Bioenergy, development and food security in Sub-Saharan Africa:

Pathways towards a more sustainable energy provision in Western Tanzanian settlements

Dissertation
zur Erlangung des akademischen Grades
Doctor of Philosophy (Ph.D.)

eingereicht an der
Lebenswissenschaftlichen Fakultät der
Humboldt-Universität zu Berlin

von
Dipl.-Geogr. Harry Konrad Hoffmann

Präsident der Humboldt-Universität zu Berlin
Prof. Dr. Jan-Hendrik Olbertz

Dekan der Lebenswissenschaftlichen Fakultät
der Humboldt-Universität zu Berlin
Prof. Dr. Richard Lucius

Gutachter/innen
1. Prof. Dr. Klaus Müller (Humboldt-Universität zu Berlin)
2. Prof. Dr. Bettina Matzdorf (Leibniz Universität Hannover)
3. Prof. Dr. Ulrike Grote (Leibniz Universität Hannover)

Tag der mündlichen Prüfung: 17.12.2015

Bioenergy, development and food security in Sub-Saharan Africa: Pathways towards a more sustainable energy provision in Western Tanzanian settlements

PhD thesis submitted by Harry Hoffmann

Contents

I Acknowledgements

The completion of this thesis would not have been possible without the substantial support of a number of individuals and institutions, which helped me to cope with the challenges of a PhD thesis – financially, scientifically and emotionally.

Outstanding in the latter regard are especially my partner Sarah but also my sister Heike, my parents, Helga and Volker, and my grandparents, Erika and Fritz, who always believed that I would be able to finish this project – even at times when I myself was not convinced any more. My grandmother Käthe Lüth would of course also have also been included here if she could have been with us ...

Scientifically, I would like to thank especially Dr. Götz Uckert ("Dr. Gotz"), Dr. Constance Reif ("Pippi Glitzerstaub"), Dr. Stefan Sieber ("Kaleun"), Dr. Frieder Graef and Prof. Klaus Müller for their patient explanations and their guidance into the world of peer-reviewed publishing: Thank you for helping me to find my way out of the countless dead ends. Additionally, I would like to thank Prof. Bettina Matzdorf and Prof. Ulrike Grote for their expert opinion on my thesis, Dr. Emil Gevorgyan for participating in the PhD commission and all anonymous reviewers working hard to improve the quality of my papers.

Furthermore, my gratitude goes explicitly to Dr. Stefan Sieber and the Leibniz-Centre for Agricultural Landscape Research (ZALF) e.V. for supplying me with financial resources over the years, in the form of a working position and a scholarship. I am particularly grateful for this as I witnessed the struggles of fellow PhD candidates at other institutions and know that the financial support I was able to benefit from (including my research stay at IFPRI) is way above average standards. Indirectly, however, this gratitude also encompasses the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economic Cooperation and Development (BMZ) as funding institutions for the projects Trans-SEC and Better-iS.

In addition, I would like to thank the inhabitants of Laela, Illagala and Kagongo for their patient co-operation and for helping the "Mzungus" to understand their world. Furthermore, this thesis would not have been possible without Ewald Emil Gervas, then the coordinator of Better-iS for ICRAF, as well as Theresia, Prisca, Julius, Phillip, George, Jimmy and Anton, all supporting data collection as enumerators or drivers. Thank you for all the fun!

II Abbreviations

CDM: Clean Development Mechanism
COSTECH: Tanzanian Commission for Science and Technology
DRC: Democratic Republic of Congo
FAO: Food and Agriculture Organization of the United Nations
FELISA: Farming for Energy for better Livelihoods in Southern Africa
FGI: Focus group interview
GACC: Global Alliance for Clean Cookstoves
HIV/AIDS: Human immunodeficiency virus/Acquired immunodeficiency syndrome
HP: Horsepower
ICRAF: World Agroforestry Centre
IC: Income class
ICS: Improved cooking stoves
IEA: International Energy Agency
LPG: Liquefied petroleum gas
MDGS: Millennium Development Goals
MFP: Multi-functional platform
RUDEP: Rukwa Integrated Rural Development Programme
SDG: Sustainable Development Goals
SE4ALL: Sustainable Energy for All
SSA: Sub-Saharan Africa
SVO: Straight vegetable oil
TANESCO: Tanzania Electric Supply Company Limited
TATEDO: Tanzania Traditional Energy Development Organization
TCS: Traditional charcoal stoves
TSF: Three-stone fires
TSH: Tanzanian Shilling
UNHCR: Office of the United Nations High Commissioner for Refugees
WHO: World Health Organization

III List of figures

IV Summary

This PhD thesis provides a detailed analysis of the traditional and modern bioenergy situations in case study villages in rural Tanzania. It adds to the current literature, as it provides (1) a detailed understanding of how to enhance and sustain traditional bioenergy production and consumption in terms of resource capacity and overall sustainability. Furthermore, (2) it adds to the understanding of the potentials and effects of straight vegetable oil (SVO) usage as an electrification option. The dissertation (3) provides insights on how traditional and modern bioenergy consumption affects food security of rural populations. Last – but not least – (4) I derive overall conclusions and policy recommendations for sustainable energy production and consumption. Therefore, this PhD thesis is comprised of three peer-reviewed papers that have already been published and one paper currently under peer revision. The papers mainly focus on the energy situation in a major case study village, the Tanzanian settlement Laela in the Rukwa region (paper 1, 2 & 3), and in addition two minor case study villages, the Tanzanian villages Illagala and Kagongo, in the Kigoma region (paper 4) are also included. The author of this thesis is first author of publications 1, 2 and 3 and co-author of paper 4.

All case study villages are located in Western Tanzania. To cover a substantial part of the existing energy portfolio, the analysis is subdivided, targeting traditional as well as modern bioenergy. This analytical approach is followed in the state of the art research section (*chapter 2*) and also in the clustering of the published papers. Both have thematic introductions and conclusions (*chapters 5 & 6*).

After a brief introduction of the global aspects and lines of discussion concerning the topic (*chapter 1*), the latest research approaches focussing on both subdivisions individually are presented in two subchapters (*chapter 2*). Here, the latest literature findings are outlined, discussed and compared to other data. Major aspects of the literature on the traditional and modern bioenergy situation in developing countries and particularly Sub-Saharan Africa (SSA) are specifically addressed to allow the reader to gain better understanding and to put the published papers into overall perspective. The methods used to assess the objectives of this thesis are subsequently outlined (*chapter 3*). The case study sites are also displayed in detail as due to space limitations some crucial aspects could only be briefly touched upon in the peer-reviewed papers (*chapter 4*). Additional insights are provided for the societal background and the food security situation in the respective case study villages.

After these initial sections to frame the wider context and to set the stage for the published papers, the latter are individually presented based on the “Energy ladder” and “Energy stack” hypothesis exemplified by van der Kroon et al. (2013) – this hypothesis is elaborated in more detail in the introduction (*chapter 1*).

The first paper (*chapter 5.2*) focusses on traditional bioenergy consumption and, based upon calculated scenarios, presents the outcomes of the introduction of firewood-efficient stoves in the case study village of Laela. Different diffusion assumptions are applied. A major result is that there is potential for firewood savings and a specific focus should be on low-income households as these are specifically the users of firewood.

The second paper (*chapter 5.3*) analyses the effects of a simulated introduction of efficient kilns in the case study village of Laela because the currently applied charcoal production methods are characterised as highly wasteful in terms of resources. Additionally, the potential introduction of efficient stoves as already presented in paper 1 is included. A major result is that efforts are urgently needed to increase the efficiency of charcoal production but that a combination of efficiency enhancements on the production and consumption sides of traditional bioenergy seems to be the most promising option. However, in order to transform the whole traditional bioenergy sector towards sustainability, immediate, well designed, and ambitious policy frameworks are required. The respective current political incidents are outlined and discussed in detail in the overall policy recommendations of this thesis (*chapter 8*).

After these analyses of scenarios concerning traditional energy production and consumption, the third paper outlines modern energy potentials, analysed and discussed for the case study village of Laela (*chapter 6.2*). The focus of these scenario designs is on the consumption of locally produced straight vegetable oils (sunflower and groundnut) for the combustion in locally used generators to produce electricity. Based on different income classes, it is concluded that, although a substitution of fossil fuels is possible to a certain level, the negative effects on food security, particularly for lower income classes, are substantial.

Correspondingly, the fourth paper (*chapter 6.3*) focusses specifically on the increase of palm oil production as a theoretical bioenergy option in the case study village of Kagongo and Illagala in the Kigoma region. Current production is suboptimal because of a variety of different hurdles such as inefficient processing technologies and inadequate planting density, strategies to increase production are outlined. Hypothetical indirect energy connections exist since palm oil is an optimal fossil fuel replacement, which is also specifically addressed by the Tanzanian government in the national biofuel guidelines (Government of Tanzania 2010).

The results of the individual papers are subsequently conflated in an overall conclusion, especially against the classification as traditional or modern fuel (*chapter 7*). The thesis ends with policy recommendations (*chapter 8*) based on the papers already published, recent developments such as the revision of the national energy policy in Tanzania (Government of Tanzania 2015) and expert interviews conducted in early 2015. The final recommendation is that the prevalence and use of improved cooking stoves needs to be increased substantially while simultaneously a number of policy measures that foster the access and availability of reliable, affordable and sustainable traditional as well as modern energy should be implemented. Furthermore, improved policy measures such as a carefully designed decriminalisation of production are also needed to allow the establishment of a more efficient charcoal value chain that focusses particularly on aspects of long-term sustainability and increased share of benefits for charcoal producers.

V Zusammenfassung

Diese Arbeit zur Erlangung des Doktorgrades (PhD) legt eine detaillierte Analyse der Situation von traditioneller und moderner Bioenergie anhand von tansanischen Dörfern, welche als Fallbeispiele dienen, vor. Sie erweitert die bisher publizierten Forschungsergebnisse, da sie (1) detailliert analysiert, wie die Produktion und die Nutzung traditioneller Bioenergie in Bezug auf Ressourcenkapazität und allgemeine Nachhaltigkeit verbessert und verstetigt werden können. Weiterhin (2) erweitert sie das Verständnis der Potentiale und Effekte der Nutzung nativer Pflanzenöle als Elektrifizierungsoption. Diese Dissertation (3) ermöglicht Einblicke, wie traditionelle und moderne Bioenergienutzung mit der Ernährungssicherheit ländlicher Bevölkerungsgruppen verknüpft ist. Nicht zuletzt (4) leite ich allgemeine Schlussfolgerungen und politische Handlungsempfehlungen für nachhaltige Energieproduktion und Energienutzung ab. Die vorliegende Dissertation besteht aus drei Artikeln, die in Blindgutachten wissenschaftlich bewertet (peer-reviewed) und anschließend publiziert wurden sowie einem Artikel, der zur Begutachtung im Blindgutachten akzeptiert wurde. Der Fokus der Arbeit liegt hauptsächlich auf der energetischen Situation in einem Fallbeispiel-Dorf, Laela in der tansanischen Region Rukwa (Artikel 1, 2 & 3), beinhaltet aber auch die entsprechende Analyse von zwei Dörfern als sekundäre Fallbeispiele, Illagalla und Kakongo in der tansanischen Region Kigoma (Artikel 4). Der Autor dieser Arbeit ist Hauptautor der Artikel 1, 2 und 3 sowie Mitautor Artikels 4. Sämtliche Dörfer, die als Fallbeispiele dienen, liegen im Westen Tansanias. Um eine fundierte Analyse zu gewährleisten, welche substantielle Teile des Energie-Portfolios einschließt, wurden Untersektionen gebildet, welche die Untersuchung traditioneller beziehungsweise moderner Bioenergie zum Gegenstand haben. Dieser analytische Rahmen spiegelt sich in der Übersicht der aktuellen Fachliteratur (*Kapitel 2*) aber auch in der spezifischen Gruppierung der publizierten Artikel wider. Die Untersektionen beinhalten sowohl eine thematische Einleitung als auch eine Zusammenfassung (*Kapitel 5 & 6*).

Nach einer kurzen Einleitung in die globalen Aspekte und Diskussionslinien des Themas (*Kapitel 1*) wird der aktuelle Stand der Forschung mit Fokus auf die Untersektionen in eigenen Unterkapiteln präsentiert (*Kapitel 2*). Hierbei wird die aktuelle Literatur zusammengefasst, diskutiert und mit anderen Angaben verglichen. Auf wesentliche Aspekte der wissenschaftlichen Diskussion bezüglich der Situation von traditioneller und moderner Bioenergie in Entwicklungsländern und besonders Afrikas südlich der Sahara wird spezifisch eingegangen, damit der Leser ein substantielles Verständnis entwickeln und die publizierten Artikel in ihren jeweiligen Kontext einordnen kann. Ebenfalls werden die angewandten Methoden, mit deren Hilfe die zentralen Fragestellungen dieser Arbeit beantwortet werden, dargestellt (*Kapitel 3*). Im Folgenden werden auch die Fallbeispiel-Dörfer im Detail beschrieben, da einige elementare

Aspekte durch die begrenzte Zeilenanzahl in den publizierten Artikeln nur skizziert werden konnten (*Kapitel 4*). Zusätzlich werden Informationen z.B. über den sozialen Hintergrund sowie die Situation der Ernährungssicherheit für die entsprechenden Orte geliefert. Nach diesen einleitenden Kapiteln, die den weiteren Kontext der vorliegenden Arbeit umreißen und die Bühne für die publizierten Artikel bereiten, werden letztere auf Basis des Ordnungssystems der „Energy ladder" und „Energy stack" Hypothesen präsentiert, welche van der Kroon et al. (2013) beispielhaft vorstellten. Dieses Ordnungssystem ist in der Einleitung genauer ausgearbeitet (*Kapitel 1*).

Der erste Artikel (*Kapitel 5.2*) konzentriert sich auf die Nutzung traditioneller Bioenergie und präsentiert, basierend auf berechneten Szenarien, die Auswirkungen der Einführung effizienter Feuerholz-Kocher in dem Fallbeispiel-Dorf Laela. Hierbei werden verschiedene Diffusionsszenarien angewandt. Ein zentrales Ergebnis ist, dass tatsächlich ein Potential für Feuerholzeinsparungen vorhanden ist. Hierbei sollte aber ein spezifischer Fokus auf einkommensschwache Haushalte gelegt werden, da insbesondere diese die Nutzer von Feuerholz sind.

Der zweite Artikel (*Kapitel 5.3*) analysiert die Effekte einer simulierten Einführung von effizienten Holzkohlemeilern in dem Fallbeispiel-Dorf Laela, da die dort derzeit angewandten Produktionsmethoden von Holzkohle als sehr ressourcenverschwendend charakterisiert werden. Zusätzlich wird die potentielle Einführung effizienter Kocher wie bereits in Artikel 1 präsentiert in die Berechnungen einbezogen. Ein Hauptergebnis ist, dass verstärkte Anstrengungen nötig sind, um die Effizienz der Holzkohleproduktion zu erhöhen. Hierbei scheint aber eine Kombination aus Effizienzsteigerungen sowohl auf der Seite der Produktion als auch auf der Seite der Nutzung von traditioneller Bioenergie in diesem Kontext die vielversprechendste Option zu sein. Um den kompletten Sektor der traditionellen Bioenergie nachhaltiger zu gestalten, werden allerdings sofortige, gut durchdachte und ambitionierte politische Rahmenbedingungen benötigt. Entsprechende aktuelle Ereignisse werden in den politischen Handlungsempfehlungen dieser Arbeit (*Kapitel 8*) dargestellt und diskutiert.

Nach dieser Szenario-Analyse mit Blick auf Produktion und Nutzung traditioneller Bioenergie werden mit dem dritten Artikel die Potentiale von moderner Bioenergie für das Fallbeispiel-Dorf Laela aufgezeigt, analysiert und diskutiert (*Kapitel 6.2*). Der Fokus dieser Szenarien liegt auf der Nutzung von lokal produzierten nativen Pflanzenölen (Sonnenblume und Erdnuss) für die Verbrennung in lokal betriebenen Generatoren zum Zwecke der Stromerzeugung. Basierend auf einem Analyseraster von Einkommensklassen wird die Schlussfolgerung gezogen, dass die negativen Effekte auf Ernährungssicherheit besonders für einkommensschwache Gruppen substantiell sind, obwohl eine Substitution von fossilen Kraftstoffen in einem gewissen Rahmen möglich ist.

Dementsprechend konzentriert sich der vierte Artikel (*Kapitel 6.3*) im Detail auf die Produktionssteigerung von Palmöl als theoretische Bioenergieoption in den Fallbeispiel-Dörfern Kagongo und Illagalla in der Region Kigoma. Die momentan erreichte Produktion ist aufgrund zahlreicher Hürden wie beispielsweise ineffizienten Verarbeitungsprozessen und nicht angepasster Pflanzdichte suboptimal; Strategien zur Produktionssteigerung werden dargelegt. Eine hypothetische indirekte Verbindung besteht nichtsdestotrotz, da Palmöl ein optimaler Ersatzstoff für fossile Kraftstoffe ist, der spezifisch in der nationalen Tansanischen Biokraftstoffrichtlinie thematisiert wird (Government of Tanzania 2010).

Sowohl die Ergebnisse der einzelnen Artikel als auch die der jeweiligen Untersektionen (traditionelle und moderne Bioenergie) werden anschließend in einer gemeinsamen Schlussfolgerung zusammengefasst (*Kapitel 7*). Die vorliegende Arbeit wird durch ein detailliertes Kapitel zu politischen Handlungsempfehlungen abgeschlossen (*Kapitel 8*), welche auf den bereits publizierten Artikeln, aber auch auf aktuellen politischen Entwicklungen wie der Revision der nationalen politischen Energierichtlinie Tansanias (Government of Tanzania 2015) und Experteninterviews beruhen, die im April 2015 durchgeführt wurden. Die zentrale Handlungsempfehlung ist, dass die Verbreitung und Nutzung von energieeffizienten Kochern substantiell erhöht werden muss. Hierbei sind parallel eine Reihe von politischen Maßnahmen zu ergreifen, welche den sowohl Zugang zu als auch die Verfügbarkeit von zuverlässiger, erschwinglicher und nachhaltiger traditioneller sowie moderner Energie begünstigen. Zudem sind diverse politischer Maßnahmen wie die Entkriminalisierung der Holzkohleproduktion notwendig. Diese sollten die Ausgestaltung einer effizienteren Wertschöpfungskette von Holzkohle ermöglichen und explizit auf langfristige Nachhaltigkeit sowie einen erhöhten finanziellen Gewinn für die Erzeuger abzielen.

VI List of publications

This dissertation is based on the following four peer-reviewed papers either published in the journal "*Regional Environmental Change*" (2014 Impact Factor (IF): 2.628) – paper 1, 3 & 4 – or accepted for review in the journal "*Food Security*" (2014 Impact Factor (IF): 1.495) – paper 2. The following numbering reflects the order of the papers presented in this thesis:

Paper 1: **Hoffmann, H.**, Uckert, G., Reif, C., Müller, K., Sieber, S. (2014): Traditional biomass energy consumption and the potential introduction of firewood efficient stoves: insights from western Tanzania. In: *Regional Environmental Change* 15: 1191–1201. doi: 10.1007/s10113-014-0738-1

Paper 2: **Hoffmann, H.**, Uckert, G., Reif, C., Graef, F., Sieber, S. (2015): Efficiency scenarios of charcoal production and consumption - a village case study from Western Tanzania. Paper accepted for review in *Food Security*.

Paper 3: **Hoffmann, H.**, Uckert, G., Reif, C., Graef, F., Sieber, S. (2015): Local biofuel production for rural electrification potentially promotes development but threatens food security in Laela, Western Tanzania. In: *Regional Environmental Change* 15: 1181–1190. doi: 10.1007/s10113-014-0596-x

Paper 4: Uckert, G., **Hoffmann, H.**, Graef, F., Grundmann, P., Sieber, S. (2015): Increase without spatial extension: productivity in small-scale palm oil production in Africa - the case of Kigoma, Tanzania. In: *Regional Environmental Change* 15: 1229–1241. doi: 10.1007/s10113-015-0798-x

Additional peer-reviewed publications co-authored in the course of this PhD project:

Graef, F.; Schneider, I.; Fasse, A.; Germer, J.U.; Gevorgyan, E.; Haule, F.; **Hoffmann, H.**; Kahimba, F.C.; Kashaga, L.; Kissoly, L.; Lambert, C.; Lana, M.; Mahoo, H.F.; Makoko, B.; Mbaga, S.H.; Mmbughu, A.; Mkangwa, S.; Mrosso, L.; Mutabazi, K.D.; Mwinuka, L.; Ngazi, H.; Nkonya, E.; Said, S.; Schaffert, A.; Schäfer, M.P.; Schindler, J.; Sieber, S.; Swamila, M.; Welp, H.M.; William, L.; Yustas, Y.M. (2015): Assessment of upgrading strategies to improve regional food systems in Tanzania: Food processing, waste management and bioenergy, and income generation. In: *Outlook on Agriculture* 44: 179–186. doi: 10.5367/oa.2015.0209

Graef, F., Sieber, S., Mutabazi, K., Asch, F., Biesalski, H. K., Bitegeko, J., Bokelmann, W., Bruentrup, M., Dietrich, O., Elly, N., Fasse, A., Germer, J. U., Grote, U., Herrmann, L., Herrmann, R., **Hoffmann, H.**, Kahimba, F. C., Kaufmann, B., Kersebaum, K. C., Kilembe, C., Kimaro, A., Kinabo, J., König, B., König,

H., Lana, M., Levy, C., Lyimo-Macha, J., Makoko, B., Mazoko, G., Mbaga, S. H., Mbogoro, W., Milling, H., Mtambo, K., Mueller, J., Mueller, C., Mueller, K., Nkonja, E., Reif, C., Ringler, C., Ruvuga, S., Schaefer, M., Sikira, A., Silayo, V., Stahr, K., Swai, E., Tumbo, S., Uckert, G. (2015): Natural resource management and crop production strategies to improve regional food systems in Tanzania. In: *Outlook on Agriculture* 44: 159–167. doi: 10.5367/oa.2015.0206

Graef, F., Sieber, S., Mutabazi, K., Asch, F., Biesalski, H. K., Bitegeko, J., Bokelmann, W., Bruentrup, M., Dietrich, O., Elly, N., Fasse, A., Germer, J. U., Grote, U., Herrmann, L., Herrmann, R., **Hoffmann, H.**, Kahimba, F. C., Kaufmann, B., Kersebaum, K. C., Kilembe, C., Kimaro, A., Kinabo, J., König, B., König, H., Lana, M., Levy, C., Lyimo-Macha, J., Makoko, B., Mazoko, G., Mbaga, S. H., Mbogoro, W., Milling, H., Mtambo, K., Mueller, J., Mueller, C., Mueller, K., Nkonja, E., Reif, C., Ringler, C., Ruvuga, S., Schaefer, M., Sikira, A., Silayo, V., Stahr, K., Swai, E., Tumbo, S., Uckert, G. (2014): Framework for participatory food security research in rural food value chains. In: *Global Food Security* 3: 8–15. doi: 10.1016/j.gfs.2014.01.001

Additional non-peer-reviewed publications authored in the course of this PhD project:

Hoffmann, H. (accepted): Energieeffiziente Kocher. In: Bauriedl, S. (Ed.): Wörterbuch Klimadebatte. Transcript, Bielefeld, Germany.

Hoffmann, H. (accepted): What to cook with? Firewood, charcoal and the problems of sustainable cooking energy provision in rural Sub-Saharan Africa and Tanzania. In: Geography Review.

Hoffmann, H. & Uckert, G. (accepted): „Bio"kraftstoffe als nachhaltige Alternative zu fossilen Brennstoffen?!? Globale Rahmenbedingungen und lokale Produktion in Tansania. In: Verhandlungen mit der Gegenwart Bd. 4. Oldenburg, Germany.

Hoffmann, H. & Uckert, G. (2014): Die UN-Initiative ›Nachhaltige Energie für alle‹ Entstehung, Einordnung und Aussichten. In: Vereinte Nationen 03/2014, 119–124.

Hoffmann, H. & Diehl, D. (2014): Farmer-to-farmer knowledge exchange. In: Rural 21 Volume 48, 28–29.

Hoffmann, H., Uckert, G., Rordorf, J. & Sieber, S. (2012): Sunflower for horsepower – potentials of locally embedded biofuel production and consumption in Laela, Western Tanzania. In: Proceedings of the 10th IFSA Conference 2012, Aarhus, Denmark.

Hoffmann, H. & Uckert, G. (2010): Development and adjustment of sustainability indicators for evaluation of outgrower schemes in bioenergy production: The case of Tanzania. In: Proceedings der 9th IFSA Conference 2010, Vienna, Austria.

1 Introduction

In recent decades, energy and energy access have not been in the focus of either international development agencies or national political decision makers in Sub-Saharan Africa (SSA) (Bailis 2015) – R. Pachauri[1] even labelled energy as "*missing* [Millennium Development Goal] *MDG*" (Williams 2009). However, while access to and use of particularly electricity has recently gained momentum (Bazilian et al. 2012), other similar approaches towards energy – especially for cooking – did not arrest significant attention when compared to other development topics such as malaria or HIV/Aids (Human immunodeficiency virus/Acquired immunodeficiency syndrome) (Kees and Feldmann 2011). A major reason for this is that cooking fuel supply was not part of the "*Food Security Equation*" in the past (Makungwa et al. 2013; p. 49). Nevertheless, energy is essential for human well-being: "*Energy sufficiency and security is a key to development and prosperity since it provides essential inputs for socio-economic development at regional, national and sub-national levels*" (Amigun et al. 2011; p. 1361).

In the recent past, the overall situation for both energy production and consumption pathways has nevertheless been changing as respective strategies, in particular for electricity access, are increasingly implemented in national policies as (high ranking) goals (Sokona et al. 2012). Furthermore, recently launched global initiatives such as "Sustainable Energy for All" (SE4All) (Hoffmann and Uckert 2014) and "Global Alliance for Clean Cookstoves" (GACC) (GACC 2015) focus on policy development, international exchange and public awareness of these complex sectors. However, contradictory evidence also exists, indicating that for example in the charcoal sector – being a major cooking energy source predominantly in urban areas of SSA (Bailis et al. 2005) – political attention is still widely absent (Zulu and Richardson2013). Nevertheless and in sum, there is increasing awareness in politics and sciences (Bugaje 2006) that the provision of reliable, secure and affordable energy services was, is and will remain a backbone for global (sustainable) development as it is – often as an underlying factor – closely associated with poverty, inequality, climate change, food security, education and migration. Policy makers, development practitioners and investors alike start perceiving energy availability as being closely associated with the economic and social progress of a society (Lahimer et al. 2013, Ahlborg and Hammar 2014, Bazilian et al. 2012). Energy access is an essential prerequisite for sustainable development in particular in the global South (Amigun et al. 2011).

1 Prof. Rajendra Pachauri, Nobel Peace Prize winner and Chairman of the United Nations' Intergovernmental Panel on Climate Change (IPCC)

The necessity of secure and reliable energy access is demonstrated by any present-day democratic governmental system, which could not function without it, especially electricity. Another one is the establishment and successful operation of competitive production facilities, which is hardly maintainable without access to modern energy services (Brew-Hammond 2007). A third one is that successful schooling and education of children, in particular girls, is substantially hindered if working capacity has to be channelled into (ever increasing) fuelwood collection (Mohammed et al. 2015, van der Kroon et al. 2013, Urmee and Gyamfi 2014) and that the negative effects of indoor air pollution result in a further weakening of social sustainability (WHO 2006, Bailis et al. 2009, Lim et al. 2012, Smith K.R. et al. 2004, Msuya et al. 2011).

