplus products to markets. One idea might be to integrate a better stove for clean cooking in the school-kitchen. This is a cornerstone for the whole social change process, Education at all levels, to make change happen and achieve a sustainable flourishing learning village community, and the next section turns the discussion to the village community of this kind.

4.2.2 Business opportunities, wellbeing and prosocial goals

This study found, according to many scholars, that concrete prosocial goals make people happy, prosocial spending promotes happiness, as well as active prosocial decisions increase donating by confronting people with an active-decision mechanism, which elicits latent prosocial behavior (see Chapter 3.2). This kind of active prosocial behavior has motivated donors like in the ABC Water project (Chapter 4.1.4; SLEF Nyagowa, 2015) and has catalyzed sustainable changes. Equally important, Women's Bank (Women's Bank portal) as well as SLEF micro and small businesses (SLEF MSB, 2014) support women's work in developing countries by providing micro-credits to start micro-businesses, funds are collected by donors in that case this is not a traditional banking business. Women can acquire domestic animals (hens, goats, lambs etc.); they can learn good agricultural practices and how to cultivate such gardens as tea plants and agriculture products of other kind. With this support, women can have professional training or education; they can acquire equipment, e.g., a sewing machine, and small kitchen facilities. Furthermore, women will learn how to establish savings- and loan-groups, which can create their own strict rules for guidance and followed-up as well as how collected funds will be saved, used, and controlled. The purpose is to empower the woman and through her reach children, her man and the whole family.

To compare these stories with the experiences in Sweden, the versatile organic products from Africa to Sweden in the Watatu shop and Watatu society place serve as an exemplar (Watatu portal). Another exemplar, Mifuko shop sells African ecologically friendly products designed in Finland but made by African artisans. In co-generative mode, African textiles can be bought via Internet and in shops as well as new leather bags and other textiles by Mifuko in Finland and Kenya (Mifuko portal, 2014) or similarly, African textiles in Sweden and Tanzania (Watatu portal, 2014). Based on these real-life on going experiences, the concrete prosocial goals can be generated and might be as below for illustrating purposes:

1. Give Clean Water and Health to the children and adults in Nyagowa in Kenya (or the name of the other specific country and area)

   a. as exemplars the ABC Water project, and the on going SLEF Nyagowa project
2. Give Clean and Nutritious School Food to the pupils and teachers
   a. as an exemplar the UN WFP program (UN WFP portal)
3. Give Safe and Healthy Lighting to the children and adults
   a. an exemplar can be framed from Nepal Light case and Safe and Healthy Lighting service
4. Give Education to children; Give a profession to women
   a. as exemplars school books and desks (SLEF School, 2014), women savings- and loan-groups, sewing machines (Women's bank Uganda 2014)
5. Give a prosocial specific gift
   a. as exemplars a school dress, a goat, a teacher to a child, a profession to a woman (Finn Church Aid, gift. 2014, Ethical Gifts)
6. Buy products made by Kenyan or Tanzanian women (or the name of the other specific country and area)
   a. as exemplars leather bags, Kiondo baskets, jewelry (Mifuko portal, 2014) cloths, tee, coffee, spices (Watatu portal, 2014)
7. Give Clean Water and Healthy environment to Health clinic in Nyagowa in Kenya (or the name of the other specific country and area)
   a. as exemplars the on going Water project SLEF Nyagowa
8. Volunteer work in Tanzania or Kenya (or the name of the other specific country and area)
   a. Co-operation work for doctors or the doctors in training (FMA, 2015)
9. This is a suggestion: Give a solar panel and decrease global warming

The cases reported above illustrate the possible prosocial goals based on the real life experiences, but the ninth goal is a proposal for an environmental prosocial goal. These experiences show the impact of prosocial behavior on the receiving countries and their economic conditions, how the beneficiaries have the possibility for food, water, education, professions, jobs and how these people might with start-up investments begin a micro business (Gundry et al., 2011). Equally important, the experiences of Mifuko confirm social enterprises as the vital actors of social change. According to a definition provided in (Lumpkin et al., 2011) 'social entrepreneurship focuses on those situations where the goal of the entrepreneur is a social mission, an effort to change the way society meets its needs'. For commercialization of new ideas to new markets, external start-ups have been applied, whenever the established companies may be poorly suited to address disruptive innovations for the markets and customers that are not served by existing product and service solutions. Social entrepreneurs might be seen as persons who are creating services and products to such the most challenging problems as the phenomena described in this licentiate thesis (see Chapter 2). Christensen et al. (2006) have defined these kind new disruptive solutions catalytic innovations, which are scalable and sustainable and "good enough" to meet the needs of these new customers in underserved markets. (AGI BOP, 2012; Bowman et al., 2009; Chesbrough, 2003; Christensen et al., 2006; Christensen, 2003; Gundry et al., 2011).

Next Mifuko tells how their team sees these innovations: '"Work of Hands and Hearts", Mifuko combines traditional African handcraft techniques with Finnish design. Mifuko workshops are all small. Several workshops employ less fortunate artisans, who are disabled or HIV-positive. Mifuko aims to support local workshops, which care about the welfare of their artisans and produce environmentally friendly products. We hope that our association with these small businesses will help talented artisans to obtain regular incomes, learn about new markets and adapt their existing skills.' (Mifuko About, 2015). It is worth mention that Stockmann sells Mifuko products (Stockmann, 2015). The TAMAA case study report provides more examples of business opportunities (Saarinen R. 2015a).

Furthermore, studies showed that proposal behavior will affect the purchasing decisions, which people do according to the values and ethics they have and that a service or product should match with customer needs, as quality research has traditionally inquired in business fields. One key aspect was that people's latent needs can be uncovered in asking actively people to contribute in prosocial behavior and made them aware of the social value of that particular behavior, the other key issue was the manner in which one was asked was crucial (Stutzer et al., 2010, 2007; Chapter 3.1.2). Indeed, being asked is an important factor in explaining why people contribute to a public good and offer to do voluntary work (Frey et al., 2004). These results agree with the findings of Meier, S. (2006), where he continued these themes and examined through surveys how prosocial behavior and happiness economics correlate and he crystallizes, 'Prosocial behaviour is widespread and quantitatively important for economic and societal outcomes. When designing institutions, prosocial behaviour has to be taken into account. If it is not, the institutions may not reach their intended goals.' Besides, the so called institutional and social environment affect how people contribute to the prosocial behavior: when others behave prosocially in people's reference group, people also donate more or do voluntary work or behave in other way pro-socially, the social norms (Social norms, the customary rules that govern behavior in groups and societies, according to Stanford Plato) defining what is a good and acceptable action (Cueva, 2012; Meier, 2006). The study (Fischbacher et al., 2001) concludes that approximately 50 percent of the people increase their contribution if the others do so as well, on the other hand, 30 percent are free-riders.

4.2.3 Sustainable Flourishing Learning Village Community and Future

Chapter 3.3 demonstrated the layered system model of the complex socio-technical solar system, where sustainable new energy services leverage capabilities to empower villagers to gratify their needs. In contrast, one percent of the world's population earns over 20 000 USD per year, while the others, 99 percent, just try to survive as Chapter 2.2 revealed. Therefore this licentiate thesis introduces, in order to bridge these two separate worlds and to overcome the barriers identified in Chapter 4.1.7 and Tables 15 and 17, the concept of Sustainable Flourishing Learning Village Community based on reviews and studies discussed in this licentiate thesis in the previous chapters. To summarize, Figure 49 shows the enlarged TAMAA concept, named the MOYO concept, where change levers could unlock lack of new energy services and make change happen, but on the other hand, corruption blocks and destroys the conditions, where change is possible to happen. The discovered change levers were as discussed Human Rights, Prosocial Goals, Commitment, Education at all levels, Collaboration, Equal Partnership, Villagers, NGOs, Universities, Companies, Service Creation and Technology Adaptation processes, as well as Green economy. The findings of the licentiate thesis suggest this MOYO concept as a change engine to empower villagers and their partners, targeting viable business environment around sustainable new services and taking advantages of promising food markets in Africa, as exemplar a local fruit factory and export of organic products (EPOPA, 2008; IFOAM, 2015, 2010; Nogamu, 2015; FAO EPOPA, 2006).

Majok Kariom envisions: ‘But if we install a factory there, a juice-factory, because there grow a lot of fruit trees, mangos, and nothing have been utilized yet. Then, if you have an energy in place, you have factories, they will work for 24 hours and people are working there, and their lives will change, and your agricultural projects will work for a whole year not only once a year, and you have education and your factory is commercial and that will change your life, your family's life and your friends', and village. So with this project (energy) we have roots in place, we have a factory, and we have schools, total change in people's lives’ (Saarinen, R., 2015a; acet 2013). The previous sectors explored Micro-small businesses, investments and prosocial goals, but now, this thesis continues with a proposal how the new MOYO concept might mitigate the consequences of global warming and cool locally.

