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Decentralized Energy in Water-Energy-Food Security Nexus in Developing Countries: Case Studies on Successes and Failures

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Abstract

Access to modern energy is vital for sustainable development. In rural areas, decentralized energy solutions may play a significant role in reducing poverty, supporting community institutions and facilitating the generation of basic services such as communication, water access, education and health services. However, the majority of dwellers in off-grid communities in developing countries have little or no access to modern energy technologies, although they are endowed with a vast potential of renewable energy resources. Decentralized energy solutions could serve as an option to solve this energy access problem. However, the previous literature indicates that there are financial, technical, infrastructural, and institutional constraints to scale up decentralized energy options. This paper seeks to study the underlying factors behind the successes and failures of household- and community-based decentralized energy technologies through local case studies from different parts of the world, analyzed through the lenses of the Water-Energy-Food Security (WEF) nexus. First, the paper reviews the literature on the main benchmarks used to evaluate the success and failure of community-based energy. Second, the conceptual framework relating decentralized energy to the WEF nexus elements is briefly described. Thirdly, the methods and data used in the paper are described, followed by the presentation of the case studies. Lastly, the paper is concluded by drawing policy lessons and recommendations. Further empirical studies are recommended to quantitatively evaluate the impacts of decentralized energy solutions on the welfare of households and communities within the framework of the Water-Energy-Food nexus.

Keywords: decentralized energy, Water-Energy-Food Security nexus

JEL classification: O13, Q40

List of Abbreviations

ARE	Alliance for Rural Electrification
DES	Decentralized Energy Solutions
FAO	Food and Agriculture Organization of the United Nations
IEA	International Energy Agency
kWh	Kilowatt hours
LPG	Liquefied petroleum gas
m^3	Cubic-meter
MHP	Micro-hydro Power
R&D	Research and Development
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USD	United States Dollars
MDGs	Millennium Development Goals
GHG	Greenhouse gas
WEF	Water-Energy-Food Security nexus

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1. Introduction

Access to modern energy services, which encompasses access to electricity and clean cooking technology, is one of the necessary inputs for the achievement of the Sustainable Development Goals (MDGs) (Modi et al. 2005; Karekezi et al. 2012). Nowadays, over 1.3 billion people lack access to electricity and 2.6 billion people are without clean cooking technology (IEA 2011). Lack of clean, affordable and sustainable energy is linked with household and community welfare in multifaceted ways (Modi et al., 2005). Moreover, many low income and off-grid households in developing countries rely on traditional biomass (IEA 2013), which often may lead to women's drudgery, children's withdrawal from school, health hazards from indoor air pollution, deforestation, soil erosion, and loss of biodiversity and related negative impacts on ecology and food security (example, labor use trade-off between food production and fuelwood collection) and so on (Guta 2014; Mirzabaev et al. 2014; Rasul 2014; van Els and Brasil 2012; Gerber, 2008; Nieuwenhout et al. 2001; Rehfuess et al. 2005).

Despite recent improvements in electricity use and better access to more efficient cooking fuel in developing regions, energy access still remains as a pressing problem (Mainali et al. 2014) specially taking into account that most of the population without access to modern energy sources live in rural areas of developing countries (84%), without connections to electric grids (IEA 2011). To overcome the physical barrier of spatial isolation, Decentralized Energy Solutions (DES), which provide energy services (electricity and/or heat) close to the user (household or community), have proved to be a solution for universal access of modern energy services. However, DES have been constrained due to upfront cost of renewable energy technologies, lack of financing opportunities and of technical capabilities (Schäfer et al. 2011). Furthermore, DES for household or community usages may face different challenges or barriers which may result in varying evidences on how DES initiatives have performed in achieving poverty reduction and improving energy access. Therefore, improving local conditions towards sustainable development requires availability of adequate energy beyond residential energy uses to include community institutions such as health care centers, schools, and facilities such as water services, telephone, internet, etc.

Box 1: Definition of key concepts

Decentralized Energy Solution (DES): a small scale and local transformation of renewable resources (wind, solar radiation, biomass, small hydropower) into electricity or thermal energy used in different activities by communities or households in different rural settings around the world.

Energy transition: a theoretical concept used to describe the relationship between economic growth (income) and energy utilization pattern.

Water-Energy-Food Security nexus: a conceptual framework that describes the interconnections among water, energy and food systems and seeks to develop joint solutions that mitigate the tradeoffs and promote synergies among these three sectors (Hoff 2011)

Additionally, lack of modern energy services is only a part of the problem for the achievement of the SDGs, since rural households and communities are facing energy, water and food security challenges. Therefore, access to these critical services is linked strongly with human wellbeing, as people require water, food and energy to work, educate and live healthy lives. This combined with exponential population growth which has created an increasing pressure on natural resources requires policy actions for more efficient use of these scarce resources (Gerber, 2008 ; Hoff 2011; von Braun 2013, FAO 2014; Guta 2014). Hence, a better understanding of DES within the framework of the Water-Energy-Food Security (WEF) nexus provides an innovative and more comprehensive insight into the role of modern energy services and might potentially lead to new solutions for sustainable development (Mirzabaev et al. 2014; Hoff 2011; von Braun 2013; Flammini et al. 2014).

1.1 Research gaps and contributions of the paper

Though many studies have evaluated the success and failure of DES, most of them have focused on certain aspect and missed important aspects of the issue. Many studies attempted to evaluate the performance of DES by focusing on a given community (geography), on single energy technology, and only on 'social-economic', 'socio-technology', or 'ecological-technology' aspects (Schäfer et al. 2011; Terrapon-Pfaff et al. 2014). Therefore, in the face of complicated challenges, to achieve positive impacts such as poverty reduction, women empowerment, improved food security, and human and environmental health, and satisfy long-term sustainability, DES should be perceived as an integral part to the Water-Energy-Food Security nexus (Villamayor-Tomas et al. 2015; Mirzabaev et al. 2014; Flammini et al. 2014). Yet studies have overlooked the critical link of DES in the Water-Energy-Food Security (WEF) nexus framework and this need to be considered in energy policy design to support rural development.

There are two gaps in the literature that served as motivation for this study. First, so far there have been only a scant number of cross country studies on the failures and successes of DES in developing countries. Second, DES is a major component of Water-Energy-Food Security nexus concept; but little is known about the barriers and incentives for DES in connection to other components of the WEF nexus.

Therefore, the research questions that the paper attempts to answer are: what are the water and food interlinkages of (selected) DES?; what are the incentives and barriers for the successful DES?; can WEF nexus concept provide a better understanding of the successes and failures of DES?; what lessons of successes and failures of DES can be learned from the selected case studies?

2. Review of Literature

2.1 Water-energy-food linkage

It is widely recognized that water, energy and food sectors have strong interconnections and interdependencies (Hoff 2011). The nexus perspective describes the interconnectedness among these three sectors; for example, the use of energy for food production and improved water supply, use of water in energy and food production, and bioenergy for food and energy production. A joint solution for exploiting the synergies and reducing the risks of trade-offs in the WEF nexus is necessary, as neglecting the inter-connectedness of the three components and focusing only on a single part may lead to sub-optimal outcomes (World Economic Forum 2011).

2.1.1 Energy and food linkage

Energy is directly used in agricultural production such as for irrigation, water pumping, mechanized agriculture, and postharvest processing and transportation (Ringler et al. 2014). At the same time some food crops (example, maize) are used for biofuel production. Energy and food production activities also compete for scarce (land, water, capital) resources that may consequently lead to fuel-food tradeoffs. However, it is asserted that "energy driven intensification has greatly reduced the need for the new cropland and deforestation" as it supports innovation that improves agricultural yield (Ringler et al. 2014). On the other hand, a "global transition towards renewable energies" has raised a concern over "land rush" with a long-term consequence on land demand or the "struggles over access to land" (Scheidel and Sorman 2011). Besides concern over "land grabbing" for biofuel development, continuing loss of tropical forest fuels competition for scarce resources between energy and food production (Mirzabaev 2014; Guta 2014, von Braun and Meinzen-Dick 2009).

