Improving the energy system for a rural community in developing countries
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Summary

About two-thirds of the global population living in rural developing countries does not have access to improved energy services for cooking, lighting and powering of elementary appliances. The cooking energy demand accounts for the largest share of the demands. This demand is usually met with inefficient stoves using biomass energy derived from common resources. People in rural areas usually cook unprocessed food requiring longer cooking hours. Cooking long time with inefficient stoves demands large amounts of firewood. Beside, poor urban households who are unable to afford modern energy services also use firewood for cooking. Heavy reliance of both rural and urban households on common resources increases the scarcity of firewood. When firewood is scarce, people shift to residues and dung instead. Use of residues and dung increases soil nutrient loss and reduces crops yield. This will be a big challenge with an increasing future population unless an urgent solution is sought. Otherwise, the associated environmental and livelihood consequences will be huge.

Many efforts have been made and are still ongoing to solve the energy problems of rural developing countries. Most of these efforts were made centrally either with national or donor program initiatives. Centrally planned activities are generally not effective to address local interests, available resources and prevailing customs, so most of them were not successful to achieve their objectives. In urban areas and western countries, connecting households simply to a central grid system can be enough to solve the societal energy problems. In contrast, meeting the rural developing country’s energy demand requires better understanding of local resources, energy demands, socioeconomic and cultural conditions. Hence an integrated and comprehensive study focusing on local resources assessment and technological options matching local demands and conditions needs to be conducted. The aim of this thesis is to determine the availability of renewable energy resources and technologies matching the rural energy demands. The findings can be vital to create an insight in the effects of local resources and demands in the adoption of modern energy technologies and to devise new ways of dealing with rural energy issues.

An integrated study requires different methodological approaches and data sources. Specific studies made in this thesis use different data sources, approaches and information reported in the literature. Finding complete data from developing countries is difficult; we used country specific information typical of conditions in developing countries. Most of the energy resources data used in this study is obtained from the Ethiopian databases. Supplementary data is taken from relevant literature on other developing countries. This study considered only renewable energy resources by taking into account the environmental and affordability issues related to fossil fuels. The availability of renewable energy resources is affected by several factors attributed to natural conditions, their individual characteristics and their conversion technologies. In addition, the potential availability of biomass energy is affected by availability and
distribution of productive land resources supporting the growth of biomass. Therefore, we made a clear distinction between large and small scale potential estimations. The estimation made at large scale has employed a top-down approach using the national average while the small scale potential assessment considered specific attributes as a bottom-up approach. Further distinction is made between the heating energy for cooking and electrical energy demand to address issues concerning technological choices influenced by the energy demand variation between urban and rural populations and the strong food cultural preferences in rural areas. The studies and analyses made in specific chapters are based on different simple and robust models comprising local resources, conversion efficiencies and demands.

The results of the assessments of renewable energy resources show a huge annual exploitable electrical energy potential from solar energy, wind energy and hydroelectric energy. These renewable sources can supply enough energy to fulfill the demand and can provide a better energy mix for a reliable grid system. However, the energy carrier (electricity) is not appropriate for cooking food, since electric cooking appliances are expensive and unaffordable with subsistent farming incomes in rural areas. While renewable energy sources can fulfill energy needs at a national scale, they are not suitable for fulfilling energy needs of the rural households except lighting and some elementary services. This shows the urgent need to address the energy demand for cooking.