The current interdependency of society and energy in developing countries can be outlined in two pathways: On the one hand, the so-called "traditional (bio)energy" or "traditional fuels" pathway, consisting in the given context mainly of firewood and charcoal but also crop residues and dung (Kaygusuz 2011). On the other hand, there is the "modern (bio)energy" pathway, which consists particularly of those energy services that are *"clean, efficient and reliable"* (Johnson 2013; p. 2) – especially and foremost electricity. The sustainability of energy production and consumption is in each case likely to depend on the local context, be it for electricity that may, for example, be inefficient and often dysfunctional when based on centralised fossil diesel fuel consumption for whole settlements like in Mpanda and Kigoma (Bertheau et al. 2014) or, as another example, solar home systems[2]. For traditional biomass it can be, for example, uncontrolled depletion of forest resources resulting in deforestation (Faße and Grote 2013, Msuya et al. 2011) or else sustainable agroforestry systems (Iiyama et al. 2014). Characteristics of traditional energy use depend on the energy carrier but are predominatly associated

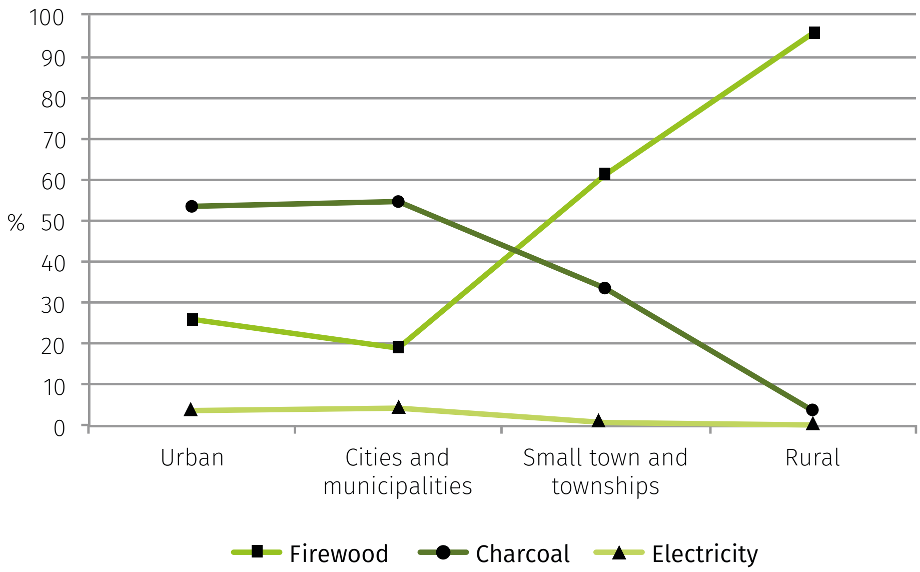

Figure 1 Energy use for cooking in large and small urban centres (based on Muzzini and Lindeboom (2008))

2 Cf. Pöppl (2014)

with cooking purposes in rural areas (mainly firewood) but also in urban and peri-urban regions (mainly charcoal) as examplified in figure 1, based on data published by Muzzini and Lindeboom (2008)[3].

These traditional fuels are often classified and defined as either "woodfuel" ("*Fuel from wood sources including solids (fuelwood and charcoal), liquids (black liquor, methanol, and pyrolitic oil) and gases from the gasification of these fuels*" (Food and Agriculture Organization of the United Nations (FAO) 2008; p. 52)) or "fuelwood" ("*Wood in the rough (such as chips, sawdust and pellets) used for energy generation*" (FAO 2008; p. 50)). Other authors, however, argue for a clearer separation, especially in "firewood" and "charcoal" as key elements of addressing the prevalent cooking energy crisis in SSA (Mwampamba et al. 2013). Availability of modern energy services is a prerequisite for economic growth and productivity but also essential for, e.g., health or educational services (cooling of drugs, lighting of schools) and often associated with urban and peri-urban areas as major economic and political centres in developing countries (Denton 2004), at least if the focus is grid-connections. However, there is also significant potential for the development of micro-grid, mini-grid and off-grid solutions (Johnson and Bryden 2012).

In addition to geographical separation, income levels of users have also been reported to affect patterns of energy usage (Mohammed et al. 2015). In which way, however, is under discussion. One approach postulates that an increase in income is associated with climbing the "energy ladder" – a concept outlined by Hosier and Dowd (1987) – from dung to electricity. This concept is empirically confirmed by Arnold et al. (2006; p. 599), among others, who point out that economic literature includes some multivariate econometric analyses "*validating the energy ladder hypothesis*". Masera et al. (2000) and Johnson and Bryden (2012), on the contrary, report a "fuel stacking" phenomenon – a simultaneous use of multiple energy sources including traditional ones whereby households with higher incomes have access to a higher diversity of energy sources. The latter concept therefore rejects the clear differentiation of the energy ladder hypothesis. An overview of literature and comparison between the two approaches is given for example by van der Kroon et al. (2013).

In any case, the availability of and access to traditional bioenergy is essential for food security as cooking energy scarcity is associated with reduced nutritional intake (Kees and Feldmann 2011, Brouwer et al. 1996b, Brouwer et al. 1996a, Hartter and Boston 2007, Makungwa et al. 2013). Furthermore, the production of charcoal in rural areas for consumption in urban areas is a significant income strategy (Maes and Verbist 2012, Peter and Sander 2009, Mohammed et al. 2015, Butz 2013).

Some researchers highlight that energy access, including modern as well as traditional energy sources, does not only urgently need to be scaled up to support the livelihoods of billions in the global South, but also need to be increasingly coupled to the climate agenda, to programs supporting particularly rural development as well as to management strategies for urban and peri-urban areas in the rapidly expanding megacities (Johnson and Lambe 2009).

3 Data extracted from the agricultural census 2003/2003

In summary, it is becoming evident that energy research in SSA is essential for sustainable development in the region. In this context, Johnson and Bryden (2012) emphasized the need for more detailed local energy studies. In addition, Legros et al. (2009; p. 2) highlighted that it needs "*continued efforts* [...] *to improve the quantity and quality of* [...] *information related to energy access as basis for designing policies and programmes to address energy poverty challenges*". This thesis aims at closing the identified research gaps through the provision of energy consumption and production analysis at the very local scale in rural Tanzania. Furthermore, it provides insights into regions where no energy-related scientific research had been conducted before. In particular, the Rukwa region has remained nearly untouched by recent agricultural science (geological, paleozoical and medical papers however are accessible) while palm-oil-specific literature on Western Africa is extremely scarce and non-existent for the Kigoma region[4]. Correspondingly, the overall objectives of my dissertation are:

- To understand how to enhance and sustain traditional bioenergy production and consumption in terms of resource capacity and overall sustainability
- To understand the potentials and effects of straight vegetable oil (SVO) usage as an electrification option
- To understand how energy production and energy consumption are interlinked with food security
- To provide policy-relevant recommendations on options to sustain energy production and consumption

These overall research objectives have been concretised in four individual research papers. In the following, an initial overview of state of the art research will provide basic insights into traditional bioenergy including (a) global consumption, (b) traditional fuels and food security, (c) kilns and charcoal production and (d) efficient stoves (*chapter 2.1*). Subsequently, the scientific discussion with focus on modern bioenergy will be highlighted including in particular (e) the use of SVO as replacement for fossil diesel, (f) sunflower and (g) palm oil insights, (h) aspects of multi-functional platforms and Jatropha curcas as well as (i) electrification issues and options in developing countries (*chapter 2.2*).

After this outline of current state of the art research an overview of the case study site selection (*chapter 3.1*) as well as quantitative (*chapter 3.2*) and qualitative (*chapter 3.3*) data collection are provided in a methods chapter (*chapter 3*). In a subsequent overview of the case study sites (*chapter* 4), initially the main one (Laela village in the Rukwa region) will be outlined (*chapter 4.1*) including (a) geography, (b) climate and soils, (c) society, (d) economy, (e) natural resources and status of (f) agriculture and food security. In addition, the secondary case study site (Kagongo and Illagala village in the Kigoma region) will also be outlined in comparable detail (*chapter 4.2*).

4 For gathering background information about the local processing methods, for example, a standard work had to be consulted from 1988 although two updated versions are commonly available – however without including the old techniques applied in Kigoma (Hartley (1988)).

The above outlined chapters provide the contexts to put the published four papers in perspective, which give in detail the overall objectives of my thesis. Following these objectives, the papers are grouped into traditional (*chapter 5*) and modern bioenergy (*chapter 6*) subsections, both including a respective introduction and conclusion to embed the case-study-specific findings in the respective scientific and political framework (*chapters 5.1 & 5.4; 6.1 & 6.4*). This order of the papers corresponds with the "Energy ladder" and "Energy stack" hypotheses (figure 2). Finally, an overall conclusion of this thesis will merge all findings (*chapter 7*) and lead to specific policy recommendations (*chapter 8*).

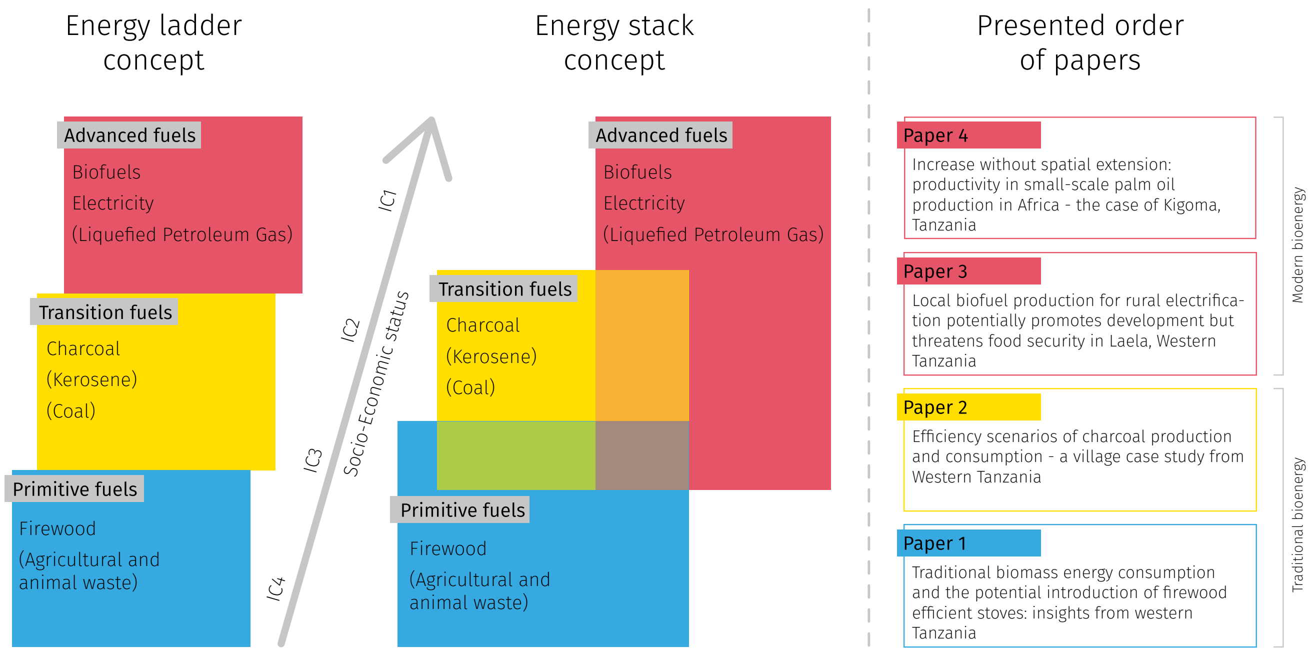

Figure 2 Order of papers in correspondence with "Energy ladder" and "Energy stack" concepts adapted from van der Kroon et al. (2013)

2 State of the art research

In the following, the current state of the art of energy-related scientific research with a focus on traditional and modern energy usage in developing countries with particular focus on SSA and Tanzania is presented. In this context, the essential aspects are individually put under the spotlight in order to provide guidance for the reader in this broad field of research. While some sub-chapters focus on very specific aspects touched upon in individual papers presented afterwards, others provide a broader overview and introduce additional concepts and viewpoints associated with the nexus of energy challenge.

2.1 Traditional bioenergy in developing countries

Global consumption

Traditional fuels such as firewood, charcoal, agricultural residues and dung (Raman et al. 2013) are and will for the foreseeable future remain by far the dominant cooking energy sources in developing countries (Kees and Feldmann 2011, Iiyama et al. 2014). Urmee and Gyamfi (2014) outline in this regard that the dependency is highest in SSA, Indonesia, India and the rest of Asia with respective rates between 60% and 80% if the total population is considered (SSA ~ 75%; Tanzania ~ 90% (Sosovele 2010)). There are, however, huge differences between the rural and urban populations when relying on biomass for cooking: The average dependency rates reported for the total population of Africa, Asia and Latin America are approximately 50% which breaks down as 80% for rural populations and 20% for urban ones. It is remarkable that even in SSA, around 60% of urban households are reliant on biomass resources (mainly charcoal) as a primary fuel for cooking. Charcoal is preferred in urban areas due to positive characteristics such as higher energy content, increased transportability and storability (avoidance of insect problems), the fact that it can be relit, and smoke-efficient combustion (Kammen and Lew 2005). On the other hand, Maes and Verbist (2012) with reference to Bailis et al. (2005), estimate the firewood, dung and crop residues dependency in rural areas of SSA to be 94% compared with 41% in urban areas; charcoal accounts for 4% and 34% respectively.

These numbers translate on a global scale to around 2.4 billion dependents, 90% of them in developing countries (Urmee and Gyamfi 2014). However, higher total numbers are also reported (Shrimali et al. (2011): 2.5 billion; Bailis et al. (2015): 2.8 billion; Jagger and Shively (2014):

3.0 billion). According to Kaygusuz (2011), this number is going to increase in the future; Raman et al. (2013) reports that by 2030, an additional 200 million people will depend on traditional fuels.

Concerning the overall quantity consumed, the World Health Organization (WHO) (2006) estimates – based on 2.4 billion dependents – that globally two million tonnes of biomass are consumed for cooking purposes (including water boiling) on a daily basis – Kammen (1995) reports that 50% of the 3.0 Gt of wood annually harvested are used as fuel (4.1 million t/day). Similarly, Bailis et al. (2015) calculate the global woodfuel demand for 2009 with 1.36 Gt (3.7 million t/day) and Jeuland and Pattanayak (2012) report that burning biomass (and coal) in traditional inefficient household stoves represents 15% of global energy use – it can be assumed that the respective definition of "stove" includes the burning process on three-stone-fires comparable with assumptions by Kshirsagar and Kalamkar (2014). Sène (2000) estimates the annual extraction of wood from forests and tree resources to be 623 million m^3 in Africa which equals, with reference to Drigo (2005) (725kg/m^3), 450 million tonnes annually or, given an African population of 862 million in 2000 (United Nations 2013b) 520 kg per person annually. Bailis et al. (2015), on the other hand, outline that the share of the global wood harvest consumed as fuel equals 9% of global primary energy consumption; Iiyama et al. (2014) report 10% respectively for "solid biomass". Adkins et al. (2010; p. 185) report, with focus on SSA, that "*a generally accepted value for household biomass use for cooking [...] range from 2.5 to 3.0 tonnes per year*". A recent study estimates that the charcoal industry in Africa alone was worth more than 8 billion US$ in 2007 while providing labour to more than 7 million people – it is also forecasted that these figures will increase to 12 billion US$ and 12 million employees respectively (The World Bank 2011b) – the Tanzanian charcoal sector alone is valued to be 650 million US$, based on annual consumption of 1 million tonnes (Peter and Sander 2009).

The respective usage of firewood and charcoal is stabilizing and even shrinking – particularly in Asia and Latin America – however the leapfrogging from traditional biomass towards modern energy sources such as Liquefied petroleum gas (LPG) has, due to a lack of technical know-how and the right cultural, social and economic conditions to institutionalise this knowledge (Murphy 2001), not been successful in SSA so far and is not likely to be so in the near future (Iiyama et al. 2014). In SSA, particularly charcoal but also firewood production and consumption have been reported to grow constantly in the last decades (Steierer 2011) and will do so in the decades to come (Arnold et al. 2006) – Africa currently produces about half of the world's charcoal (Kshirsagar and Kalamkar 2014). Iiyama et al. (2014) report the average annual growth rates of firewood and charcoal consumption between 2000 and 2010 in SSA to be 1% and 3% respectively – the latter being higher than the average annual population growth rate of 2.6%.

One reason for the increased demand is the sharp population growth in SSA where the current population of about 1 billion is projected to reach between 3.1 und 5.7 billion by the end of the century as especially the population growth rate between 2050 and 2100 will surpass that of the world (Gerland et al. 2014, United Nations 2013b). Another one is urbanisation as this process is associated with a switch from the consumption of firewood to the more resource-consuming charcoal (Mwampamba et al. 2013). Hosier et al. (1993) claim, with special reference to charcoal consumption, that a 14% increase is associated with a rise in the urbanisation level of 1% in a Tanzanian case study – Ncube (2012) reports African urbanisation growth levels to be 3.5% annually since 1990 with constant growth rates projected until 2050. However, strong regional disparities are reported even on the sub-national level as, for example, in the Tanzanian case urbanisation rates of 4.8% have been reported for Dar es Salaam and even 7.1% for the city of Arusha (Potts 2009).

The effects of this traditional energy carrier dependency on forest degradation and deforestation have been controversial over the last few decades, with the discussions meandering between calls for immediate global action to the necessity of narrower location and time specific analyses (Hiemstra-van der Horst and Hovorka 2009, Maes and Verbist 2012, Mwampamba et al. 2013, Bailis et al. 2015). While, for example, Iiyama et al. (2014; p. 140) outlines that "*displacement for agriculture appears to be the most important driver for deforestation in humid forest areas [...] and charcoal often a byproduct of forest clearance*" Chidumayo and Gumbo (2013) attribute 33% of deforestation in Tanzania to charcoal production – according to their calculation, this is a world record. Mwampamba (2007) even perceives the attribution of charcoal production in deforestation in Tanzania as between 30–60%; Makundi (2001) believes that 70% of Tanzanian forest loss due to woodfuel consumption – 43% due to direct removals – could be realistic. Msuya et al. (2011; p. 1369) concludes that "*more than 2.8 million ha of forest will be cut to fulfil the demanded charcoal for Dar es Salaam alone*" by 2030.

With reference to the effects of charcoal and firewood production and use, a recent review points out that deforestation or, more frequently, degradation of forest "*may occur or not*" at the local level depending on the specific context (Mandelli et al. 2014; p. 674) while Munslow et al. (1988; p. 11) simply refers to "*mosaics of varying levels of stress*". With special regard to firewood Neufeldt et al. (2015; p. 3) summarise that "*firewood is usually collected sustainably, and the drudgery experienced by women and children in walking long distances for firewood is usually caused by local scarcity rather than widespread deforestation*".

In Tanzania, for example, there is evidence that firewood collection rarely represents a threat to forests (Mwampamba 2007) while the effects of charcoal production seem to be quite different (Chidumayo and Gumbo 2013). However, Mwampamba et al. (2013) perceive the common knowledge about direct links between charcoal and deforestation to be a myth while Gmünder et al. (2014) highlight that charcoal production leads not to land use change but to temporal deforestation only – however, constant and increasing pressure on forest resources will inevitably lead to deforestation and subsequently (top)soil erosion and exhaustion (Campbell et al. 1996). In Uganda however, general population growth is claimed to be the most significant driver of deforestation (Wallmo and Jacobson 1998). Other researchers perceive knowledge gaps to be only marginal by outlining that the impact of woodfuel consumption is well documented (Murphy 2001) while Hartter and Boston (2007; p. 85) simply state that "*in the end, human daily caloric intake is what drives fuelwood consumption and ultimately the loss of natural forest.*" It is possible that the question of whether traditional fuel production (charcoal) and consumption (firewood) results in deforestation or forest degradation is a matter of scale: On a micro-scale, clear evidence can be found (cf. Luoga et al. (2000)) while on a macro-scale, no clear evidence exists (Mandelli et al. 2014).

It is common sense however that charcoal production with the technology currently applied in rural areas "*proved to be wasteful in resources*" (Kimaryo and Ngereza 1989; p. 12) – Kammen and Lew (2005) exemplify that the woodfuel equivalent of charcoal is 4–6 times larger compared to firewood, MacCarty et al. (2010; p. 161) report that energy losses in the production process of charcoal "*can be as much as 70%*".

However, charcoal production represents a transfer of financial resources to the rural areas (Hiemstra-van der Horst and Hovorka 2009) – whether the bottom of the pyramid profits substantially (Butz 2013) or not (Khundi et al. 2011) is under discussion. Nevertheless, there are additional reports that fuelwood businesses contribute to the income of economically marginalized urban and rural residents, especially in times of financial stress (Mohammed et al. 2015, Butz 2013).

Traditional fuels and food security

Adequate availability of and access to traditional fuels has tremendous importance for the survival of the worlds' poor as it is strongly related to the "*acquisition of sufficient nutrients from the available food*" as a principal component of food security (Boko et al. 2007; p. 454). The major reason for this is that heat, resulting from the combustion of traditional fuels, degrades some nutrients or food matrices and makes them more easily available for absorption by the human body. According to Kees and Feldmann (2011) there is anecdotal evidence from Malawi that villagers affected by cooking energy restrictions stopped cooking food that needs simmering, such as beans, or that food is only half cooked. Murphy (2001) also reports that protein-rich hard meals such as beans may be avoided in favour of fast cooking low-protein meals – additionally, water purification by cooking might be suspended. This is especially important as beans are an excellent source of proteins, vitamins and certain minerals as well as complex carbohydrates and polyunsaturated free fatty acids (Reyes-Moreno et al. 1993). On the other hand, Palmer and MacGregor (2008) report that Namibian households respond to scarcity by increasing labour input to collecting time rather than reducing energy consumption by substitution between fuels.

There are, however, only sporadic publications available that clearly highlight the connection between food security and cooking energy supply – the paper of Makungwa et al. (2013) represents a recent exception. Substantial work on this topic was done by Inge Brouwer in Malawi and the respective papers are still frequently cited (Brouwer et al. 1996a, Brouwer et al. 1997, Brouwer et al. 1996b).

Other authors such as Pinstrup-Andersen and Pandya-Lorch (1998) however, highlight in their food security analysis mainly agricultural expansion and respective deforestation as a result of food needs and therefore only indirectly include traditional fuel scarcity.

Kilns and charcoal production

Charcoal, as outlined mainly but not exclusively the fuel of the urban population in developing countries, is primarily produced in rural areas by a multitude of small-scale charcoal makers often operating in times of minimised field work (dry seasons) (Tabuti et al. 2003) or in times of additional financial needs (Butz 2013). The rate of regulation in this sector generally differs between regions particularly in Africa and is, for example, in Central and West Africa more formalised than in East Africa (Schure et al. 2013). However, the quantity of charcoal produced on the continent is substantial – Steierer (2011) estimates that the African wood charcoal production increased between 2004 and 2009 by 29.8% to reach 29.4 million metric tonnes while all other world regions combined produced 17.6 million metric tonnes in the same year. Furthermore, the total share of 63% in 2009 is even higher than the total share in 2004 (52%). In the Tanzanian case, Peter and Sander (2009) estimated that one million tonnes of charcoal were consumed annually while CAMCO (2014) calculate – for the baseline year 2012 – with 2.3 million tonnes for the reference year 2012. According to projections by the latter, this will likely double (again) by 2030. GEF (2013) forecasts the production and consumption development pathways for Africa as a whole and concludes that the continent will become, due to the massive increase in demand, a net-importer of wood, with all of the resulting implications such as increased unsustainable harvesting and skyrocketing prices.

Generally, a number of different production pathways and techniques exist for charcoal fabrication, and these differ mainly in their recovery rates. Common to all pathways is a process called "carbonisation" that is outlined by Vos and Vis (2010; p. 16) as being *"the method of burning wood or other biomass in the absence of air after which it breaks down into liquids, gases and charcoal"*. This process normally takes place in charcoal kilns, which are differentiated according to their recovery level, size, level of mobility, construction material and overall level of professionalism – overviews are provided by Iiyama et al. (2014), Schenkel et al. (1998) and especially Emrich (1985). The most simple kilns are also the most widespread ones: The pit kiln with recovery rates of 12% and the traditional earth mound kiln with reported recovery rates between 8% and 30%, depending on the literature source (Iiyama et al. 2014) – Kimaryo and Ngereza (1988; p. 3) however state that *"in Tanzania almost all charcoal is produced by using traditional earth kilns"*. Other authors such as Maes and Verbist (2012) generalise that traditional charcoal production methods reach conversion efficiencies of 10–15%. A more detailed analysis of different recovery rates as extracted from literature is outlined in Annex 1. A detailed economic analysis of a charcoal production process including labour costs is outlined by Luoga et al. (2000) and Kimaryo and Ngereza (1989) for Tanzanian case study sites; Felix and Gheewala (2011) provide a comparable recent literature overview for the same country.

A measure to improve the currently very inefficient production of charcoal via traditional kilns is the implementation of improved kilns such as the best known Senegalese Casamance kiln (Schenkel et al. 1998) that reaches efficiency rates of up to 30% (Vos and Vis 2010) by redirecting the hot gases via a chimney constructed out of oil drums to optimise carbonisation efficiency. Furthermore, the wood piles are organised in a way to optimise the circulation process (Schenkel et al. 1998). Iiyama et al. (2014), on the other hand, report respective efficiency rates of 17% to 30% for Casamance kilns and 26% to 27% for other improved earth kilns designs. Zulu and Richardson (2013; p. 136) outline in this context that the *"promotion of appropriate and more efficient charcoal production kilns along with more effective control of indigenous forest harvesting would also help reduce the amount of wood used, lower production costs and promote conservation"*. In Tanzania, experimental field trials as well as the respective adaptation by local producers were reported to achieve positive results (Kimaryo and Ngereza 1988) but more recent reports conclude to the contrary (Peter and Sander 2009). However, Schenkel et al. (1998) underline that the crucial factor for achieving high recovery rates and minimising losses is the charcoal producer's experience. They state that *"good carbonization performances are obtained only by charcoal makers who master their technique whatever it is"*. It is noteworthy however that technical improvements in the sector of efficient kilns stopped with the Casamance kiln (Kimaryo and Ngereza 1988) in the late 1970s (Sepp (2014); oral communication) and that the number of (donor driven) approaches aiming at the diffusion of respective improved charcoal production techniques have been low when compared to the diffusion of efficient stoves, for example (Mwampamba et al. 2013). One reason is the status of charcoal as "blind spot" on the political agenda in most African countries – Zulu and Richardson (2013) illustrate this by referring to a post-conference communiqué of an African Energy Ministers conference in 2011 focussing on energy access and low-carbon economic growth that failed to even mention charcoal. Owen et al. (2013; p. 146) furthermore highlight in a review of African energy policies that decision makers in the governments in nearly all cases envision a development pathway whereby poverty reduction and economic growth is strongly based upon fossil fuels and therefore outline *"anything-but-biomass"* policies. However, an overview of the respective energy policies in developing countries is provided by Bailis (2015). An example of a suboptimal charcoal policy in Tanzania is a sudden ban of charcoal consumption in the country substantiated with forest protection that resulted in a massive price increase (cf. Figure 3). Another reason is that low adaptation rates of improved charcoal kiln techniques are related by Vos and Vis (2010) to the mainly stationary character of improved kilns, the existence of investment costs beyond the 20.5 US$ needed for purchase of reusable tools (Luoga et al. 2000) and the demand of skilled labour.