2.1.2 Water and energy linkage

Water and energy use are closely intertwined. Water is used at all stages of energy supply value chain (production, extraction, refinement and processing) of biofuel production and fossil fuel based power plants operation (coal, gas, nuclear), and more directly in hydroelectric power production. Energy is also required at all the stages of water supply value chain (extraction, underground water pumping, treatment and purification, distribution, heating and cooling water) for different beneficial purposes (Olsson 2011). In fact, DES plays an important role in water treatment, to address clean water availability problem in remote communities of developing countries; but a study identified number of sustainability challenges related to renewable energy use such as limited local capacity (example, lack of skilled labor), lack of spare parts and other socio-economic factors (Schäfer et al. 2014). A study on “water and energy footprints of global food production” indicated that the footprint was significant at all scales (locally, nationally and globally) not only in terms of food security but also in terms of “ecosystem health and productivity” (Khan and Hanjra 2009).

2.1.3 Water and food linkage

There is intricate linkage between water and food which is further “compounded by climate changes” (Hanjra and Qureshi 2010). Water is one of the critical inputs in agricultural production. It is asserted that agriculture is “the sector where water scarcity has the greatest relevance” (FAO, 2012). Particularly small scale farmers located in arid and semi-arid areas who depend on rainfed agriculture are vulnerable to water scarcity. In this sense water scarcity arises from “human interference with the water cycle” (FAO, 2012). Besides, increasing irrigation demand, water is ingredient to food processing industries. For instance, poor upstream agricultural practices (such as: soil erosion, deforestation and land degradation, and use of chemical fertilizer) negatively affect the availability and quality of water (Rasul 2014; Ringler et al., 2014). Policy actions are required for “tackling climate change, preserving land and conserving water, modernizing irrigation infrastructure” (Hanjra and Qureshi 2010) and to support investment on technologies for improving water productivity and agricultural energy use efficiency (Khan and Hanjra 2009).

2.2 Energy utilization pattern, leapfrogging, stacking and ladder

2.2.1 Energy utilization pattern

To understand the problem of lack of modern energy services and their linkage with WEF nexus, it is important to understand the rural energy demand. In most rural households in low income countries, most of the energy consumption is thermal energy with very little electricity consumption (Patanothai et al. 2011). Thermal energy is the basis to fulfill the very basic human needs (food, heat), while electricity access is dependent on rural households income (Barnes & Floor, 1996). In fact, electricity consumption can be used as a proxy of urbanization or improvement in the energy ladder (ibid). Barnes & Floor (1996 Table A1) provide an energy pattern that is used as a basis for further analysis in this paper, which establish the type of energy source used in rural settings (eg. wood, diesel) based on income and sector (rural household, agriculture and rural industry).

2.2.2 Energy ladder and energy stacking

There are rich debates on the energy transition concepts in the literature (Mirzabaev et al. 2014; Guta 2014). The debate is on whether energy transition process follows the *energy ladder* or the *energy stacking*. These theoretical concepts were used extensively to describe the relationship between energy choice and income or economic growth. The former as the name implies conceptualizes energy choice as a linear step by step transition process with increase in income; energy users abandoning less efficient and cheap traditional biomass and shift to intermediate energy sources (charcoal and coal); and then to modern, safe and efficient energy sources like electricity (Hosier and Dowd 1987; Leach 1992). In contrast, the energy stacking states that there is no unique, simplistic and monotonic energy transition process; but energy consumers use multiple energy sources and their choice is dictated by multitude of socio-economic and cultural preferences (Guta 2014; Heltberg 2004; Masera and Navia 1997).

2.2.3 Energy Leapfrogging

The "energy leapfrogging" has gained increasing attention in energy transition literature recently. It refers to a process of energy transition pathways that involves a bypass of the conventional energy and a leap directly to the more efficient, safe and environmentally friendly energy technologies (Murphy 2001). Accordingly, developing countries have the opportunity to borrow the advanced energy technologies from industrialized countries to make a “leapfrog” from less sophisticated energy technologies to modern, cleaner energy alternatives without the need to go through the pollutant energy sources such as coal, gas and so on (Marcotullio and Schulz 2007). In practical terms, however, a rapid and fast energy transition from traditional biomass and coal to electricity may be difficult to take place especially in remote communities of developing world (Zhang 2014; Guta 2014). The most successful “leapfrogging” has taken place recently in the mobile phone technology as the millions of people in developing countries have bypassed the landline technology and skipped directly to use of the mobile phone.

Energy technology leapfrogging, however, appears to be much more challenging (Murphy 2001). Energy leapfrogging needs a simultaneous “institutional leapfrogging” (Han et al. 2008). In developing countries energy leapfrogging is limited by lack of technological capability (Murphy 2001; Gallagher 2006). Therefore, in developing countries energy transition has been constrained by interplay of factors such as socio-economic factors, risk taking behavior, institutional and technical capabilities of the stakeholders (Guta 2014; Mirzabaev et al. 2014; Murphy 2001). Thus, it is dependent on and constrained by household’s, communities and regional cumulative technological capabilities, and is, thus, an ‘incremental’ or ‘gradual process’ that requires technical capacity development, awareness raising and improvements in living standards and so on (Guta 2012; Murphy 2001).

2.3 Successes and failures of Decentralized Energy Solutions in energy transition

A number of studies have attempted to assess the successes and failures of community-based decentralized energy solutions in developing countries. A study assessing “the sustainable rural energy decision support system (SURE DSS)” indicated that energy supply in rural communities is complex and is not a simple selection of a technology but it also involves multiple criteria (given below) and has a strong link to livelihoods (Cherni et al. 2007).

2.3.1 Social factors and decentralized energy

The performance of DES depends on the political setting, socio-cultural tradition and cooperation among multiple stakeholders, legal rules and regulations (Terrapon-Pfaff et al. 2014; Wirth 2014; USAID/ARE 2011). Participation is a key factor and reduces "bureaucracy and transaction costs" (Gollwitzer 2014). Communities and households participate in various design processes and implementation stages that enhance ownership and operation of the system, maintenance and management through community organizations or cooperative societies.

Similar to other investments, community participation is believed to improve the long term sustainability of decentralized energy projects (Holland et al. 2001). For instance, in Nepal, it was indicated that the community-based approach has improved long-term sustainability due to local ownership, and promoted the scaling up of decentralized energy program that has benefited from "effective partnership and innovative funding mechanism" (UNDP 2011). In the case of South Tyrol in Italy, a study found that "community spirit and local tradition" play a central role in biogas cooperatives in determining who should be included or excluded in the scheme and on the choice of plant location and scale, thus, community as an "individual institutional" setting shapes community investment decision (Wirth 2014). A study on selected community in Mexico stated that "adaptive and decentralized energy" reduces vulnerability of communities to climate change crisis and it increases resilience of communities and reduces stresses after the crisis (León-Camacho et al. 2014). However, often DES in developing countries is initiated and established with assistances from outside (government, non-government or international donors and supporters) (Gollwitzer 2014; Schäfer et al. 2011) making it susceptible to uncertainty without continued support of outsiders. Community-based approach through empowering and creating inclusive local participation in planning and execution of project would enable direct control of local players in monitoring and management of resources to improve sustainability of investment decisions (Haider 2009).

2.3.2 Institutional factors and decentralized energy

Community-based DES is considered a 'common property resource' thus, the institutional structure constrains or enables the investment initiatives (Gollwitzer 2014). Not only free market, but also government failures are prevalent in environmental protection and thus both were ineffective in delivering the socially and environmentally optimal outcome (Wohlgemuth and Madlener 2010) due to two main reasons (Hepburn, 2010): (i) in order to design and implement appropriate environmental policy and to achieve proper coordination among the multiple stakeholders the state government lacks readily available and quality information; (ii) government organ is made up of a collective of people who are subject to "manipulation" and lobbying by self-interested individuals and thus fails to achieve optimal outcome for the wider public.

In this context, the community approach has been considered as a valid alternative to "government and market based" provision of energy (Oteman et al. 2014). However, community-based energy investment faces complex barriers. Even among "developed nations like Germany, the Netherlands and Norway, renewable investment failed to establish itself without government intervention" (Wohlgemuth and Madlener 2010). In order to increase "stability and predictability" of DES institutional organization should be established to facilitate discourse among different government levels actors and enable community to play important role (Oteman et al. 2014). Thus, structured legal rules and binding contracts are critical factors for the success of DES (USAID/ARE 2011), but on the other hand, DES was found to enhance local governance capacity in Nepal (UNDP 2011). This is because decentralization increases a "space for local actors" (Oteman et al. 2014).