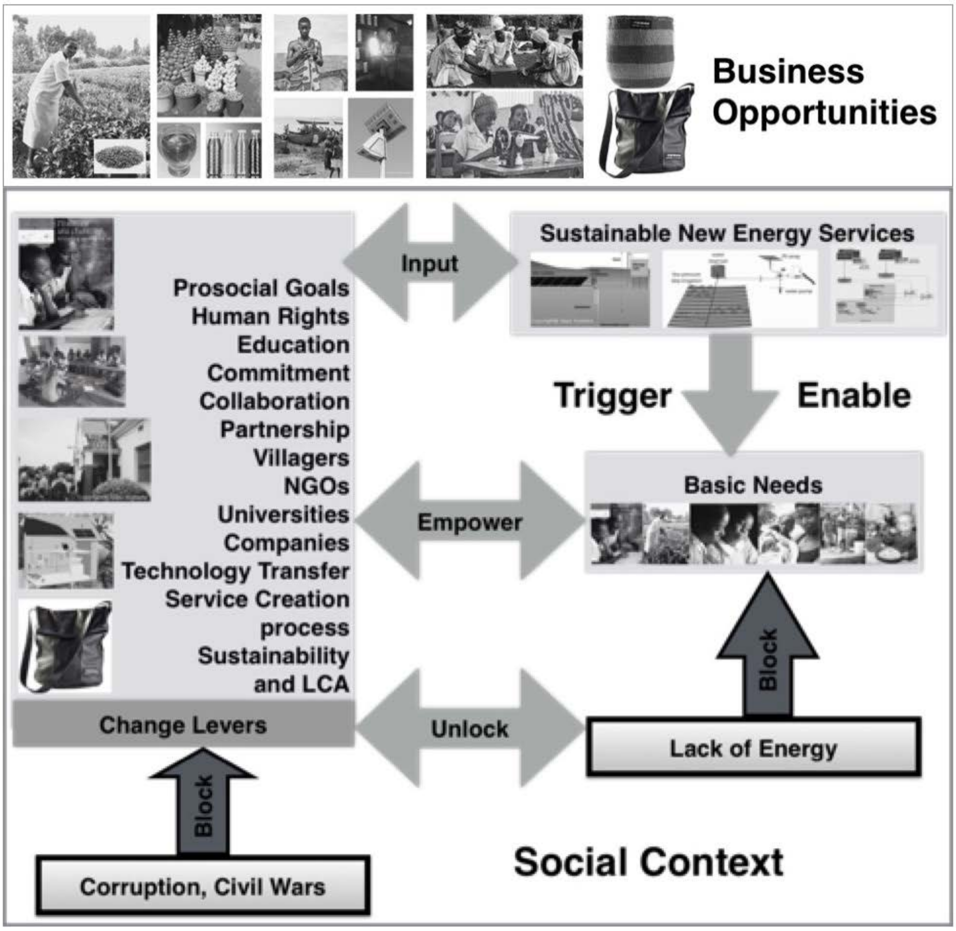


Figure 49. Concept MOYO, Saarinen R. (2015b). Photos (Photo Ref.)

As discussed in Chapters 2.2, 4.1.5, 4.1.6 and 4.2.2, Africa’s food market potential is the largest one and this proposal by Kariom fits this future picture (Corbo et al., 2014). This licentiate thesis reviewed the waste gasification based on fluidized bed technology and suggests broadening the scope from Village Community to larger communities, cities. By gasifying all kinds of municipal, factory, agricultural, and forest wastes or residues, the community will not only tackle waste management problems, but it will receive suitable energy for electrification in combined heat and power facilities, exemplified by the integration of a fruit factory and waste gasification. This licentiate suggests a new real-life study on this future opportunity to empower larger communities, from villages to cities.

The fluidized bed technology was applied for a new process in the polysilicon production as reviewed in Chapter 3.4.3 and Appendix 1. As a gasifier, Fluidized bed technology has already been utilized for municipal wastes, and agricultural and forest residues. Fluidized boilers and cogeneration have been employed for process industries since 1980s and this ties this mature technology to fruit juice industry, which operates as a food processing industry and produces wastes to manage. Figure 50 illustrates a municipal waste management system operating in Finnish town and consists of two 80 MW_{th} gasifiers (Basu P., 2006; Bertholz, 2013; Corbo et al., 2014; UNEP, 2007).

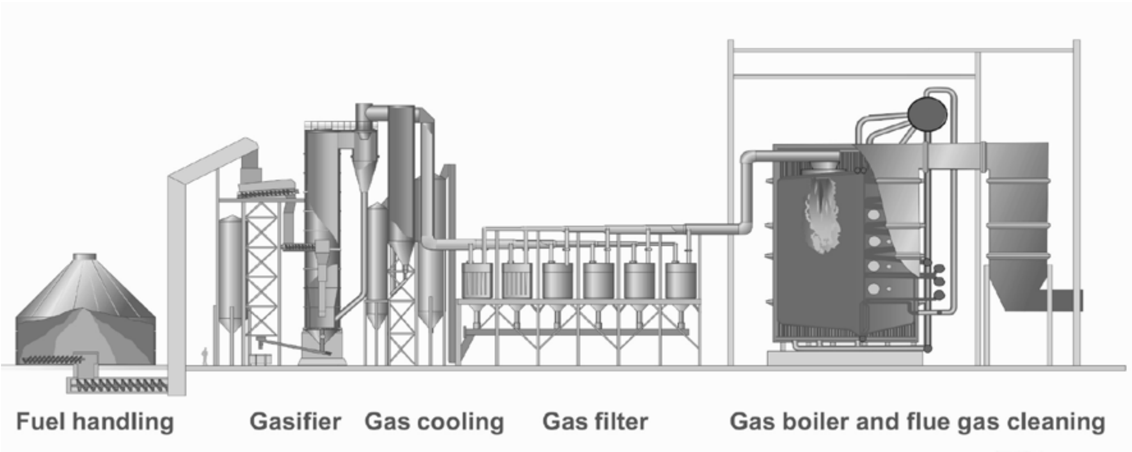


Figure 50. Waste gasification for power production, Bertholz, (2013)

5 Discussion

The licentiate thesis examined which new sustainable energy services can meet African villagers' well-being, what are those needs and what kind of flourishing village community is required to produce opportunities to gratify their needs and create businesses. Beyond the examination, this research created the new services, Clean Water, Drip Irrigation to Food Markets, and Safe and Healthy Lighting, and equally important, the discovered needs along with the related services were integrated into the MOYO concept. This concept is based on the layered solar socio-technical system to describe the social context, where change livers work as inputs for the change process and where new sustainable energy services trigger this social change in villagers' quality of life. Turning to the implications of the results, the structure of this discussion follows the created services in the relationship of the discovered needs by starting from the most commonly researched and implemented need, Clean Water.

The results of this study demonstrated that the service, Clean Water due to the solar PV panels and submersible pumps (see Chapter 4.1.4) is stable and working. Because of clean water for drinking, food, cooking, animal care, gardening, and agriculture practices, the water-based diseases decrease (see Chapters 2.1.3, and 2.1.4). These kinds of successfully functioning systems can be evidenced in such the public domains as in (SLEF ABC Water, 2012; SLEF Nyagowa, 2015; NAPS Water, 2015) and fall in the prosocial goals projects discussed in Chapter 4.2. One of the major obstacles, poverty, have led NGOs, and especially FBOs to install water pumps; thus, the lack of technical knowledge of these solar systems within NGOs might account for only 61% of rural population having clean drinking water and the poorest 20% only 34% in Sub-Saharan Africa in 2010 (see Figure 6). The lack of governmental support in providing clean water supply systems was not the focus of this thesis, but the fact is that many Sub-Saharan countries belong among the poorest in the world (see Chapter 2.1.5). This brings the discussion to the second created service, Drip Irrigation to Food Markets for discussion.

The service, Drip Irrigation to Food Markets (Chapter 4.1.5) broadens the service, Clean Water to enable a prolific agriculture with versatile crops and increasing yields, thus creating opportunities for Nutritious Food. This service generates micro- to medium-sized businesses, and village-farmers can sell diverse products to local markets, or farmers are able to cultivate organic products for exports such as the EPOPA program (Chapter 4.1.6) experimented, this program funded by SIDA (2015, 2008). Similarly, the Benin solar-powered drip irrigation system was funded by NDF and has reached eight gardens by 2014 (NDF Benin, 2014), the solar technology provided by NAPS systems (NAPS, 2014). Both these public cases have been successful, and the technology in Benin is stable and the EPOPA model has proven its sustainability to export African organic products (Nogamu, 2015). As the baseline review (Chapter 2.2) reported, food markets are the main sector in BOP markets, and estimations for the future indicate Africa's total agriculture and agribusiness could create an industry opportunity of 1 000 billion USD.

The most interesting findings were among the sustainable solar-powered prolific agriculture and promising food markets that this created service, Drip Irrigation to Food Markets a) decreases water use (compare this aspect with the economic water scarcity in Sub-Saharan Africa, Appendix E in TAMAA Appendices, Saarinen R., 2015a), b) improves soil conditions, c) decreases deforestation and soil erosion (Chapter 2.1.8), d) in a smart and sustainable way increases food security, and e) leads to a local cooling effect (IPCC, 2013). In conclusion, solar-powered irrigation decreases CO_2 emissions, cools locally, and increases plants (photosynthesis, land cover change, mitigates desertification). Further research should be conducted to investigate how the integrated solution can meet those needs described in Maslow's hierarchy of needs (Figure 1), by joining these created service —Drip Irrigation to Food Markets and Clean Water —and the similar kind of exports models like EPOPA. Figure 49 elucidates how the new sustainable services are capable of unlocking obstacles when communities try to meet their basic needs. Having discussed the other services, this section now turns to the third new service, Safe and Healthy Lighting.