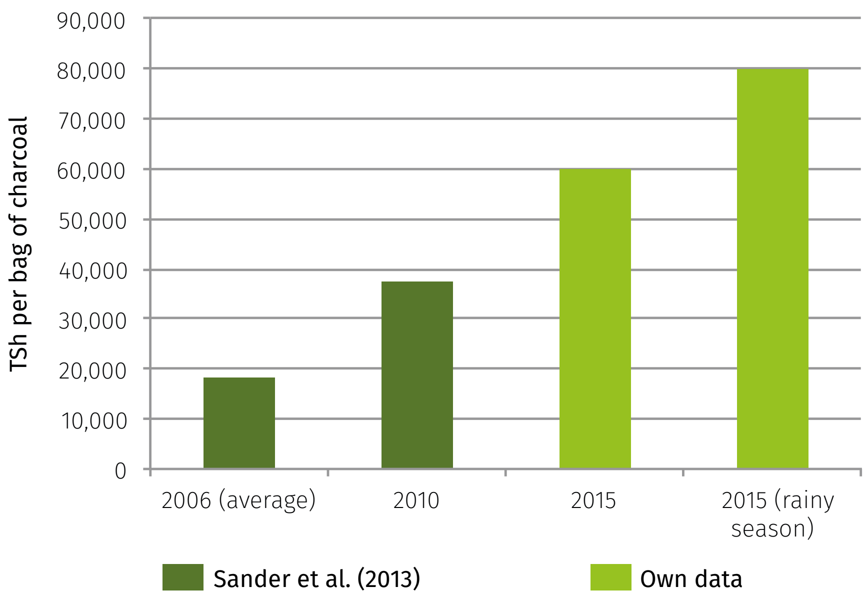

Figure 3 Comparison of charcoal retail prices in Dar es Salaam over time in Thousand Tanzanian Shilling (2006 data averaged from prices presented by Sander et al. (2013))

The specific charcoal sector in Tanzania is mainly characterised by its illegal status (Peter and Sander 2009), resulting in very poor margins for the producers. Furthermore, this illegality substantially decreases likeliness of producers to shift to more efficient but also more cost intensive production techniques due to the risk of confiscation (Peter and Sander 2009). Mwampamba et al. (2013; p. 79) illustrate the generally low returns for producers with reference to Malawi and Kenya where the charcoal makers gain 21% and 20% respectively while *"12% to 30% is captured by 'private taxes' otherwise known as bribes"* – Peter and Sander (2009; p. 8) refer in this context to anecdotal evidence outlining that *"public sector employees and authorities are commonly believed to be dominant actors in the illegal transport and trade of charcoal"*. In addition, charcoal production is associated with deforestation and forest degradation although the real impact remains to be discussed (Mwampamba et al. 2013, Chidumayo and Gumbo 2013, Hosier 1993). Potentially negative effects of the local population, despite low financial returns, could be mitigated by reforestation and afforestation programs as well as the establishment of tree plantations closely linked with sustainable local production cycles (Faße et al. 2014, Iiyama et al. 2014, Gmünder et al. 2014). This could strengthen added value at production sites and decrease negative effects on resources and climate (Zanchi et al. 2013). However, it might be challenging to implement these systems due to the multiplicity of involved actors and policies – an additional obstacle might be influential networks and the incentive structure that governs particularly the charcoal sector (Sander et al. 2013).

Nevertheless, charcoal production and consumption will continue to increase in the future as prices are skyrocketing (GEF 2013). This is also true for charcoal prices in Dar es Salaam. Figure 3 compares retail price levels in thousand Shilling (TSh.) as extracted from Sander et al. (2013) and correlates them with own unpublished data obtained from interviews in Dar es Salaam in early 2015. The result of this dramatic price shock will most likely be an increased number of charcoal producers in the rural areas as, even though the relative share of profits is currently low, overall profitability still increases. The effects on forests and forested areas remain to be seen. In addition, the dissemination of charcoal-specific, improved cooking stoves (ICS) particularly in urban settlements is likely to be fostered by these developments.

Stoves

Two approaches often attempted in order to lower the negative outcomes of traditional energy consumption (which include forest degradation, indoor air pollution, increasing households spending and emission of CO_2) are (1) the introduction of ICS as replacements for traditional charcoal stoves (TCS) and (2) the introduction of ICS as a replacement for three-stone fires (TSF) in the case of firewood consumption. Generally, the efficiency of TCS has been equated to the efficiency of TSF (MacCarty et al. 2010) which is commonly characterised by a respective rate of 10% (Bhattacharya et al. 2002, Okello et al. 2013, Mwandosya and Luhanga 1993). However, values of 7% (Wiskerke et al. 2010), 15–18% (Mwandosya and Luhanga 1993) and even 20% (Kshirsagar and Kalamkar 2014) have also been reported.

Improved, fuel efficient cooking stoves – the ICS – hold, in contrast to traditional cooking methods, the potential to assist charcoal and firewood users on the consumption side (Ochieng et al. 2013) while options to increase efficiency on the production side, particularly for charcoal by optimising charcoal kilns, are rare (Mwampamba et al. 2013). However, ICS include a multitude of different designs for different fuels as well as efficiency rates, price levels, applicability options and emission characteristics (MacCarty et al. 2010, Adkins et al. 2010, Sutar et al. 2015). There is no universally accepted definition or classification of efficient cook stoves (Urmee and Gyamfi 2014) – Kshirsagar and Kalamkar (2014) for example list nine different classification schemes. ICS are referred to as "*improved stoves*" (Shrimali et al. 2011), "*improved cook stoves*" (Lewis and Pattanayak 2012), "*clean cook stoves*" (Simon et al. 2014), "*non-traditional cook stoves*" (Ramirez et al. 2014), "*improved biomass cook stoves*" (Just et al. 2013) or "*energy-saving stoves*" (Mombo et al. 2014). Simon et al. (2014) apply the term "*advanced combustion stoves*" for more technically advanced next-generation stoves; Kshirsagar and Kalamkar (2014) refer to "*advanced biomass stoves*" for factory-based production and quality control. However, these terms refer to a multitude of design models, occasionally marketed by different brands (MacCarty et al. 2010, Urmee and Gyamfi 2014) that all share basically the goal to improve upon the shortcomings of the TCS, namely low thermal and fuel efficiency, unsafe operation and sub-optimal emissions negatively affecting human health (Urmee and Gyamfi 2014), while ensuring lower costs and ease of use (Kshirsagar and Kalamkar 2014). Grieshop et al. (2011) summarise the respective aims as decreasing indoor air pollution, increasing heating efficiency and decreasing the amount of fuel used. Whether the potentially promising co-production of cooking heat and electricity will be implemented on a wide scale remains to be seen (O'Shaughnessy et al. 2014).

A substantial driver in recent years for the diffusion of ICS is climate funding even though Bailis et al. (2015; p. 1) highlight that their findings with regard to the unsustainable woodfuel harvest are lower than estimates from carbon offset projects as these are "*probably overstating the climate benefits of improved stoves*". Furthermore this very recent publication outlines only four high impact countries where ICS distribution should focus. Tanzania is not one of them[5]. However, there are also reports about the non-function of ICS altogether: Hanna et al. (2012) outline in an Indian case study that, although short term improvements in smoke inhalation and fuel consumption can be observed, there is no effect over long term horizons while Wallmo and Jacobson 1998 report that "*fuelwood consumption did not differ significantly between improved and traditional stoves under actual field conditions*". In this context, however, the so-called "rebound effect" also needs to be considered whereby a reduction of e.g. charcoal consumption due to more efficient ICS might encourage households to purchase a second stove or to boil water where this was not done previously. While this is a positive outcome from the households' perspective, this will raise, not lower, the fuel consumption (Mwampamba et al. 2013).

Regarding the overall situation in Tanzania there are some meta-studies that provide insights, mainly focussing on the market situation – the majority of these references are not peer-reviewed though (Global Village Energy Partnership 2012b, Riedjik 2011, Otiti 2010, Pursnani 2011, Clough 2012). Their findings are nevertheless summarised here with special emphasis on reasons for failure or success of implemented ICS diffusion programs. The respective situation is nevertheless complex and information is hardly, if at all, accessible. The official governmental

5 These countries are Ethiopia, Lesotho, Somalia and Togo

body reported to be mainly responsible for the coordination, the Tanzanian Ministry of Energy and Minerals (Clough 2012) does not provide relevant information. However, Peter and Sander (2009) calculated the costs for a nation-wide marketing campaign highlighting benefits of ICS (1.5 million US$) and for a respective technical optimisation programme (0.5 million US$).

In general, it can be stated that a huge variety on national and international NGOs are involved in the ICS sector via training of producers, dissemination of ICS or providing respective education (Global Village Energy Partnership 2012b). However, most of the relevant programs were smaller scale with short-lived funding (Global Village Energy Partnership 2012a). Claims that the dissemination of ICS in Tanzania is in its advanced stage might therefore be exaggerated (Otiti 2010).

Dissemination of efficient stoves in Tanzania has been ongoing since the early 1980s (Otiti 2010) with a first major effort being the local adaptation of a successful Kenyan stove (Kenyan Ceramic Jiko) (Clough 2012, Global Village Energy Partnership 2012a) which is currently used by 80% of urban Kenyan households (Agbemabiese et al. 2012). However, it is reported that until the turn of the millennium – more recent literature could not be found – only 54,000 ICS have been disseminated in Tanzania (AFREPREN 2004). One potential reason for this is that sector activities are uncoordinated, including a general lack of commercialisation (Clough 2012). Specifically for Dar es Salaam, Palmula and Beaudin (2007) reported that 20% use a charcoal specific ICS; representativeness for the urban and peri-urban area is claimed. Based on the total population of the region (4.36 million) and the average Tanzanian household size (4.8 HHmembers/HH) for 2012 (UNFPA Tanzania 2013), these figures result in roughly 180,000 ICS charcoal stoves in use in the biggest urban settlement in Tanzania. Firewood specific ICS seem negligible as only 7% of interviewees use firewood as a cooking energy carrier (Palmula and Beaudin 2007).

Riedjik (2011) on the other hand analyses the nationwide situation in a desk study and concludes that at least four million ICS had been disseminated by 2010. Based on these figures, Global Village Energy Partnership (2012b) estimated, under the assumption that an average ICS lasts 1.3 years, that 400,000 households owned an ICS by the time of the study.

A third overview of the Tanzanian ICS sector was published by the "Breathing Space Programme" financed by the Shell Foundation. According to Global Village Energy Partnership (2012b), 17% of peri-urban and 48% of urban charcoal users owned a charcoal-specific ICS, equating to approximately 400,000 stoves. A publication summarising the results of this project did however not include these figures but argued, as the outcome of field trials, that they should focus on a market-based approached for ICS dissemination (Pursnani 2011). It is also reported that 2.7 million households cook with a TCS outlining the market potential for ICS (Global Village Energy Partnership 2012b). Riedjik (2011) however, estimates the market potential to reach 4 million households (75% in rural areas) which are currently not aware of the money and energy saving potentials of ICS. This is in line with Kammen and Kirubi (2008) who generally point out that efficient stove dissemination in rural areas needs to increase sharply.

Although the price pressure from ever increasing fuel (charcoal) prices is supposed to be high (for a detailed analysis of urban charcoal prices cf. Sander et al. (2013) and The World Bank (2011a)), the market penetration rate of ICS is claimed to be 5% on a national basis with higher penetration rates in urban areas (47–68%) (Global Village Energy Partnership 2012a).

However, Legros et al. (2009) report, based on data from 2007, that the adoption rate of ICS reaches just 1% in Tanzania within households relying on solid fuels for cooking. Knowledge of end users' perception regarding price, looks, size, affordability, user-friendliness, durability, time and money savings still remains limited (Riedjik 2011).

In sum, the situation is highly complex and confusing with very different figures existing. There is, however, a national association of ICS producers to be formed by the end of 2015, substantially increasing the likeliness of reliable diffusion and production data in the future.

2.2 Modern energy in developing countries

In addition to the potential analysis of traditional energy development pathways in Laela, the option to implement modern bioenergy – namely electricity based on a replacement of fossil diesel via SVO for the use in stationary diesel generators – was also research focus in Laela and, in the context of increased palm oil production, indirectly in the region of Kigoma, Tanzania. As a basis for understanding, in the following, backgrounds and critical aspects are outlined, discussed and put into perspective.

SVO as fossil diesel replacement

Sunflower oil but also groundnut oil and palm oil are explicitly denoted as potential biofuel feedstocks applicable in the Tanzanian context by the "Guidelines for sustainable liquid biofuels development in Tanzania" (Government of Tanzania 2010). Even though in the guidelines the production of electricity is only associated with co-generation, respective SVOs also hold the potential to be utilised for the production of electricity in off-grid systems by using SVOs as replacements for fossil fuel in diesel engines. This application pathway is in line with the findings of Blin et al. (2013; p. 581) outlining that "*one of the most advantageous branches in the biofuel sector is seen to be the production of straight vegetable oil (SVO) for direct use as fuel in diesel engines*". Furthermore, this application option is underlined by Johnson and Bryden (2012; p. 290) who state that "*there is significant potential for the development of micro-grid or off-grid solutions to reduce the costs and impact of electricity*". Already today, a significant proportion of the total installed power capacity in SSA comes from decentralised generator sets: In East Africa this proportion is 8% and in West Africa it even peaks at 19% (Mandelli et al. 2014).

It is in this context essential to note that the direct application of SVOs does not include transesterification as a chemical transformation necessary in the production for biodiesel, a process outlined in detail by Demirbas and Demirbas (2007) and Sidibé et al. (2010). The latter process, which is highly dependent on large-scale industrial processing plants, has in the past nevertheless also been highlighted as a promising alternative income strategy for (female) small-scale farmers in SSA in the context of so-called "outgrower schemes" (Banda 2009, Ejigu 2008). This centralised production pathway was perceived as a promising option for African economies (Amigun et al. 2008, Mulugetta 2009) – if these assumptions and respective results are, with the recent substantial global drop in crude oil prices (figure 4) (EIA 2015), still valid is beyond the analysis of this thesis but potentially questionable.

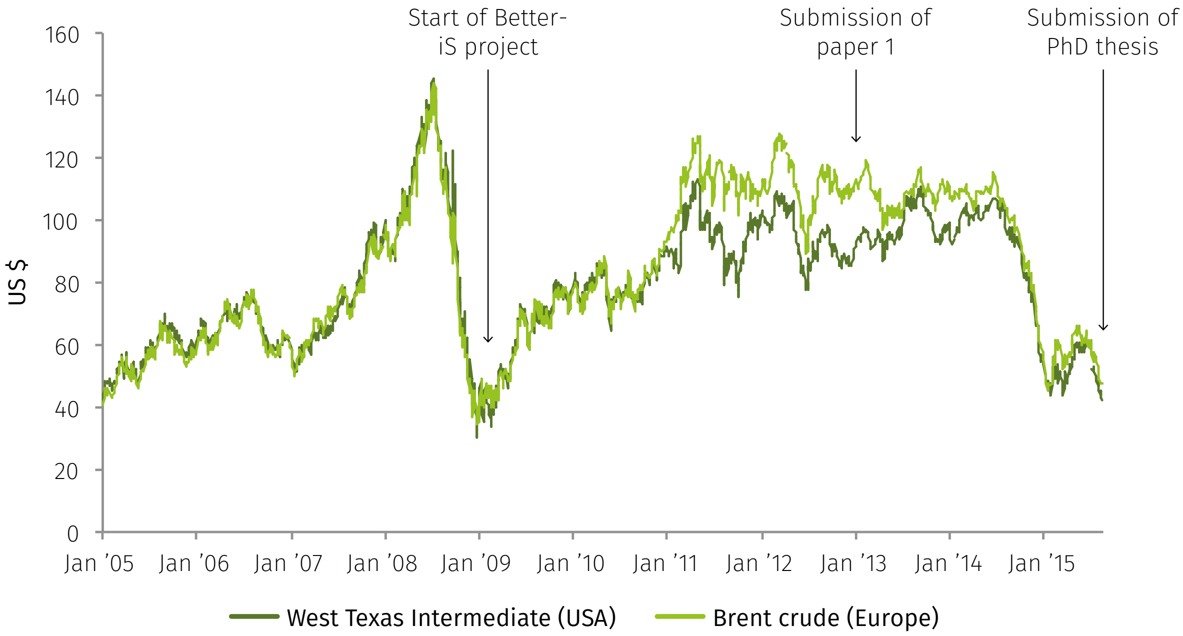

Figure 4 Crude oil prices for major benchmark classifications and relevant dates

However, there is evidence that the use of SVO is more environmentally friendly than the use of biodiesel (Esteban et al. 2011) but questions regarding purifying techniques and general quality remain (Blin et al. 2013) although official specifications do exist, at least for some vegetable oils, for example, in Tanzania (RLDC 2008). The local production of oilseeds including subsequent conversion into SVO on a village scale to fuel local diesel engines has the advantage of only requiring reasonable investments and offering a high level of flexibility in terms of production capacity (Blin et al. 2013). Furthermore, stationary diesel engines are, as outlined by Blin et al. (2013; p. 585) "*perfectly suitable for use with fuels such as […] SVO with lower cetane numbers than diesel*". In addition, diesel-powered generator sets have been the widespread solution to improve the access to electricity among rural households for decades as they require relatively low investment costs, represent relatively simple technology that does not depend on civil work, have a very short installation time and are highly flexible (Lahimer et al. 2013). Latter authors nevertheless also report in their overview study that diesel-powered generators are the most expensive option for generating electricity and are characterised by weak production utilisation and short system life spans and are associated with high costs of maintenance and operation as a result of the moving components. However, while modern diesel engines need to be fuelled with SVO/fossil diesel blends or, alternatively, equipped with additional tanks to allow the engine to reach a certain operational temperature with fossil fuels before being able to combust SVO without residues (Blin et al. 2013), the so-called “Lister engines” from China or India, commonly available in Africa (Burn and Coche 2001), can be used without these adaptations (Sanga and Meena 2008) as they use indirect-injection combustion systems with a swirl chamber operating at high temperatures (Sidibé et al. 2010).

A highly crucial aspect with regard to the use of biofuels including biodiesel as fuel is the so-called “food vs. fuel” debate (Monbiot et al. 2005, Thompson 2012, Harrison 2009, Poudel et al. 2012, Holt-Giménez 2007) which refers to the (potential) negative effects of biofuel production on food security. While some authors claim that a link between food price increases and biofuel production on a global level cannot be proven directly (Ajanovic 2011), other authors find different results (Nonhebel 2012, Mitchell 2008). In any case, the situation is complex (Rathmann et al. 2010) and the implementation of safety measures has already been recommended (Escobar et al. 2009, Tilman et al. 2009, Tirado et al. 2010). From the current political and industrial state of the global biofuels industry, it is nevertheless interesting to recall claims such as those by Prof. Moreira outlining that the usage of high yielding energy crops can replace 50% of global oil consumption while simultaneously creating 300 million jobs as well as generating 50% of the global electricity demand (Monbiot et al. 2005). However, this discussion is highly complex and very controversial among scientists (Timilsina and Shrestha 2011, Mitchell 2011). In politics however, the use of biofuels derived from edible crops in developing countries is commonly not supported (any more), a situation that will likely remain constant even if crude oil prices start rising again. This debate nevertheless focusses on large-scale production and processing operations including controversial land allocations (Vermeulen and Cotula 2010, Cotula et al. 2008) and not on village-level solutions.

Sunflower

Sunflower (Helianthus annuus L.) grows in moderate climates at temperatures between 20 and 26 °C with and an optimum temperature of 27–28 °C in sunny, dry weather in deep soils capable of supplying abundant water, although the respective oil content of the seeds decreases with increasing heat stress. However, the plant has a high resistance to temperature fluctuations and survives temperatures between 8 °C and 34 °C – although humidity conditions are crucial during the 15–20 days before and after flowering (Grompone 2005). In Tanzania, sunflower is one of the most important oilseed crops and it is likewise one of the main cash crops in the Rukwa region (The World Bank 2007). Furthermore it has, according to Mpagalile et al. (2008; p. 5) “*a potential of contributing to poverty reduction if rigorous promotional activities are put in place*”. However, the sunflower yield potential reported for Tanzania (0.37 tonnes/hectare) is also earmarked as the global minimum value obtained in 1994 while in other world regions, 2.5 tonnes/hectare could be reached in the same year (Grompone 2005). In Rukwa region, however, the introduction of sunflower as a cash crop took place in the late 1990s only (Jerve and Ntemi 2009). In Tanzania, groundnuts and sunflower are the major oilseeds produced with 40% and 36% respectively – the globally dominating palm oil accounts for only 1% (RLDC 2008). However, as oil extraction is not common, particularly for groundnuts, “*sunflower oil* [is] *the most important vegetable oil produced in Tanzania*” (RLDC 2008; p. 7). Sunflower seed (as well as oil palm fruit) production is outlined in figure 5 in accordance with FAOSTAT (2013). However, all oil palm data is based on FAO estimates as well as all sunflower data from 1996–2004. Official data is only available for sunflower seed production data from 2010; the remaining data is based on unofficial sources. Even though we focus on stationary diesel engines running on locally produced sunflower oil, not on a highly exotic option, the general risks of rural electrification are still substantial[6], as outlined in detail by Lahimer et al. (2013).

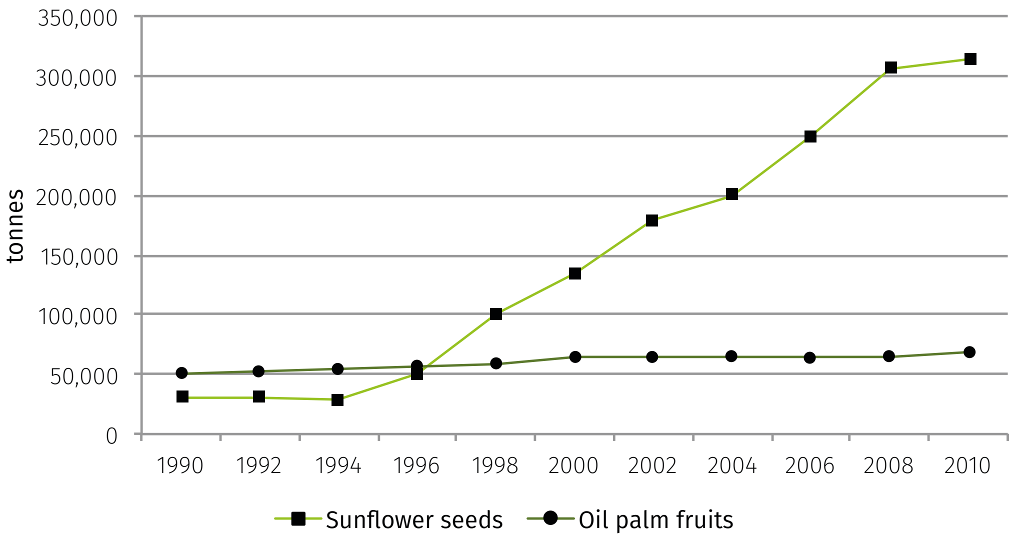

Figure 5 Sunflower seeds and oil palm fruits production from 1990 to 2010 in Tanzania (FAOSTAT)

Oil palm

The oil palm (Elaeis guineensis Jacq.) is one of the main permanent crops of humankind, as currently 30% of global vegetable oil production is derived from it (Carter et al. 2007) and the overall production area is forecast to increase from 9.1 million hectares in 2009 (Carter et al. 2007) to reach 21 million ha in 2050 as global demand is predicted to double by then (Corley 2009). However, the area that by far dominates production – with 80% of global production (Reinhardt et al. 2007) – is South-East Asia, in particular Malaysia and Indonesia (Tan et al. 2009), where yields of around 4 tonnes of palm oil per hectare can be achieved (Reinhardt et al. 2007). The biggest African producer, Nigeria, only accounted for 3% of the global palm oil production in 2004 (Reinhardt et al. 2007) and East Africa is negligible in this context – Bazmi et al. (2011) analysed the potential for using palm oil as fuel for electrification and excluded East Africa in his study[7]. Tanzania is especially characterised by Carrere (2013; p. 71) as being "*not (yet) a palm oil producing country*". However, the National Biofuel Guidelines include oil palm as an energy crop for biofuel production applicable in Tanzania (Government of Tanzania

6 The multitude of factors to be considered include user affordability, low project profitability, lack of professionalism and over-dependence on subsidies

7 Included, however, were West Africa, Central Africa, Southeast Asia and Latin America

2010), potentially indicating a stronger political support in the future. Although Tanzania has the potential to produce palm oil and respective production is slowly increasing (cf. figure 5), the country in 2008 still imported 180,000 tonnes of palm oil to meet the national demand (FAO 2011). In the local West Tanzanian setting however, palm oil plays a crucial role, particularly in the diet of low-income households, due to its micronutrient-rich nature (Orozco et al. 2006). In contrast to industrialised production and processing facilities in East Asia, manual processing still dominates in the Kigoma region (Hyman 1990).

Multi-functional platforms (MFPs) and Jatropha curcas

In a broader framework, the inspiration of the theoretical approach towards SVO use for electricity generation was derived from the concept of the so-called "Multifunctional platforms" (MFPs) as designed and operated primarily in West Africa (Burn and Coche 2000, Brew-Hammond and Crole-Rees 2004, Sanga and Meena 2008) mainly for the use of Jatropha curcas. This concept, which is outlined by Brew-Hammond and Crole-Rees (2004; p. 18) as consisting *"[…] of a source of mechanical and electrical energy, provided by a diesel engine of 8 to 12 horse power (hp), that is mounted on a chassis and to which a variety of end-use equipment can be added"* has, however, not remained uncontested due to its general approach (Nygaard 2010) or with special regard to wage limitations. This is particularly true when Jatropha curas is focused on as an oil bearing crop (Grimsby et al. 2012). In this context, the Tanzanian NGO "Tanzania Traditional Energy Development Organization" (TaTEDO) initiated a respective case study project in the village of Laela to test and potentially replicate achievements claimed by donors and the government in Mali (Angstreich and Jackson 2007, Martin et al. 2009). In summary, the organisations' knowledge in this regard was expected to be advanced – indeed, already in 2008, a comprehensive guidebook for implementation had been designed (Sanga and Meena 2008) and there are reports outlining the planned installation of 30 MFPs nationwide (Grimsby et al. 2012, Dimpl 2011) – although whether these plans became reality is unknown. In Laela, however, the MFP installation failed due to various reasons (e.g. wrong technical compatibility between generator and engine) even though scientific results suggested generally high likeliness of success, such as outlined by Wiskerke et al. (2010; p. 155): "*Of all the analyzed options, Jatropha oil production as a substitute for diesel in an off-grid electrification project is the most profitable energy related option per hectare.*" There has been a substantial number of Jatropha projects in Tanzania, SSA and globally (Wahl et al. 2012). Particularly for the Tanzanian case study, a number of papers focussed upon the respective implementation (van Eijck et al. 2014, Wiskerke et al. 2010, Grimsby et al. 2012, Romijn and Caniëls 2011, Segerstedt and Bobert 2013). However, to the authors knowledge, none of the former Jatropha based operations is still active.