2.3.3 Environmental factors and decentralized energy

Despite the economic benefits of decentralized energy, there is mixed evidence on its ecological sustainability. DES such as biogas, improved cook stoves, micro hydropower and solar power helped rural communities of Nepal to mitigate climate change through reducing carbon emission (Sapkota et al. 2014). The authors computed the amount of carbon emission reduced from implementation of these technologies for the next 20 years and estimated it at about 51 million tons. In contrast, a study in Guizhou Province in southwest China on micro hydropower (MHP) evaluated the cost of the project and indicated that the eco-friendliness of the project remains highly contested due to impact on the downstream drying-up of the river and recommended a cautious approach to maximize the benefits and mitigate negative ecological impacts (Pang et al. 2015). Moreover, because of adoption of less efficient energy conversion technologies, the emission of GHG carbon dioxide (CO_2) per unit of energy from biomass and coal in developing countries is higher than that from petroleum products and gas in industrialized countries (Sathaye & Ravindranath 1998).

Nevertheless, there is a limited research on environmental factors affecting DES sustainability. This is related to complex environmental factors and impacts associated with DES such as reduced indoor air pollution, waste production, deforestation, decarbonaization of energy system, global climate change mitigation and wider ecosystem dimensions over the entire life cycle (LC) of initiatives which was under-researched in developing countries.

2.3.4 Economic factors and decentralized energy

Economic viability of DES depends on the business model that could include household ability to pay, government subsidies, or international donations which need to cover investment cost and in the long term maintenance and equipment replacements costs. Studies have indicated that in off-grid communities in developing countries, the conventional diesel electricity generation can be cost effectively substituted by renewable sources (Alfaro and Miller 2014; Herran and Nakata 2012). A study in the case of Liberia, Alfaro and Miller (2014) computed the levelized cost of electricity and indicated that households can afford biomass and small hydropower, but not electricity generation from diesel and solar PV because for these sources the levelized cost[1] is beyond the household's purchasing power or willingness to pay. Decentralized biomass energy in remote rural communities of Colombia was found to reduce the system net cost and carbon emissions (Herran and Nakata 2012). This is because it reduces transportation cost and supports sustainable local development (Mangoyana and Smith 2011). Extended payment schedule, low interest rates and taxes improve household electricity affordability (Lahimer et al. 2013).

Financial constraints or lack of credit are the key determinants of long-term sustainability of DES, and encompass not only upfront installation cost, but also costs of operation and management of the projects over time (USAID/ARE 2011). Small scale renewable energy investment is often discriminated against by the capital markets (Wohlgemuth and Madlener 2010), making role of government and other external actors indispensable. In developing

[1] Levelized Cost refers to the long run breakeven per unit cost of electricity generation

countries, lack of long-term credit and related uncertainties present significant obstacle to community-based energy. Given scarce resources, competing demands from other economic sectors (for example, education, road or other public finance), and limited local financial capacities, the government budget may not be able to finance the energy infrastructure. For instance, a cross country study assessed the impacts and ex-post sustainability of small scale energy, and indicated that financing local energy technology development was constrained by “limited length and amount of funding” (Terrapon-Pfaff et al. 2014). Government and donor organizations play a crucial role in controlling over ‘technological specification‘ and/or supporting project subsidies for installations (USAID/ARE 2011; Rolland and Glania 2011) but the subsidies for maintenance or replacement are often not included, but are key inputs for sustaining the DES over time. Thus, “sustainable deployment of renewable energy in development” through DES requires tariff policies which need to be evaluated in terms of associated welfare losses (Thiam, 2011). Moreover, community-focused microfinance schemes for low income clients may help to tackle the financial barriers (Raha et al. 2014).

Moreover, in this context, international climate change funds such as clean development mechanism (CDM) were created to support renewable energy in developing countries. However, so far, such policies were only moderately successful (Skjærseth and Wettestad 2008). Although investing in smart grids was found to contribute to a rapid transition to low carbon economy, there are complex problems attributed to “value capture and redeployment” due to the mismatch between where benefit arises and cost is incurred (Hall and Foxon 2014).

3. The conceptual framework

Based on the literature review and a research in progress in the Center for Development Research (Mirzabaev et al. 2014), the following is a proposed conceptual framework to study the energy transition provided by DES and Water-Energy-Food Security nexus in rural communities.

There are economic, environmental, social, policy-related, technological and institutional drivers that shape the WEF nexus for a specific household and community. Consequently, due to the bounded interaction any change on water, energy, and food derived from present drivers, will have significant impacts on the WEF nexus outcomes regarding food security, energy poverty, poverty reduction, environment conservation, and quality of life of rural settlements. DES is a means for energy transition in households and communities and, consequently, a change in energy within the WEF nexus. However, there are barriers and drivers that prevent or enable DES. WEF nexus outcomes have a feedback effect on existing drivers which at the same time have a feedback effect on existing barriers.

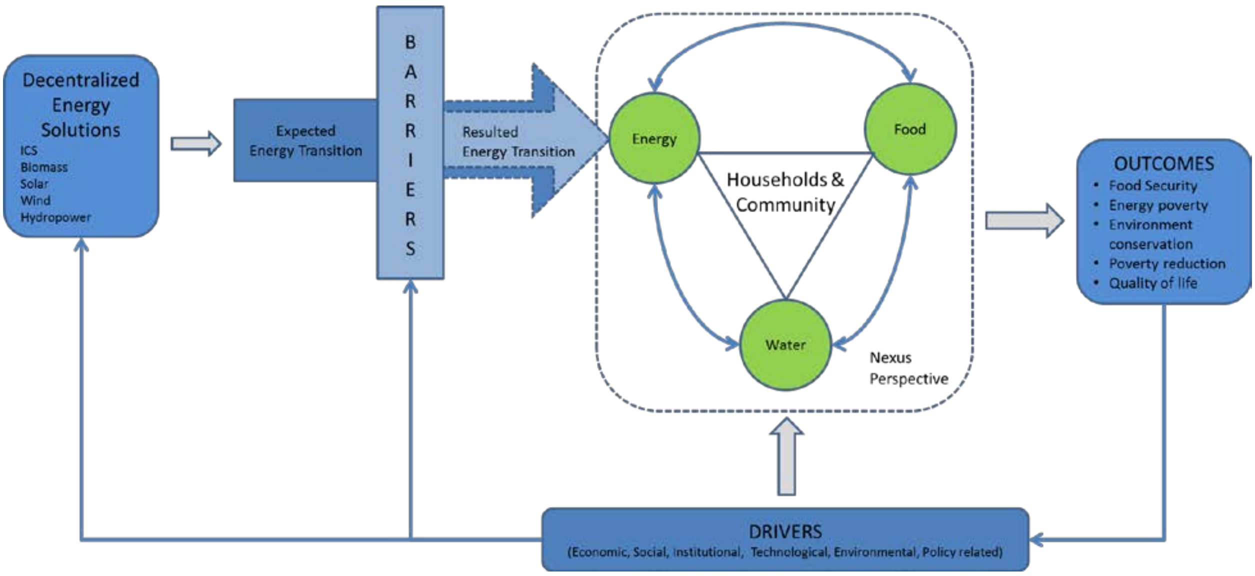

Figure 1: The conceptual framework

The proposed conceptual framework will be used to analyze selected case studies around the world with different DES. For each case study the links between the energy service provided by the DES with water and food will be identified, together with their implications on WEF nexus outcomes. Also, the barriers and drivers that prevented or enabled the expected energy transition will be identified. Finally, the conceptual framework will guide the exploration and assessment of feedback effects among outcomes, drivers and barriers.

4. Methodology and data

The paper employs a qualitative approach to understand the specific underlying factors behind successes and failures of community energy initiatives. This is based on narratives of specific case studies from cross country community energy experiences in developing countries. The case studies constitute a review of various documents such as project documents, nationally available statistics and own empirical studies on community energy projects to identify the causes of successes and failures of the projects. The paper reviews literature to identify the research gaps and to understand the state of the art and experiences in DES to enhance access to modern energy services (electricity and/or thermal energy) using renewable energy sources.