The service, Safe and Healthy Lighting (Chapter 4.1.3), was created by the new Research process (Chapter 4.1.2) and Technology Adaptation process (Chapter 4.1.8) and this service is based on the LED lighting and solar PV panels, which are considered stable technologies. The service provides a safe and healthy environment (see Chapter 2.1.4) for schools, hospitals, working environments in firms and other buildings, among others, as well as for public areas. The solar-powered electrification (Figures 23-25), the illumination systems, and the new created services built layered solar powered community systems (Figures 20 and 24). Preliminary, secondary, and tertiary educations, as well as apprenticeship contracts harness villagers with opportunities to achieve their full potential, self-actualization (Figure 1), and to be full members of society. In a flourishing community, villagers can gratify their social needs, have opportunities to empower others, and work together in collaborative learning organizations (see Chapters 3.1, 3.2, 3.4). Although the technology is stable, the availability of the system components might raise concerns as discussed in Chapter 4.1.7, for example where to acquire LED-lamps. This turns the discussion to the new created MOYO concept for a sustainable flourishing learning village-community.

The findings of the licentiate thesis suggest this MOYO concept could act as a change engine to empower villagers and their partners, develop a viable business environment around sustainable new services and take advantages of promising food markets in Africa, exemplified a local fruit factory and the export of organic products. To highlight some key and interesting findings in prosocial goals and behavior related to new disruptive solutions, catalytic innovations might be scalable and sustainable and 'good enough' solutions to meet the customer needs in the MOYO concept. This cross-functional multidisciplinary thesis research demonstrated that concrete prosocial goals and happiness economics could boost the social change towards the wellbeing of African villagers. The other change levers found in the MOYO concept are Human Rights, Education, Commitment, Collaboration, Partnership, Villagers, NGOs, Universities, Companies, Technology Transfer, Service Creation process, and Green economy. The licentiate thesis has focused on integrating human needs, new energy services, and new technologies into an open complex dynamic socio-technical system, and suggests for the further research on building a real-life MOYO concept for Flourishing Learning Village Community.

Conclusions

Returning to the questions posed at the beginning of this thesis, it is now possible to state that Flourishing Learning Village Community, based on the created MOYO concept and the new sustainable energy services, have capabilities to empower villagers and meet their versatile needs. Notwithstanding, the wide gap between the vision and the reality of the widespread poverty, unproductive agriculture practices, and lack of energy and business opportunities, this licentiate thesis aimed to investigate which are those change levers, which can foster and generate a difference in villagers' quality of life. Consequently, in bridging the gap and acquiring a shared knowledge and meaning to answer this question, this study connected the theory, research philosophy, and practical knowledge of experienced people involved in cooperation development work. Because of the diverse needs of customers (villagers) and the complexity of this solar-powered socio-technical community system, the needs and requirements of customers are captured in multiple methods. Therefore, this research provided the voice for these professionals co-worked with Africans and applied collaborative knowledge generation and in-depth face-to-face interviews in TAMAA Case, which laid the foundation for the thesis. This raised the research question as to which kind of socio-technical system, learning community, and partnership model may produce wellbeing for villagers.

The results of this research suggest that creating a viable business environment around new energy services and taking advantage of promising food markets—Africa's total agriculture and agribusiness could create opportunities for 1 000 billion USD— will lead to more holistic approaches to overcome such obstacles as a lack of banking, funding, jobs, diverse education, and knowledge adaptation, among others. New services, Drip Irrigation to Food Markets, Clean Water and Safe and Healthy Lighting in the MOYO concept provide not only basic needs such as clean water, nutritious food, lifelong health, but capabilities to cultivate versatile agricultural products for local markets and attractive commodities for export as exemplified in the EPOPA model. Likewise, the MOYO model can work as a catalytic innovation, which is scalable and sustainable to meet the needs of these new customers in underserved markets, Africans' wellbeing within Flourishing Village Community, where they can gratify their needs.

To bridge the two separate worlds, the one percent of a world population earning over 20 000 USD per year and the remaining 99 percent, this licentiate thesis took a view of prosocial behavior as an action and mechanism to bridge the gap between customer (villager) needs and the current reality. This study suggested that the most serious obstacle is not poverty but the problems in meeting and bridging the prosocial needs of people of the prosperous world to reflect the needs of African villagers and city dwellers. The results of this research support the idea that proposal behavior will affect the purchasing decisions, which people make according to the values and ethics, they espouse. This statement is aligned to the traditional quality research in the fields of business: a service or product should match with customer needs. One of this key aspect is that people's latent needs can be uncovered in actively asking people to contribute in a specific prosocial behavior and make them aware of the social value of that particular behavior. Studies in these kinds of purchasing behaviors extend our knowledge of the role of the specific concrete prosocial goals. According to several studies, this can promote happiness and benefit the receivers of benevolences and are valid at individual, community, and social levels. Therefore, this licentiate thesis emphasized democratic dialogue, co-operation of actors from different organizations, local commitment and involvement, and trust when triggering a social change in building the shared knowledge of villagers, NGOs, companies and researchers.

The scope of this study was limited to solar-powered services in terms of renewable resources, and thus wind resources, which are available in certain areas of Africa like in Kenya and Tanzania, were not assessed and integrated into the MOYO concept. Therefore, this calls for further study to broaden this licentiate thesis. Likewise, the licentiate study did not investigate the improved cooking facilities, and this issue is a subject for further study as well.

However, this licentiate thesis suggested a fruit and juice factory and waste gasification, and broadens the scope from Village Community to larger communities, cities. By gasifying all kinds of municipal, factory, agricultural, and forest wastes or residues, the community will not only overcome waste management problems but it will receive suitable energy for electrification in combined heat and power facilities, exemplified by the integration of a fruit factory and waste gasification. This licentiate suggested a new real-life study of this future opportunity to empower larger communities, from villages to cities. As Henry Ford argued, ‘Coming together is a beginning, keeping together is a progress, working together is a success’.

Photo References

Page 2: Women's Bank Uganda (2014); '*Jackline - en av REP-stödpersonerna - vid sitt tefält'*, Rael Leedjärv-Östman, SLEF Bilder REP (2015); Brenton et al. (p.22, cover page); UNESCO EFA (2014, cover page); '*Working together'* Ritva Saarinen (2014); SLEF MSB (2014); '*Kimbilio Ruth&Veikko'*, Irja Aro-Heinilä (2013); '*Healthy Women, Healthy Children'*, FELM (2014); '*Kimbilio Work'*, Irja Aro-Heinilä (2013); SLEF Water (2014); '*Vatten Pumpen i Västra Kenya'*, Göran Stenlund, SLEF ABC Water (2012); '*School feeding programmes help keep children in school and create markets for poor farmers'* WFP/Edward Parsons, Africa Renewal (2007) (UN WFP portal, 2014)

Page 26: '*A woman and her garden, Solar Electricity Systems'* NAPS Brochure, (NAPS Water, 2015; Stanford Benin, 2011): '*Kenyan schoolgirls using a solar tasks lamps'*, Jamie Seno, Lighting Africa; For the other photos, see the photos related to Page 2 above

Page 30: Women's Bank DR Congo (2014); '*Tanzanian children in a kindergarten'*, '*Kimbilio Mr. Kimwaga & Mr. Mmbaga'*, '*Kimbilo women working with bricks*, '*Working together'*, Irja Aro-Heinilä; '*Kvinnoförsamling'*, David Stenlund. SLEF Women (2014). For the other photos, see the photos related to Page 2 above

Page 31: '*SLIM 12 V LED Light'*, Airam portal; NAPS School (2015); '*Solar electrification system'*, NAPS Health (2015). For the other photos, see the photos related to Page 2 and Page 30 above

Page 38: For the photos, see the photos related to Page 2, Page 30 and Page 31 above

Page 62: For the photos, see the photos related to Page 2, Page 26, Page 30 and Page 31 above

Page 71: '*Homeware, Baskets and Bags'*, Mifuko portal (2014). For the other photos, see the photos related to Page 2, Page 26, Page 30 and Page 31 above

Page 75: Afipek (2015); daveb & Squiffy Blog; '*A Maasai pastoralist in Kenya utilizes his mobile phone to keep tabs on his herd'*, Sven Torfinn, Food Tank (2015); '*A young girl showing off a solar lantern in the central charging station kiosk / Wim Verdouw'* Markus Linder, UNFCCC (2014); NAPS Light (2015). For the other photos, see the photos related to Page 2, Page 26, Page 30, Page 31, and Page 71 above

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Appendices

Appendix 1: Silicon and solar cell production processes
Appendix 2: Terms and Definition

Appendix 1: Silicon and solar cell production processes

Chapter A) Polysilicon (polycrystalline silicon) production processes:

Silicon is the second most abundant material after oxygen in the crust of the Earth, where quartz contains silicon dioxide (SiO_2). Two processes for obtaining silicon are utilized, first a metallurgical route (ARC Furnaces) (Figure 1a) and then a chemical route (silicon solidification) (Figure 1b). Metallurgical-grade silicon (MG-Si) manufactured in electric arc furnaces has to be further purified to polycrystalline silicon (p-silicon), before solar-grade silicon is suitable for the manufacturing of electronic components such as integrated circuits or solar cells. (Alsema, 2012; Braga et al., 2008; Ceccaroli & Lohne, 2003; Filtvedt et al., 2010; Pizzini, 2010; Tangstad, 2013; Woditsch & Koch, 2002; Xakalashe & Tangstad, 2011).