Electrification

Electrification is, as outlined, a precondition for the development of modern industries and the application of modern technologies. Despite this crucial importance, the electricity coverage rate in Tanzania is low – it has been reported that only 2% of rural households and 39% of urban households have access to electricity (Sosovele 2010). Wiskerke et al. (2010) reports 10% as nationwide electricity access rate for 2001 while 90% of the country's energy requirements are obtained from traditional fuels. The annual growth rate of electricity demand in Tanzania is, according to Felix and Gheewala (2011), 9–10%. In SSA as whole, electricity access rates of roughly 25% have been reported but in the East African community, less than 10% of rural schools, clinics and hospitals have access (Brew-Hammond 2007). On a continent-wide basis, South Africa is estimated to account for about 50% of the continent's total installed electricity generation capacity (Karekezi 2002) while the total electricity generation capacity in all 48 countries in SSA remains low and in 2008 it equalled the capacity of Spain (Eberhard et al. 2008). The majority of electricity produced in Tanzania is fed into a central grid and is produced by hydro-power (Ahlborg and Hammar 2014). This production pathway increasingly faces challenges due to extended droughts (Sosovele 2010). Additionally, transmission and distribution losses in the national grid system have been reported to exceed 20% in Tanzania which is far beyond the world average (9.2%) (Dasappa 2011). The country has carried out a power sector reform including an increased encouragement of the private sector and the establishment of a rural energy agency that focusses on electrification beyond the grid network (Ahlborg and Hammar 2014). However, problems, particularly associated with corruption (Tansania Information 2014) persist. Electricity access in rural areas is still uncommon but an increasing number of projects and initiatives can be observed, particularly in the area of solar home systems where, for example, a German company is strongly involved (Pöppl 2014). Furthermore, independent electrification co-operatives are gaining increasing momentum in Tanzania despite substantially higher tariffs in comparison to the highly subsidised ones from the Tanzanian national electric company "Tanzania Electric Supply Company Limited" (TANESCO) (Ilskog et al. 2005). Nevertheless, a substantial lack of detailed evaluations on conducted energy access projects in rural areas of SSA has been reported (Ilskog and Kjellström 2008).

3 Methods

Although Tanzania ranks low in the Human Development Index (HDI) – 152 out of 187 (United Nations 2013a) – the country nevertheless frequently publishes agricultural data, among them the "national sample census of agriculture". Even though these nationwide data collections provide insights into the situation of agriculture in the country, a very recent one (2007/2008) is based on less than 50,000 interviews, representing approximately 0.1% of the population. Critical aspects in the framework of this thesis however – like cooking fuels – are furthermore not addressed in depth: a question like "energy use and availability in the household" including the subsection "main source of energy for cooking" (question 10.3.2; p. 184) for example, allows only one possible answer (Government of Tanzania 2011).

In sum, quantitative and qualitative data availability and collection in developing countries such as Tanzania has been characterised as challenging, both in terms of data quality and ease of the process. This was not different during the research stays for this thesis in the Rukwa and Kigoma regions, where, due to their remoteness, the process of scientific data collection was much less known among villagers and even some officials than in other areas of Tanzania such as the Morogoro region and the coastal regions.

3.1 Case study selection

Based on a literature analysis focussing on recently installed MFPs (cf. chapter 2.2) in Tanzania, Laela was selected as the main case study site (3 out of 4 papers). The reason was that the research objective of this thesis was embedded in the Better-iS research project which aimed, among other things, at defining the optimal setting for MFP installation in detail to derive on-hand information for scientific audiences and political decision makers. Although other MFPs in the country were identified in the villages of Engaruka and Leguruki, those were already case study areas for a number of scientific studies (Messemaker 2008). Alternative Jatropha projects in Tanzania were also under scientific analysis (Loos 2009, van Eijck and Romijn 2008).

Apart from these organisational aspects, the Rukwa region is a "food basket" region of Tanzania (Jerve and Ntemi 2009) growing, alongside maize, oil bearing crops such as sunflower and groundnuts: thereby providing a wide range of potential SVO to focus upon.

As no official data was available beforehand, sampling strategies had to be developed on-site in close collaboration with local governmental experts (e.g. agricultural extension officers), village and sub-village leaders as well as key informants in the respective villages

Figure 6 Ongoing FGI and group picture in Laela

(cf. figure 6). The latter were mainly individuals with a higher educational background (e.g. school teachers) and/or holders of traditional titles, mainly elders. Additionally, the research team identified influential women in the villages to include them in the discussion as the other key informants tended to be men in both case study areas.

The Kigoma region was selected as the secondary case study site (1 out of 4 papers) due to the existence of oil palm trees in the region which provided the opportunity to focus on an additional oil-bearing crop complementary to sunflower and groundnut. Furthermore, the biofuel production company “Farming for Energy for better Livelihoods in Southern Africa”

(FELISA), which focusses on producing biodiesel from palm oil, was active in the area at the time of the survey (Molony 2009). In addition to simulating the potential use of SVO directly in the case study villages (Illagala and Kagongo) – as realised in paper 4 – the city of Kigoma also offered the realistic option of utilising substantial quantities of SVOs, because the electricity for the whole settlement is produced by five diesel generators (Bertheau et al. 2014) fuelled with fossil diesel transported from Dar es Salaam (approximately 1400 km). Analogous to the case study site in Laela, sampling strategies had to be developed on-site. Experts for respective case study regions were identified either in the villages or on regional policy levels.

3.2 Quantitative data collection

Laela village

Data for this thesis was mainly derived from an in-depth household survey carried out in the case study village of Laela in Western Tanzania as well as an in-depth household survey carried out in the district of Kigoma. Furthermore, expert interviews as well as focus group discussions were conducted. The main survey was conducted in Laela. Here, 160 (n) out of the indicated 1260 (N) households were interviewed, resulting in a sample size of 12.7%. As this sample size would only have been able to provide limited answers in the case of randomized sampling, we also applied a stratified sampling process (United Nations 2005, Turner 2003). The resulting stratification is based on a definition of four income classes (ICs) in the village, mutually derived via focus group interviews with village representatives and key opinion holders, both male and female. To guarantee the validity of the results, the aim was to collect data from at least 30 households per IC. By applying this approach, different social groups in the village were displayed adequately as energy consumption is coupled to income, particularly when charcoal is taken into account (Lee 2013). The derived income classes are: IC1 ("rich"), IC2 ("above average"), IC3 ("self-sufficient") and IC4 ("Below self-sufficiency"). These classification schemes correspond well with the results of a wealth ranking exercise carried out by Nathaniels and Mwijage (2000), even though the society in their case study villages was categorized in three compartments ("wealthy", "middle-wealth" and "poorest"). Furthermore, their classification approach was based on individual interviews with three key informants – an approach most likely also applicable in Laela as well, even though in that case consensus was reached by discussing the classification with village representatives.

After this initial stratification of the households in Laela into ICs, the participants of the focus group interview mutually agreed upon a village list containing estimations of (1) the overall number of households per sub-village and (2) respective IC distribution per sub-village. Subsequently, the individual sub-village heads of all five sub-villages were asked – all were present in the discussion and their understanding of our research approach was therefore presupposed – to request that villagers in their sub-village participate in the interviews (judgemental sampling). Due to (1) time and budget restrictions, (2) the impossibility of sanctioning the sub-village leaders, or at least the ability only to comment critically on their selection, as their cooperation was vital for further research and (3) the impossibility of sending the present farmers away without paying them for an interview, interviews with farmers not belonging to the desired IC were nevertheless conducted. This occurred occasionally and resulted in an unequal number of interviews per IC (cf. paper 3) as well as in more than 30 interviews per IC. As a result of this sampling process, average values per IC, as extracted for paper 1 and 2, are based on an adequate number of interviews. According to the stratified sampling method, however, weighting factors had to be applied in order to derive results for the whole village.

For the subsequent calculations after data cleaning, the differentiation between the ICs was validated using statistical analysis, applying the t-test SPSS (version 15). Here, a clear significance for the main averaged factors such as "value of assets per household member (HHmem)" and "total savings per HHmem" could be proven for a differentiation between IC 1 and the other ICs (cf. paper 1). In addition to these published values, other ones additionally prove this discrepancy between the ICs (Annex 2). Even though this very high differentiation in wealth initially appears to be unexpected, our results are in line with Willis (1981; p. 124) who outlines, with reference to the inequality in cultivated holdings, that these are a "*visible index of a social order that is relatively stable and durable*". Furthermore, he reports that in his four case study villages, 18% of the adult male population held plots that amounted to more than half of the total village land under cultivation while these agricultural production areas are also more optimally located as being closer to the villages. These findings are verified by Tröger (2004), who traces these unequal power and wealth distribution back to the Ujamaa period and reports that the wealthy households are the ones who settled in the village originally before additional Tanzanians were forced to migrate – obviously restricting the access of the latter to the most fertile areas.

Thus it appears logical that the social inequality reported by Willis (1981) as well as Tröger (2004) culminated in strong economic inequalities at the time of the village survey in 2010.

Applied conversion factors for local units

As derived values from the villages were given in the locally applied "*gunia na debe*" system ("bag and bucket") (Zorya and Mahdi 2009; p. 14), recalculations into Standard International (SI) had to be applied. Particularly for traditional units of energy consumed, we applied 15 kg for a headload of firewood and 28 kg for a bag of charcoal; the respective energy values decided upon are 15.0 MJ/kg and 30.8 MJ/kg. Even though we tried to define the weight of each unit orally in the village – a procedure necessary because no measurement gauges were present due to the use of the "*gunia na debe*" system – the given values meandered widely. Zorya and Mahdi (2009) outline the challenges in the Tanzanian maize markets by applying the local units and outline an error margin of 40%, particularly for the units "bags". This comes from overfilling maize bags ("*Rumbesa*" phenomenon). Furthermore, a frequently cited paper[8] also focussing on biomass energy supply in Tanzania also reports from the data collection in four case study villages the weight of a headload to be between 13 and 30 kg. As a result, the authors discard the value of 30 kg but adopt a number of literature sources. In sum, 16 kg was chosen as the factor for a headload of firewood while applying 15.9 MJ/kg (Wiskerke et al. 2010). An overview of respective weights of charcoal units as well as firewood units is presented in Annex 1. Additionally, a more detailed overview about traditional kiln efficiencies is provided.

3.3 Qualitative data collection

To complement the quantitative data collection, seven expert interviews and four focus group discussions were conducted to embed the quantitative data in a broader perspective.

The derived data included information about the sunflower value chain and specifically aspects about the failed MFP installation. It also allowed us to gather insights into the wider natural surroundings and generally enabled us to build up trust between the villagers and the research team.

A clear advantage was the opportunity to better characterise the ICs. The poorest IC, IC4, for example, was outlined as consisting, among others, of people with disabilities and older people, whereby it was estimated that their harvest lasts for 3–4 months to feed only themselves. As a result, these HH are forced to work as casual labourers during the rest of the year – this group was also characterised as being involved in charcoal production. In contrast, the HHs of IC1 were characterised, apart from working on their fields, as being also strongly involved

8 33 citations (30.09.2015)

in off-farm activities such as trading and processing. With reference to the overall situation of Laela, the participants of the FGI estimated that 10–15% of their agricultural area only could be characterised as fertile while the main (environmental) problems outlined were deforestation, population growth and a decline in precipitation. The main outlined underlying reasons for deforestation are (in this order): (1) charcoal production, (2) brick production, (3) firewood, (4) wildfires, (5) livestock (grazing) and (6) timber extraction. Counter measures suggested include a general awareness-raising campaign and general encouragement to plant trees and enforce environmental by-laws.

However, the qualitative data collection boosted the understanding of the researchers and helped to foster closer collaboration with key persons in the village.

4 Case studies

The main household survey was conducted in the remote settlement of Laela (latitude: -8.572949; longitude: 32.045885) situated in the municipality "Sumbawanga rural" – and on the geological unit "Ufipa plateau" – in the Rukwa region/Western Tanzania. This survey was the foundation for the papers 1, 2 and 3 (chapter 5.2, 5.3 & 6.2) and allowed in-depth analysis of the energy development potential. In the following chapter, different aspects and details about the wider region and, where possible, reasonable and necessary, about the municipality will be outlined to increase understanding for the local setting and frame the papers and subsequent results of this thesis.

4.1 Main case study site Laela

Geographic location

The Rukwa region is located between 3° and 9° south of the equator and between 30° and 33° east, bordering Zambia in the south, the Tanzanian regions of Tabora and Mbeya in the East, the region of Kigoma in the North and Lake Tanganyika in the West, the latter being the Western arm of the Great Rift valley (Urassa 2010). The total area of the region is estimated at 75,000 km^2, 9% of this being inland water (Government of Tanzania 2007). The World Bank (2007) reports that although 34% of the total area is characterised as arable land, only 25% of this (8.5% of the total area) is cultivated – large areas are nearly inaccessible due to poor infrastructure and/or tse-tse fly infestation. The agricultural sector is dominated by small-scale farmers and approximately 70% of the cultivated land is used by farmers managing between 0.5 and 2.0 ha (The World Bank 2007). The local forests are characterised by Burgess et al. (2010; p. 343) as being "*Central Zambezian miombo woodlands*" – further details on this specific type of African forested area are outlined by Campell (1996).

Rukwa is located on the Central African plateau and is characterised by its remoteness, indicated by the general lack of paved roads and the non-availability of a railway line. The World Bank (2007) reports 4700 km of roads with only 8.5 km paved (0.2%). The region is subdivided into four main administrative units: Nkasi, Mpanda, Sumbawanga urban and Sumbawanga rural, the latter including the case study village Laela.

Climate & soils

According to the Government of Tanzania (2007; p. 1), the region "*enjoys favourable climate conditions*" with average rainfall ranging from 800 mm to 1300 mm and a unimodal rain season from October/November to April/May (Wandel and Holmboe-Ottesen 1992); Brown and Abell (2013) even reports 2500 mm in the Ufipa Highlands. The rainfall has been characterised as reliable for a long period but in recent years, low rainfalls became common (The World Bank 2007). This potential climate change indicator is plausible and likely to increase further as for example Rowhani et al. (2011) expect a nationwide increase in temperatures of between 2°C and 4°C by 2100. In accordance with these reports, Jerve and Ntemi (2009) report anecdotal evidence outlining a drop in the ground water table in many areas and a decline in yields per acre in dry-land farming. Arndt et al. (2012) on the other hand, forecasts, based on crop models, a maximum maize yield increase of 2% in the best case but also reductions of up to 10% for Sumbawanga rural by 2050.

The annual mean maximum temperature in Rukwa varies between 24°C and 27°C, the annual mean minimum temperature varies between 13°C and 16°C (Government of Tanzania 2007).

The World Bank (2007) distinguishes between six agro-ecological zones in Rukwa with different soil characteristics, altitudes and precipitation regimes. The Ufipa plateau, the second largest zone, is characterised as gentle plains with moderately sloping hills, ferralic soils (EU Commission 2013), an altitude between 1000 and 2500 m and precipitation between 800 and 1200 mm; Urassa (2010; p. 191) further specifies the soils as "*predominantly leached, acidic and ferralic with loamy or sandy top soils becoming more clay in depth*", Tröger (2004; p. 263) characterises the land surrounding Laela as "*marginal*".

Society

A number of different tribes have settled in the region (Fipa, Lungu, Mambwe and Nyika) whereby all, except the Nyika, belong to the Wafipa people (Tröger 2004). Furthermore, large groups of refugees are living in the region, having been displaced mainly from Burundi and the Democratic Republic of Congo (DRC) (Urassa 2010). The lingua franca in the region is Kiswahili although other tribe specific languages are also in use (Kifipa, Kimambwe, Kilungu, Kikonongo, Kinyamwanga) (The World Bank 2007). From a historic perspective, the Rukwa region was strongly affected by the national villagisation programme ("ujamaa") (von Freyhold 1979) during the socialistic period in the 1970s – a relocation and concentration program of the population due to optimised political control, agricultural production and social welfare (Tröger 2004) – when 77% of the region's population was resettled (Jerve and Ntemi 2009). Potentially due to the geographical isolation of the area, Rukwa (and particularly Sumbawanga) remains one of the regions in Tanzania that reports frequent superstition triggered attacks on albinos (Migiro 2015) and the Wafipa (or Fipa) are known until today for being "*masters of* *witchcraft*" (Jerve and Ntemi 2009; p. 11). Furthermore, the population on the Ufipa plateau is challenged by an increasing erosion of traditional mechanisms guaranteeing social coherence with negative effects on food security, particularly for food-insecure households (Tröger 2004).

The region is experiencing dramatic population growth that even exceeds the national average: 3.6% (1988 to 2002) and 2.9% respectively (Jerve and Ntemi 2009) and negative impacts on living conditions including food security have been forecasted (Tröger 2004). A major reason for immigration is the common belief in Tanzania that Rukwa is one of the few regions where agricultural land is still available (Jerve and Ntemi 2009). Although correct for some regions it is essential to note that particularly on the Ufipa plateau land shortages have been reported (The World Bank 2007) – Wandel and Holmboe-Ottesen (1992) had already reported sporadic one-way travel distances of two hours to reach fields for some households. A major segment of the immigrants are agro-pastoralists from Tabora, Shinyanga and Mwanza and almost inevitable conflicts between farmers and livestock keepers have been reported (The World Bank 2007). Nevertheless, the Rukwa region is still among the Tanzanian regions with the lowest percentage population distribution by region (Government of Tanzania 2013).

Life expectancy was, according to the national census of 2002, 55 years, but has since been reduced to 45 years particularly due to HIV/Aids according to the World Bank (2007). However, the government of Tanzania (2006) forecasts life expectancy to increase from 45 years in 2003 to 52 in 2025.

Economy

The major backbone of Rukwa's economy is agriculture. According to Urassa (2010) and Jerve and Ntemi (2009), 90% of the region's economically active population is engaged in mainly small-scale agriculture while the industrial development is negligible. However, some mining activities are ongoing but quantification seems to be difficult since much of the incomes generated are not registered (Jerve and Ntemi 2009). Although the Katavi National Park is located within the region, its touristic importance is very limited due to the concentration of tourism in the north of Tanzania (Arusha) and the very limited accessibility (Urassa 2010).

Natural resources

In total, 6.9 million ha of area coved by forests have been reported for the Rukwa region with 26% of this located in Sumbawanga rural – less than 2% is demarcated as forest reserve (The World Bank 2007). Concerning the use of these resources, Jerve and Ntemi (2009; p. 18) report that deforestation in low-land areas has "*escalated*" but that this is not only a recent phenomenon as the Fipa people had used slash-and-burn practices (*ntemele*) for centuries – however, the villagisation process and the ever-since increasing population growth have accelerated the process beyond the limits of sustainability. This is particularly true for the densely populated Ufipa plateau which is characterised by Urassa (2010; p. 191) as "*almost deforested plateau with open grassland vegetation*". Willis (1981; p. 124) also describes the settlement structure of the region as "*villages* [...] *separated from other villages by wide expanses of apparently empty and largely treeless countryside*" and furthermore specifies that "*it is possible* *that the Fipa plateau was not always barren of trees, and that at one time it was clothed with tropical forest that was virtually destroyed by the activities of a population of slash-and-burn cultivators*". Counter measures initiated by donors (e.g. Rukwa Integrated Rural Development Programme (RUDEP)) faced a multitude of challenges including (1) the continuous practice of *ntemele* resulting in annual bush fires during the dry season, (2) reluctance to invest in tree planting due to non-existent or unsafe land titles – a challenge also known from, for example, Namibia (Palmer and MacGregor 2008; p. 21) – so making profit is highly uncertain and (3) strongly increasing demand for firewood due to population growth also results in an exploding demand for burnt bricks (Jerve and Ntemi 2009). Particularly for the Ufipa plateau, 700,000 ha or 46% have been reported as being "*completely deforested*" (The World Bank 2007; p. 15).

In addition, the use of traditional farming practices aiming at conserving soil fertility (*intumba*; a system of compost mounding) declined (Tröger 2004, Willis 1981) which led to increasing pressure on the natural resources.

Agriculture and food security

The staple foods in the region are maize, rice and beans, other food crops commonly produced and consumed are groundnuts, finger millet, sweet potatoes, sorghum, wheat and sugarcane (The World Bank 2007). Since the 1970s, there has been a gradual shift from millet as a major food crop to maize (Wandel and Holmboe-Ottesen 1992) that was accompanied by the widespread use of "modern" techniques of cultivation, namely ploughing and the use of fertilizer. However, this shift was associated with negative impacts on nutrition security as dishes made from maize tend to have low energy density due to a high water-binding capacity and therefore generally a low nutrient content.

Recently introduced cash crops are Irish potatoes and especially sunflower, the latter introduced in the mid-1990s (Jerve and Ntemi 2009); Wandel et al. (1992) for example do not report sunflower production in the early 1990s. Furthermore, tobacco cultivation plays an increasingly vital role in the area around Mpanda (The World Bank 2007).

In the district "Sumbawanga rural", only 5.9% of the residential households are able to consume three meals per day and 48.2% report food insufficiency at least occasionally (Government of Tanzania 2007). The data for the Rukwa region as a whole, derived from Government of Tanzania (2007) and Government of Tanzania (2012b), is outlined in figure 7.

On the contrary, Jerve and Ntemi (2009; p. 19) summarise that "*Rukwa is still a poorly developed economy, but food is generally available*" and that "*poverty levels remain high, while extreme poverty linked to food deficit is low*." Wandel et al. (1992; p. 1) furthermore reports that "*in spite of a surplus production of grains, the area has a relatively high rate of malnutrition among preschool children*". The latter might be explained by an additional paper, highlighting that male selling strategy (explicitly against the will of women[9]) rather than insufficiencies in harvest were often the reason for food shortages (Wandel and Holmboe-Ottesen 1992).

9 The authors furthermore highlighted that a *"higher educational background for the mother tended to relate to a longer period with maize in stock, whereas there was the opposite tendency for the father"* (p. 106)

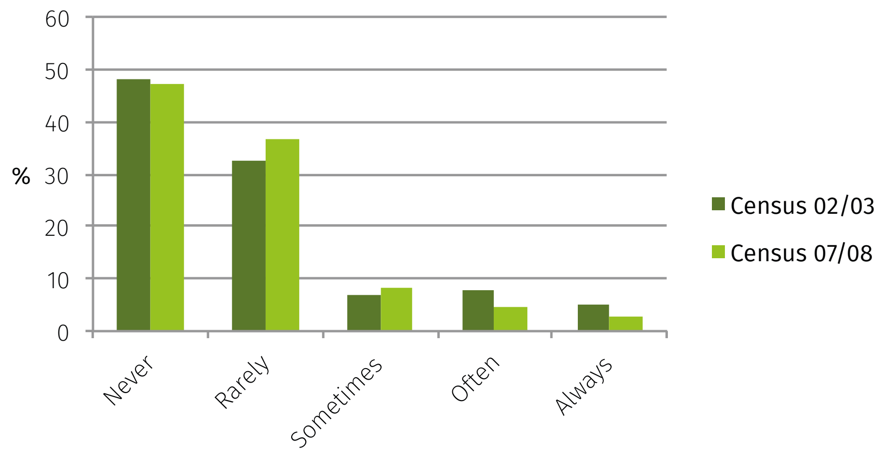

Figure 7 Frequency of problems satisfying the household food requirements according to the official census 02/03 and 07/08 in the Rukwa region

During the mid to late 1970s, Rukwa region was nevertheless outlined by the authorities as a “food basket region” and it was central to the National Maize Project that started in 1976 (Jerve and Ntemi 2009). Furthermore, the agricultural production in Rukwa region increased three times between 1989/90 and 2005/06 with particular growth in the production of traditional food crops such as finger millet, cassava, sweet potato and sorghum – an explanation for the latter might be that new migrants are settling in areas less suitable for maize and beans (Jerve and Ntemi 2009).

4.2 Excursus: Secondary case study site Kigoma

The two secondary case study sites, the villages Kagongo and Illagala, are situated in the region of Kigoma which is located on the shores of Lake Tanganyika in North-West Tanzania. The geographical situation of the region is between longitudes 29.5 and 31.5 East and latitudes 3.5 and 6.5 South and has an area of 45,000 km^2 (Government of Tanzania 1998) bordering the Rukwa region in the south, Tabora region in the east and Shinyanga as well as the Kagera region in the north. The majority of the region is covered by arable land and grazing area (27%) as well as natural forests (45%) and its topography varies between 800 m at the shores of lake Tanganyika to 1750 m in the eastern part (Government of Tanzania 1998). The precipitation in the region is unimodal with precipitation between 600 to 1500 mm annually. Mean daily temperatures range between 25°C in December and 20°C in September. The soils along the lake shore, where the case study villages are situated, are characterised as *“deep and well drained comprising dark reddish brown fine sandy loams partly stony and severely eroded”* (Government of Tanzania 1998; p. 3).

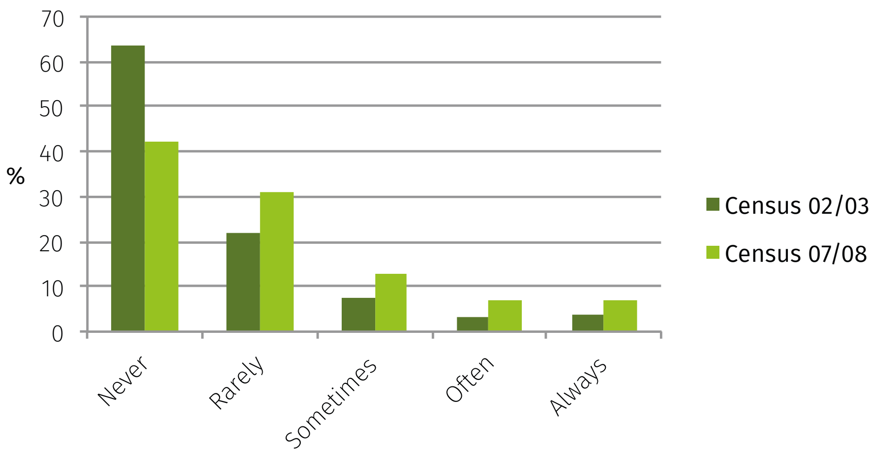

Figure 8 Frequency of problems satisfying the household food requirements according to the official census 02/03 and 07/08 in Kigoma region

The food security situation in Kigoma is slightly better when compared to Rukwa (cf. figure 8). As in the case of the Rukwa region, maize production dominates cereal production in the region (Government of Tanzania 2008) alongside cassava, beans and especially oil palm production (Government of Tanzania 1998).

Official statistics about palm oil production in Kigoma region however, differ widely: While the Government of Tanzania (2008) reports 40,500 tonnes palm oil production by 15,800 smallholders on 10,290 ha as the outcome of the national agricultural census in 2002/2003 (3.9 tonnes per hectare) the Government of Tanzania (2012a) reports as a result of the national agricultural census 2007/2008 a total of 12,000 tonnes of palm oil production by 30,900 smallholders on 20,700 ha (0.58 tonnes per hectare) – why these differentiations are so substantial (factor 6.7) is beyond our analysis but might underline the challenges of data collection in developing countries as outlined in chapter 3.

However, Kagongo and Illagala were selected due to mutual agreement with local experts outlining the palm oil production in the wider region being adequately displayed by these examples – they were chosen as they represent acceptable case study sites for the range of palm oil growth options.