Selection of case study meets various criteria. Firstly, the authors have research experience on energy issues in the selected countries. Secondly, the countries represent different geographic contexts (Asia, Africa, Latin America), that have different experiences of successes, and failures, cover one or more rural energy uses (electricity, cooking, heating) and various energy sources (improved cook stove, bioenergy, hybrid technologies etc.) explained in 2.2.1.

Moreover, based on experiences of the case studies, the effectiveness of introduction of DES on targeted areas was analyzed by providing suggestions to amend prevailing policies. The case studies also discuss the relationship of the different DES to the new WEF Security nexus concepts.

As is observed from Table 1, the ranges of technology varies from simple ICS to micro-hydro where the end -use are principally based on two categories of thermal and electricity. Hence, these case studies incorporated four major renewable sources of biomass, hydro, solar and wind. Of the technologies, biogas and ICS are based on individual household level whereas micro-hydro, wind-solar hybrid, biomass gasifier and jatropha oil expeller are managed on community level. Moreover, the diversity of technologies in different case studies can also be analyzed in view of energy process. The case studies were organized on the basis of key information discussed in Table 2.

Table 1. Brief descriptions of case studies

Case study	Technology	Specifications	End-use applications	Number of beneficiaries	Sources
Chunfeng village, China	Household level biogas	8 to 10 m^3, main feedstock pig dung	Cooking and lightening	136 hhs	Qin and Quan(2014)
Andean region, Ecuador	Improved cooking stoves	800 improved cookstoves installed in rural families located in two province of the Ecuadorian Andean Region	Cooking and heating	800 hhs	(Zevallos, et al, 2013)
Bati *woreda* in Oromia zone in Amhara region, Ethiopia	Jatropha oil expellers	Jatropha cultivation on communal degraded land, Jatropha seeds and oil	Cooking and lightening	300hhs (in 2008)	Portner et al. (2014); Bach (2012); Amsalu et al. (2013)
Garkha village, Bihar, India	Biomass Gasifier	128 KW, For the feedstock, local farmers incentivized to grow Biomass (Dhaincha) in their otherwise barren lands)	Electricity for irrigation water pumping, agro processing, households, businesses, schools and medical facilities	1000 households and businesses, 10 irrigation water pumping enterprises, 1 school and 2 medical clinics	MNRE (Ministry of New and Renewable Energy), India 2012
Sikles village, Nepal	Micro-hydro	100 kw	Lighting Radio & television Grinding machine	360 hhs	Gurung et al. (2011)

Table 2: Template of case study discussion

Case study	Description of the technology, direct and indirect "products and serviced"	Barriers	Discussion of the nexus linkages
household biogas digester in Chunfeng Village in China	• **Direct products:** Biogas • **Indirect products:** Value add products (fertilizer)	• Lack of training for households • Lack of enough services for maintenance at household level	***Water*** • Reduce the contamination caused by the chemical elements • Reduce the drinking water pollution caused by discarded pig dung and discharge of sewage ***Food*** • Use anaerobic digestion effluent and residue as a high quality fertilizer to improve food production • Free the households from biomass collection for food production
Improved cook stoves experiences in Ecuador	• **Direct products:** Improved cookstoves • **Indirect products**: less wood consumption, health improvement for women and children, heating and gathering area	• Strong link to traditional cooking practices and belief that present situation is not burdening household quality of life • People's mistrust and bad experiences with previous ICS initiatives • Difficult to use ICS and not suitable for communal gatherings • Lack of local providers and ICS industry	***Water*** • Reduction of deforestation and therefore enhancement of water regulation ***Food*** • Better conditions for food preparation • Initiation of healthy practices such as wash hands before eating, consumption of boil water, kitchen and house cleaning.
Community based Jatropha in Bati woreda, Northeastern Ethiopia	• **Direct products:** Jatropha seeds and oil or biodiesel • **Indirect products**: income, value add products, ecosystem	• Lack of technical support • Lack of professional biofuel manpower • Lack of stable market • lack of fund for finalizing the	• **Water**: Reduced land degradation, deforestation, soil erosion and improved water retention and reduced hydroelectric dam siltation • **Energy**: energy substitution for traditional biomass and fossil fuels. • **Environment:** reduced indoor air pollution and carbon emission • **Poverty reduction and food**

Case study	Description of the technology, direct and indirect "products and serviced"	Barriers	Discussion of the nexus linkages
	restoration and associated benefits	biodiesel processor factory • Low Jatropha yield	**security**: financial and time saving from energy expenditure and biomass collection respectively, income, employment, etc.
Biomass Gasifier based power plant in Garkha village, Bihar, India	• **Direct benefits:** Wastelands reclaimed for agriculture, Cheap and reliable electricity for food production, Electricity for households, businesses, schools and medical facility • **Indirect benefits:** Improved farm productivity, Development of Human Capital in village, Improved village economy	• High capital cost compared to conventional technologies • Financing is a challenge as this investment is considered risky by Banks • Competition with highly subsidized grid electricity for agricultural loads • Evacuation of surplus power to grid is a challenge • Sustainable biomass supply chain for the gasifier is a challenge	**Food production** • Cheaper and reliable power to pump irrigation water • Improved medical service facilitates improved productivity of farm households • Cultivation of Dhaincha (Energy crop) in barren land fixes nitrogen and improves productivity of land • Cheap power for agro processing **Energy** • Replacement of diesel with clean source of electricity • Char which is a residue of plant can be used for making charcoal briquettes for cooking **Water** • Cheap power gives possibility to draw drinking water from greater depths with lesser chances of contaminated drinking water **Poverty reduction** • Increasing business activities provides greater employment opportunities **Environment** • Significant saving of diesel based emissions due to reduced diesel genset operations

Case study	Description of the technology, direct and indirect “products and serviced”	Barriers	Discussion of the nexus linkages
Micro-hydro plant in Siklesh village, Nepal	• **Household use:** lighting , communication and entertainment • **Community use:** Agro-processing mills	• Lower load factor • Lack of infrastructure and market hinder to link energy with economic activities	• **Energy** – Replacement of kerosene with clean source of electricity for lighting. Interventions of communication and entertainment facilities Substitution of traditional agricultural mills with modern one • **Food** – Better environment for preparation and consumption of food especially during evening period. • **Water** – No direct impact (Although possibility to carry out water pumping via electricity for both drinking and irrigation) • **Environment** – The stoppage of kerosene burning for lighting has reduced indoor air pollution

5. Results of case studies

5.1 Rural household biogas digester construction project in Chunfeng Village in China

Implementation: Chunfeng Village is located in mountainous areas of Junlian County at the border of Sichuan Province and Yunnan Province. It covers an area of 347 ha, among which the area of arable land is 267 ha. There are 203 households with total population of 864 people (Qin and Quan, 2014). People living there at one time depended heavily on firewood and coal for cooking. Direct combustion of these types of energy caused many serious consequences such as indoor air pollution and environmental damage. In order to improve the rural living standards and to reduce the pollution from rural energy use, the MOA (Ministry of Agriculture) started the 'Prosperous eco-farmyards' plan in 2000 (CPPCC, 2004). As the 'core instrument' of this plan, the household-based biogas digester construction project was promoted in Chunfeng Village from 2003 (MOA, 2002). By 2013, 136 biogas digesters had been built in Chunfeng Village. The penetration of biogas had been about 72% (Qin and Quan, 2014).

Description of technologies or products and services*:* In the process of the implementation of the household-based biogas digester construction project, the required size of biogas digester is on average 8 ~10 m^3. Before 2011, the biogas digesters with ordinary brick and concrete structure were built in Chunfeng Village. In recent years, Fiberglass-Reinforced Plastic (FRP) dome cover digesters have been promoted in Chunfeng Village. Compared with the former one, the FRP digester can produce at least a third more biogas using the same amount of feedstock. Besides, the household biogas digester project emphasizes a three-in-one ecological agriculture mode of 'pig rising (livestock feeding) - biogas digester - orchard cultivation (planting industry)'. The system consists of toilet/livestock house (pig sty), biogas digester and orchard (field). The human and animal wastes are used as feedstock to produce biogas for cooking. Then the biogas slurry and residues can be used as fertilizer in orchard or field around farmer's house, while the anaerobic digestion effluents can be used to feed pigs mixing with fodders. In the case of Chunfeng village, the main feedstock used to produce biogas is pig dung. According to the statistics, one household biogas digester can produce 600-810 m^3 of biogas per year to meet the demand of a household with 5 members for cooking. One household has to feed 3-5 pigs to maintain the sufficient biogas supply for living. Approximately 6 ton biogas slurry and residues can be generated from the process of anaerobic fermentation for one biogas digester (ABJC, 2005). Besides, the households are also required to rebuild sanitary toilet as well as to install the biogas stove in kitchen to improve the quality of their lives.