Aa) Metallurgical-grade silicon (MG-Si) production in Figure 1a

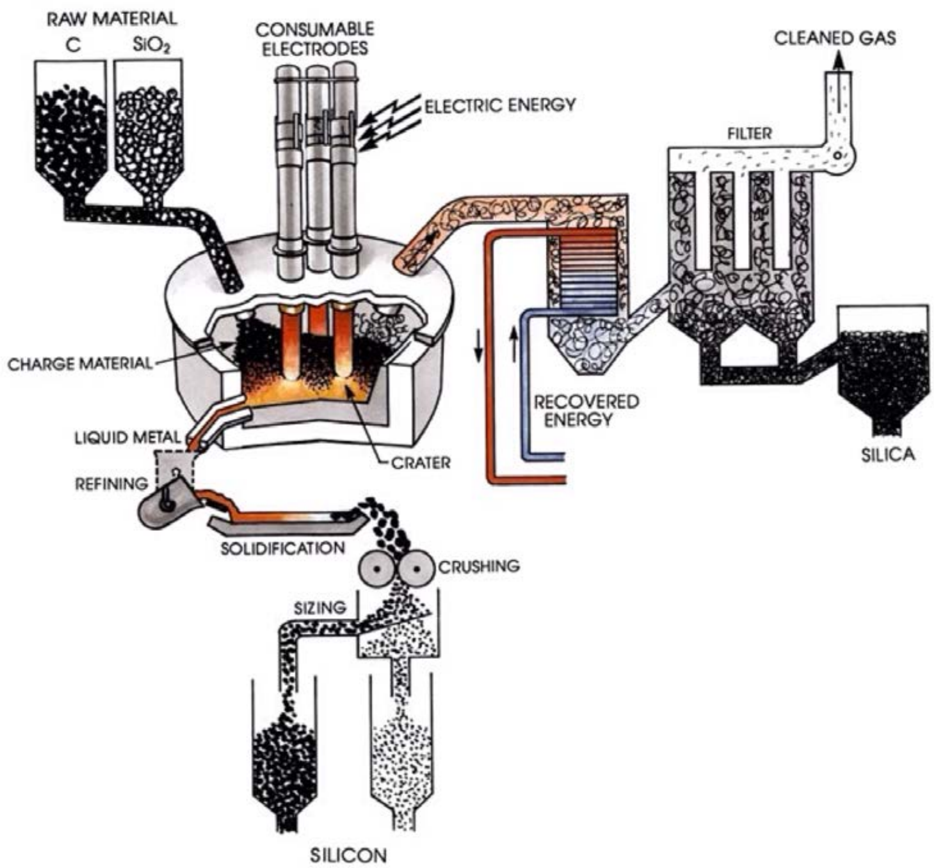

Figure 1a. Typical industrial silicon furnace for the production of metallurgical-grade silicon (MG-Si), the process description in Ceccaroli & Lohne (2003), Tangstad (2013) and Xakalashe & Tangstad (2011), the original picture in Schei (1998)

The metallurgical-grade silicon, which is today the cheapest silicon on the market (Pizzini, 2010), needs to be produced at the high process temperature (typically approximately 2 000 °C) and it needs electricity of (10-)11-13(14-16) kWh/kgMG-Si according to (Ceccaroli & Lohne, 2003; Jungbluth, 2005, p. Table IV; Pizzini, 2010; Takiguchi & Morita, 2011, p. 332; Xakalashe & Tangstad, 2011, p.88). Nowadays MG-Si is produced by the carbothermic reduction of silicon dioxide in a three-electrode ARC furnace (Abdellatif, 2011; Ceccaroli & Lohne, 2003; Tangstad, 2013).

Metallurgical-grade silicon has a typical specification of 98.5–99.5% for Si (Ceccaroli & Lohne, 2003; Woditsch & Koch, 2002) and impurities such as carbon, alkali-earth and transition metals, as well as hundreds of ppmw (parts per million by weight) of boron (B) and phosphorus (P). Some selected impurities should be reduced as low as ppb (part per billion) levels, which levels are obtainable by going through the process named as gas and chemical vapor deposition (CVD) as shown Figure 1b (Ceccaroli & Lohne, 2003; Filtvedt et al., 2010; Korec, 1980; Pizzini, 2010; Wilke et al., 1986; Xakalashe & Tangstad, 2011) or through upgraded metallurgical (UMG) route. One by-product of the silicon smelting is silica (about 0.2 to 0.4 tons of condensed silica fume per ton of silicon metal), which can be reused for versatile industrial processes. The other one, the off-gas from the silicon furnace, has an energy content of the same order of magnitude as the electrical energy input to the furnace and can be directed to an energy recovery system such as in Figure 1a. References (Ceccaroli & Lohne, 2003; Xakalashe & Tangstad, 2011; Tangstad, 2013) provide the detail description of the MG-Si production.

Ab) Polysilicon production in Figure 1b

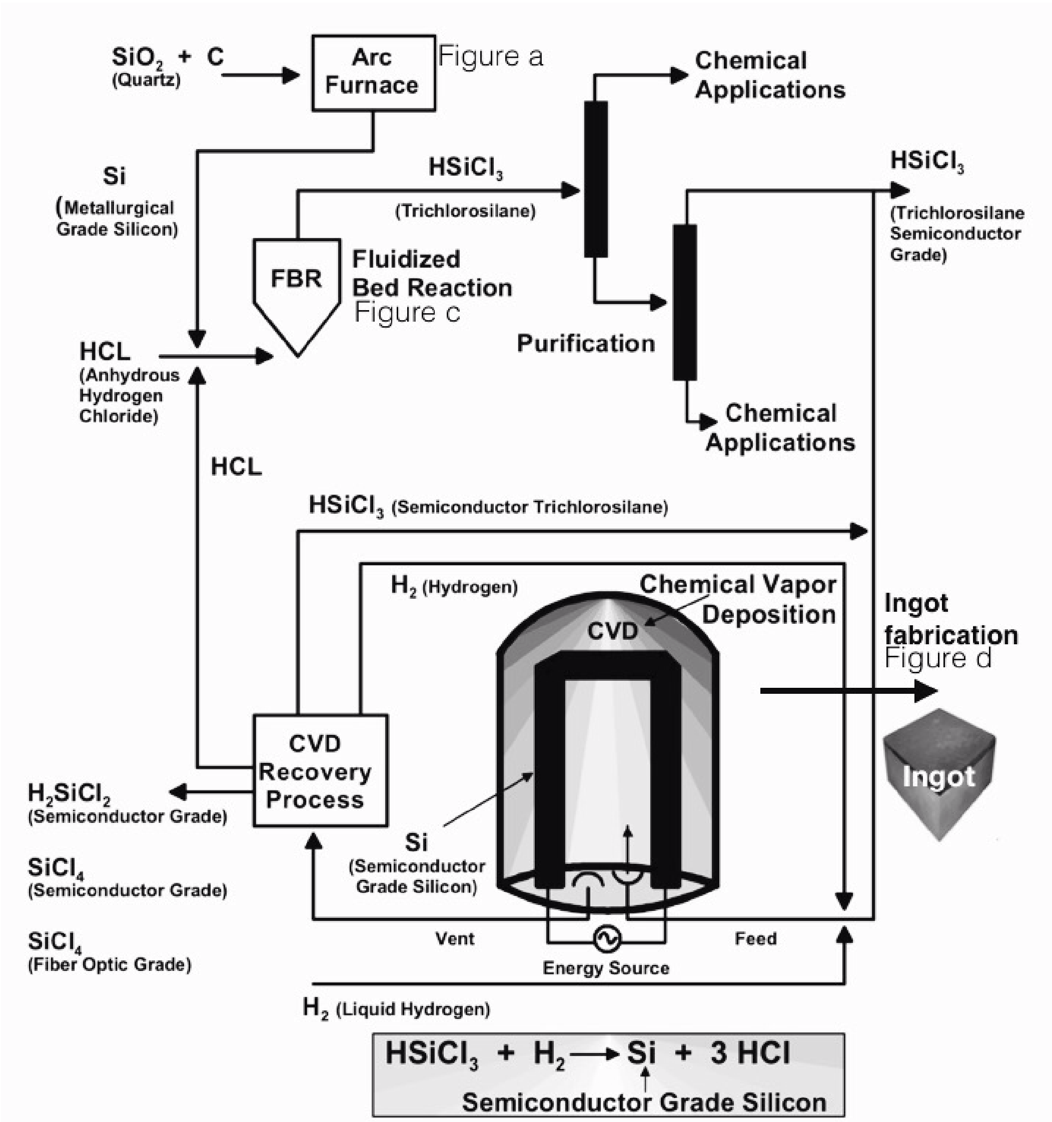

Figure 1b. Typical process flow sheet for the production of prime polysilicon (semiconductor grade silicon), the integration of FBR and Siemens CVD in the traditional Siemens process, Woditsch & Koch (2002), Xakalashe & Tangstad (2011)