Up till now wood was used to supply the energy needs for cooking. Due to ongoing deforestation and scarcity households need to change to residues from agriculture (straw, manure) instead. However, both straw and manure also have a function in agriculture for soil improvement. Using them in open fire stoves will seriously affect the food production. Conversion into biogas can be efficient and helps in saving soil nutrient loss since residues can be recycled in the form of slurry. However, its production requires sufficient supply of bio-wastes. Due to large variation in resource availability between households, the large majority of the households do not have sufficient bio-wastes to produce enough biogas for their cooking. This means that even when modern, energy efficient techniques are used at a household scale the largest share of the population is not able to generate enough energy for cooking. However, when the system is analyzed from another perspective (at a community scale) a different conclusion which can bring new possibilities into perspective will appear. Hence, combining households and their resources at a village scale can provide better possibilities for using biogas system. The possibilities are realized based on the principles of sharing resources and employing co-digestion. This optimization process helps to match the available resources to the cooking demand. Nevertheless, production of enough energy for the cooking demand requires sufficient supply of feedstock, water and removal of its slurry on daily basis. Biogas production involving transportation of these resources cannot be a viable option due to its high labor costs. Sustainable and viable biogas production can be achieved when all the resources are available nearby.
In general, meeting the rural households’ cooking energy demand is very challenging. Electrical energy from renewable energy sources is not appropriate for the rural cooking condition and too expensive to afford the costs of appliances with subsistent farming income. Biogas energy is appropriate for the cooking demand, but majority of the households do not have sufficient resources to produce enough biogas at the household scale. A community biogas system can be a better alternative to meet the demand if its production is optimized and resources are available nearby. The sustainability of this system can be realized through system integration and better understanding of local socioeconomic conditions.
Samenvatting


Er is (en er wordt nog steeds) veel werk verzet om tot een oplossing te komen voor de problematiek rondom de energievoorziening op het platteland van ontwikkelingslanden. De meeste initiatieven vonden plaats op centraal niveau door ofwel nationale programma’s of donor-programma’s. Veel van de op centraal niveau ontplooiide activiteiten zijn niet in staat geweest om op een adequate manier om te gaan met lokale belangen, beschikbare bronnen en gebruiken en gewoontes, waardoor de meeste van die programma’s weinig succesvol bleken. In stedelijke gebieden en westerse landen is het oplossen van energieproblematiek vaak een kwestie van het aansluiten van huishoudens op een gecentraliseerd energienetwerk. In plattelandsgebieden van ontwikkelingslanden daarentegen vereist het voorzien in energiebehoeften meer begrip van lokale bronnen en de gedetailleerde energievraag, en van sociaaleconomische en culturele aspecten. Een uitgebreide integratieve studie rondom het samenspel van lokaal beschikbare bronnen en technologie, de lokale energievraag en de lokale situatie is noodzakelijk. Het doel van dit proefschrift is om vast te stellen wat de beschikbaarheid is van hernieuwbare energiebronnen en -technologie ten behoeve van de energievraag op het platteland. De conclusies van dit onderzoek kunnen essentieel zijn in het ontwikkelen van inzicht in de effecten van lokale bronnen en de lokale vraag op het overgaan op moderne energietechnologie en in het ontwikkelen van nieuwe manieren om met energieproblematiek op het platteland om te gaan.

Een integratief onderzoek vereist een diverse set methodes en bronnen. De onderzoeken in dit proefschrift gebruiken verschillende gegevensbronnen, benaderingen en informatie
afkomstig uit literatuur. Het vinden van complete datasets voor ontwikkelingslanden is moeilijk; vaak hebben we gebruik gemaakt van informatie over specifieke landen die typerend zijn voor de situatie in ontwikkelingslanden in het algemeen. De meeste energiegerelateerde gegevens die we in dit onderzoek gebruikt hebben, is afkomstig van Ethiopische databases. Verdere informatie is afkomstig uit literatuur rondom andere ontwikkelingslanden. Dit onderzoek beschouwt hernieuwbare energiebronnen vanuit het oogpunt van de milieuvoorwaarden en betaalbaarheid van fossiele brandstoffen. De beschikbaarheid van hernieuwbare energiebronnen is afhankelijk van verschillende factoren die samenhangen met de omgevingssituatie, de karakteristieken van de energiebron, en de conversietechnologie. De beschikbaarheid van biomassa wordt bovendien bepaald door de beschikbaarheid en verdeling van land dat geschikt is om biomassa op de verbouwen. Om die reden hebben we onderscheid gemaakt tussen schattingen voor grootschalige en kleinschalige ontwikkelingsmogelijkheden. De schatting voor grootschalige ontwikkeling maakt gebruik van een top-down aanpak op basis van een nationaal gemiddelde, terwijl voor de schatting voor kleinschalige ontwikkeling een bottom-up aanpak gevolgd wordt waarin specifieke aspecten gebruikt worden. Verder onderscheid is gemaakt tussen warmte-energie voor kookdoeleinden en elektrische energievraag. Hierbij komt aan het licht dat bepaalde keuzes met betrekking tot technologie samenhangen met de verschillen in energievraagpatroon en etniciteit tussen mensen op het platteland en stedelingen. De onderzoeken en analyses in verschillende hoofdstukken van dit proefschrift zijn gebaseerd op eenvoudige en robuuste modellen waarin lokale bronnen, conversie-efficiënties en vraagpatronen een rol spelen.