Barriers and enablers: Subsidies provided by central and local governments to the households in Chunfeng Village who are willing to build new biogas digesters in their houses boosted the households' motivation to use biogas. There still exist some barriers which could hinder the further development of the household biogas project. Too little attention has been given to the quality as opposed to quantity in infrastructure construction due to the overemphasis of low-cost construction, resulting in short service life of the digesters and the stoves. Lack of sufficient knowledge and skills regarding effective operation and management as well as enough services for maintenance at household level may cause disuse of the digesters. In addition, the new biogas technologies cannot be applied into practice and timely popularized in bigger scales, due to a lack of matching policies and institutional arrangements.

WEF nexus linkages: With respect to the effects of biogas use on water resources, the household biogas digester project not only mitigates the contamination of drinking water by human and animal fecal matters (Chen et al., 2010), but also reduces the pollution of local surface and ground water caused by using chemical fertilizers and pesticides (He et al., 2013). In addition, the use of biogas instead of firewood protects forests and thus can avoid the damage to watershed caused by deforestation and excessive exploitation of forest resources (Zhang et al., 2012). For the linkage between biogas use and food issue, the 'three-in-one' mode changed the traditional agricultural production methods of the households integrating with the development of courtyard economy and the improvement of food production efficiency. It reduces the food production cost by decreasing households' expenditure on chemical fertilizer. The high-quality sludge-like organic fertilizers (i.e. anaerobic digestion residues and effluents, which could be regarded as by-product of biogas conversion process) are applied to backyard orchards or nearby fields to produce food without the pollution caused by the chemical elements (Zhang et al., 2012). The crop yields are raised by the improvement in the fertility of the soil through increasing the amount of organic and micronutrient elements in it. Besides, the use of biogas reduces the need for the traditional biomass energy such as crops straw and firewood, therefore reduce the time spent on collecting and processing them, and thus free the household labor from workload of biomass collection to food production (Gosens et al., 2013).

5.2 Improved cook stoves experiences in Ecuador

Implementation: In 2010, Improved Cook stoves (ICS) were distributed among 800 rural families settled in the highland region of the Ecuadorian Andes (3200 – 4200 m.a.s.l), which up to now is the biggest experience documented in Ecuador, and constitute a significant case study. There are multiple underlying factors that had driven this initiative (Zevallos et al. 2013). First, the precarious cooking conditions combined with the lack of basic services affected population health and ultimately the quality of life, which is highlighted as the main aim to be improved after project implementation. Second, project implementer's[2] knowledge and long experiences (30 years) in the local context, combined with the availability of funds from international cooperation[3] were key for project identification and preparation. Third, deforestation due to fuel wood consumption is highlighted as a critical situation that needs to be mitigated in Andean communities. Fourth, high cost and availability of Liquid Petroleum Gas (LGP), which is the main subsidized[4] source for cooking in Ecuador, are described as burden factors for household economies preventing the families to shift to modern fuels for cooking.

Description of technologies or products and services*:* The ICS installed in the study area was based on a certified model implemented in similar climatic conditions in Peru (Zevallos et al. 2013), It is a fixed cook stove with two cooktops and chimney, built with adobe and bricks. After six months of ICS usage the documented impacts include (Zevallos et al. 2013). First, an average reduction of wood consumption of 40% with a maximum value of 70%. Second, improvements on cooking conditions, such as a better position to cook leading to less time for cooking, less risk for fire accidents, physical modifications of kitchens after ICS installation (painting, shelves, household landfills, eco-refrigerators) and initiation of

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[2] www.adra-es.org
[3] Program Energy and Environment Alliance in the Andean Region www.energiayambienteandina.net
[4] LPG Price in USD. International price = $USD 12, Ecuador = $1.65, study area $5

household health practices (consumption of boiled water, animals out of the kitchen, wash hands before eating, cleaning the kitchen and house). Third, women and children feel less pain in the eyes, headaches and throat pains. Fourth, due to warm temperature and kitchen cleanliness it became a frequent place to gather family members and neighbors.

Barriers and enablers: There are different barriers and enablers that influenced ICS adoption and consequently energy transition in the case study (Zevallos et al. 2013). First, the strong bound to traditional cooking practices, and the belief that the present cooking situation is not burdening the health constrained people interest on ICS. Second, people believed the project had hidden government strategies to increasing the cost of subsidized LPG, which combined with previous bad experiences with ICS created a high distrust among population regarding the project intentions. Third, husbands had a strong influence on preventing wives participation due to their mistrust about project intentions. To tackle these barriers, the implementer developed a communication plan in cooperation with "guide mothers[5]" installing pilot ICS in their houses in order to demonstrate in practice the real benefit of ICS usage which has a positive effect on enhancing trustfulness and speeding up project acceptance, especially among husbands. Fourth, the lack of some local providers compliances to delivered specialized parts of the ICS (hot plate) delayed the construction phase affecting again mistrust among population, which was solved through the importation of these parts from Peru and the partial construction of the ICS and other kitchen improvements (shelves, eco-fridge, landfills). Fifth, poorest families required more time to fulfill the project requirement on providing materials for the construction of ICS, nevertheless, their willingness to do that was high. Sixth, the initial use of ICS by users was difficult which led to higher wood consumption, more time for cooking time, problems with smoke that did not go out through the chimney. To tackle these problems the implementer provided periodic visits to each household until users followed maintenance and usage instructions, in this sense guide mothers were key on transferring the information and up-taking ICS. Based on the experience, at least one month is required to guarantee a proper training and start feeling the benefits of ICS. Seventh, although the project was not an initiative from government institutions, the participation of Parrish and Communal governments during project proposal and implementation were key for funding access and

[5] Volunteer women in charge of health issues within the community

project implementation. The success of ICS in the study area has demonstrated that it attracts new users and therefore, a local industry of ICS in the region will be desirable to scale up ICS adoption, nevertheless it will require a strong government support and policies that can be influenced by further research of ICS application in Andean regions.

WEF nexus linkages: Based on previous information (Zevallos et al. 2013) the following water-food-energy linkages can be highlighted. The reduction of wood consumption has an impact on reducing deforestation and therefore water regulation, but further research work is required to quantify this effect. Regarding energy links, less wood consumption reduces energy poverty, nevertheless the use of LPG still was present since it helps to cook fast when there are communal gatherings, hence better designs and technological improvements of ICS could help to reach a complete transition to modern energies. Regarding food linkages, the adoption of ICS encouraged the construction and use of other technologies (eco-fridge, household landfill, shelves) which improved food preparation, health conditions, and a reduction of indoor gas emissions, all of them influencing ultimately food security. Also, the kitchen cleanliness and warm temperature create a household gathering area enhancing social cohesion and improving the quality of life.

5.3 Community based Jatropha in Bati woreda, Northeastern Ethiopia

Implementation: In Bati, Jatropha has been known to the smallholder farmers since 1970 for its vital services. These include its roles as 'hedge or living fence' on farm boundaries and around household gardens, and as a source of energy and income and so on (Portner et al. 2014; Bach 2012). Beside the traditional system, the new community approach was initiated in 2008 due to partly Jatropha's role in rehabilitating 'degraded' or 'marginal' land, 'valley bottom' or 'pastureland' as an alternative to tree plantation. Furthermore, as part of the green growth strategy, Ethiopia has emphasized biofuel blending. To this view, the community approach is regarded as a better alternative to the large scale biofuel which has been criticized due to food security impacts. The new community Jatropha project was initiated by two organizations in Bati: the organization for Rehabilitation and Development of Amhara (ORDA) and *Woreda's* office of Agriculture and Rural Development (Amsalu et al. 2013). ORDA supports the program through technical capacity building and training farmers.

A cooperative of about 300 famers were organized and began production of jatropha on 'degraded communal land in the year 2008 (Amsalu et al. 2013).