As pointed out previously, MG-silicon has to be purified in the CVD reactor (Figure 1b) to produce polysilicon. Most of the polysilicon is made by pyrolysis of silane or trichlorosilane (TCS) in a bell reactor, called a Siemens reactor. Figure 1b illustrates how this purification is achieved in a hydro chlorination process where trichlorosilane (TCS, $HSiCl_3$) is produced. At the present, this traditional Siemens TCS-CVD route dominates the markets (Braga et al., 2008; Buy & Ceccaroli, 2014; Ceccaroli & Lohne, 2003; Filtvedt et al., 2010; Xakalashe & Tangstad, 2011; Ydstie & Du, 2011) despite the expensive investment and production costs such as the greater energy intensity of 65-90-100-120-150-200 kWh/kgSi or even more according to studies on (Braga et al., 2008, p.419; Goodrich et al., 2013, p.114; Pizzini, 2010, p.1528; Takiguchi & Morita, 2011, p. 332; Xakalashe & Tangstad, 2011, p.90), the energy demand correlating to the sophistication rate of this TCS-CVD process. Table 1j in Chapter B section Bf below indicates that approximately the half of the total energy requirements for multi-crystalline silicon module accounts to the polysilicon production (MG-Si and polysilicon, excluded capital costs, in Table 1j named as silicon winning and purification) (Alsema, 2012; Filtvedt, 2013; Goodrich et al., 2013; Pizzini, 2010). The demand for electronic grade silicon due to increased use of pure semiconductor silicon limits the PV market expansion and has recently boosted the research work for low-cost Fluidized Bed Reactor (FBR) processes (exemplified in Figures 1ca and 1cb), which covered less than 10% of all solar grade silicon currently manufactured (Buy & Ceccaroli, 2014, p.635). Nevertheless, a competitive CVD technology based on FBR has been studied for decades (Buy & Ceccaroli, 2014; Braga et al., 2008; Du & Ydstie, 2012; Filtvedt, 2013; Filtvedt et al., 2010; Goodrich et al., 2013; Ranjan et al., 2011; Tejero-Ezpeleta et al., 2004; Ydstie & Du, 2011) in order to reduce the costs of the traditional Siemens process and to produce solar grade silicon and achieve a continuous operation on high space-time yields, the FBR approach suggesting the energy demand as low as 5-10-12-20-30 kWh/kg (Buy & Ceccaroli, 2014, p.641; Goodrich et al., 2013, p.114; Jungbluth et al., 2012, p.40). Furthermore, Goodrich et al. (2013) have investigated opportunities to further reduce manufacturing costs for the wafer-based monocrystalline silicon PV module supply chain (Figure 1g in the section Bc below). Likewise, Gløckner and de Wild-Scholten (Gløckner & de Wild-Scholten, 2012; de Wild-Scholten & Gløckner, 2012) have conducted LCA studies for ESS (Elkem Solar Silicon®) and compared this with the Siemens-based process, and Buy & Ceccaroli (2014) have compared Siemens polysilicon, FBR-polysilicon and UMG-silicon.

This licentiate thesis presents here the current typical process shown in Figure 1b for producing polysilicon, the Siemens process, which is the integration of a low-cost FBR and a Siemens Chemical Vapor Deposition (CVD) (Woditsch & Koch, 2002; Xakalashe & Tangstad, 2011). The purification of MG-silicon happens first in the FBR, the FBR vessel filled with silicon particles, and anhydrous hydrogen chloride (HCL), also referred to as hydrogen chloride gas, is injected at the bottom of the reactor to fluidize the particles as shown in Figures 1b and 1ca. The MG-silicon and HCL react in the FBR-reactor together with in the presence of a catalyst (hydrogen H), in order to produce TCS, HCL fed from the CVD Recovery Process and the MG-silicon from the arch furnace (Figure 1a). This process to produce TCS is called hydroclorination of metallurgical grade silicon in the FBR. After further purification as shown in Figure 1b, the TCS is then reduced by hydrogen in a Siemens reactor containing heated silicon rods (Figure 1b) and the semiconductor grade silicon is produced in this CVD-reactor. The CDV-reactor needs H2 and from FBR produced HSiCl3, which goes through purification processes into CDV-reactor. Those impurities that are not needed for solar cell production are very small (Ceccaroli & Lohne, 2003, p.177; Müller et al., 2006, p.258; Xakalashe & Tangstad, 2011, pp.87-90). As exemplified, the commercial hydroclorination FBR cyclone can be found in reference (GT FBR). The energy demand for this Siemens-based process could be 90 kWh/kg (Goodrich et al., 2013, p.114) and the scenario with FBR as CVD of 12 kWh/kg.

Ac) Fluidized Bed Reactor (FBR) in Figure 1ca

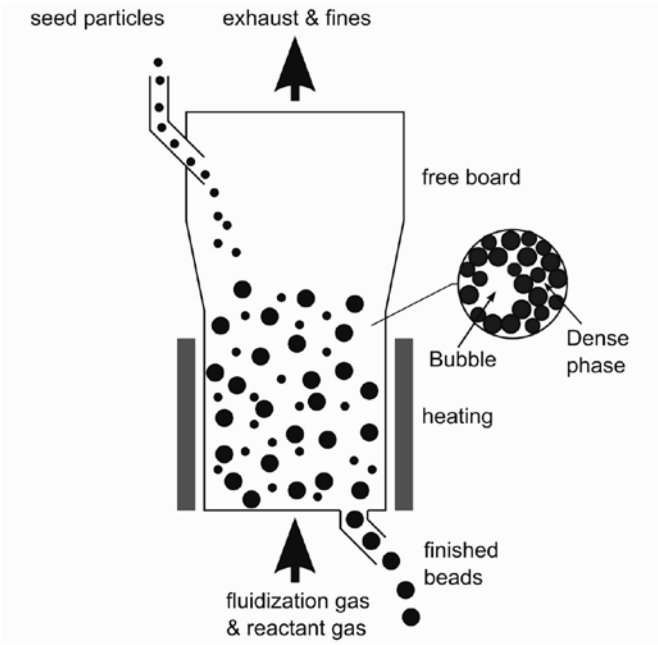

Figure 1ca. Fluidized Bed Reactor, Filtvedt (2013). FBR has been modified and utilized for versatile purposes like energy production of different fuels, waste management, and solar grade silicon (Basu, P., 2006; Ceccaroli & Lohne, 2003; Filtvedt et al., 2010; Grace, 2010; Ydstie & Du, 2011).

Fluidized Bed Reactor (FBR) as CVD in Figure 1cb

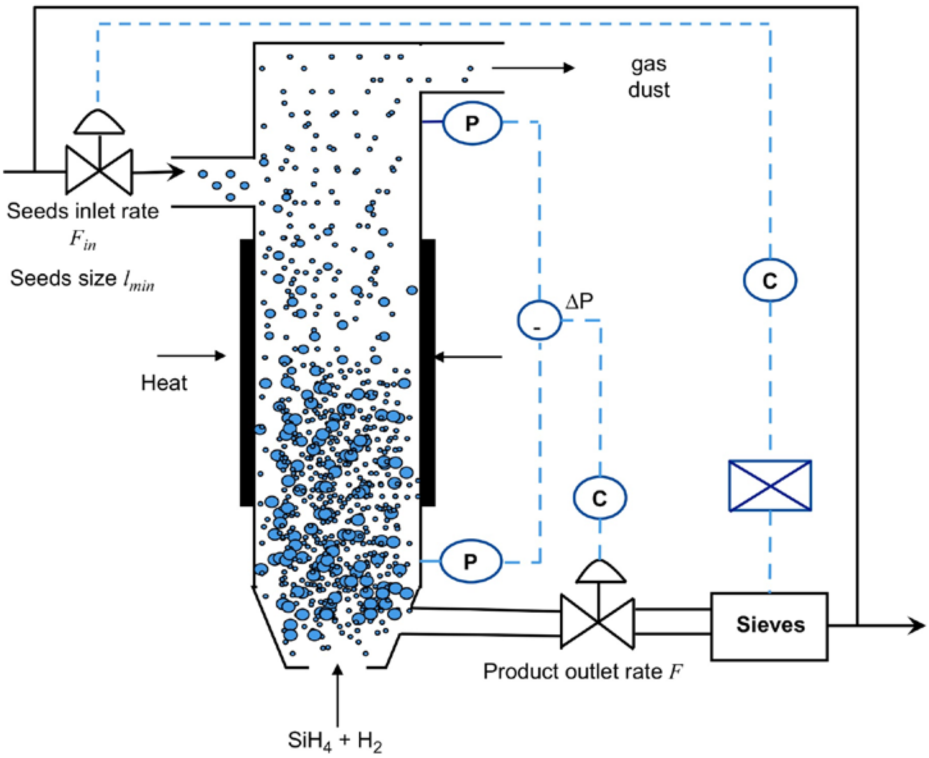

Figure 1cb. FBR with inventory control system. Du & Ydstie, 2012, p.122

Ad) Ingot Fabrication in Figure 1d

The next step involves, after the polysilicon process, converting solar-grade silicon into thin sheets (wafers) for use as solar cells (solar-grade silicon refers to any grade of silicon usable in manufacturing solar cells, including polysilicon and UMG-silicon; whereas the semiconductor silicon is the end-product from traditional Siemens process in Figure 1b, see Appendix 2 Terms and Definitions), the majority of silicon wafers being Czochralski (CZ) single crystalline or multicrystalline (mc) material. For ingot casting or crystallization, the common two crystallization techniques are applied, the Czochralski growth process for single crystal ingots and the Bridgman process for multi-crystalline silicon ingots. During ingot casting or crystallization, the impurities such as phosphorus (P) or boron (B) are added to the silicon raw material prior to the melting of the silicon, and a simple set of equations determines the amounts of each kind of feedstock to be added to the mix. The classical Czochralski-grown technique is a well-known and mature batch process shown in Figure 1da and comprehensively described in literature. Cz ingots have a round cross section, and after sizing the ingot to a square or rectangular shape to be utilized for a solar cell, the cropped and slapped materials are then fed back into the growth process again. The energy consumption required varies from the standard (127)-100 or 85.6 kWh/keg to 40 kWh/kg or even as low as 31.1 kWh/kg (Ferrazza, 2012, p.88; Jester, 2002; Jungbluth et al., 2012. p.43; Jungbluth, 2005, p.TableIV; Takiguchi & Morita, 2011, p. 332; Xakalashe & Tangstad, 2011). This licentiate thesis applies the energy demand of 40 kWh/kg. (Ferrazza, 2012; Koch et al., 2003; Xakalashe & Tangstad, 2011).