De resultaten van het onderzoek naar hernieuwbare energiebronnen laten zien dat er een enorm exploiteerbaar potentiaal aan elektrische energie beschikbaar is vanuit zonne-energie, windenergie en waterkracht. Deze hernieuwbare energiebronnen kunnen voldoende energie genereren om aan de vraag te voldoen en bieden bovendien een betere energiemix voor een betrouwbare energienetwerk. Desalniettemin is de energiedrager (elektriciteit) niet geschikt voor kookdoeleinden aangezien elektrische kooktoestellen duur zijn en niet betaald kunnen worden met inkomsten uit zelfvoorzienende landbouw in plattelandsgebieden van ontwikkelingslanden. Hoewel hernieuwbare energiebronnen kunnen voorzien in de vraag op landelijke schaal, zijn ze niet geschikt om te voldoen aan de energievraag van plattelandshuishoudens – met uitzondering van licht en enkele basisbehoeften. Dit onderstreep de noodzaak om de energievraag voor voedselbereiding aan te pakken.

Tot nu toe werd vooral brandhout gebruikt om te voorzien in de energiebehoefte voor voedselbereiding. Door verregaande ontbossing en schaarste zijn huishoudens genoodzaakt om hun toevlucht te nemen tot alternatieven zoals restmateriaal uit landbouw (stro en mest). Echter, in de landbouw hebben zowel stro als mest een functie als bodemverbeteraar. Stro en mest gebruiken om in open vuur te verbranden om op te koken heeft serieuze gevolgen voor voedselproductie. Conversie naar biogas kan efficiënt
zijn en voorkomt het verlies van nutriënten doordat overblijfselen kunnen worden gerecycled in de vorm van digestaat. Het produceren van biogas vereist echter een voldoende aanvoer van biomassa. Door de grote variatie in beschikbaarheid van grondstoffen, blijft er bij de meerderheid van de huishoudens niet voldoende biorestmateriaal over om genoeg biogas van te produceren om op te koken. Echter wanneer het systeem vanuit het perspectief van een kleinschalige gemeenschap bekeken wordt, kunnen andere conclusies getrokken worden. Het combineren van huishoudens en grondstoffen op dorpsachaal biedt betere mogelijkheden voor het gebruik van een biogassysteem. De mogelijkheden hiervoor hangen samen met principes van gedeelde grondstoffen en co-vergisting. Een optimalisatie-proces helpt om beschikbare grondstoffen en energievraag voor voedselbereiding met elkaar in balans te brengen. Desalniettemin vereist de productie van voldoende energie om te voorzien in de energievraag voor voedselbereiding een voldoende beschikbaarheid van grondstoffen, water, en dagelijkse afvoer van restmateriaal. Het produceren van biogas waarbij transport van grondstoffen noodzakelijk is, is vanwege hoge arbeidskosten geen haalbare optie. Duurzame en haalbare biogasproductie is mogelijk indien alle benodigde grondstoffen in de directe omgeving beschikbaar zijn.

Voorzien in de vraag naar energie voor voedselbereiding in plattelandshuishoudens in ontwikkelingslanden is in het algemeen een grote uitdaging. Elektrische energie uit hernieuwbare energiebronnen is slecht verenigbaar met de situatie in plattelandskeukens – en inkomens uit zelfvoorzienende landbouw zijn onvoldoende om de kosten te dekken die samenhangen met elektrisch koken. Energie uit biogas zou een geschikt alternatief zijn, maar de meerderheid van de huishoudens genereert niet voldoende grondstoffen om voldoende biogas te produceren om in hun eigen behoeften voorzien. Als de productie van biogas kan worden geoptimiseerd en de benodigde grondstoffen zijn dichtbij voorhanden, dan kan een gemeenschappelijk biogassysteem een beter alternatief zijn. De duurzaamheid van een dergelijk systeem kan worden gerealiseerd door integratie van het hele systeem en een beter begrip van de lokale socio-economische situatie.
Acknowledgments