In the existing range, Kagongo (coordinates: 4°47’40.0’’S; 29°38’53.1’’E) was selected as an example for comparably unfavourable natural conditions for palm oil production and Illagala (coordinates: 5°11’51.6’’S; 29°50’34.8’’E) as being relatively favourable. As researchers operating in the region have to present their projects to the regional authorities, these governmental experts functioned as one main pillar of case study selection while the local experts of the only biofuel company in the region focussing on palm oil (FELISA) (Molony 2009, Hongo and de Keyser 2005) functioned as second main pillar.

Kakongo is situated 15 km north of Kigoma city and is characterised by a hilly landscape with comparably low soil fertility according to expert interviews. The main staple crops in both villages are maize and cassava accompanied by beans and groundnuts while the major permanent crops are palm oil trees, nearly exclusively grown by small-scale farmers in mixed cropping systems.

Illagala, in contrast, is, due to its location at the river banks of one of the main Tanzanian rivers – the Malagarasi – favoured as water availability is neither in agriculture nor in processing a limiting factor. Furthermore, the starting point of the Malagarasi delta area is situated here.

Even though the settlement is situated 60 km south of the main regional settlement, Kigoma city, the infrastructure is challenging as dirt roads are the main routes. The village is has a land area of 24,000 ha (Mwageni et al. 2015).

5 Traditional bioenergy

5.1 Introduction: The context of the papers

As outlined in the state of the art research (chapter 2) (combined) approaches towards improved production and utilisation of traditional bioenergy are essential for long-term sustainability in the context of forestry and erosion control, work load (rural areas) as well as expense minimization (urban areas), food preparation and respiratory health particularly among women and children. Although all these aspects are crucial and, with different levels of intensity, are focussed on through a variety of different donor approaches in Tanzania, none of these approaches successfully reached the Rukwa region by the time of the survey (Jerve and Ntemi 2009). Firewood scarcity in particular was reported as becoming an increasing challenge in Laela during the focus group interviews conducted (cf. chapter 3.3). Clear indications for this were increasing incidents of firewood theft in the few private forests remaining on the one hand and the increasing use of corn cobs as fuel on the other. Expert interviews as well as own trajectory walks furthermore revealed that uncontrolled charcoal production was also a problem for sustainability in the forest sector. However, in addition to the use of traditional

Figure 9 Deforestation due to expansion of agricultural area in the hills north of Laela

bioenergy, forest clearance for agricultural purposes also played a role in deforestation (figure 9) and provides virtual evidence from the southern slopes of the hills north of Laela. In these recently established fields, the leftovers of forest clearance can still be seen.

Based on the traditional bioenergy-related findings from the quantitative survey, however, the introduction of ICS as well as optimised charcoal production techniques were simulated for the settlement of Laela in papers 1 and 2. By applying this approach, it was shown that the current quantity of traditional bioenergy used will increase in the years and decades to come. To substantiate claims for potential donor or governmental programs, the potential introduction of firewood-efficient stoves as well as the potential introduction of efficient kilns is therefore simulated, resulting in massive relief for the natural environment and subsequently for the small-scale farmers who depend the most on healthy and sustainable surroundings.

5.2 Paper 1

Traditional biomass energy consumption and the potential introduction of firewood efficient stoves: insights from Western Tanzania

Reg Environ Change
DOI 10.1007/s10113-014-0738-1

Traditional biomass energy consumption and the potential introduction of firewood efficient stoves: insights from western Tanzania

Harry Hoffmann · Götz Uckert · Constance Reif · Klaus Müller · Stefan Sieber

Received: 10 March 2014 / Accepted: 24 November 2014

Abstract Having access to firewood and charcoal for cooking purposes is essential for the world's poor. In this paper, we outline the consumption patterns of firewood and charcoal energy recorded at a specific south-western Tanzanian village (Laela) based on a household survey carried out in late 2010 ($n = 160$). We identify varying consumption rates among four relative income classes (rich, above average, self-sufficiency, below self-sufficiency). We furthermore simulate the effects of different dissemination levels (10, 25, 50, 100 %) for a specific type of efficient wood stove over the years 2010, 2015 and 2030, with a predicted increase in future energy consumption rates that correspond with population growth. Our findings suggest that energy consumption will increase until 2030. We also foresee excellent energy-saving potentials in different diffusion and adaptation scenarios. The limitations of the study as well as its developmental potentials are also addressed with one focus on the possible effects on local forests. The factors utilised and the results obtained are discussed and compared with other values drawn from the current literature. Furthermore, the pro-poor development potential is examined by using the energy-saving capacity of different dissemination/adaptation scenarios. Additionally, hurdles and hypothetical setbacks that may occur during the process of efficient stove dissemination are described. In sum, our findings highlight the need for efficient stove diffusion programmes to carefully incorporate weaker income classes within rural communities.

H. Hoffmann (✉) · G. Uckert · C. Reif · K. Müller · S. Sieber
Leibniz Centre for Agricultural Landscape Reserach (ZALF) e.V., Eberswalder Straße 84, 15374 Müncheberg, Germany
e-mail: harry.hoffmann@zalf.de

Keywords Firewood · Charcoal · East Africa · Energy efficiency · Deforestation · Land-use conflicts

5.3 Paper 2

Efficiency scenarios of charcoal production and consumption – a village case study from Western Tanzania

Seite 52–65

Efficiency scenarios of charcoal production and consumption – a village case study from Western Tanzania

Harry Hoffmann[1,*], Dr. Götz Uckert[1], Dr. Constance Reif[1], Dr. Frieder Graef[2], Dr. Stefan Sieber[1]

Acknowledgments

We would like to express our gratitude to the helpful and friendly people of Laela and the German Federal Ministry for Economic Cooperation and Development (BMZ) as well as the German Federal Ministry of Education and Research (BMBF) for financing the projects Better-iS (http://www.better-is.com/) and Trans-SEC (http://www.trans-sec.org). Furthermore, we thank the Advisory Service on Agricultural Research for Development (BEAF) of the Deutsche Gesellschaft für Internationale Zusammenarbeit (giz) for facilitating the project Better-iS. Additionally we thank the Leibniz-Centre for Agricultural Landscape Research ZALF e.V. for financing FSA-Africa which additionally supported this publication.

Abstract

Traditional bioenergy, explicitly firewood and charcoal, is the most important cooking energy source in Sub-Saharan Africa. As particularly charcoal consumption is – in line with urbanisation and population growths – increasing strongly in Tanzania, this article provides case study insights from Western Tanzania focussing on (1) uncovering forest resource depletion associated with charcoal usage, mainly in very low conversion rates, as the kiln technology locally applied is highly wasteful in resources. Furthermore, (2) the effects of the potential introduction of efficient charcoal stoves is calculated and related to respective efficiency increases in the charcoal production process for the reference year 2030. We focus in our analysis on four different income classes to mirror the respective resource consumption per economic segment. Our results show that an increase in kiln efficiency would substantially lower forest resource consumption, particularly from richer, mainly charcoal consuming income classes. It is furthermore concluded that a combination of the introduction of efficient charcoal stoves and an increase in conversion efficiency provides optimal resource conservation results. We furthermore urge policy makers in the country to develop a consistent traditional biomass policy supporting particularly poorer households and to reduce current unsustainable forest consumption.

Keywords

Traditional biomass, charcoal, firewood, efficient stoves, Tanzania, land use conflicts

1. Introduction

Energy is scarce in developing countries and energy poverty is a prevailing phenomenon, with dry regions in Africa especially affected (Wiskerke et al. 2010). In Sub-Saharan Africa (SSA), woodfuels[1] account for more than 80% of the primary energy supply and more than 90% of the population depend on these so-called traditional energy carriers, mainly for cooking purposes (Iiyama et al. 2014). However, fuelwood[2] consumption dominates overall energy consumption (Maes and Verbist 2012). This dependency on woodfuels has not changed considerably in the last decades in SSA (Kammen and Lew 2005) or in Tanzania (Butz 2013; Menéndez and Curt 2013; Kaale 2012; Peter and Sander 2009). Projections

1: Leibniz Centre for Agricultural Landscape Research (ZALF), Institute of Socio-Economics, Eberswalder Straße 84, 15374 Müncheberg, Germany

2: Leibniz Centre for Agricultural Landscape Research (ZALF), Leibniz Centre for Agricultural Landscape Research, Eberswalder Straße 84, 15374 Müncheberg, Germany

*: Corresponding author (harry.hoffmann@zalf.de, tel.: +49 (0)33432 82-113; fax: +49 (0)33432 82-308)

1 Woodfuels are defined by FAO as "*Fuel from wood sources including solids (fuelwood and charcoal), liquids (black liquor, methanol, and pyrolitic oil) and gases from the gasification of these fuels*" (FAO 2008) - In the rural Tanzanian context, woodfuels are exclusively either "fuelwood" or "charcoal".

2 Fuelwood is defined by FAO as *"Wood in the rough (such as chips, sawdust and pellets) used for energy generation"* (FAO 2008) – in this paper, we perceive the terms "fuelwood" and "firewood" to be interchangeable.

also do not predict major consumption changes (Iiyama et al. 2014) and in 2030, biomass use will still account for at least 75% of residential energy in SSA with the total number of consumers rising by more than 40% during 2000-2030 (Arnold et al. 2006). Furthermore, the population in Tanzania is predicted to quintuple by the end of the century (United Nations; Department of Economic and Social Affairs; Population Division 2013) with corresponding consequences for energy demand - similar coupled growth in demand for biomass in line with population growth is predicted for Uganda (Okello et al. 2013). Following Steierer (2011), Tanzania produced 3% of global charcoal while China and India both account for 4%. In addition to this, climate change and its effects on agriculture and forests (Ahmed et al. 2011) will likewise trigger and amplify trends of land-use change and increase pressure on natural resources.

Although the contribution of charcoal to national energy consumption is currently still rather small, growth rates of 1% for firewood and 3% for charcoal between 2000 and 2010 in SSA have been reported – the latter being higher than the average population growth (Iiyama et al. 2014); Zulu and Richardson (2013) predict a doubling of charcoal consumption and a 24% increase in firewood consumption by 2030.

Charcoal production in SSA, including Tanzania, is mainly carried out in traditional earth-mound kilns (Iiyama et al. 2014), which can be described as stacks of wood sealed with a cover layer of organic material (leaves, grass) and a soil cover to avoid uncontrolled oxygen supply (Annex 1). An improved method additionally includes a reusable metal chimney and a foundation designed to optimise smoke and heat transfer inside the kiln ("Casamance kiln"; cf. Annex 2) (Vos and Vis 2010; Schenkel et al. 1998). One reason for the comparably low efficiency of traditional kilns is that poor design leads to unequal oxygen flow resulting in pockets of fully burnt material close to pockets of uncarbonised wood (Kimaryo and Ngereza 1989). In both production pathways, setting fire to the stack of wood initiates carbonisation – a detailed description of the process is outlined by Schenkel et al. (1998) and Emrich (1985). The efficiency of the production process depends on a variety of factors such as the production method applied (traditional vs. improved kilns), wood density (tree species), size and order of wood pieces used, billet moisture, size of the kiln, final temperature of carbonisation, time of treatment, adequate handling (for instance avoidance of charcoal fines), mechanisms (or lack thereof) for extinguishing fires and even on the weather conditions (Kimaryo and Ngereza 1989; Mwandosya and Luhanga 1993; Schenkel et al. 1998). Apart from these rather technological aspects (Sepp and Mann 2009), the producer's level of experience is another important determining factor of production efficiency – potentially even more important (Kammen and Lew 2005). It is estimated that 80% of Tanzanian charcoal is produced illegally (Wiskerke et al. 2010; Peter and Sander 2009) by unskilled, rural, marginalised groups who often operate in times of food and/or income shortages, in particular at the end of the dry seasons (Tabuti et al. 2003). Business involvement in charcoal production is therefore reported to be mainly based on the unavailability of other income sources (Arnold et al. 2006). In one specific case study, mainly women were involved in the production process (Butz 2013). Producers receive, according to (Peter and Sander 2009), van Beukering et al. (2007) and Sander et al. (2013) only one third of the revenue. Nevertheless, an increasing number of producers are entering the market year by year as prices continue to rise (van Beukering et al. 2007; Sander et al. 2013). The result is that gaining substantial, long-lasting experience as well as mastering improved techniques to maximise production efficiency is uncommon among producers. According to Butz (2013), population growth, drought, social and economic marginalisation and lack of other marketable resources are the main causes of the rapid increase in charcoal production in the country. In addition to lacking know-how, improvements such as the inclusion of a chimney or better piling techniques are either unknown or require investment beyond the 20 US$ calculated as necessary for reusable tools for the traditional earth mound technique (Felix and Gheewala 2011). Reasons why producers are reluctant to invest include a lack of investment capacity and risk aversion; the latter is due to possible confiscation by authorities (as production is illegal), or the risk of theft of equipment during production. Beyond sustaining inefficient production and unregulated tree felling, the illegality of the charcoal sector additionally leads to tax losses of about 100 million US$ annually (Peter and Sander 2009). However, the conversion process of the vast majority of charcoal produced in Tanzania is inefficient, with total charcoal kiln efficiencies reported to vary between 8 and 30%, most likely depending on the calculation methods applied (van Beukering et al. 2007; Kammen and Lew 2005; Tabuti et al. 2003; Mwandosya and Luhanga 1993; Kimaryo and Ngereza 1989; Allen 1985; Abdallah and

Monela 2007; Maes and Verbist 2012; Mwampamba 2007; Peter and Sander 2009; Karsenty et al. 2003; Emrich 1985). Vos and Vis (2010) report that producers in the field find reaching carbonisation efficiency between 25% and 30% very challenging; MacCarty et al. (2010) outline energy losses in the charcoal production process to reach 70%. However, the charcoal value chain, although most likely destructive and inefficient, might at least be perceived as a means of transferring financial assets from urban to rural areas (Hiemstra-van der Horst and Hovorka 2009) and fuelwood production and trade serves as a safety net for the poorest people (Maes and Verbist 2012).

On the consumption side, efficiency gains can be achieved by using alternative, more efficient charcoal stoves ("rocket-type"), where energy savings of 33% on average are reported by MacCarty et al. (2010) in comparison to traditional charcoal stoves – related reports of 80% energy savings (Simalga and Maliwichi 2011) seem rather unlikely under field conditions. Moreover, usage habits can furthermore strongly affect performance (Bentson et al. 2013). However, the diffusion of efficient charcoal stoves in Tanzania is limited, with a market penetration rate of, depending on the author, only between 20 and 40% even in urban areas (Peter and Sander 2009). Reasons for this low penetration are past failures of programmes, lower efficiency rates under field conditions (MacCarty et al. 2010; Adkins et al. 2010) and a lack of political support (Zulu and Richardson 2013). The status as a political "blind spot" of charcoal and woodfuels in general is verified for the entire SSA region (Zulu and Richardson 2013; Ghilardi et al. 2013) and Tanzania in particular (Sander et al. 2013). It is also shown to be extremely counterproductive, as charcoal is indisputably a highly important sector of the Tanzanian economy – the value chain for supplying Dar es Salaam alone is associated with one million jobs and revenues of 350 million US$ (van Beukering et al. 2007; Sander et al. 2013). In contrast to this, costs for intensification of information and marketing campaigns for improved stoves are estimated at 1.5 million US$ nationwide (Peter and Sander 2009). However, formalising the value chain is also associated with certain risks and challenges as outlined by Schure et al. (2013). The development and diffusion of more efficient charcoal conversion technology and general production know-how can nevertheless contribute to improved management and better regulated demand and supply of wood energy in Tanzania (Mwandosya and Luhanga 1993).

Whereas firewood is mainly the fuel of the (rural) poor, charcoal is in contrast the energy carrier of the (urban) rich (van Beukering et al. 2007; Maes and Verbist 2012; Chidumayo and Gumbo 2013) as 80% of the latter but only 5% of the former are estimated to utilise charcoal (Mwampamba 2007; van Beukering et al. 2007; Maes and Verbist 2012). The reasons for preferring charcoal include a higher energy content per volume, easy storage due to resistance against insects and excellent burning characteristics including less smoke production (Kammen and Lew 2005). On a quantitative basis, it was estimated the total annual charcoal consumption in Tanzania is one million tonnes (Peter and Sander 2009) with Dar es Salaam alone consuming 1600 t per day (Sosovele 2010) while a more recent study outlines the national consumption at two million tonnes (CAMCO 2014). However, charcoal is not exclusively consumed by the urban and semi-urban population but also by wealthier households in rural regions where its production is a major contributor to the income of the marginalised poor (Kammen and Lew 2005).

Of special importance for Tanzania are deforestation and forest degradation effects associated mainly with charcoal production but also occasionally with firewood collection (for related discussion viz. Hoffmann et al. (2015)). Chidumayo and Gumbo (2013) ascribe 33% of Tanzanian deforestation occurring in 2009 to charcoal production (globally the first place), while Mwampamba (2007) claims a plausible percentage to be even between 30% and 60%. In any case: The profits from charcoal production do not incorporate the hidden costs in the current production and consumption cycles (Tabuti et al. 2003; Luoga et al. 2000). Counteractive measures such as a switch in energy sources or efficiency increases in production and consumption are subsequently indispensable, especially if future population growth is included in the planning processes. However, although the first option is tempting as for instance one litre of domestically produced ethanol gel ("biofuel") could replace two kilogrammes of charcoal (Mitchell 2011) or an LPG industry could potentially be fuelled by domestic sources, it has been reported to be unrealistic in the near future due to fiscally unsustainable levels of subsidies, a lack of required infrastructure and household incomes that are generally too low for purchasing alternative fuels (Iiyama et al. 2014). Moreover, according to Zulu and Richardson (2013), putting too much faith in the "energy transition" theory has in the past undermined realistic and proactive policymaking on charcoal in SSA.

Despite the high importance of woodfuel energy production and consumption in developing countries and especially SSA, detailed local energy case studies and corresponding local projections are rare. If data is available, it is mainly aggregated on the national scale but high variances for different approaches and from different sources are common (Iiyama et al. 2014) – Bailis (2009) exemplifies this in a Kenyan case study. One reason for these fluctuations is that national projections "do not capture local complexity" (Mahiri and Howorth 2001). For Tanzania, Mwandosya and Luhanga (1993) characterised national estimates about woodfuel consumption, woodfuel demand, wood supply, tree stocks and yields as "extremely uncertain". Understanding the "charcoal challenge" in its full complexity is currently hindered by data gaps as outlined by Foell et al. (2011), Chidumayo and Gumbo (2013) and Kammen and Lew (2005). Johnson and Bryden (2012) subsequently called for more "detailed energy studies for isolated rural villages where many of the world´s poor" live. With regard to mitigating the negative effects associated with charcoal, Iiyama et al. (2014) conclude that "major components of an integrated strategy for a sustainable charcoal industry are improved kilns, improved cooking stoves and sustainable supply in the framework of enabling policies". In accordance with these requirements we base our analysis on household energy data calculated for a Tanzanian local case study village in the Rukwa region – a remote area for which no energy data was available until recently (Hoffmann et al. 2014; Hoffmann et al. 2015).

Consequently, the objective of this paper is (1) to assess the close-to-real quantity of pre-carbonisation fuelwood associated with the charcoal consumption of different income classes (ICs) in 2010 for a case study village in Western Tanzania. For the 2010 "close-to-real" reference scenario (baseline scenario), a conservative efficiency rate of 11.1% is defined as we found the applied technology to be rudimentary (cf. Annex 1). Based on the baseline scenario under (1), the (2) effects of different production and consumption pathways are projected for the reference year 2030 focussing on different levels of kiln efficiency as well as different levels of efficient stove dissemination, referring to the distribution of efficient stoves within the village (Kees and Feldmann 2011). The increased rate of energy consumption is defined in accordance with population growth only: we assume no technical progress, no changes in consumption behaviour and no changes in per capita consumption and therefore presuppose linear correlation in latter factors to mirror remoteness of the region. Additionally, basing the population growth projections on official documents for the reference scenario allows the derivation of implementable and hands-on policy recommendations from our range of findings.

2. Case study area

Rukwa region is one of the most remote regions in Tanzania (The World Bank 2007), situated on the south-eastern banks of Lake Tanganyika. The precipitation regime in the region is unimodal (800–1200mm annually; The World Bank (2007)) with annual temperatures ranging from 13 degrees Celsius in June/July to 27 degrees Celsius from October to December (Government of Tanzania 2008). The rainy season in the region lasts from October to May, the rest of the year is characterised as "dry season". According to The World Bank (2007), rainfall in Rukwa was reliable in the past, but the region has recently been experiencing particularly low rainfall, which is attributed to environmental destruction.

The typical diet in Rukwa consists, as in many other regions of Tanzania, of maize meal ("Insima"), typically consumed with beans (Tröger 2004; Government of Tanzania 2007). Especially at the lake shores, rice is also grown and consumed with fish. According to the EU Commission (2013), the soils in the region are classified as ferralic, and are further characterised by low inherent fertility and relatively low water-holding capacity. The major crops grown are maize, cassava, groundnut, millet and beans. The socio-cultural development of the Ufipa plateau, the geological/geomorphological sub-region where the case study village Laela is situated, is highly complex and characterised by radical societal changes since the 1960s. Tröger (2004) outlines a weakening of traditional authorities and, as a result, also of the system of values which in turn increasingly threatens traditional systems of resource distribution that avoided food insecurity – especially for economically weaker households. The Ufipa plateau is generally classified by Urassa (2010) as an almost deforested plateau with open grassland vegetation; The World Bank (2007) highlights land shortages occurring on the plateau. Laela is situated in Sumbawanga Rural District, one of the four sub-regions of Rukwa, where, according to Government of Tanzania (2007), only 5.9% of the residential households are able to consume three meals per day and 48.2% report food insufficiency.

Laela, the case study village (Latitude: -8.572949; Longitude: 32.045885), is the main settlement of the same-titled ward and situated in the sub-region of Sumbawanga Rural. The settlement itself consists of five sub-villages and its population is estimated at 5460 inhabitants living in 1260 HH. However, the total population of the ward is approximately more than three times higher (Government of Tanzania 2003). According to the IEA (2006), the time it takes to collect firewood in the region is among the highest in Tanzania (5 km travelled) indicating resource depletion especially in the forest sector. This finding is underlined by a focus group interview, mentioning wood theft – most likely an outcome of shortages – as an increasing problem in the settlement. Furthermore, interviewees stated that in recent times, corn cobs are additionally burnt as fuel for cooking purposes, which was uncommon before. Reasons for increasing shortages of forest-based resources have been reported, in order of importance, as being charcoal production, brick production, firewood collection and forest fires. An environmental village committee exists in Laela that has the duty to enforce environmental by-laws which in turn, "enforce sustainable environmental conservation by prohibiting cultivation practices […] on steep areas, and in forest areas under village jurisdiction" (Mahonge 2010). However, as in the Tanzanian case study outlined by Mahonge (2010), the committee is physically present but functionally incapable, one reason being strongly limited societal support. The remaining local forests are Miombo forests, which are generally characterised as being located on nutrient-poor soils with an undergrowth of grass and herbs (Shackleton and J.M. 2011).

3. Material and methods

3.1 Data collection

In late 2010, a household survey was conducted in Laela covering 160 of approximately 1260 households (n=160) (Hoffmann et al. 2014; Hoffmann et al. 2015). The survey included among other things household composition (members, gender, age), household possessions (land, assets, livestock), agricultural practices and crops as well as energy consumption data. The sampling process is based on four income classes (ICs) that were defined by local representatives and opinion holders in a focus group interview so as most adequately to differentiate the population along economic lines of fragmentation. The defined groups are "rich" (IC1), "above average" (IC2), "self-sufficient" (IC3) and "below self-sufficiency" (IC4) in accordance with Nathaniels and Mwijage (2000) – reporting a comparable economic grouping for a survey in Southern Tanzania – and Tröger (2004) as well as Willis (1981). The latter two generally report strong economic segregation in their case study villages on the Ufipa plateau, Willis (1981) outlines already in 1981 that in his case study villages 18% of the population claim over 50% of the village areas.

Although key economic indicators differed substantially among the defined ICs, statistically sound variations could only be derived for the distinction between IC1 and all other ICs – detailed analyses of this process are outlined in Hoffmann et al. (2014) and Hoffmann et al. (2015). However, because the quantitative differences for key economic variables between the ICs are beyond dispute and because personal observation during data collection underlined substantial differences between economic subgroups of the population in Laela, further analysis was based on this sampling structure.

3.2 Dataset analysis

For the dataset analysis, SPSS (version 15) was used. Initially we conducted minor data cleaning to exclude or adjust implausible and incongruent details. As energy specific values were collected on the basis of local units (headloads and oxen cart for firewood; bags, buckets, tins, etc. for charcoal), these had to be reconverted to SI (kg and MJ). Our calculations are based on factors derived from conservative literature and mainly refer to a firewood headload weight of 15 kg (18.0 MJ/kg) and a charcoal bag weight of 28 kg (30.8 MJ/kg), the latter in accordance with the official weight in Tanzania (Peter and Sander 2009). Other units such as buckets and oxen carts were of very minor importance. The reason for the approach of using literature-derived factors is that due to the complete lack of measurement gauges in the village, details outlined by the farmers concerning weight and volume differed widely. This procedure is in line with e.g. Wiskerke et al. (2010).

As calculated in Hoffmann et al. (2015) daily energy consumption values per household member and IC in 2010 are as follows: IC1: 0.55 kg firewood /0.21 kg charcoal; IC2: 0.79 kg firewood /0.04 kg charcoal; IC3: 1.05 kg firewood /0.04 kg charcoal; IC4: 1.1 kg firewood /0.02 kg charcoal. These consumption values were used in the following as the basis for calculating the pre-carbonisation fuelwood amount reflected in the respective charcoal consumption rates in 2010 as well as the scenario development.

3.3 Calculation of the fuelwood/charcoal ratio in 2010

As charcoal reflects a certain input/output ratio of fuelwood, the first key element for calculations, kiln efficiency rates displaying the conversion from wood to charcoal were extracted from literature (van Beukering et al. 2007; Kammen and Lew 2005; Tabuti et al. 2003; Mwandosya and Luhanga 1993; Kimaryo and Ngereza 1989; Mwampamba 2007; Maes and Verbist 2012) and subsequently grouped to derive (1) the average of the lowest efficient conversion factors from fuelwood to charcoal outlined (11.1%) (cf. Annex 1 for an example of an inefficient kiln in Laela) and (2) an average of the total kiln efficiency spectrum outlined by the authors (15.6%). Additionally, (3) a high efficiency factor was defined to display the application of improved techniques and/or better production know-how (20.0%) (cf. Annex 2 for an example of improved charcoal kiln).

In a subsequent step, those three charcoal conversion factors were applied to the charcoal consumption rates extracted from the survey to emphasise the close-to-real fuelwood to charcoal conversion factor (11.1%) in 2010 as well as potential efficiency improvements (15.6% and 20.0%). The aim was to get an idea of the amount of fuelwood entering the charcoal production cycle before carbonisation for each of the different ICs at the time of the survey. This was done by applying formula 1. The results are displayed in figure 1.