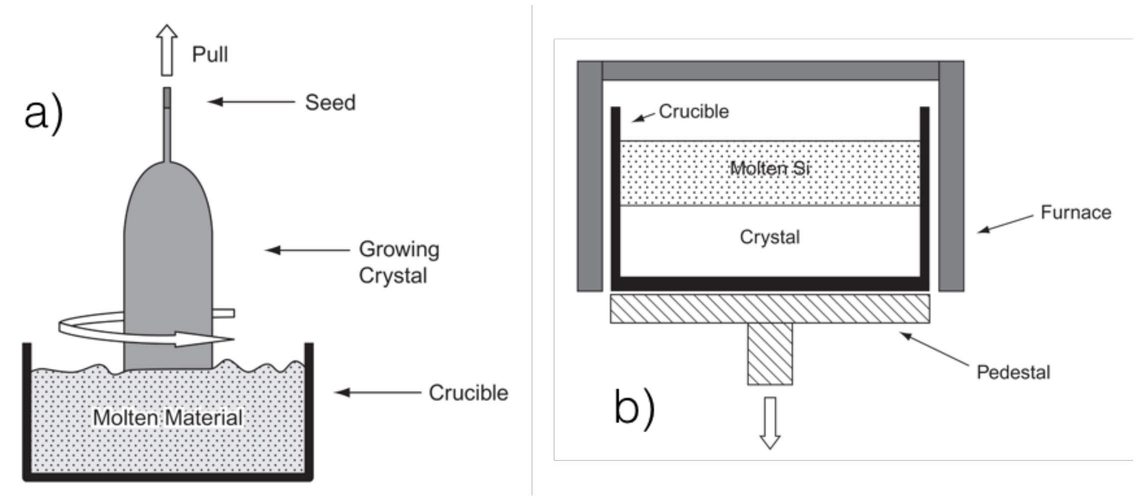

Figure 1d): a) Schematic of Cz growth principle, (Ferrazza 2012, p88). And b) of mc-Si ingot growth, both melting and crystallization of the silicon is performed in a Si3N4-coated quartz crucible, (Koch et al.2003, p.215; Ferrazza 2012, p.89)

Most of the multi-crystalline silicon for the photovoltaic industry is produced by the multi-crystalline ingot block casting process, which melts silicon material in a crucible, as shown in Figure 1db above. The produced multi-crystalline has a multi-grained structure with inclined crystal planes that meet at grain boundaries, usually the grains vary in size between several millimeters to centimeters. Alternatively to the Bridgeman process, the block-casting can be employed; where for the crystallization process a second crucible (block casting) is used (see Figure 6.7 in Koch et al., 2003, p.215). A multi-crystalline silicon ingot is rectangular or square, which is best suited for a solar module. Silicon nitride (Si3N4) crucibles for directional solidification are used and are an alternative to silica (SiO2) crucibles. Coating a quartz crucible with Si3N4 for the melting of the silicon raw material has two main advantages: 1) the reusability of the crucible for several castings and 2) potentially very low oxygen content in the solidified ingots (Modanese et al. 2012, p.27). The reader is referred to references for further details (Bidiville, 2010; Ferrazza, 2012; Koch et al., 2003; Modanese et al. 2012; Schönecker et al.; Xakalashe & Tangstad, 2011). The typical energy demand for producing a multi-crystalline silicon ingot is 10 kWh/kg (Ferrazza, 2012, p.89).

Chapter B) From Ingot to Module:

Ba) From Ingot to Module process in Figure 1e

Before sawing, the high-purity solar-grade silicon undergoes a crystallization step to minimize defects prior to the wafering process as described in the previous section. The typical plant layout for the industrial production of crystalline silicon wafers is illustrated in (Cheung 2010; Xakalashe & Tangstad, 2011, p.94), and the process flow depicted from ingot to module in Figure 1e. The monocrystalline silicon ingots are first sawed into squared blocks with a cross section defined with the final wafer size, while the multicrystalline silicon ingots already have a proper square or rectangular shape as discussed in the previous section and they are only cutting to blocks. The lost materials (approximately 25% of monocrystalline and 15% of multicrystalline ingots) are recycled back to the ingot production processes. (Bidiville, 2010; Jungbluth et al., 2012; Koch et al., 2003; NorSun portal; Xakalashe & Tangstad, 2011). The solar cell process was discussed in Chapter 3.4.2 and the coating of a cell in the section Bd) Solar cell production below.

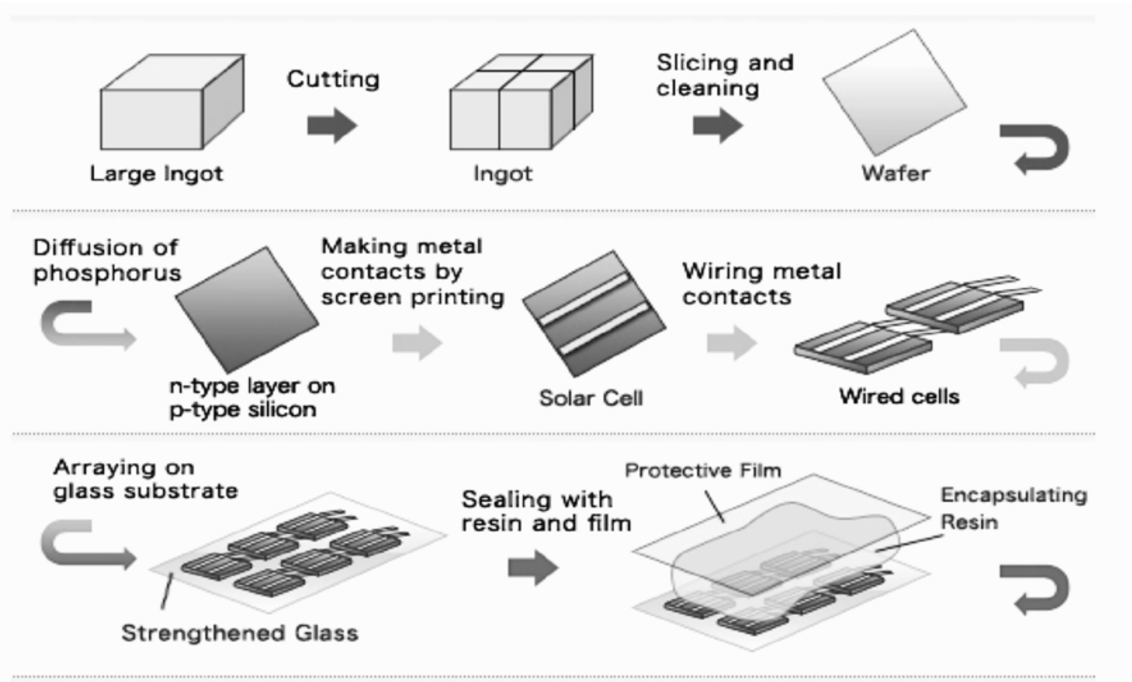

Figure 1e: From ingot to module, (Cheung, 2010)

Bb) Wafering process in Figure 1f

Wafers are produced from blocks by the multi-wire saw designed for that purposes slicing bricks to thin wafers. The silicon ingot on the holder is pushed against the moving wire web and sliced into hundreds of wafers at the same time (Figure 1fa). This automated process operates with high mechanical precision and a thin wire (160 μm diameter) web pushes an abrasive-based slurry into the silicon brick to be cut. The slurry is typically a mixture of poly (ethylene glycol) (PEG) and abrasive silicon carbide

(SiC) particles. For cost decrease purposes, the slurry is recycled back to the slurry tank until it is pumped again on the wires, recovering the silicon carbide (SiC) in the slurry. This slurry can be based on fluids that are water washable, this type of waste-treatment system being more sustainable than with oil-based procedures. This sawing process has high material losses and results in high costs; therefore new techniques like ribbon growth techniques or the thin film technology have been developing for cheaper solar cells. Improving the process for producing thinner and stronger wafers can also reduce the electricity costs. Energy needed to produce one wafer is 0,3 kWh/wafer (Jungbluth 2005, p.; Jungbluth et al., 2012, p.52). SEMI™ has defined the requirements for silicon wafers to be utilized in solar cell manufacturing although commercial suppliers have applied variations to these standards to some degree, as exemplified in Tables 1-3 in (Ferrazza, 2012, pp.80-82). The reader is referred to references for further details (Applied Materials; Bidiville, 2010; Ferrazza, 2012; Jungbluth et al., 2012; Jungbluth, 2005; Koch et al., 2003; SEMI™; Xakalashe & Tangstad, 2011).