Description of technologies or products and services*:* Households in Bati use bundle of energy sources for residential cooking and lightening needs. Jatropha seed is utilized directly for these purposes. But Jatropha can also be processed into oil (biodiesel) which can be utilized for residential and transportation fuel. Jatropha seed and oil have the potential to substitute charcoal and fuelwood, and fossil fuels (Amsalu et al. 2013). Alleviating energy expenditure which was a significant financial burden to farmers in the area (Portner et al., 2014) greatly contributing to improvement in peoples' livelihoods. A study estimated annual household expenditure on residential energy for a typical household in Bati which was about US$ 370 or 18.5% of household budget (Portner et al., 2014). Energy substitution of diesel and traditional biomass with Jatropha seeds and oil contributes to improved health, clean lightening for children to read and for women to perform domestic chores after daylight; reduced labor use for fuelwood collection, and reduced energy expenditure.

However, there are scant detail of quantitative assessment of the success and failure the project so far. The evidence is mixed. Although households have been using Jatropha seeds as one of their energy option since four decades it has not led to residential energy transition (Portner et al. 2014). Amount of Jatropha harvested from the 'hedge or living fence' was not sufficient to support residential energy transition. A study estimated the amount of Jatropha seed needed to produce biodiesel to fully substitute household energy consumption from Jatropha hedges; and found that it would require threefold increase (Portner et al. 2014). This means that farmers should plant more jatropha on crop land; which gave justification for cultivation of jatropha on communal pastureland. So far in the Bati woreda*,* Jatropha has been cultivated on 28,000 hectares of 'degraded' or 'marginal' lands or 'bottom valley' (Amsalu et al. 2013). Yet a study assessed the economic benefit of small scale jatropha in Bati using a household survey (Portner et al. 2014). Despite a threefold increase in jatropha price in Bati over the period 2009-2012, local farmers have not benefited economically from the project but there is a potential for economic benefit over the long run (Portner et al. 2014).

Barriers and enablers: The main barriers are identified which include: "low jatropha yields, poor market linkages, and lack of financial and technical support" (Amsalu et al. 2013). Low

Jatropha yield relates to the quality of land, but also water availability is inevitably a key factor, although there are mixed evidences. A study indicated that in Bati Jatropha was preferred to tree plantation on degraded communal land because of its resistance to drought stresses, being poisonous for animal to browse, and greater accessibility in the area (Bach 2012). On the contrary, drought stress was found to be underlying factor for failure of large-scale biofuel projects in Ethiopia (Wendimu 2013). Another barrier relates to the little attention on further biofuel value chain development as emphasis was given only to cultivation of Jatropha (Portner et al. 2014). Biodiesel processer factory has been installed in Kombolcha, near to the project which was sought to help process jatropha seed into biodiesel. Nevertheless, due to financial constraint the factory has not yet been functional (Amsalu et al. 2013). Technical barriers are prevalent due to limited local technical capability to operate and maintain the factory.

In Bati there are “stoves and lamps fueled by crushed Jatropha seeds or oil” (Bach 2012). But Jatropha oil cookers were not utilized satisfactorily due to the fact that majority of households were not able to afford it and jatropha production from hedge was not sufficient (Portner et al. 2014). Local craftsmen need to be trained to produce stoves and lamps from cheap, easily accessible raw materials. It was suggested that to tackle the barriers and enable realization of economic and energy transition benefits policy should emphasize farmers, local jatropha seeds processer, and creation of stable market, training and establishing professional biofuel workers (Portner et al. 2014).

WEF nexus linkages: The project contributes to WEF nexus both directly and indirectly. In contrast to large scale biofuel investment the Bati project was initiated not only for increased biofuel production but as discussed above it has enabled in achieving synergies for improved soil and water retention, and reduced land degradation. It was implemented for “rehabilitation of gullies”, “soil and water conservation” and “for purpose of afforestation” (Portner et al., 2014). Alternative energy (biodiesel) substitution for biomass and fossil fuel contributes to energy transition not only in domestic sector but also in the transportation sector. This contributes to greenhouse gas reduction, carbon sink and climate change mitigation efforts. The financial saving from energy substitution in terms of reduced energy expenditure can be used for buying food and liberated time can be used for more food production. Moreover, jatropha by-products can be used for production of ‘value added products' (example, fertilizer and biogas) which can potentially contribute to improved food and energy security (Portner et al. 2014). Reduced deforestation and enhanced water and soil conservation creates a win-win outcome for tackling reservoir siltation and enhanced hydropower generation in the downstream.

5.4 Biomass Gasifier based Mini Grid in Garkha village, Bihar, India

Implementation: Garkha is a village located in the Bihar province of India. It comprises of 1465 families with a total population of 9319 (Census of India 2011). Due to highly unreliable electricity from grid, villagers were earlier dependent on high cost and polluting diesel generators for their household electricity needs, farm irrigation needs and their local businesses. In 2006, Saran Renewable Energy (SRE) installed a Biomass Gasifier power plant of 128 KW capacity in the village that now provides power to around 1000 households and businesses (MNRE 2012) at a price which is around 36% to 53% cheaper than existing diesel genset based electricity enterprises in the village and around. SRE has also innovatively chosen Dhaincha (woody shrub) as the major feedstock for the gasifier plants which is grown in the waterclogged wastelands of the village.

Description of technologies or products and services: The project utilizes down-draught-open-top type biomass gasifier and gas engines, designed to supply 128 KW electric power at 240 V. The cost of the entire power plant is INR 8,300,000 (140,000 USD @ 1 USD= 60 Rs) with the gasifier and generation plant making 90% of this cost. While, SRE was able to secure 25% of this cost as a bank loan, the rest of the payment was invested by directors of this company. For giving sustainability to the feedstock supply for the plant, SRE has incentivized farmers to grow Dhaincha (woody shrub) in their fields which otherwise remain water logged and barren during Kharif season as this area lies in the low land between river Ganga and Gandak. While, this give sustainable raw material supply to the gasifier, it gives income generation (INR 5000-7500 (USD 800-1200) per hectare) to farmers. The gasification plant operates daily for about 10 hours from 10 am to 9 pm with current peak demand of 90% and an average demand of 65%. It charges INR 7.5 / kWh (0.125 USD/ kWh) per unit to the customers whereas the tariffs with diesel generator could vary between INR 12 -16 / kWh (0.2- 0.25 USD/ kWh). This gasifier system has intensified productive activities in the village such as Grain and Oil Mills, Saw Mill, Welding shop etc which were earlier relying on expensive diesel electricity or unreliable electricity grid. It has also been able to supply power to 10 irrigation pumps which are close to the transmission line and this have lowered the price of water supply to farmers by half as compared to diesel based systems used earlier. It has also facilitated effective working of medical clinics which can now use its medical aids (run by electricity) such as nebulizer effectively which were earlier lying useless. It has also facilitated free power supply to the study center which gives computer education to children and aid in developing human capital in the village.

Barriers and enablers: Biomass gasifier is a very promising technology for decentralized rural electrification as it is available in variety of small sizes, is a dispatchable system (DFID 2013), can utilize variety of biomass residues as usable biomass feedstocks and can generate additional income for the rural households who can contribute feed stock to the plant (Yadoo et al. 2012). Besides SRE, there are also few other noteworthy and successful biomass gasifier based initiatives such Husk Power mini Grids in Bihar, India which utilizes locally produced rice husks as feedstocks and sell electricity to the villagers (Palit and Sarangi 2014). The idea of biomass gasifier has been catching up in the last few years, however, there are several technical, institutional and financial barriers which impede the widespread of such initiatives. High initial costs of this technology vis a vis conventional technologies is a major barrier (Bhattacharya and Cropper 2010) and this problem aggravates with the challenge of generating finance for setting up Gasifier plants in the villages as banks consider financing in rural areas as a risky investment. Yet another challenge for this technology is the competition it faces with highly subsidized electricity for agricultural loads in rural areas, which could have been the lucrative customers for this technology. Guaranteed purchase of any surplus power from Gasifiers by electricity grid could have been a risk mitigating strategy for this technology, however, it needs dedicated and active 11 KV lines but this is not established in rural areas and even if it exists, electric utilities are hesitant in evacuating small capacity power into the grid. Sustainable supply of biomass residues is a major technical and institutional challenge for the success such technology (Palit et al. 2013) and the availability of some biomass fuels may fluctuate depending on their harvest cycle (Yadoo et al. 2012). Further, agricultural residues which is generally used as feedstock for biomass gasifier has already a great competition as cooking fuel for marginal farmers.