My journey began in 2007 when I joined the Center for Energy and Environmental sciences (IVEM) for my master study winning the Eric Bluemink Fund (EBF). It was my first time to go abroad which seems challenging to adapt. However, adaptation to the environment did not take me long time, thanks to my Dutch classmates. Rather, I was very eager to explore something related to my career. Basically, most of the courses are multidisciplinary in their nature; however, energy related topics attracted me most as they are new for me. That paved me ground to consider renewable energy for my master thesis. Luckily, I conducted my training thesis study on energy related topic under the supervision of Sanderine. During this time Sanderine helped me to learn how to think critically, develop self-confidence and believe in myself. Hence, I had wonderful time to develop my research skill and explore any opportunity for further study. Even though, I did my master’s thesis at medical faculty, I was very eager to come back to IVEM and continue working with Sanderine. Ton Schoot Uiterkamp was my second adviser who always was encouraging, showing me direction and advising me how to realize my dream. However, I was not successful to continue my PhD at that time due to financial constraints, so I came back home sadly but not without hope. I continued discussing with Sanderine on the potential research topics but finding finance for the project remained an issue. Almost after two years we were to give-up, but I got a chance of communicating with Peter Weesie through Sanderine. Thanks for both of them; they invited me to IVEM to start working on my PhD as a Sandwich scheme based on financial means from the department. This gave me a privilege to stay some months at IVEM every year and much of the time at my home University in Ethiopia. Working at distant without adviser is very challenging but leaving family and children is more challenging for me. So, it was cost and balance to adjust myself and manage my work. Sanderine you are not only my academic adviser but also a great person who helped me a lot to overcome such conditions. Without you my dream cannot be realized. I could not find words to express what you deserve for your kind helps rather than simply sayings thank you.

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About the author

Gudina Terefe Tucho was born in Gidami, Ethiopia in 1977. He did his bachelor study in Jimma University, Ethiopia in environmental health Sciences and graduated in July 2006. In August 2006 he employed at the department of environmental health sciences and technology as a technical assistant. During this time he assisted senior staffs of the department in the teaching-learning processes when he inspired for further education. Being at the University was a privilege for him to get access to internet services and able to explore opportunity for further studies. Luckily, he got admission in 2007 for master’s study at department of Energy and environmental sciences (IVEM) of the University of Groningen with the scholarship from Eric Bluemink and graduated in August 2009. During this time, he learned several courses related to energy system analysis, environmental and natural resources management and sustainability studies. However, energy related courses attracted him most since they are new for him. These courses equipped him to continue with his PhD on energy related topic. However, he could not directly continue his PhD at that time due to unavailability of funding for his project. Then, he came back to Jimma University and reinstated to a lecturer position at his department and served for two years while looking for any funding opportunity for his PhD. However, he could not successful in finding fund for his project. Thanks to Sanderine, Peter Weesie and IVEM he started his PhD project in 2011 with the financial support from IVEM. His project focuses on renewable energy resources assessments, conversion and supply in rural developing countries with special emphasis on biogas and solar energy technologies. During the course of his project, he has able to develop substantial skills on scientific writing processes, confidence and experiences of designing and conducting independent research. This enables him to publish some of his PhD projects on international peer reviewed Journals. Currently, he is working at department of Environmental health sciences and technology in Jimma University.

During his PhD project, he attended some international summer school short term training courses. In 2012 he attended European International Relations Summer School: World Society & Energy Transition from July 9-20 in Groningen; organized by Globalization studies Groningen and other organizers of the European International Relations Summer School 2012. In the same year, he attended a PhD course on renewable energy in developing countries from June 19-21, 2012 at Enschede in The Netherlands; organized by research school for socio-economic and natural sciences of the environment (SENSE).

Publications during the PhD project

1. Gudina Terefe Tucho and Sanderine Nonhebel; 2016. Alternative energy supply system to rural village in Africa. Under review in Renewable and Sustainable Energy Reviews