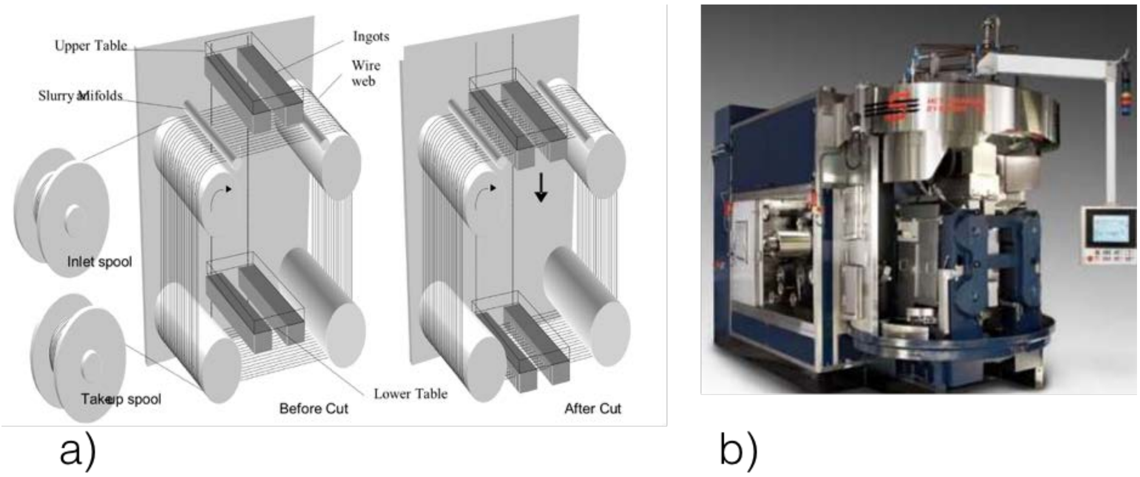

Figure 1f: a) Slicing saw; b) Machine first saws ingots to bricks and then slices them, (Applied Material; Bidiville, 2010, p.9)

Bc) Wafer-based Cz-Si module supply chain from polysilicon (excluded the production chain of MG-Si and polysilicon) in Figure 1g

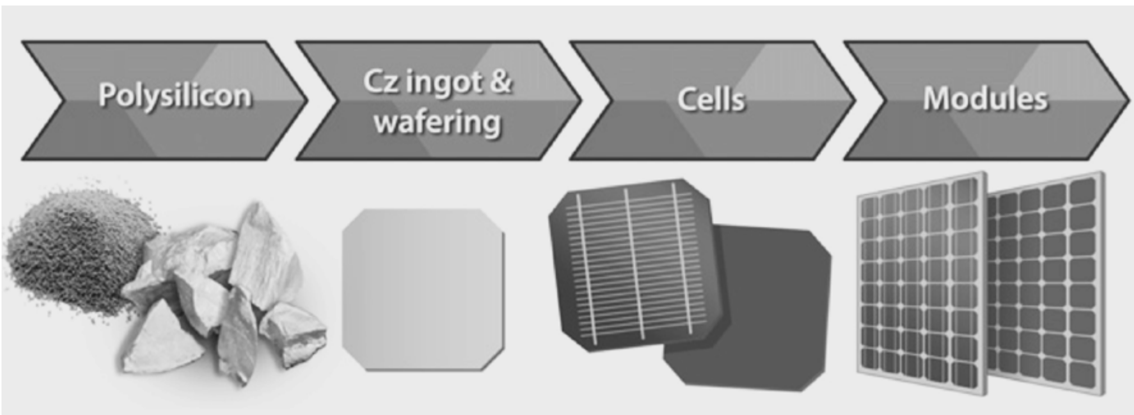

Figure 1g. The primary steps of the wafer-based c-Si module supply chain, (Goodrich et al., 2013)

Bd) Solar cells production

New wafers go through cleaning, etching and texturing processes in the manufacturing of a solar cell as shown in Figure 1e above and in Figure 26 in Chapter 3.4.2, which chapter investigates a solar cell and its properties and functionality. Anti-reflective coating (ARC) and the surface texture reduce the reflection of light from the front surface of the cell by affecting to the angle of light (Figure 1ha below). After the wafers are etched to remove the damaged layer near the surface, this etching step creates a surface texture on the top of the cell for reducing the primary reflections, this chemical multilayered texture shown in Figure 26 and Figure 1hb below (distributed upside pyramids). This light-trapping mechanism allows the fabrication of a thinner solar cell, as the light can travel distance much larger than the actual cell thickness. Figures 26, 1hb and 1i exemplify a modern textured solar cell, and more exemplar figures are shown in (Green M.A., 2012; Li et al., p.2; Singh et al., 2013, p.131; Szlufcik, 2012; Zielke et al., 2011). The energy requirements to process a crystalline silicon cell are 0,2 kWh/dm²cell according to (Jungbluth 2005, p.Table IV; Jungbluth et al, 2012, p.62). The reader is referred to references for further details (Ferrazza, 2012; Green, M.A., 2012; Green, M.A., 1982; Lai et al., 2011; Makvart & Castañer, 2012; McGehee, 2012; Szlufcik et al., 2012; Tobías et al., 2003; Wenham et al., 2007; Yang et al., 2013).

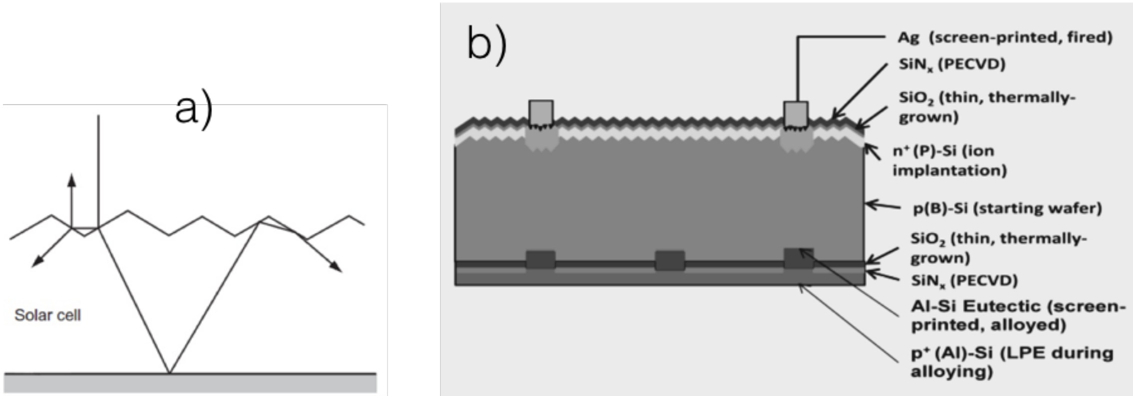

Figure 1h. a) The textured top surface reduces reflection from the solar cell and, when combined with a reflecting back surface, helps to confine or 'trap' light within the cell, (Makvart & Castañer, 2012, p.18); b) 19.6% efficient planar cells on silicon, plasma-enhanced chemical vapor deposition (PECVD) technique, (McGehee, 2011, Sources: Lai et al., 2011; Yang et al., 2013)

Chemical texturing and ARC deposition strongly influence on the solar cell efficiency. Because thinner wafers considerably reduce the cost of solar cells and result in more efficient solar cells due to the higher built-in field (see Chapter 3.4.2 and Figure 29a), hydrogen containing silicon nitride (SiNx:H) thin film deposited by plasma enhanced chemical vapor deposition (PECVD) is widely used as a passivation layer in ARC for crystalline silicon solar cells (for PECVD see e.g. Boogaard, 2011). This surface passivation with silicon nitride (SiNx) layer increases the lifetime of carriers (see Chapter 3.4.2 and Figures 26 and 27) and further reduces the reflectivity of the top surface due to its anti-reflective coating characteristic. Regarding antireflection, passivation, and efficiency, Lee et al. (2012) and Li et al. (2014) have found that double-stack antireflective coatings have noticeable advantages over single-layer coatings. Lee et al. (2012) showed that for instance a solar cell with 60-nm/20-nm SiNx:H (deposited by PECVD) double stack coatings has 17.8% efficiency, while that with an 80-nm SiNx:H single coating has 17.2% efficiency; this improvement of the efficiency was due to the effect of better passivation and antireflection. Likewise, Li et al. (2014) prepared a double-layer coating of SiO_2/SiNx:H deposited by PECVD. As a result, the monocrystalline solar cells showed the better efficiency as 17.80% compared with 17.45% for single SiNx:H ARC. On the other hand, Zielke et al. (2011) implemented a crystalline solar cell of PERC-type (passivated emitter and rear cell, Green M.A., 2012), which has SiNx and SiO_2 thin layers, but instead of PECVD, they utilized an ALD-AlO_x passivation layer (Atomic-layer-deposited ALD). This aluminum oxide (AlO_x) layer was placed between the Al contact grid and the phosphorus-diffused n+-emitter as shown in Figure 1i. The findings reported the best efficiency of 21.7 %, which was independently confirmed at Fraunhofer ISE CalLab (Freiburg, Germany). These exemplified experiments indicated how important this chemical texturing and ARC is for the efficiency of a solar cell and for a PV system, thus next is described briefly how this all fit to the whole solar cell processing. (Iftiquar et al, 2012; Lee et al., 2012; Li et al., 2014; Rentsch et al., 2009; Szlufcik, 2012; Zielke et al., 2011).