WEF nexus linkages: The Garkha project has great synergies with WEF nexus. As reported in MNRE 2012, the gasifier plant of Garkha has been providing reliable power to around 10 water pumps in the village at half the price as they were earlier paying (through diesel power) and this means that farmers can now do better irrigation in less cost which will further impact the food production. This shall not only impact the farmers owing these water pumps but also the other small farmers who purchase water from these water pump owners. With this electricity facility, farmers are also able to remove water from their water logged fields and using them for farm production. The 2 medical clinics in the village have also benefitted from this project as they can now easily use the much needed medical equipments such as nebulizers etc which were earlier lying useless, and they can also handle medical emergencies in the dark. Better medical services will further facilitate productivity of farmers who earlier would have lost several days in ill health without any medical services. Further, the project has also been able to incentivize farmers for growing Dhaincha (Woody shrubs) in their otherwise barren fields in Monsoon season. This shrub has a property of fixing nitrogen in the soil which decreases the requirements of fertilizers for the Rabi season crops in the same field. One another possible spillover effect of the project could be the clean cooking solution for villagers as one of the residues of Gasifier plant is the char, which can be developed into charcoal briquettes and be used by village households as clean cooking fuel. If this is realized, this shall further effect the food production as farmers can save their time from collecting fuelwood for cooking and can utilize it in their farm activities. The other possible synergies could be the harnessing of clean drinking water. In rural areas, most of the village household are dependent on handpumps for pumping drinking water and their bore pipes are generally at very shallow depths. Water at shallow depths has greater chances of water contamination, however using electricity, water can be pumped from greater depths which shall further reduce the possibility of water contamination. The project also facilitates poverty reduction the village. With the reliable power in the village, local businesses will be encouraged and this will boost local employments.

5.5 Micro-hydro plant in Siklesh village, Nepal

Implementation: With the initiation of Annapurna Conservation Area Project (ACAP), the micro-hydro plant (MHP) of maximum output power of 100 kW was built in 1994 in Siklesh village to provide electricity to 346 households. The total cost for the completion of MHP was USD 121,755 where the share of donation from project was 86 % whereas the remaining contribution was in the form of labor by community. The monthly tariff has been fixed on the basis of wattage with USD 0.007/watt of electricity.

Description of technologies or products and services*:* With the intervention of MHP, the villagers have enjoyed with multilevel benefits in terms of health, indoor air environment, education and women empowerment. The use of kerosene lanterns has been completely stopped and hence reduced the effect of indoor air pollution. Similarly, the earlier practice of using open field area as a latrine was fully controlled after electrification which has led to improve sanitary management of whole village. In the same way, the establishment of two modern agro-processing mills in a village has significantly reduced drudgery especially for women and children as they had to spend at least 9 hours to grind their crops on traditional water mill which was located quite farther from a village. Hence, their saved time has been utilized for education and agricultural activities. Moreover, the children are able to fully utilize their evening time for study in a clean environment .Similarly, by targeting women and elderly persons, the informal education training program at evening time was initiated by ACAP after electrification where major issues such as health, income-generating activities and other social problems are also discussed. Likewise, the MHP has brought a social revolution in village via establishment of communication networks such as radio, television and phone which has enabled villagers not only to make contact with their relatives, friends who are in abroad but also to get aware about many crucial issues such as using condoms to prevent sexually transmitted diseases (STD), Acquired immune deficiency syndrome (AIDS), child trafficking, social exclusion, etc.

Barriers and enablers: Even though the clear switching up to energy ladder from kerosene to electricity for lighting has been observed, however, the generated electricity have not been able to utilize to replace fuelwood for cooking. This is mainly because of lack of suitable electric appliances which has not been widely accepted even in urban areas in Nepal. Of various electric cooking appliances, rice cooker is only the device that has been extensively used in Nepal. In Siklesh village, the open access of forest to collect fuelwood and costs associated with electric ovens are observed to be main drivers which has hindered the use of electricity for cooking and heating. Apart from establishment of agro- processing mills, no other significant impact on increasing agricultural productivity has been observed in a village. Because of lack of infrastructure, market opportunity and other employment opportunities, most of the young generations have turned their priority from agriculture to migration abroad especially to golf countries in search of job. On the other hand, no motive among elderly persons to follow modern practices of agriculture by linking MHP has been reported. As a result, about half of cultivated land was abandoned in village. As the prevailing use of electricity is mainly limited for lighting of 1 to 2 hours in morning and 3 to 4 hours in evening, hence the foremost challenge of MHP in a village is to enhance the linkage of electricity with income generation activities by utilizing energy generation of remaining hours. In fact, the issue is quite common to most of the MHPs in Nepal where the average load factor is only limited to 25 to 30 % and hence these plants are commercially not viable (Sovacool et al.2011; Fulford et al. 2000). With only development motives, the MPHs are being promoted by heavily subsidized by 60 to 80 % of the total cost by aid groups. (Fulford et al.2000)

WEF nexus linkages: In Nepalese context, despite hasty development of MHP in many rural areas, the linkage of energy with end-use applications for both cooking /heating and income generating activities is extremely poor because of which the potential contribution to WEF nexus has not been fully realized in practice. The foremost reason is associated with the provision of subsidy on MHP only for the remote and inaccessible areas where no national grid exist. Hence, because of lack of infrastructure and market opportunities on those areas, the challenges are there to utilize optimum uses of electricity. Nevertheless, with the introduction of MHP in a village, some remarkable contributions to WEF nexus have been observed. For instance: the electricity at kitchen during evening time has significant benefits in terms of preparation and consumption of food because of provision of better-quality lighting as compared to kerosene lantern. Because of higher luminous flux in electric light, the management of kitchen activities has become quite convenient which especially facilitates to maintain quantity and quality of food in more effective manner. Similarly, as mentioned earlier, with the establishment of modern agricultural processing mill, the villagers have been able to engage their saved time on agricultural activities. The further potential of MHP has been observed to contribute to WEF nexus by boosting load factor with the intervention of water pumping for irrigation for higher food production. Similarly, by enabling villagers with further economic activities associated with end-use applications of electricity to adopt electric ovens, it may also reduce remarkable fuelwood consumption and thus helps to maintain water reserves by maintaining forest resources.

6. Discussion of lessons from case studies

In this paper we attempted to provide an interdisciplinary framework to evaluate the successes and failures of DES in developing countries through the lenses of WEF nexus. First, the paper couples the energy transition theory with the relatively new WEF nexus concept to assess the barriers to adoption of DES and the determinants of the success and failure of energy transition to enable the WEF security. Second, the paper explored selected DES from Africa, Asia and Latin America to offer policy lessons. In addition to the geographic coverage and the differences in cultural, tradition, institutions and other heterogeneities the case studies covers diverse technologies. This has increased the breadth of our discussion.

But there are important limitations of this study. The major limitation is lack of detail empirical data. The paper relied on secondary data sources to identify barriers or factors that hinder wider adoption DES technologies in developing countries and assess the determinants of success and failure of the initiatives with regard to energy transition and interactions with the food and water system. However, the paper could not quantitatively evaluate the actual level of impacts.

Moreover, there are complex synergies, tradeoff, and feedback effects which need to be quantified empirically to evaluate the success and failure of DES in developing countries. Thus, a more comprehensive interdisciplinary study should use detail empirical data that covers the entire life cycle of DES to evaluate the level of impacts; and assess feedbacks and drivers of DES within the context of the WEF nexus.

On the basis of our case studies key lessons were learned about the interaction of DES in relation to the WEF nexus.

Based on the analysis of the case from Chunfeng Village, it can be seen that the household-based biogas digester project plays a vital role in rural energy transition process in China. It can improve the living standard of the household not only by improving the access to affordable, clean energy sources with high quality and efficiency, but also by bringing many positive impacts on WEF nexus. However, there still exist some technical and institutional barriers for working out the potentials of the household-based biogas digester project on the WEF nexus. The most important challenge is to motivate the household to participate into the project. Trainings of the knowledge and skills regarding to operation and management of biomass digester should be provided to the household to further expand the use of biogas and ensure continued use of current biogas installations. Meanwhile, the services for maintenance are needed to be strengthened. Moreover, the long-term financial support should be offered to promote the new biogas technologies in rural areas.