Formula 1: Calculation of daily fuelwood input needed for charcoal consumption per household member and Income class for the year 2010 including different kiln efficiencies

$IC_{WF2010} = (IC_{CC2010}/Eff*100) + IC_{FW2010}$

IC_{WF2010} = Upstream fuelwood input associated with charcoal consumption per IC (Consumed firewood and identified pre-carbonisation woodfuel amounts needed for charcoal production)

IC_{CC2010} = IC-specific charcoal consumption in 2010 as extracted from survey

Eff = Efficiency rates (11.1%, 15.6%, 20.0%)

IC_{FW2010} = Fuelwood consumed per IC in 2010 as extracted from survey

However, for the data collection period in 2010, we define a conversion efficiency rate of 11.1% as a close-to-real scenario since kiln technologies applied were very simple (cf. Annex 1). Efficient consumption devices (efficient stoves) were incorporated in the scenario development for 2030 only as the data collection indicated a negligible number of stoves in 2010 (Hoffmann et al. 2015).

3.4 Scenario development for the year 2030

To design consumption scenarios for 2030, the population size of Laela in 2030 had to be estimated as a second key element for calculations: Predicting this factor was crucial, as the estimated population increase between 2010 and 2030 was then applied to forecasting the energy consumption growth in the same time period ("energy growth factor"). The projection of the population in 2030 was based on the annual population size of "Sumbawanga Rural" from 2010-2025 as extracted from Government of Tanzania (2006). An average annual growth rate was calculated for this time period (+3.41% / 2010: 482.987; 2025: 798.886). The calculated factor was applied to project the population size in 2030 (2030: 944.863) as official data ends in 2025 (Government of Tanzania 2006). Based on these calculations, for the scenario we estimated that the population in Laela and correspondingly the energy consumption in the village will increase between 2010 and 2030 by 95.6% while the proportional consumption of firewood and charcoal is assumed to remain constant.

As a third key element for calculations, the efficient stove saving potential was adopted from MacCarty et al. (2010) and defined as being constant with a saving potential of 33.0%. In accordance with efficiency pathways, we determine efficient charcoal stove market penetration rates of 0%, 10%, 50% and 100%. In this context we equalate "penetration" with "utilisation".

However, the starting point for calculating the energy projection for the year 2030 was the theoretically higher efficiencies in 2010. It is also noteworthy that efficient stoves were not included in the calculation of fuelwood input for charcoal consumption in 2010 (cf. formula 1) as their market penetration is proven to be negligible by data collection (Hoffmann et al. 2015).

Consequently, the different scenarios including population growth up to 2030 as well as three different kiln efficiency and four different efficient stove dissemination scenarios were calculated with formula 2.

Formula 2: Calculation of daily Energy carrier consumption in 2010 per Household member and Income class including different kiln efficiencies and different efficient stove market penetration

$IC_{WF2030divEFF} = IC_{WF2030} - (IC_{WF2030}/100*(ESP/100*DR)$

$IC_{WF2030divEFF}$ = Upstream fuelwood input associated with charcoal consumption for different efficient stove penetration scenarios

IC_{WF2030}= Fuelwood input for charcoal consumption 2030 for different kiln efficiencies based on IC_{WF2010} multiplied by population/energy growth rates (95.6%)

ESP = Efficient stove saving potential (33.3%)

DR = Market penetration rate (0%, 10%, 50%, 100%)

The results were then multiplied by the average household size (IC1: 7.7; IC2: 6.9; IC3: 6.1; IC4:5.7) as well as the total number of households per IC (IC1: 160; IC2: 258; IC3: 387; IC4: 455) to find the total daily quantitative energy carrier consumption rates in kg per IC. To display the multitude of different results adequately, figure 2 was designed.

4. Results

4.1 Outline of the upstream fuelwood input associated with charcoal consumption

We base our calculations on the quantitative energy carrier as extracted from the household survey (Hoffmann et al. 2014; Hoffmann et al. 2015). When different kiln efficiency factors are applied following formula 1, the theoretical upstream fuelwood input associated with measured charcoal consumption increases substantially, as outlined in figure 1. Here we focus on the close-to-real conversion efficiency of 11.1%.

Figure 1 demonstrates that IC1 consumes the least of all the ICs when only firewood or weight of energy carrier is the focus ((a) and (b)). However, the charcoal consumption of IC1 in particular conceals fundamentally higher fuelwood resource consumption, as a recalculation to pre-carbonisation status reveals that IC1 is by far the most resource-consuming IC. Even if the highest efficiency ratio is utilised ((b.3) 20.0%), IC1 still consumes approximately 30% more fuelwood than IC4. If the least efficient and probably most realistic conversion efficiency is applied ((b.1.) 11.1%), an average IC1 household member consumed twice the fuelwood resources of an average IC4 household member in Laela in 2010.

4.2 Projection of production and consumption pathways for 2030

Based on the results outlined in figure 1 and following the inclusion of the energy growth factor (equal to population growth) up to 2030, different market penetration rates of efficient charcoal stoves were incorporated to display increasing technology adoption in consumption technology (cf. formula 2). Subsequently, (1) the average number of household heads per IC and (2) the absolute number of households per IC were included to display potential development pathways of the total daily fuelwood consumption for the year 2030 per IC (Figure 2).

The recalculated close-to-real reference scenario from figure 1 (b.1) is outlined in figure 2 on the left (“2010”); deviations are based on varying factors for household size and total households in the village. If equal conversion efficiency to 2010 (11.1%) and no efficient stove utilization are simulated for 2030, the overall energy consumption will nearly double. On the other hand, if efficient stoves are to be introduced to 100% of households and if efficiency of conversion can be increased to 20.0%, the fuelwood input for charcoal consumption will even shrink in comparison to 2010, most notably for IC1.

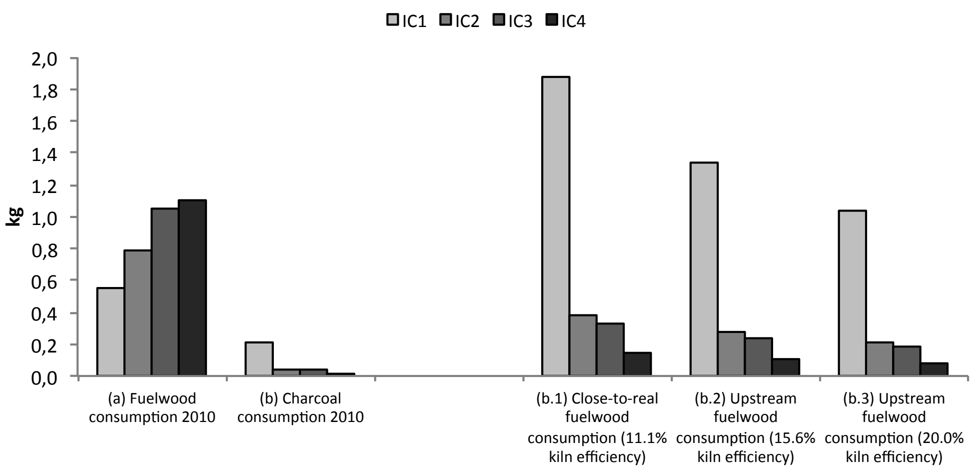

Figure 1: Daily fuelwood (a) and charcoal (b) as well as fuelwood/charcoal rations (b.1; b.2; b.3) per household head and IC for 2010 in kg

Due to varying impacts of average household sizes per IC and the total number of households, there is a substantial gap in total energy carrier consumption in IC2 when compared to the other ICs. However, this gap closes if the highest conversion efficiencies and highest stove dissemination rates are incorporated. But even if these very positive development pathways are utilised, the overall energy carrier demand in the village will increase substantially by 2030, also based on fuelwood consumption alone.

5. Discussion and conclusion

With regard to the baseline values as extracted from the survey, wide ranges of energy consumption ratios seem feasible. Johnson and Bryden (2012) provide an overview that in Kenya for example, as a neighbouring country of Tanzania, consumption values reported vary from 300 to 1200 kg of fuelwood annually per capita (0.8-3.3 kg/cap/day cf. figure 1). Adkins et al. (2010) characterise biomass consumption of 2.5 to 3.0 tonnes annually per household in SSA as a "generally accepted value" – when the weighted average household size in Laela of 6.2 is applied (not included in calculations above), the consumption rates in Laela are between 1.1 and 1.3 kg/cap/day. The latter values refer, in contrast to the former ones, on woodfuels and not on fuelwood alone.

Data collected by Brouwer et al. (1997) in Malawi revealed that 8.1-9.9 kg of fuelwood were collected (and inevitably used) per person per week (1.2 – 1.4 kg/cap/day). These literature-derived values underline that the daily energy consumption in Laela as outlined in figure 1 can possibly be taken as close-to-real and that the defined factors reflect reality. With regard to figure 2, no literature could be found that explicitly focuses on the upstream fuelwood for charcoal production accordingly.

The in-depth analysis of the fuelwood/charcoal ratio in the case study village of Laela reveals that IC1 is by far the biggest biomass consumer. This finding appears to be generalisable as it highlights the potentially immense forest degradation and deforestation potential of charcoal users and therefore potentially more wealthy income groups – not exclusively but prevailingly urban dwellers. It can be assumed that (1) the Tanzanian population is going to quintuple by the end of the century (United Nations; Department of Economic and Social Affairs; Population Division 2013), (2) that more wealthy income groups are using and are going to use forest resources more than the average and (3) that the majority of the urban population depends and will continue to depend on charcoal. Consequently, the Tanzanian government should approach this massive "charcoal challenge" from both the consumption and the production side as this combination seems to be the most effective strategy to address further degradation of forest resources as outlined in figure 2. Although strat-

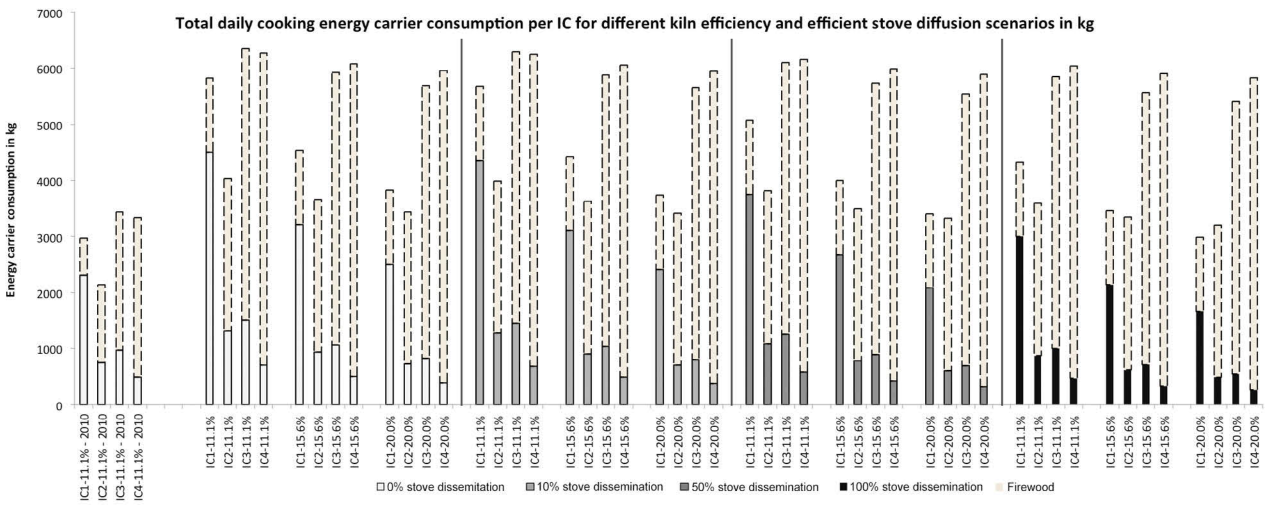

Figure 2: Daily energy consumption per IC for 2010 (low efficiency assumption) and 2030 for firewood and charcoal in kg

egies addressing either the increase of production or of consumption individually might also be partly fruitful, a combined approach that includes fuel production and fuel consumption would be the more promising (Iiyama et al. 2014). However, since fuelwood consumption will still be a major factor for energy carrier consumption, we also recommend supporting the market penetration rate of efficient firewood stoves as replacements for three-stone fires (cf. Hoffmann et al. (2015)). Efficient payment schemes and/or subsidies might be necessary to support purchases among less wealthy income groups because purchasing declines rapidly as prices increase (Adkins et al. 2010).

An outlier with regard especially to the results in figure 2 is the total energy consumption of IC2. We would have expected the energy consumption of the different ICs to follows a linear pathway such as in the 20.0% kiln efficiency/100% stove dissemination scenario. We assume that the increase in households per IC cannot buffer the drop in charcoal consumption, although we perceive the latter to be realistic development.

We adopt literature-derived factors because data from the village does not exist. This is in line with Mwampamba (2007) and Wiskerke et al. (2010) deriving weights for charcoal bags (30 kg) and firewood headloads (16 kg). A detailed outline of literature-derived weight factors, outliers and likeliness of adequacy is given in Hoffmann et al. (2015).

Our projections of population growth in a rapidly developing society might be questionable. We base our calculations on Government of Tanzania (2006) but the high mobility of the Tanzanian population is difficult to forecast for the coming decades. However, we assume the other remaining exogenous factors "technological change", "migration" and "behavioural changes" to be constant because this mirrors the remoteness of the region – we perceive substantial changes to be unlikely in the mid to long term.

We forecast equal energy consumption patterns for 2030 as in 2010 for the scenario development. This is mainly based on the fact that sufficient energy replacements for cooking will not be available in the mid-term (Iiyama et al. 2014). While for example a switch from kerosene to solar as major energy carrier for lighting is likely or at least possible to occur in the short to mid-term even in rural areas of SSA, cooking will continue to be powered by biomass. The cooking fuel alternative LPG is, although positive examples in China and Brazil among others exist, not likely to be implemented widely in the coming decades in Tanzania as the fuel is often too expensive for the users meaning that a very efficient subsidy is a precondition for success (Maes and Verbist 2012). Furthermore, a functioning replacement and transportation infrastructure must be established to guarantee the constant availability of LPG (Iiyama et al. 2014).

Kiln efficiency scenarios as outlined are based on detailed literature research ("Calculation of the fuelwood/charcoal ratio in 2010"). Although direct measurements would have been preferable, we can assume that the three factors applied cover the majority of published values. We therefore believe these efficiency rates to be realistic. We also extracted the saving potential of efficient charcoal stoves from literature. However, as outlined by MacCarty et al. (2010) a vast variety of different saving potentials exist, and we applied the average as outlined in this publication. Furthermore we apply four different market penetration scenarios to mirror the whole span of development pathways. We recalculate the upstream fuelwood consumption based on the conversion efficiency from fuelwood to charcoal. According to Maes and Verbist (2012), the efficiency of charcoal production is normally expressed by the conversion efficiency, which is the amount of charcoal produced per kg of dry wood. Therefore, it would have been an option to expand the calculation complexity by incorporating moisture content of wood in accordance with, for example, formulas outlined by Openshaw (1983). We did not incorporate this because this moisture content is unknown and fluctuates between 12–15% for air-dry wood (Openshaw 1983; Simpson 1998) and up to 100% if freshly cut wood is used. A close-to-real assumption would nevertheless be air-dry wood as charcoal producers tend to bark trees long before processing them (see Annex 3) in order to minimize negative effects on efficiency.

One of the main practical implications of our study is that a combined approach of simultaneously applying improved consumption technology and higher production efficiency is the most promising option to fight degradation of Tanzanian forest resources with regard to charcoal production. We additionally outline the (highly) above-average resource consumption of wealthier ICs in comparison to other ICs. Even if charcoal is, in contrast to fuelwood, a traded good and locations of production and consumptions consequently differ, this inequality is beyond dispute and leaves poorer households, which mainly depend on fuelwood, with even fewer resources to sustain their livelihoods. Lowering their access to energy will most likely result in lowered availability of nutrients and food access, either because of a change in diet, limited simmering time or a lack of cooking time by the women also responsible for firewood collection (Kees and Feldmann 2011; Brouwer et al. 1997; Hartter and Boston 2007).

5.1 Conclusion

We outline biomass energy consumption for cooking in a remote case study area and furthermore forecast potential energy consumption in 2030 based on population growth. Our results indicate that charcoal production is a major contributor to forest resource depletion and that wealthier and/or urban income groups consume, due to their above-average charcoal consumption, higher shares of forest resources. We therefore urge policy makers to develop pathways that allow and enhance education of charcoal processing as this would substantially lower fuelwood use. However, we also show that the market penetration of efficient stoves should be pushed forward because a combined approach of efficiency gains on the production and the consumption side is likely to be most effective in lowering the pressure on forest resources. However, as population and therefore resource extraction is growing constantly, there is urgent need to design adequate policies – a first step would be to clearly discuss the challenges associated with biomass use.

6. References

Abdallah, J. M., & Monela, G. G. (2007). Overview of Miombo Woodlands in Tanzania. *Working Papers of the Finnish Forest Research Institute, 50*, 9–23.

Adkins, E., Tyler, E., Wang, J., Siriri, D., & Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy for sustainable development*, 14(3), 172–185, doi:10.1016/j.esd.2010.07.003.

Ahmed, S. A., Diffenbaugh, N. S., Hertel, T. W., Lobell, D.B., Ramankutty, N., Rios, A. R., et al. (2011). Climate volatility and poverty vulnerability in Tanzania. *Global Environmental Change*, 21(1), 46–55, doi:http://dx.doi.org/10.1016/j.gloenvcha.2010.10.003.

Allen, J. C. (1985). Wood energy and preservation of woodlands in semi-arid developing countries: The case of Dodoma region, Tanzania. *Journal of Development Economics*, 19(1–2), 59–84, doi:http://dx.doi.org/10.1016/0304-3878(85)90039-2.

Arnold, J. E. M., Köhlin, G., & Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: Changing Perspectives. *World Development*, 34(3), 596–611, doi:10.1016/j.worlddev.2005.08.008.

Bailis, R. (2009). Modeling climate change mitigation from alternative methods of charcoal production in Kenya. *Biomass and Bioenergy*, 33(11), 1491–1502, doi:http://dx.doi.org/10.1016/j.biombioe.2009.07.001.

Bentson, S., Still, D., Thompson, R., & Grabow, K. (2013). The influence of initial fuel load on Fuel to Cook for batch loaded charcoal cookstoves. *Energy for sustainable development*, 17(2), 153–157, doi:http://dx.doi.org/10.1016/j.esd.2012.10.011.

Brouwer, I. D., Hoorweg, J. C., & VanLiere, M. J. (1997). When households run out of fuel: Responses of rural households to decreasing fuelwood availability, Ntcheu District, Malawi. *World Development*, 25(2), 255–266, doi:10.1016/s0305-750x(96)00100-3.

Butz, R. J. (2013). Changing land management: A case study of charcoal production among a group of pastoral women in northern Tanzania. *Energy for sustainable development*, 17(2), 138–145, doi:10.1016/j.esd.2012.11.001.

CAMCO (2014). Biomass energy strategy (BEST) Tanzania. Tanzania biomass energy strategy and action plan. Final report. (pp. 138). Dar es Salaam, Tanzania: European Union Energy Initiative Partnership Dialogue Facility.

Chidumayo, E. N., & Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for sustainable development*, 17(2), 86–94, doi:http://dx.doi.org/10.1016/j.esd.2012.07.004.

Emrich, W. (1985). *Handbook of Charcoal Making* (Vol. 7, Solar Energy R&D in the European Community, Vol. Series E). Dordrecht, Netherlands: D.Reidel Publishing Company for the Commission of the European Communities.

EU Commission (2013). Soil atlas of Africa. In E. Kommission (Ed.). Brussels, Belgium: EU Commission.

FAO (2008). *Forests and energy : key issues* (FAO Forestry Paper, Vol. 154). Rome, Italy: Food and Agriculture Organization of the United Nations.

Felix, M., & Gheewala, S. H. (2011). A Review of Biomass Energy Dependency in Tanzania. *Energy Procedia*, 9(0), 338-343, doi:10.1016/j.egypro.2011.09.036.

Foell, W., Pachauri, S., Spreng, D., & Zerriffi, H. (2011). Household cooking fuels and technologies in developing economies. *Energy policy*, 39(12), 7487–7496, doi:http://dx.doi.org/10.1016/j.enpol.2011.08.016.

Ghilardi, A., Mwampamba, T., & Dutt, G. (2013). What role will charcoal play in the coming decades? Insights from up-to-date findings and reviews. *Energy for sustainable development*, 17(2), 73–74, doi:http://dx.doi.org/10.1016/j.esd.2013.02.007.

Government of Tanzania (2003). 2002 Population and housing census. General report. http://web.archive.org/web/20040320145246/http://www.tanzania.go.tz/census/census/districts/sumbawangarural.htm2014.

Government of Tanzania (2006). Rukwa. Regional and district projections Volume XII. In National Bureau of Statistics (Ed.). Dar es Salaam, Tanzania: United Republic of Tanzania Ministry of Planning, .

Government of Tanzania (2007). Regional report: Rukwa region. In National Bureau of Statistics (Ed.), *National sample census of agriculture 2002/2003* (Vol. VI). Dar es Salaam, Tanzania.

Government of Tanzania (2008). Agriculture and livestock. http://www.rukwa.go.tz/kurasa/kilimo_mifugo/kilimo/index.php. Accessed 01.07.13.

Hartter, J., & Boston, K. (2007). An integrated approach to modeling resource utilization for rural communities in developing countries. *Journal of Environmental Management*, 85(1), 78–92, doi:10.1016/j.jenvman.2006.08.003.

Hiemstra-van der Horst, G., & Hovorka, A. J. (2009). Fuelwood: The “other” renewable energy source for Africa? *Biomass & Bioenergy*, 33(11), 1605–1616, doi:10.1016/j.biombioe.2009.08.007.

Hoffmann, H., Uckert, G., Reif, C., Graef, F., & Sieber, S. (2014). Local biofuel production for rural electrification potentially promotes development but threatens food security in Laela, Western Tanzania. *Regional Environmental Change*, 1–10, doi:10.1007/s10113-014-0596-x.

Hoffmann, H., Uckert, G., Reif, C., Müller, K., & Sieber, S. (2015). Traditional biomass energy consumption and the potential introduction of firewood efficient stoves: insights from western Tanzania. *Regional Environmental Change*, 1-11, doi:10.1007/s10113-014-0738-1.

IEA (2006). Energy for Cooking in Developing Countries. In IEA (Ed.), *World Energy Outlook* 2006 (pp. 419–445): OECD Publishing.

Iiyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., & Jamnadass, R. (2014). The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. *Current Opinion in Environmental Sustainability*, 6(0), 138–147, doi:http://dx.doi.org/10.1016/j.cosust.2013.12.003.

Johnson, N. G., & Bryden, K. M. (2012). Energy supply and use in a rural West African village. *Energy*, 43(1), 283–292, doi:10.1016/j.energy.2012.04.028.

Kaale, B. Tanzania: Impact of Cooking Energy Scarcity on Gender. (2012, 22.08.). *Tanzania Daily News*.

Kammen, D. M., & Lew, D. J. (2005). Review of Technologies for the Production and Use of Charcoal. In National Renewable Energy Laboratory (Ed.), *Renewable and Appropriate Energy Laboratory Report* (pp. 19). Golden, USA: National Renewable Energy Laboratory.

Karsenty, A., Blanco, C., & Dufour, T. (2003). Forest and climate change: Instruments related to the United Nations Framework Convention on Climate Change and their potential for sustainable forest management in Africa. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Kees, M., & Feldmann, L. (2011). The role of donor organisations in promoting energy efficient cook stoves. *Energy policy, 39*(12), 7595–7599, doi:10.1016/j.enpol.2011.03.030.

Kimaryo, B. T., & Ngereza, K. I. (1989). Charcoal production in Tanzania using improved traditional earth kilns. In C. IDRC, CIID (Ed.), *Manuscript Report 216e* (pp. 27). Moshi, Tanzania: Tanzania Forestry Research Institute, Timber utilization research centre.

Luoga, E. J., Witkowski, E. T. F., & Balkwill, K. (2000). Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. *Ecological Economics, 35*(2), 243–257, doi:10.1016/S0921-8009(00)00196-8.

MacCarty, N., Still, D., & Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy for sustainable development, 14*(3), 161–171, doi:10.1016/j.esd.2010.06.002.

Maes, W. H., & Verbist, B. (2012). Increasing the sustainability of household cooking in developing countries: Policy implications. *Renewable & Sustainable Energy Reviews, 16*(6), 4204–4221, doi:10.1016/j.rser.2012.03.031.

Mahiri, I., & Howorth, C. (2001). Twenty years of resolving the irresolvable: approaches to the fuelwood problem in Kenya. *Land Degradation & Development, 12*(3), 205–215, doi:10.1002/ldr.433.

Mahonge, C. (2010). *Co-managing complex social-ecological systems in Tanzania. The case of Lake Jipe wetland, PhD Thesis Wageningen University*. Wageningen, The Netherlands: Wageningen University.

Menéndez, A., & Curt, M. D. (2013). Energy and socio-economic profile of a small rural community in the highlands of central Tanzania: A case study. *Energy for sustainable development, 17*(3), 201–209, doi:10.1016/j.esd.2012.12.002.

Mitchell, D. (2011). Biofuels in Africa. Opportunities, prospects and challenges. *Directions in development - Countries and regions*. Washington D.C., USA: The World Bank.

Mwampamba, T. H. (2007). Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability. *Energy policy, 35*(8), 4221–4234, doi:10.1016/j.enpol.2007.02.010.

Mwandosya, M. J., & Luhanga, M. L. (1993). Energy and development in Tanzania: Issues and perspectives. *Energy policy, 21*(5), 441-453, doi:10.1016/0301-4215(93)90034-D.

Nathaniels, N. Q. R., & Mwijage, A. (2000). Seed fairs and the case of Marambo village, Nachingwea district, Tanzania: Implications of local informal seed supply and variety development for research and extension. In ODI Agricultural research & extension network (AgREN) (Ed.), *Network paper 101* (pp. 1–12). London, UK: Overseas Development Institute.

Okello, C., Pindozzi, S., Faugno, S., & Boccia, L. (2013). Development of bioenergy technologies in Uganda: A review of progress. *Renewable and sustainable energy reviews*, 18(0), 55–63, doi:http://dx.doi.org/10.1016/j.rser.2012.10.004.

Openshaw, K. (1983). Wood Fuel Surveys - Annex III - (b) Measuring fuelwood and charcoal. http://www.fao.org/docrep/q1085e/q1085e0c.htm. Accessed 27.07.13 2013.

Peter, C., & Sander, K. (2009). Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. A policy note. (pp. 54). Washington D.C., USA: Sustainable Development, African region, The World Bank.

Sander, K., Gros, C., & Peter, C. (2013). Enabling reforms: Analyzing the political economy of the charcoal sector in Tanzania. *Energy for sustainable development*, 17(2), 116–126, doi:http://dx.doi.org/10.1016/j.esd.2012.11.005.

Schenkel, Y., Bertaux, P., Vanwijnbserghe, S., & Carre, J. (1998). An evaluation of the mound kiln carbonization technique. *Biomass and Bioenergy*, 14(5–6), 505–516, doi:http://dx.doi.org/10.1016/S0961-9534(97)10033-2.

Schure, J., Ingram, V., Sakho-Jimbira, M. S., Levang, P., & Wiersum, K. F. (2013). Formalisation of charcoal value chains and livelihood outcomes in Central- and West Africa. *Energy for sustainable development*, 17(2), 95–105, doi:http://dx.doi.org/10.1016/j.esd.2012.07.002.