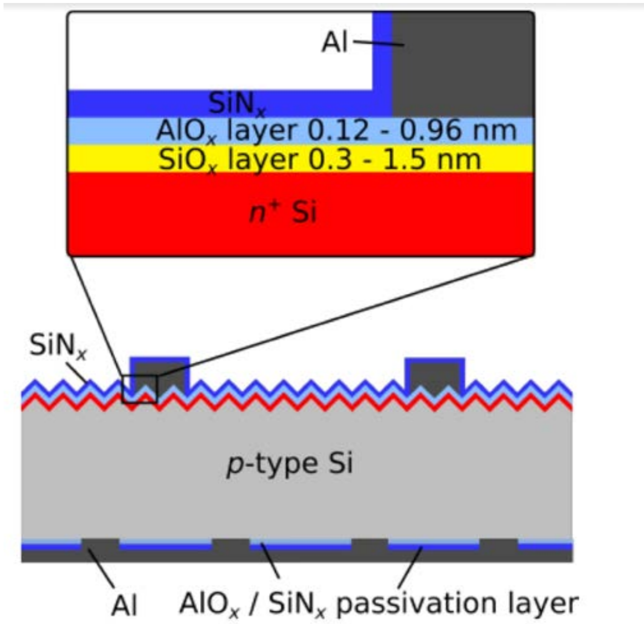

Figure 1i. PERC solar cell experimented in (Zielke et al., 2011, p.1115)

The normal cell-process sequence would consist of 1) the p-type silicon wafer, 2) saw damage removal from the starting wafer by etching, 3) chemical (etching) texturing of the top surface, 4) top-surface phosphorous (n-type dopant) diffusion (n+ diffusion), edge (junction) isolation and etching to remove diffusion oxides and the junction at the rear of the cell, 5) ARC deposition of a silicon nitride (SiN_x) antireflection coating (as described previously, other type of variations might be possible) to the top cell surface 6) front-contact print as the front metallization, screening and drying, 7) back-contact print, 7) co-firing, and 8) testing and sorting. (Green M.A., 2012; Tobías et al., 2003, p.271-276, Figure 7.6). The PERC-cell processing in (Figure 2 in Zielke et al., 2011, p.1116) provides a modified process flow with 15 steps. In the future scenarios, copper due to cost reasons, replaces the silver used for the metallization paste (p.20). The buried-contact solar cell (Figure 26 in Chapter 3.4.2, n++ buried grooves) (Green M.A., 2012; Szlufcik, 2012; Wenham et al., 2007) was developed for the metallization to improve the efficiency of the screen-printed cell approach and generate electricity at lower cost. Grooves are typically laser-processed into the top cell surface to locate the cell metallization although mechanical or chemical approaches could be used. This section has indicated how many and versatile chemicals and metals are required to produce an efficient solar cell at low cost.

Bf) The structure of energy requirements in Table 1j:

Breakdown of the energy requirements for a typical multicrystalline silicon PV module using present-day production technology (in MJ of primary energy per m² module area), Siemens based process for producing polysilicon.

Table 1j. The structure of energy requirements for a mc-silicon module (Alsema 2012, p.1101)

Process	**Energy requirements (MJ_{prim}/m^2 module)**
Silicon winning and purification	2200
Silicon wafer production	1000
Cell/module processing	500
Module encapsulation materials	200
Overhead operations and equipment manufacture	500
Total module without frame)	**4200**
Module frame (aluminium)	400
Total module (framed)	**4600**

Appendix 2: Terms and Definitions

Term	Definition
Case	The 'case' is the real-life set of events from which data will be drawn. (Yin 2004, p.xiv)
Case Study	The 'case study' is the substance of your research inquires, consisting of your research questions, theoretical perspectives, empirical findings, interpretations, and conclusions. (Yin 2004, p.xiv)
Causality	1. The relationship between cause and effect (Oxford Dictionaries online) 2. The relationship between something that happens and the thing that causes it (Merriam-Webster online) The relationship between a cause and its effect or between regularly correlated events or phenomena (Merriam-Webster online)
Causation	an action causing something; the relationship between cause and effect (Oxford Dictionaries online)
Cause	1. a person or thing that gives a rise to an action, phenomenon, or condition (Oxford Dictionaries online) 2. a principle, aim or movement that, because of deep commitment, one is prepared to defend or advocate (Oxford Dictionaries online)
Causal relationship	a relationship between A and B is causal if A causes B to occur. In realism this indicates the operation of a mechanism (Robson 2002, p.545)
Class	1.a group of people, animals, or other things that can be considered or studies together because they are similar in some way (Longman 1995) 2. a group, set, or kind marked by common attributes or a common attribute (Merriam-Webster online) 3. a set or category of things having some property or attribute in common and differentiated from others by kind, type, or quality (Oxford Dictionaries online)
Concept	1. an idea deriving from a given model (Silverman 2006, p.13) 2. conceptual modeling, the theory about what is happening and why, particularly when expressed in diagrammatic form, is sometimes referred to as a conceptual framework (Robson 2002, p.63) 3. conceptual framework 'the system of concepts, assumptions, expectations, beliefs, and theories that supports and informs your research' (Maxwell, 1996, p.25). (Robson 2002, p.6) 4. Models- visuals, verbal, numeric -allows us to describe interrelationships of the concepts that comprise or inform the theory. (Kane et a. 2009, p.437).
Critical realism	Through theory and observations, and as a result of previous experiments, they develop knowledge and understanding about the mechanism through which an action causes an outcome. (Robson 2002, p.30)

DALY	Disability-adjusted life year, in terms of lost years of healthy life. Combines loses years due to premature death with years of healthy life loses due to illness and disability WHO 2009, p.v., p.5.
Engineering systems	A class of systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions in society (MIT ESD, 2008; Weck et al. 2011, p.31)
Fermi energy (E_F)	'The Fermi energy (E_F) is the energy at which the probability of occupation by an electron is exactly one-half' (Sze, 2002, p.34)
Mechanism	1. a natural or established process by which something take place or is brought about (Oxford Dictionaries online) 2. a system that is intended to achieve something or deal with a problem (Longman 1995) 3. a process, technique, or system for achieving a result (Merriam-Webster online)
Methodology	1. a general approach to studying research topics (Silverman 2006, p.13) 2. the theoretical, political and philosophical backgrounds to social research and their implications for research practice, and for the use of particular research methods. (Robson 2002, p.549)
Method	1. a specific research technique (Silverman 2006, p.13) 2. what specific techniques will you use to collect data? How will the data be analyzed? How do you show that the data are trustworthy? (Robson p.81)
Model	1. an overall framework for looking at reality (e.g. behaviorism, feminism) (Silverman 2006, p.13) 2. a model is an abstract representation of a phenomenon or set of related phenomena (Easterbrook 2007, p.12) 3. a representation of a system or some other aspects of research interest. It may be expressed in symbols, equations and numbers, or in pictorial images (e.g. Boxes and links between them), or in words. Models are mainly used to help explain and understand the phenomena of interest (Robson 2002, p.549)
Ontology	1. nature of the world (Maxell 2009, p.224) 2. the branch of metaphysics dealing with the nature of being (Oxford Dictionaries online) 3. a subject of study in Philosophy that is concerned with the nature of existence (Longman 1995) 4. ontology is a fundamental interpretation of the ultimate constituents of the world of experience. (Catholic Encyclopedia) 5. a branch of metaphysics concerned with the nature and relations of being (Merriam-Webster online) 6. an ontology is a specification of a conceptualization (Stanford Knowledge System Laboratory)
Process	1. a series of actions that someone takes in order to achieve a particular result (Longman 1995)

	2. a series of actions or operations conducing to an end (Merriam-Webster online) 3. sequence of interdependent and linked procedures, which, at every stage, consume one or more resources (employee time, energy, machines, money) to convert inputs (data, material, parts, etc.) into outputs. These outputs then serve as inputs for the next stage until a known goal or end result is reached. (Business Dictionary) 4. qualitative research is in getting at the processes that led to those outcomes, processes that experimental and survey research are often poor at identifying. (Maxell 1996, p.
Prosocial behavior	Relating to or denoting behavior which is positive, helpful, and intended to promote social acceptance and friendship. (Oxford Dictionaries Online
Solar-grade silicon	1. solar-grade silicon refers to any grade of silicon usable in manufacturing solar cells, including polysilicon and upgrade metallurgical silicon (UMG-silicon) (Buy & Ceccaroli, 2014,p.635)
System	1. A group of related parts that work together as a whole for a particular purpose (Longman 1995) 2. An organized set of ideas, methods, or ways of working (Longman 1995) 3. A system is constituted by the set X of its elements and their characteristics and by the set R of relations between the elements and the system's environment. These relations manifest themselves as an exchange of matter, information and/or energy and they determine the structure of the system" (Oman 2004)
Triangulation	1. a method of finding your position by measuring the lines and angles of a triangle on a map (Longman 1995) 2. use of more than one approach to the investigation of a research question in order to enhance confidence in the ensuing findings. (Bryman A.) 3. triangulation in social science refers to efforts to corroborate or support the understanding of an experience, a meaning, or a process by using multiple sources or types of data, multiple methods of data collection, and/or multiple analytic or interpretive approaches (Oxford Bibliographies online)
Wellbeing	The state of being comfortable, healthy, or happy (Oxford Dictionaries Online)