Based on the Ecuadorian case study, the use of ICS have a positive effect improving working conditions for women, which has a trickledown effect on food preparation and health, nevertheless further research is required to assess the level of impact. Also, ICS has the potential to reduce fuel wood consumption and therefore deforestation which impacts water regulation. Nevertheless further research is required to understand this interlinkage. The design and technology transfer are key aspects that require special attention in planning interventions, in order to ensure technology adoption, it has demonstrated that pilot installation are more useful to encourage people participation and trustfulness. Considering the high amount of subsidies for LPG in Ecuador, new mechanism of financing should be explored to make feasible the implementation of renewable energy technologies that usually has high up-front costs.

In Bati, Ethiopia jatropha oil and seed has contributed to household income and energy substitution but there are significant challenge. The old system of jatropha production on hedge by household in the area was found not sufficient to enable “energy leapfrogging”. In addition to growing aridity, land degradation and desertification condition in Bati; this has offered an additional impetus for the community approach. However, underdevelopment of biofuel value chain attributed to incompleteness of factory or plant that processes jatropha seed to oil, lack of professional workers, and lack of stable market remained major hindrances to ‘biofuel economy’ in Bati. Nevertheless, in addition to energy security the project has directly contributed to water and land resource conservation. Amelioration of land degradation and soil erosion or ecological restoration, and water conservation directly contributes to food production and reducing reservoir siltation. Furthermore, the use of jatropha ‘by-product’ for production of ‘value adds’ products (biogas, fertilizer and soap etc.) has a great potential to contribute to wider economic development and profitability of the project. Such an integrated loop of bioeconomic and economic sector is crucially important for rural development (example, job creation), but the key role of technological innovation should not be overlooked (von Braun 2013). Besides, decentralized bioenergy, for instance creates potential opportunities when it is integrated into a loop of production system-improved efficiency or reduced waste, transportation cost and emission (Mangoyana and Smith 2011).

The analysis of Garkha, India case study shows that Biomass Gasifier technology could be an effective solution for rural electrification in India where it also has significant synergies with WEF nexus. However, there is a great need to overcome barriers associated with this technology. Sustainable biomass supply chain is one of the biggest challenges for the successful operations of this technology and there is no universal solution for the same, however it is site specific and needs local innovations & local participation as we saw in Garkha case study. Local entrepreneurship is an effective solution for the same and therefore it is needed to encourage skill and entrepreneurship development programs, so that local youths are strengthened to take up such initiatives in their areas. Combining gasifier operation with productive activities in the village such as water pumps, agro processing etc increases the viability of such initiatives. Also, for encouraging private sector or local youths to invest in this technology, government has to streamline effective financing mechanisms for this technology. Government also has to develop effective regulatory mechanisms to mitigate the risks associated with the technology such as buying back the surplus power in the grid.

In Nepalese context, despite hasty development of MHP in many rural areas, the linkage of energy with end-use applications for both cooking /heating and income generating activities is extremely poor because of which the potential contribution to WEF nexus has not been fully realized in practice. The foremost reason is associated with the provision of subsidy on MHP only for the remote and inaccessible areas where no national grid exist. Hence, because of lack of infrastructure and market opportunities on those areas, the challenges are there to utilize optimum uses of electricity. Moreover, after the operation of grinding machine with electricity obtained from micro-hydro, the use of diesel was also stopped in Nepal. As compared to thermal application for cooking, the switching of kerosene to electricity for lighting seems to be relatively stable.

Therefore, intervention measures should target building capacity of participants and stakeholders and make the initiatives reliable and sustainable. Innovative policies and actions by a wide range of stakeholders that need to deal with the cross cutting issues discussed in the case studies and scale up DES through synergizing its benefits and reducing risks within the WEF nexus perspective. These policies and actions include (Mirzabaev, et al. 2014).

Governance: Better institutional arrangements and governance in general that promote local participation, promotion of collective actions initiatives, ensure the optimal and more efficient use of scarce resources like land, water for energy and food production and to exploit the ancillary benefits and reduce side effects of decentralized energy discussed in the case studies. Policies should consider the synergistic interlink of decentralized energy with the Water-Energy-Food Nexus. These, for instance, includes but not only limited to generation of value added products, more efficient use of biomass resources (including waste), preservation of environmental resources.

Innovations: to promote local production of technology, it will require cooperation between industrialized and non-industrialized countries for technology transfer, where the private sector plays a central role. Technological innovation should be embedded into the community's socio-cultural set up, political and ecological context to create sense of ownership among all the beneficiaries (Terrapon-Pfaff et al. 2014).

Incentives: Better and efficient subsidies, tax benefits, improved infrastructure, higher market access for decentralized energy technologies

7. Conclusion and recommendations

This paper explored case studies in developing countries to identify specific underlying factors for the successes and failures of DES initiatives. We investigated the contributions of DES to the energy transition in remote villages in order to better understand how this interacts with and enables realization of the synergies of the WEF security nexus and mitigation of the trade-offs, and to identify ultimate feedback effects on societal welfare.

The paper investigated the case studies using a common conceptual framework. The case studies identified the existence of strong interlinkages of DES with WEF nexus, and thus, suggest that optimizing the positive synergies and mitigating trade-offs should consider the feedback effects on the welfare of the society. The results indicate that despite vital role of DES, the initiatives have not resulted in complete energy transition or “leapfrogging” in those communities and households still rely on multiple energy sources due to number of barriers to adoption of DES and intricate determinants of the energy transition process. Furthermore, the synergies and trade-offs of the initiatives in the WEF interlinkage are not fully realized. Nevertheless, despite the barriers to adoption of DES and their further operation, the initiatives played important role in improving energy access and contributed to sustainable rural development and improved societal welfare such as enhanced food security, income, health, women empowerment and resource conservation.

All in all, the case studies indicated that DES contributes positively to household and community livelihoods and is an integral component of the WEF nexus, of sustainable socio-economic development and poverty alleviation efforts and ecological sustainability. Therefore, successes and failures of DES depends on the enablers put in place to synergize its linkage with WEF nexus and measures to mitigate the trade-offs. Future studies using quantitative empirical data to evaluate the actual level of impacts are recommended.

Notwithstanding, the case studies identified a number of critical challenges that need to be addressed to make DES more sustainable, and in order to achieve gains that last for longer time, and to scale them up. Most often DES initiatives focus on installation of technologies but many projects face ex-post problems related to technical maintenance and costs of operation and management, and coordination problems. The analysis indicates that policy tools should consider the local specific social, institutional, economic, environmental and technological aspects and skills of the households and other role players on the value chain to enable the initiatives sustain themselves without external assistance and gradually transform themselves into self-financing businesses.

In conclusion, a coordinated and multidisciplinary approach needs to be created and implemented to support social, economic, technical and institutional innovations to make DESs sustainable and pro-poor, in managing and coordinating the linkages among, and facilitating the synergies along the WEF value chains (Villamayor-Tomas et al. 2015). We recommend further quantitative and interdisciplinary studies to more specifically estimate the level of impacts and explore the feedbacks, synergies and trade-offs within the WEF nexus framework.

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Annex

Table A3: Rural energy use patterns in developing countries by end uses (Barnes & Floor 1996)

End use	Income stage		
	Low	Medium	High
Household			
Cooking	Wood, crop residues and dung	Wood, crop residues, dung, kerosene and biogas	Wood, kerosene, biogas, LPG and coal
Lightening	Candles and kerosene (sometimes none)	Candles, kerosene and gasoline	Electricity, kerosene, gasoline
Heating	Wood, crop residues and dung (often none)	Wood, crop residues and dung	Wood, crop residues, dung and coal
Other	None	Electricity and storage cells	Electricity and storage cells
Agriculture			
Tilling	Hand	Animal	Animal, gasoline, Diesel, tractor and small power tiller
Irrigation	Hand	Animal	Diesel and electricity
Postharvest processing	Hand	Animal	Diesel and electricity
Industry			
Milling and Mechanical	Hand	Hand and animal	Hand, Animal, diesel and Electricity
Process heat	Wood and residue	Coal, charcoal, wood, and residues	Coal, charcoal, kerosene wood, and residues