Sepp, S., & Mann, S. (2009). Wood Fuel Supply Interventions. Lessons learned and recommendations. In European Union Energy Initiative (euei) Partnership Dialogues Facility (EUEI PDF) (Ed.), *Biomass Energy Strategy* (BEST). Eschborn, Germany.

Shackleton, C. M., & J.M., C. (2011). Annex 6: Silviculture and management of miombo woodlands to improve livelihood outcomes. In B. Campbell, & P. Dewees (Eds.), *Managing the Miombo Woodlands of Southern Africa. Policies, incentives and options for the rural poor. Technical Annexes* (pp. 101–123).

Simalga, T., & Maliwichi, L. (2011). Promotion of household renewable energy technologies in rural communities: Challenges and experiences from Sub-Saharan Africa. *Scientific Research and Essays*, 6(27), 7, doi:10.5897/SRE10.767.

Simpson, W. T. (1998). Equilibrium moisture content of wood in outdoor locations in the United States and worldwide. In U.S. Department of Agriculture (Ed.), *Research Note* (pp. 1–11). Madison, WI, USA: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Sosovele, H. (2010). Policy Challenges Related to Biofuel Development in Tanzania/Politische Herausforderungen in Bezug auf Biokraftstoffe in Tansania. *Africa Spectrum*, 45(1), 117–129.

Steierer, F. (2011). Highlights on wood charcoal: 2004-2009. In FAO Forestry Department (Ed.). Rome, Italy.: FAO.

Tabuti, J. R. S., Dhillion, S. S., & Lye, K. A. (2003). Firewood use in Bulamogi County, Uganda: species selection, harvesting and consumption patterns. *Biomass and Bioenergy*, 25(6), 581–596, doi:10.1016/S0961-9534(03)00052-7.

The World Bank (2007). Growth Prospects for Rukwa Region: Constraints and Opportunities. (pp. 57). Washington D.C., USA: World Bank.

Tröger, S. (2004). Handeln zur Ernährungssicherung im Zeichen gesellschaftlichen Umbruchs. Untersuchungen auf dem Ufipa-Plateau im Südwesten Tansanias. In H.-G. Bohle, & T. Krings (Eds.), *Studien zur Geographischen Entwicklungsforschung* 27. Saarbrücken, Germany: Verlag für Entwicklungspolitik.

United Nations; Department of Economic and Social Affairs; Population Division (2013). World Population Prospects: The 2012 Revision; Highlights and Advanced Tables. Working paper No. ESA/P/WP.228.

Urassa, J. K. (2010). *Rural household livelihoods, crop production and well-being after a period of trade reforms: a case study of Rukwa, Tanzania; PhD Thesis University of Sussex*. Sussex, UK: University of Sussex.

van Beukering, P., Kahyarara, G., Massey, E., di Prima, S., Hess, S., Makundi, V., et al. (2007). Optimization of the charcoal chain in Tanzania In Poverty Reduction and Environment Management (PREM) Programme (Ed.), *PREM Working paper*. Amsterdam, The Netherlands: Institute for Environmental Studies, Vrije Universiteit.

Vos, J., & Vis, M. (2010). Making Charcoal Production in Sub Saharan Africa Sustainable. Utrecht, The Netherlands: NL Agency; Netherlands Programmes Sustainable Biomass

Willis, R. (1981). *A State in the Making. Myth, History and Social Transformation in Pre-colonial Ufipa.*: Bloomington, USA.

Wiskerke, W. T., Dornburg, V., Rubanza, C. D. K., Malimbwi, R. E., & Faaij, A. P. C. (2010). Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania. *Renewable and sustainable energy reviews, 14*(1), 148–165, doi:10.1016/j.rser.2009.06.001.

Zulu, L. C., & Richardson, R. B. (2013). Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. *Energy for sustainable development, 17*(2), 127–137, doi:10.1016/j.esd.2012.07.007.

7. Annex

7.1 Annex 1: Charcoal kiln discovered in the hillside North-East of Laela

7.3 Annex 3: Barked tree to dry wood before processing to charcoal

7.2 Annex 2: Highly efficient Casamance kiln observed in Ulaya Mbuyuni in 09/2014

5.4 Traditional bioenergy: Conclusion and recommendation

Research papers 1 and 2 highlighted that the sector of traditional bioenergy is of high importance for sustainable development in Laela. The scenario analysis demonstrated that with comparably minimal changes in consumption (firewood) and production (charcoal), the forest resources already under pressure could at least be relieved. However, as outlined by Kees and Feldmann (2011), the domain of cooking is very traditional in many societies and changes occur only gradually – but change in this sector is nevertheless inevitable.

One approach applicable to Laela might include the design and implementation of stoves via a participatory bottom-up approach as exemplified by Honkalaskar et al. (2013). An adaptation is nevertheless grounded in detailed analyses of the status-quo including a careful examination of the wishes and expectations but also of gender-related structures from the villagers' side. Furthermore, potential shortcomings of commonly applied approaches need to be addressed directly in order to avoid replication of project failure as outlined by Hanna et al. (2012). With emphasis on charcoal, the scenario analysis points out a win-win situation for producers, consumers and the environment as higher production efficiencies are likely to result in higher producer revenues, less forest resource consumption and lower – or at least constant – prices for consumers. Nevertheless, even if respective governmental regulation is adopted, efficiency increases will have to be accompanied by the design of sustainable forest conservation strategies as otherwise the increasing income will simply attract more producers.

However, on the political level a glimmer of hope exists with the currently debated new Tanzanian national energy policy (Government of Tanzania 2015). In contrast to the Tanzanian national energy policy approved in 2003 (Government of Tanzania 2003), where traditional energy sources were mainly negatively highlighted[10], the national policy currently under revision addresses "*Solid biomass*" in its own section (Government of Tanzania 2015; p. 18). It clearly urges the government to (1) promote efficient conversion and use of solid biomass, (2) encourage sustainable production of solid biomass, (3) promote and enhance fuel switch from wood fuel to other sources for cooking, (4) promote modern use of solid biomass for the generation of electricity, (5) create awareness and develop capacity for bio-electricity generation and (6) provide incentives for private investments in bio-electricity generation (ibid.). In summary, sustainable use of biomass is likely to be increasingly encouraged in Tanzania – which might avoid future policy failures such as the sudden and total ban of charcoal in 2006 (Sander et al. 2013). The latter resulted not in less consumption but in skyrocketing consumer prices, as no substitutes were available. Whether the additional focus on biomass-based electricity generation will support these measures or foster competition for dwindling biomass resources remains to be seen.

10 Policy Statement 44. *"Promote application of alternative energy sources other than fuelwood and charcoal, in order to reduce deforestation, indoor health hazards and time spent by rural women in search of firewood"* (p. 28)

6 Modern Bioenergy

6.1 Introduction: The context of the papers

Modern bioenergy and particularly electricity are the backbones of pro-poor development in urban and rural areas as they play a critical role across the whole spectrum of development activities – respective energy services were outlined as "*a powerful engine for social and economic growth*" (Brew-Hammond and Crole-Rees 2004; p. 10). On a regional and supra-regional basis, (street) lighting, for example, as a result of increased electrification, correlates strongly with economic growths and underlines the close interrelation between the availability of modern energy services and economic progress of a given society (Henderson et al. 2012). For the case study villages focused upon in this thesis however, modern energy availability is equivalent with a number of progressive developments. The availability of electricity, for example, is mainly associated with lighting to increase safety for women and extend learning opportunities for children. Additionally, business opportunities arise from reloading mobile phones. The direct transfer of mechanical energy from a combustion engine – potentially powered by SVO – could, on the contrary, allow the (increased) use of maize grinders, milling machines and dehullers, potentially lowering work pressure on women and increasing the share of small-scale farmers in the value chain. The latter approach was, at least temporally, already realised in Tanzania in specific case study sites (Martin et al. 2009). The papers presented in the following directly address the use of locally produced edible oils for electricity generation on an energy basis (Laela) or highlight the general potential to increase production of palm oil (Illagala/Kagongo) with an implicit energy usage option.

6.2 Paper 3

Local biofuel production for rural electrification potentially promotes development but threatens food security in Laela, Western Tanzania

Reg Environ Change
DOI 10.1007/s10113-014-0596-x

Local biofuel production for rural electrification potentially promotes development but threatens food security in Laela, Western Tanzania

Harry Hoffmann · Götz Uckert · Constance Reif · Frieder Graef · Stefan Sieber

Received: 29 January 2013 / Accepted: 1 February 2014

Abstract The impacts of biofuel production and the adequacy of the associated production structures are controversial matters despite a projected medium-term growth rate increase. Concurrently, electricity is increasingly perceived as a prerequisite for development. In this article, we assess the potential impacts of the local production of biofuels for electricity production on development and the food supply in the village of Laela in Western Tanzania. Based on a village survey, focus group discussions and expert interviews, we calculated the potential food security effects on four different economic types of farmer groups. The objective of this analysis was to evaluate the potential use of sunflower and groundnut oils as substitutes for fossil fuels for the production of electricity. The baseline framework is based on a comparison of crop production data with current fossil fuel consumption. The ex-ante scenarios assess the gap between the estimated yield losses and the increasing fuel demand through 2015. These comparative analyses of schemes in which vegetable oil production replaces a given level of crop production showed that replacing food crops with crops producing biofuel will most likely impact local food security negatively, causing increased hunger, especially for the poorest farmers and even if climate change is not considered.

Keywords Biofuels · Rural electrification · Food security · Vegetable oil · Tanzania

H. Hoffmann (✉) · G. Uckert · C. Reif · F. Graef · S. Sieber
Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany
e-mail: harry.hoffmann@zalf.de

6.3 Paper 4

Increase without spatial extension: productivity in small-scale palm oil production in Africa – the case of Kigoma, Tanzania

Reg Environ Change
DOI 10.1007/s10113-015-0798-x

Increase without spatial extension: productivity in small-scale palm oil production in Africa—the case of Kigoma, Tanzania

Götz Uckert[1] · Harry Hoffmann[1] · Frieder Graef[2] · Philipp Grundmann[3] · Stefan Sieber[1]

Received: 14 May 2014 / Accepted: 16 April 2015

Abstract The global demand for palm oil has increased sharply in the past and is expected to double over the coming decades. Land use changes resulting from the concomitant expansion of oil palm cultivation have caused further deforestation, which in turn has had a severely negative impact on the environment and climate. Sustainable intensification strategies are therefore required to meet the growing demand for palm oil while simultaneously improving farm household incomes, increasing food security and self-sufficiency. Palm oil production in Africa and especially in Tanzania is dominated by small-scale subsistence farming systems that are characterised by low productivity and low yields, even in regions with the most suitable cultivation conditions. By conducting stakeholder interviews, focus-group discussions and a household survey, we analysed palm oil production in the Western Tanzanian Province of Kigoma in order to gain a more complete picture of oil palm farming in smallholder systems and to better understand how smallholders evaluate certain options for the intensification of palm oil production. We identified and evaluated locally existing best practices from the farmers' perspective and identified factors which may have a positive impact on production levels. Our case study sites are characterised by large oil palm plantations that have been operating since colonial times. Also examined were farm plots with an average of 35.7 palm oil trees per acre. Palms are cultivated to produce edible vegetable oil and are used for firewood. The results indicate large differences between output levels that result from the agricultural management practice employed (e.g. using hybrid varieties, sub-optimal planting densities and low weeding or organic fertilising inputs). The processing technology used in the households examined was not conducive for changing the situation from low to high yields and productivity levels. A shift from subsistence to market-orientated production generates income opportunities for farmers and helps meet the ever-increasing demand for palm oil. Our results indicate that an improved small-scale palm oil production system, including agroforestry or mixed cropping and general intensification of plant maintenance, may increase yields without putting additional pressure on natural forests—a step towards ensuring palm oil is produced in a supply chain that avoids deforestation.

Keywords Farming systems · Biofuel · Agroforestry · Food security · Palm oil · Land use change

Electronic supplementary material The online version of this article (doi:10.1007/s10113-015-0798-x) contains supplementary material, which is available to authorized users.

✉ Götz Uckert
uckert@zalf.de

1 Institute of Socioeconomics, Leibniz Centre for Agricultural Landscape Research e.V. (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany

2 Institute of Land Use Systems, Leibniz Centre for Agricultural Landscape Research e.V. (ZALF), Müncheberg, Germany

3 Leibniz-Institut für Agrartechnik Potsdam-Bornim (ATB) e.V., Max-Eyth-Allee 100, 14469 Potsdam, Germany

6.4 Modern bioenergy: Conclusion and recommendation

The papers presented above provide details about the potential to substitute fossil fuels for electricity generation with locally produced SVOs (Laela) and to optimise palm oil yields – hypothetically with the option for use as SVO. Both case studies focus therefore on modern biofuels, which are included by van der Kroon et al. (2013) in the definition of "*advanced fuels*" (figure 2). In the case of Laela, even though a substitution is theoretically possible up to a certain level, a replacement is likely to negatively affect food security of poorer households if local value chains are assumed. If this approach is transferred to the case study villages in Kigoma, a similar development seems theoretically possible if the SVOs produced here are used for fossil fuel replacement in one of the five generators in Kigoma town (Bertheau et al. 2014).

As described in the state of the art research overview (chapter 2.2), SVOs generally represent an opportunity for use in generators and combustion engines in rural areas of developing countries. However, if these approaches are to be applied in the case study villages, a detailed analysis of the positive and negative outcomes particularly on food insecure households is a precondition for socially well-balanced implementation. While closed local production and consumption circles are in general a good idea to keep added value in a specific region, maladaptation of this approach might have negative outcomes. In addition, the use of edible oil for combustion will most likely not be politically and socially feasible as national and international NGOs strongly oppose correlated projects. Therefore, alternative electrification models might be more feasible as exemplified for a hybridization of diesel-based, off-grid systems with PV and storage systems (Bertheau et al. 2014).

7 Overall conclusion

In the course of this research project, a number of different aspects focussing on traditional as well as modern energy provision and consumption in Western Tanzania were addressed, mainly based methodologically on quantitative household surveys and analytically on the analysis of simulated development pathways.

A central conclusion is that traditional energy provision – and the associated cooking energy that makes it a central aspect of food security – is already and will in the future increasingly be challenged, particularly in the case study region of Laela. Major reasons for this are inefficient utilisation (TCS, TSF) as well as inefficient charcoal production technologies currently applied. Based on this, other reasons include a diminishing resource base as forests and wood resources in general are under pressure, one reason being, although not solely, increased cooking energy demand but also other stressors such as wildfires and the need to increase production of burnt bricks for constructing houses. However, the major underlying reason for respective increasing pressure is population growths in the region, which even exceeds the high national average.

The analysis of modern energy aspects, on the contrary, revealed that SVO-based electrification options are likely to not adequately address social sustainability if closed local production/consumption loops are the aim. Although the simulated concept of a closed SVO production-consumption cycle in the case study village is highly attractive to keep value creation local by avoiding the purchase of imported fossil fuels, this concept holds the direct risk of increasing food insecurity, particularly for lower segments of society. Although this approach holds the potential to create jobs in production and, to a limited extent, processing as well as a potential stabilisation of farm gate prices as a result of the creation of a second market, the direct impact for most of the village population is likely to be negative.

Potential mitigation pathways for the outlined stress on forest resources, which is likely to contribute directly and indirectly (increased overland flow, decreased water reservoir capacity) to already threatened food security in the mid- to long-term, are an increased efficiency in the process of fuel consumption and production via the use of ICS and/or (more) efficient charcoal production. However, as the realisation of positive outcomes associated in particularly with ICS dissemination are not automatically guaranteed, independent long-term monitoring processes should be established in order to derive guidelines for (culturally) appropriate strategies or designs assuring success for the good of consumer health, global climate and effective investment, potentially from international climate funding. An aspect worth considering in the context of ICS dissemination is also the so-called “rebound effect”; another one is the application (or non-application) of subsidies. Furthermore, more efficient charcoal production techniques generally lead to higher incomes for producers and will consequently attract a higher quantity of producers, thus potentially counterbalancing positive effects for forest resources in particular. However, reforestation efforts should be initiated based on the design of realistic policies implemented on the local level by active and influential (environmental) committees. This measure is nevertheless associated with (more) secure land titles as reforestation will only be implemented by individuals and families if long-term benefits are likely to affect the implementers. In addition, traditional as well as official laws might foster this development[11]. The latter aspect is, although highly relevant, nevertheless beyond the scope of this thesis, but recent personal communication with Tanzanian experts (April 2015) suggests that the focus of politicians might have shifted slightly towards a more efficient and sustainable production and consumption of traditional bioenergy.

Optimising and transforming the so far suboptimal outcomes of the use of locally produced SVOs for electrification, however, might be even more challenging than improving the efficiency of the traditional bioenergy sector. A major reason is that the side conditions since the time of data collection, the submission of paper 3 and the handing in of this thesis have changed dramatically as the volatile crude oil prices meandered between roughly 70 US $ per barrel in late 2010, reached 110 US $ per barrel in early 2014 and then dropped to 45 US $ per barrel in September 2015[12] (figure 4). As a consequence all of the mid- to large scale biofuel projects operating in Tanzania at the beginning of this thesis at least stopped focussing on the production of biofuels for transportation, indicating that the financial feasibility for the production of a fossil fuel substitute are (currently) not guaranteed because of the low fossil fuel price. Although the concept suggested for Laela differs from these approaches as the simulated approach in Laela would also strengthen local value chains and energy independence, overall financial feasibility is nevertheless a precondition for the success of locally closed production-consumption chains of SVOs for electricity generation. This aspect, together with international civil society, public and the media arguing against consuming edible vegetable oils for energy production, is likely to hinder the realisation of such projects in the short to mid-term. This also holds true for the case study villages in the Kigoma region. Nevertheless, the application of five large fossil-fuel-powered generators providing electricity for the settlement of Kigoma offers the opportunity to create long-term contracts with the operating company, the national Tanzania Electric Supply Company Limited (TANESCO). This might potentially offer more secure business relationships as a major and most likely reliable buyer is present which is likely to enhance the willingness of farmers to provide the produced SVOs to this company.

11 In Saxony, Germany, for example, marriages as well as the purchase of property in the 18th century was only allowed if six fruit-bearing trees were planted in advance – similar strategies might be implemented on the local level in contemporary Tanzania (SCHURICHT W 2009)

12 At the time when the project Better-IS was applied for, respective prices peaked in 140 US$ per barrel.

The general conclusions of this thesis are therefore that (1) in particular the traditional energy provision and consumption, which is the major food-security-related energy aspect for all households located in the case study villages, urgently needs to be redesigned towards increased sustainability and that (2) the local use of SVOs for electrification should, if at all, only be carefully adapted to local circumstances – safety measures to avoid negative effects on already food-insecure households must be guaranteed.

8 Policy recommendations

Based on the research conducted, some general remarks concerning policy implementation can be derived.

8.1 Traditional bioenergy

An outcome for the case study village, the wider area and in fact many regions in SSA is that a singular approach towards at least sustaining the energy supply for traditional cooking will most likely not be sufficient. Therefore, a combination of (1) the widespread implementation and use of culturally adapted ICS within all income groups, (2) adequate agroforestry approaches based on secure land titles and/or well managed cooperative approaches, and (3) an optimised charcoal production via improved processing strategies or training are vital in order to secure future wood energy supply and lower the negative effects of deforestation and forest degradation (Iiyama et al. 2014, Neufeldt et al. 2015, Kimaryo and Ngereza 1989). To achieve these aims – and in line with the outcomes of an expert meeting of the World Agroforestry Centre (ICRAF) in May 2015 (Neufeldt et al. 2015) – the correction and update of the traditional fuel perception in SSA is highly necessary to find sustainable solutions.

8.2 Modern bioenergy

In the sector of modern energy supply, one focus should be on renewable energy options such as solar and hydro powered electrification, especially for lighting. Though *"on a small-scale, locally produced plant oils [...] can successfully be used to power diesel engines and generators in rural villages"* (Kaygusuz 2011; p. 946), this option entails the risk that lower income groups may become food insecure. Therefore, the use of edible plant oils such as sunflower, groundnut or palm cannot be recommended as such. Furthermore this option will most likely not be politically feasible from the national government and the donor community (cf. "food vs. fuel" debate chapter 2.2).

8.3 Overall policy recommendations

The overall policy recommendations derived from of this PhD thesis can therefore be summarised as follows:

ICS dissemination should be fostered

1) ICS should be widely promoted as highly *"convenient, modern and […] affordable"* (Kees and Feldmann 2011; p. 7599) and their dissemination needs to be aggressively pursued in both rural and urban areas. This recommendation is strongly backed by Peter and Sander (2009) who calculate that an intensification of information and marketing campaigns for improved stoves and fuel switching would cost only 3 million US$ in Tanzania. Furthermore, ICS need to be developed and tested with a strong focus on their long-term, real-life performance and the given (cultural) realities on the ground. Situations as outlined by T.A. Aleinikoff, Deputy High Commissioner in the Office of the United Nations High Commissioner for Refugees (UNHCR) (*"We're in a situation where everybody and his brother has invented a cookstove and none of them have really worked well for us"* (The Guardian 2014)) need to be avoided by all means. This is also essential in the context of the Clean Development Mechanism (CDM) as climate funds are increasingly channelled into this complex sector, often without proper mid- to long-term monitoring of the real-world implications (Simon et al. 2012). Some researchers, however, perceive governmental support for accessing carbon credits as an alternative for direct public subsidies for ICS (Shrimali et al. 2011) while others perceive carbon finance as part of the solution to promote ICS (Vos and Vis 2010). In short, information about ICS needs to be spread widely and their implementation and adaption needs to be strongly supported by the national and regional governments. In this context, recently-developed training modules for forestry and agricultural extension officers in Tanzania as developed by the Tanzanian Commission for Science and Technology (COSTECH) (oral communication) are a promising option and their impacts need to be monitored closely.

Reliable, ambitious but realistic policies needed

2) Optimised and well-adapted policies are essential for the long-term success of sustainable development in the energy sector. This includes (1) a legalisation and formalisation of the strongly growing charcoal value chain and (2) sustainable policies in the ICS sector including reliable long-term support mechanisms for producers and/or adopters. Whether subsidies are advisable (Adkins et al. 2010) or not (Pursnani 2011) remains open for further discussion. Furthermore, (3) reliable policy development to harmonise electricity options via grid-electrification, home systems and micro- and mini-grids are essential. Tanzania has launched a power sector reform, including the establishment of a rural energy agency and the instalment of an off-grid feed-in tariff, and has therefore

made progress with reference to the latter. However, reported lacks of planning capacity, coordination and staff remain to be overcome (Ahlborg and Hammar 2014). Innovative technological solutions might also be able to simultaneously address the outlined policy challenges such as electrification and charcoal production (de Miranda et al. 2013) or electrification and the use of ICS (O'Shaughnessy et al. 2014). A negative example for badly adopted policy development is the charcoal ban in 2006 which did not lower the pressure on resources but raised prices (Sander et al. 2013). On a larger scale, the proceedings of the African Energy Ministers conference *"Road to Durban: Promoting Sustainable Energy Access for Africa"* are also an example for suboptimal policy development, as this document fails to mention charcoal on a political level (Government of South Africa 2011). In summary, a variety of different policy measures need to be agreed that guarantee reliable, affordable and sustainable traditional as well as modern energy access for the Tanzanian population. These efforts, in the traditional sector, have to include production and processing optimization and in the modern energy sector need an improved business environment to allow investment from third parties. With the formulation of an updated energy policy in late 2015 (Government of Tanzania 2015), Tanzania seems to be on a good track – the crucial point remains local implementation of the new nation-wide legislation.

Regulation in the charcoal sector needs to be optimised

3) As outlined above, SSA and Tanzania are witnessing substantial increases in charcoal demand due to population growth and urbanisation. Currently, the market prices for charcoal are skyrocketing (cf. figure 3) but strong and efficient regulation is widely absent. Therefore, "*changing the energy paradigm is a development and political imperative"* (Ejigu 2008; p. 161). In this context, a better regulation of charcoal production, transport and trade is highly advisable as fiscal revenues for the Tanzanian state are also likely to increase (Peter and Sander 2009). However, anecdotal evidence suggest that politically powerful actors are involved in this sector, most likely hindering short-term political reforms (Sander et al. 2013) – Schure et al. (2013; p. 103) summarise this for West- and Central Africa: *"There are many vested interests in the informal systems with producers and rent-seeking actors along the chain and few motivations or disincentives to change"*. Nevertheless change and better regulation in this sector are absolutely essential for long-term sustainability. These can be economic with increased state revenues, ecological with a decrease of forest resource degradation in the producer regions, and social with a formalisation of producers allowing them to form associations to increase their profit margins.

Knowledge about and data from energy consumption and production, however, is hardly sufficient to derive clear policy recommendations. Even though there are claims that the data are reliable, there are often huge variances between databases of even international organisations like the International Energy Agency (IEA) and FAO. Mwampamba et al. (2013; p. 78) demonstrate this for charcoal production in specific countries and conclude that *"the reliability of this data for many developing countries is weak, implying that basing national policies on even an average between the two databases is a potentially dangerous approach"*.

A highly promising development is the recent rise of organisations such as GACC and SE4All (Hoffmann and Uckert 2014) which concentrate on turning political attention towards the improvement of access to and availability of sustainable energy. Official acceptance of the Sustainable Development Goals (SDG) by the UN general assembly on the 25th of September 2015 in New York is also particularly important in this context. In contrast to the MDGs, where energy was largely absent (Williams 2009), the SDGs goal no. 7 is explicitly to *"ensure access to affordable, reliable, sustainable and modern energy services for all"* (United Nations 2015). This is likely to boost action towards lifting the billions of people living in energy marginality to a productive, energy-safe existence.

9 References

ABDALLAH JM AND MONELA GG 2007. Overview of Miombo Woodlands in Tanzania. Working Papers of the Finnish Forest Research Institute 50, Vantaa, Finland: Finnish Forest Research Institute, p. 9–23.

ADKINS E, TYLER E, WANG J, SIRIRI D AND MODI V. 2010. Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. Energy for Sustainable Development 14: 172–185.

AFREPREN 2004. The potential contribution of renewables to Africa's energy sector: Summary for policy makers. Nairobi, Kenya: AFREPREN - African Energy Policy Research Network, Heinrich Böll Foundation Regional Office for Eastern and Horn of Africa, p. 47.

AGBEMABIESE L, NKOMO J AND SOKONA Y. 2012. Enabling innovations in energy access: An African perspective. Energy Policy 47, Supplement 1: 38–47.

AHLBORG H AND HAMMAR L. 2014. Drivers and barriers to rural electrification in Tanzania and Mozambique – Grid-extension, off-grid, and renewable energy technologies. Renewable Energy 61: 117–124.

AJANOVIC A. 2011. Biofuels versus food production: Does biofuels production increase food prices? Energy 36: 2070–2076.

AMIGUN B, MUSANGO JK AND STAFFORD W. 2011. Biofuels and sustainability in Africa. Renewable and Sustainable Energy Reviews 15: 1360–1372.

AMIGUN B, SIGAMONEY R AND VON BLOTTNITZ H. 2008. Commercialisation of biofuel industry in Africa: A review. Renewable and Sustainable Energy Reviews 12: 690–711.

ANGSTREICH MG AND JACKSON M 2007. Review of TaTEDO. Integrated sustainable energy services for poverty reduction and environmental conservation program. ISES-PRECP. NORAD Collected Reviews, Oslo, Norway: NORAD-Norwegian Agency for Development Cooperation, p. 38.

ARNDT C, FARMER W, STRZEPEK K AND THURLOW J. 2012. Climate Change, Agriculture and Food Security in Tanzania. Review of Development Economics 16: 378–393.

ARNOLD JEM, KÖHLIN G AND PERSSON R. 2006. Woodfuels, livelihoods, and policy interventions: Changing Perspectives. World Development 34: 596–611.

BAILIS R 2015. Energy policy in developing countries. In: PATZ, J AND LEVY, B (Eds.) Climate Change and Public Health, Oxford, UK: Oxford University Press. p. 291–302.

BAILIS R, COWAN A, BERRUETA V AND MASERA O. 2009. Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. World Development 37: 1694–1705.

BAILIS R, DRIGO R, GHILARDI A AND MASERA O. 2015. The carbon footprint of traditional woodfuels. Nature Climate Change 5: 266–272.

BAILIS R, EZZATI M AND KAMMEN DM. 2005. Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa. Science 308.

BANDA K 2009. South Africa: Growing sunflowers and soja in Limpopo Province for biodiesel production. In: KARLSSON, G AND BANDA, K (Eds.) Biofuels for sustainable rural development and empowerment of women Case studies from Africa and Asia, Leusden, The Netherlands: ENERGIA Secretariat, p. 29–33.

BAZILIAN M ET AL. 2012. Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. Utilities Policy 20: 1–16.

BAZMI AA, ZAHEDI G AND HASHIM H. 2011. Progress and challenges in utilization of palm oil biomass as fuel for decentralized electricity generation. Renewable and Sustainable Energy Reviews 15: 574–583.

BERTHEAU P, CADER C, MÜLLER H, BLECHINGER P, SEGUIN R AND BREYER C. 2014. Energy Storage Potential for Solar Based Hybridization of Off-grid Diesel Power Plants in Tanzania. Energy Procedia 46: 287–293.

BHATTACHARYA SC, ALBINA DO AND ABDUL SALAM P. 2002. Emission factors of wood and charcoal-fired cookstoves. Biomass and Bioenergy 23: 453–469.

BLIN J, BRUNSCHWIG C, CHAPUIS A, CHANGOTADE O, SIDIBE SS, NOUMI ES AND GIRARD P. 2013. Characteristics of vegetable oils for use as fuel in stationary diesel engines—Towards specifications for a standard in West Africa. Renewable and Sustainable Energy Reviews 22: 580–597.

BOKO M, NIANG I, NYONG A, VOGEL C, GITHEKO A, MEDANY M, OSMAN-ELASHA B, TABO R AND YANDA P 2007. Africa. In: PARRY, ML, CANZIANI, OF, PALUTIKOF, JP, VAN DER LINDEN, PJ AND HANSON, CE (Eds.) Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, p. 433–467.

BREW-HAMMOND A 2007. Challenges to increasing access to modern energy services in Africa. Background paper. Maputo, Mozambique: FEMA - Forum of Energy Ministers of Africa 2007, p. 36.

BREW-HAMMOND A AND CROLE-REES A 2004. Reducing rural poverty through increased access to energy services. A review of the multifunctional platform project in Mali. Bamako, Mali: UNDP - United Nations Development Programme, Mali office.

BROUWER ID, DEN HARTOG AP, KAMWENDO MOK AND HELDENS MWO. 1996a. Wood quality and wood preferences in relation to food preparation and diet composition in Central Malawi. Current Opinion in Environmental Sustainability 35: 1–13.

BROUWER ID, HOORWEG JC AND VANLIERE MJ. 1997. When households run out of fuel: Responses of rural households to decreasing fuelwood availability, Ntcheu District, Malawi. World Development 25: 255–266.

BROUWER ID, WIJNHOVEN TMA, BUREMA J AND HOORWEG JC. 1996b. Household fuel use and food consumption: Relationship and seasonal effects in central Malawi. Ecology of Food and Nutrition 35: 179–193.

BROWN A AND ABELL R. 2013. Lake Rukwa [Online]. Available: http://www.feow.org/ecoregions/details/lake_rukwa [Accessed 12.09. 2015].

BUGAJE IM. 2006. Renewable energy for sustainable development in Africa: a review. Renewable and Sustainable Energy Reviews 10: 603–612.

BURGESS ND ET AL. 2010. Getting ready for REDD+ in Tanzania: a case study of progress and challenges. Oryx 44: 339–351.

BURN N AND COCHE L. 2000. The multifunctional platform: Decentralised energy for gender-aware poverty reduction in rural west Africa. ENERGIA News 3: 15–17.

BURN N AND COCHE L 2001. Multifunctional platform for village power: Mali. In: KARLSSON, GV (Ed.) Generating opportunities: case studies on energy and women, New York, USA: UNDP - United Nations Development Programme, p. 61–70.

BUTZ RJ. 2013. Changing land management: A case study of charcoal production among a group of pastoral women in northern Tanzania. Energy for Sustainable Development 17: 138–145.

CAMCO 2014. Biomass energy strategy (BEST) Tanzania. Tanzania biomass energy strategy and action plan. Final report. Dar es Salaam, Tanzania: euei pdf - European Union Energy Initiative Partnership Dialogue Facility, p. 138.

CAMPBELL B, FROST P AND BYRON N 1996. Miombo woodlands and their use: Overview and key issues. In: CAMPBELL, B (Ed.) The Miombo in transition: Woodlands and welfare in Africa, Jakarta, Indonesia: CIFOR - Center for International Forestry Research p. 1–10.

CAMPELL B 1996. The Miombo in transition: Woodlands and welfare in Africa. Jakarta, Indonesia: CIFOR - Center for International Forestry research.

CARRERE R 2013. Oil palm in Africa: Past, present and future scenarios. World Rainforest Movement, p. 1–78.

CARTER C, FINLEY W, FRY J, JACKSON D AND WILLIS L. 2007. Palm oil markets and future supply. European Journal of Lipid Science and Technology 109: 307–314.

CHIDUMAYO EN AND GUMBO DJ. 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. Energy for Sustainable Development 17: 86–94.

CLOUGH L 2012. The improved cookstove sector in East Africa: Experiences from the Developing Energy Enterprise Programme (DEEP). London, UK: GVEP - Global Village Energy Partnership International, p. 108.

CORLEY RHV. 2009. How much palm oil do we need? Environmental Science & Policy 12: 134–139.

COTULA L, DYER N AND VERMEULEN S 2008. Fuelling exclusion? The biofuels boom and poor people's access to land. London, UK: IIED - International Institute for Environment and Development, p. 82.

DASAPPA S. 2011. Potential of biomass energy for electricity generation in sub-Saharan Africa. Energy for Sustainable Development 15: 203–213.

DE MIRANDA RC, BAILIS R AND VILELA ADO. 2013. Cogenerating electricity from charcoaling: A promising new advanced technology. Energy for Sustainable Development 17: 171–176.

DEMIRBAS AH AND DEMIRBAS I. 2007. Importance of rural bioenergy for developing countries. Energy Conversion and Management 48: 2386–2398.

DENTON F. 2004. Reducing the gap between projects and policies: a comparative analysis of the "butanisation" programme in Senegal and the Multifunctional Platform (MFP) experience in Mali. Energy for Sustainable Development 8: 17–29.

DIMPL E 2011. Small-scale electricity generation from biomass. Part III: Vegetable oil. Eschborn, Germany: GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit, p. 23.

DRIGO R 2005. WISDOM East Africa. Woodfuel integrated supply/demand overview mapping (WISDOM) methodology. Spatial woodfuel production and consumption analysis of selected African countries. Rome, Italy: FAO - Food and Agriculture Organization of the United Nations, p. 78.

EBERHARD A, FOSTER V, BRICENO-GARMENDIA C, OUEDRAOGO F, CAMOS D AND SHKARATAN M 2008. Underpowered: The state of the power sector in Sub-Saharan Africa. Summary of background paper 6. Africa infrastructure country diagnostic, Washington DC, USA: The World Bank, p. 11.

EIA. 2015. Petroleum & Other liquids [Online]. Washington DC, USA: EIA - U.S. Energy Information Administration. Available: http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm [Accessed 12.09. 2015].

EJIGU M. 2008. Toward energy and livelihoods security in Africa: Smallholder production and processing of bioenergy as a strategy. Natural Resources Forum 32: 152–162.

EMRICH W 1985. Handbook of Charcoal Making. Solar Energy R&D in the European Community, n. 7, Dordrecht, Netherlands: D. Reidel Publishing Company for the Commission of the European Communities, 278 p.

ESCOBAR JC, LORA ES, VENTURINI OJ, YÁÑEZ EE, CASTILLO EF AND ALMAZAN O. 2009. Biofuels: Environment, technology and food security. Renewable and Sustainable Energy Reviews 13: 1275–1287.

ESTEBAN B, BAQUERO G, PUIG R, RIBA J-R AND RIUS A. 2011. Is it environmentally advantageous to use vegetable oil directly as biofuel instead of converting it to biodiesel? Biomass and Bioenergy 35: 1317–1328.

EU COMMISSION 2013. Soil atlas of Africa. Brussels, Belgium: EU Commission.

FAO 2008. Forests and energy: key issues. FAO Forestry Paper 154, Rome, Italy: FAO - Food and Agriculture Organization of the United Nations, p. 73.

FAO 2011. Foreign agricultural investment country profile. United Republic of Tanzania. FAO Investment Policy Support, Rome, Italy: FAO - Food and Agriculture Organization of the United Nations, p. 31.

FAOSTAT. 2013. Food and Agricultural Organization Statistical Database. [Online]. Available: http://faostat3.fao.org/home/index.html [Accessed 12.09. 2015].

FAßE A AND GROTE U. 2013. The economic relevance of sustainable agroforestry practices — An empirical analysis from Tanzania. Ecological Economics 94: 86–96.

FAßE A, WINTER E AND GROTE U. 2014. Bioenergy and rural development: The role of agroforestry in a Tanzanian village economy. Ecological Economics 106: 155–166.

FELIX M AND GHEEWALA SH. 2011. A Review of Biomass Energy Dependency in Tanzania. Energy Procedia 9: 338–343.

GACC. 2015. Global Alliance for Clean Cookstoves [Online]. Available: http://www.cleancookstoves.org/ [Accessed 12.09. 2015].

GEF 2013. Africa will import - not export - wood. Chevy Chase, USA: GEF - Global Environment Fund, p. 16.

GERLAND P ET AL. 2014. World population stabilization unlikely this century. Science 346: 234–237.

GLOBAL VILLAGE ENERGY PARTNERSHIP 2012a. Tanzania Market Assessment. Executive Summary. London, UK: GACC - Global Alliance for Clean Cookstoves, p. 4.

GLOBAL VILLAGE ENERGY PARTNERSHIP 2012b. Tanzania Market Assessment. Sector Mapping. London, UK: GACC - Global Alliance for Clean Cookstoves, p. 70.

GMÜNDER S, ZAH R, RAINHARD J AND CHARRON-DOUCET F 2014. Transforming Tanzania's Charcoal Sector. Life Cycle Assessment Component. Zurich, Switzerland: Quantis Switzerland/Germany, p. 96.

GOVERNMENT OF SOUTH AFRICA 2011. African energy minister conference proceedings report. Road to Durban: Promoting sustainable energy access for Africa. September 15th – 16th, 2011. Johannesburg, South Africa, p. 112.

GOVERNMENT OF TANZANIA 1998. Kigoma region. Socio-economic profile. Dar es Salaam, Tanzania: The planning commission Dar es Salaam and the Regional commissioner's office Kigoma, p. 188.

GOVERNMENT OF TANZANIA 2003. The national energy policy. Dar es Salaam, Tanzania: Ministry of Energy and Minerals, p. 36.

GOVERNMENT OF TANZANIA 2006. Rukwa. Regional and district projections Volume XII. Dar es Salaam, Tanzania: National Bureau of Statistics and Ministry of Planning, Economy and Empowerment, p. 194.

GOVERNMENT OF TANZANIA 2007. Regional report: Rukwa region. Volume Vo. National sample census of agriculture 2002/2003, Dar es Salaam, Tanzania: National Bureau of Statistics, Ministry of Agriculture and Food Security, Ministry of Water and Livestock Development, Ministry of Cooperatives and Marketing, Presidents Office, Regional Administration and Local Government, p. 332.

GOVERNMENT OF TANZANIA 2008. Regional report: Kigoma region. Volume Vp. National sample census of agriculture 2002/2003, Dar es Salaam, Tanzania: National Bureau of Statistics, Ministry of Agriculture and Food Security, Ministry of Water and Livestock Development, Ministry of Cooperatives and Marketing, Presidents Office, Regional Administration and Local Government, p. 334.

GOVERNMENT OF TANZANIA 2010. Guidelines for liquid biofuels development in Tanzania. Dar es Salaam: Ministry of Energy and Minerals, p. 24.

GOVERNMENT OF TANZANIA 2011. National sample census of agriculture 2007/2008 Volume 1: Technical and operation report. Dar es Salaam, Tanzania: National Bureau of Statistics, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock and Fisheries Development, Ministry of Water, Ministry of Industry and Trade, Prime Minister's Office, Regional Administration and Local Government, p. 199.

GOVERNMENT OF TANZANIA 2012a. Regional report: Kigoma Region. Volume Vq. National sample census of agriculture 2007/2008, Dar es Salaam, Tanzania: National Bureau of Statistics, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock and Fisheries Development, Ministry of Water, Ministry of Industry and Trade, Prime Minister's Office, Regional Administration and Local Government, p. 401.

GOVERNMENT OF TANZANIA 2012b. Regional report: Rukwa region. Volume Vp. National sample census of agriculture 2007/2008, Dar es Salaam, Tanzania: National Bureau of Statistics, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock and Fisheries Development, Ministry of Water, Ministry of Industry and Trade, Prime Minister's Office, Regional Administration and Local Government, p. 409.

GOVERNMENT OF TANZANIA 2013. Population Distribution by Administrative Units; Key Findings. 2012 Population and Housing Census, Dar es Salaam, Tanzania: National Bureau of Statistics and Office of Chief Government Statistician Zanzibar, p. 12.

GOVERNMENT OF TANZANIA 2015. The draft national energy policy 2015. Dar es Salaam, Tanzania: Ministry of Energy and Minerals.

GRIESHOP AP, MARSHALL JD AND KANDLIKAR M. 2011. Health and climate benefits of cookstove replacement options. Energy Policy 39: 7530–7542.

GRIMSBY LK, AUNE JB AND JOHNSEN FH. 2012. Human energy requirements in Jatropha oil production for rural electrification in Tanzania. Energy for Sustainable Development 16: 297–302.

GROMPONE MA 2005. Sunflower Oil. In: SHAHIDI, F (Ed.) Bailey's Industrial Oil and Fat Products, Hoboken, USA: John Wiley & Sons, Inc., p. 655–730.

HANNA R, DUFLO E AND GREENSTONE M 2012. Up in Smoke: The influence of household behavior on the long-run impact of improved cooking stoves. Working paper series 12–10, Cambridge, USA: MIT - Massachusetts Institute of Technology; Department of Economics, p. 72.

HARRISON RW. 2009. The Food versus Fuel Debate: Implications for Consumers. Journal of Agricultural and Applied Economics 41: 493–500.

HARTLEY C. 1988. The oil palm (Elaeis guineensis Jacq.) 3rd edition. Harlow, UK: Longman.

HARTTER J AND BOSTON K. 2007. An integrated approach to modeling resource utilization for rural communities in developing countries. Journal of Environmental Management 85: 78–92.

HENDERSON JV, STOREYGARD A AND WEIL DN. 2012. Measuring Economic Growth from Outer Space. American Economic Review 102: 994–1028.

HIEMSTRA-VAN DER HORST G AND HOVORKA AJ. 2009. Fuelwood: The "other" renewable energy source for Africa? Biomass & Bioenergy 33: 1605–1616.

HOFFMANN H AND UCKERT G. 2014. Die UN-Initiative ›Nachhaltige Energie für alle‹ Entstehung, Einordnung und Aussichten. Vereinte Nationen 3: 51–56.

HOLT-GIMÉNEZ E. 2007. The biofuel myths [Online]. New York, USA: The New York Times Company. Available: http://www.nytimes.com/2007/07/10/opinion/10iht-edholt.1.6588231.html?pagewanted=all [Accessed 12.09. 2015].

HONGO H AND DE KEYSER S 2005. FELISA: The potential for biofuels in Southern Africa. Partners for Africa newsletter, Stockholm, Sweden: SEI - Stockholm Environmental Institute.

HONKALASKAR V, BHANDARKAR U AND SOHONI M. 2013. Development of a fuel efficient cookstove through a participatory bottom-up approach. Energy, Sustainability and Society 3: 16.

HOSIER RH. 1993. Charcoal production and environmental degradation: Environmental history, selective harvesting, and post-harvest management. Energy Policy 21: 491–509.

HOSIER RH AND DOWD J. 1987. Household fuel choice in Zimbabwe: An empirical test of the energy ladder hypothesis. Resources and Energy 9: 347–361.

HOSIER RH, MWANDOSYA MJ AND LUHANGA ML. 1993. Future energy development in Tanzania: The energy costs of urbanization. Energy Policy 21: 524–542.

HYMAN EL. 1990. An economic analysis of small-scale technologies for palm oil extraction in Central and West Africa. World Development 18: 455–476.

IEA 2006. Energy for Cooking in Developing Countries. In: IEA (Ed.) World Energy Outlook 2006, Paris, France: IEA - International Energy Agency, p. 419–445.

IIYAMA M, NEUFELDT H, DOBIE P, NJENGA M, NDEGWA G AND JAMNADASS R. 2014. The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Current Opinion in Environmental Sustainability 6: 138–147.

ILSKOG E AND KJELLSTRÖM B. 2008. And then they lived sustainably ever after?—Assessment of rural electrification cases by means of indicators. Energy Policy 36: 2674–2684.

ILSKOG E, KJELLSTRÖM B, GULLBERG M, KATYEGA M AND CHAMBALA W. 2005. Electrification co-operatives bring new light to rural Tanzania. Energy Policy 33: 1299–1307.

JAGGER P AND SHIVELY G. 2014. Land use change, fuel use and respiratory health in Uganda. Energy Policy 67: 713–726.

JERVE AM AND NTEMI EJK 2009. Rukwa Ruka - The attempt of a foreign donor to uplift a neglected region: A study of the impact of Norwegian aid to Rukwa Region, Tanzania. CMI Report R 2009: 12, Bergen, Norway: CMI - Chr. Michelsen Institute, p. 109.

JEULAND M AND PATTANAYAK S. 2012. Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. PLoS ONE 7.

JOHNSEN FH 1999. Buring with Enthusiams: Fuelwood scarcity in Tanzania in terms of severity, impacts and remedies. Oslo, Norway: Forum for Development Studies, p. 107–131.

JOHNSON FX AND LAMBE F 2009. Energy access, climate and development. Stockholm, Sweden: CCD - Commission on climate change and development, p. 11.

JOHNSON NG AND BRYDEN KM. 2012. Energy supply and use in a rural West African village. Energy 43: 283–292.

JOHNSON O 2013. Universal Energy Access: Moving from technological fix to poverty reduction. Briefing Paper 6/2013, Bonn, Germany: DIE/GDI - German Development Institute / Deutsches Institut für Entwicklungspolitik, p. 4.

JUST B, ROGAK S AND KANDLIKAR M. 2013. Characterization of Ultrafine Particulate Matter from Traditional and Improved Biomass Cookstoves. Environmental Science & Technology 47: 3506–3512.

KAALE B. 2012. Tanzania: Impact of Cooking Energy Scarcity on Gender [Online]. Dar es Salaam, Tanzania. Available: http://allafrica.com/stories/201208220433.html [Accessed 12.09. 2015].

KAMMEN DM 1995. From fuel efficiency to social utility: Lessons from cookstove design, dissemination and use. In: GOLDEMBERG, J AND JOHANSSON, TB (Eds.) Energy as an instrument for socio-economic development, New York, USA: UNDP - United Nations Development Program.

KAMMEN DM AND KIRUBI C. 2008. Poverty, Energy, and Resource Use in Developing Countries. Annals of the New York Academy of Sciences 1136: 348–357.

KAMMEN DM AND LEW DJ 2005. Review of technologies for the production and use of charcoal. Renewable and Appropriate Energy Laboratory Report, Golden, USA: National Renewable Energy Laboratory, p. 19.

KAREKEZI S. 2002. Poverty and energy in Africa - A brief review. Energy Policy 30: 915–919.

KAYGUSUZ K. 2011. Energy services and energy poverty for sustainable rural development. Renewable & Sustainable Energy Reviews 15: 936–947.

KEES M AND FELDMANN L. 2011. The role of donor organisations in promoting energy efficient cook stoves. Energy Policy 39: 7595–7599.

KHUNDI F, JAGGER P, SHIVELY G AND SSERUNKUUMA D. 2011. Income, poverty and charcoal production in Uganda. Forest Policy and Economics 13: 199–205.

KIMARYO BT AND NGEREZA KI 1988. Dissemination of the Casamance earth kiln for charcoal production in Tanzania. Moshi, Tanzania: Tanzania Forestry Research Institute, Timber utilisation research centre, p. 25.

KIMARYO BT AND NGEREZA KI 1989. Charcoal production in Tanzania using improved traditional earth kilns. Manuscript Report 216e, Moshi, Tanzania: IDRC - International Development Research Centre, p. 27.

KSHIRSAGAR MP AND KALAMKAR VR. 2014. A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. Renewable and Sustainable Energy Reviews 30: 580–603.

LAHIMER AA, ALGHOUL MA, YOUSIF F, RAZYKOV TM, AMIN N AND SOPIAN K. 2013. Research and development aspects on decentralized electrification options for rural household. Renewable and Sustainable Energy Reviews 24: 314–324.

LEE LY-T. 2013. Household energy mix in Uganda. Energy Economics 39: 252–261.

LEGROS G, HAVET I, BRUCE N AND BONJOUR S 2009. The energy access situation in developing countries: a review focusing on least developed countries and sub-Saharan Africa. New York, USA: UNDP - The United Nations Development Programme; WHO - The World Health Organization, p. 142.

LEWIS JJ AND PATTANAYAK SK. 2012. Who Adopts Improved Fuels and Cookstoves? A Systematic Review. Environmental Health Perspectives 120: 637–645.

LIM SS ET AL. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 380: 2224–2260.

LOOS T 2009. Socio-economic impact of a Jatropha-project on smallholder farmers in Mpanda, Tanzania. A case study of a public-private partnership project in Tanzania. MSc thesis. Hohenheim, Germany: University of Hohenheim, Institute for Agricultural Economics and Social Sciences in the Tropics and Subtropics, p. 157.

LUOGA EJ, WITKOWSKI ETF AND BALKWILL K. 2000. Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. Ecological Economics 35: 243–257.

MACCARTY N, STILL D AND OGLE D. 2010. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. Energy for Sustainable Development 14: 161–171.

MAES WH AND VERBIST B. 2012. Increasing the sustainability of household cooking in developing countries: Policy implications. Renewable & Sustainable Energy Reviews 16: 4204–4221.

MAKUNDI W. 2001. Potential and Cost of Carbon Sequestration in the Tanzanian Forest Sector. Mitig Adapt Strat Glob Change 6: 335–353.

MAKUNGWA SD, EPULANI F AND WOODHOUSE IH. 2013. Fuelwood Supply: A Missed Essential Component in a Food Security Equation. Journal of Food Security 1: 49–51.

MALIMBWI RE AND ZAHABU EM 2008. Woodlands and the charcoal trade: the case of Dar es Salaam City. Working Papers of the Finnish Forest Research Institute 98, Vantaa, Finland: Finnish Forest Research Institute, p. 93–114.

MANDELLI S, BARBIERI J, MATTAROLO L AND COLOMBO E. 2014. Sustainable energy in Africa: A comprehensive data and policies review. Renewable and Sustainable Energy Reviews 37: 656–686.

MARTIN M, MWAKAJE AG AND EKLUND M. 2009. Biofuel development initiatives in Tanzania: development activities, scales of production and conditions for implementation and utilization. Journal of Cleaner Production 17, Supplement 1: S69–S76.

MASERA OR, SAATKAMP BD AND KAMMEN DM. 2000. From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. World Development 28: 2083–2103.

MENÉNDEZ A AND CURT MD. 2013. Energy and socio-economic profile of a small rural community in the highlands of central Tanzania: A case study. Energy for Sustainable Development 17: 201–209.

MESSEMAKER L 2008. The green myth? Assessment of the Jatropha value chain and its potential for pro-poor biofuel development in Northern Tanzania. MSc thesis. Utrecht, The Netherlands: Utrecht University, Faculty of Geosciences, International Development Studies (IDS) p. 97.

MIGIRO K. 2015. U.N. condemns surge in hunting and killing of albinos in East Africa [Online]. Available: http://www.reuters.com/article/2015/03/10/us-eastafrica-albinism-idUSKBN0M61I520150310 [Accessed 12.09. 2015].

MITCHELL D 2008. A Note on Rising Food Prices. Policy Research Working Paper 4682, Washington DC, USA: The World Bank, p. 21.

MITCHELL D 2011. Biofuels in Africa. Opportunities, prospects and challenges. Directions in development - Countries and regions, Washington DC, USA: The World Bank.

MOHAMMED YS, BASHIR N AND MUSTAFA MW. 2015. Overuse of wood-based bioenergy in selected sub-Saharan Africa countries: review of unconstructive challenges and suggestions. Journal of Cleaner Production 96: 501–519.

MOLONY T 2009. Tanzania Palm Oil. In: FAO (Ed.) Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa, Rome, Italy: FAO - Food and Agriculture Organization of the United Nations, p. 72–76.

MOMBO F, LUSAMBO L, SPEELMAN S, BUYSSE J, MUNISHI P AND VAN HUYLENBROECK G. 2014. Scope for introducing payments for ecosystem services as a strategy to reduce deforestation in the Kilombero wetlands catchment area. Forest Policy and Economics 38: 81–89.

MONBIOT G, READ P, TRINIDADE S, MOREIRA J, WOODS J, JOHNSON FX, YAMBA F AND ROSILLO-CALLE F 2005. Policy Debate on Global Biofuels Development. Renewable Energy Partnerships for Poverty Eradication and Sustainable Development and Renewable Energy for Development, Stockholm, Sweden: Partners for Africa, SEI - Stockholm Environmental Institute, p. 12.

MPAGALILE JJ, ISHENGOMA RC AND GILLAH P 2008. Agribusiness innovations in six African countries. The Tanzanian experience. Morogoro, Tanzania: The World Bank Institute, p. 82.

MSUYA N, MASANJA E AND TEMU A. 2011. Environmental Burden of Charcoal Production and Use in Dar es Salaam, Tanzania. Journal of Environmental Protection 2: 1364–1369.

MULUGETTA Y. 2009. Evaluating the economics of biodiesel in Africa. Renewable and Sustainable Energy Reviews 13: 1592–1598.

MUNSLOW B, KATERERE Y, FERF A AND O'KEEFE P 1988. The fuelwood trap. A study of the SADCC region. London, UK: Earthscan Publications Ltd.

MURPHY JT. 2001. Making the energy transition in rural east Africa: Is leapfrogging an alternative? Technological Forecasting and Social Change 68: 173–193.

MUZZINI E AND LINDEBOOM W 2008. The urban transition in Tanzania: Building the empirical base for policy dialogue. Washington DC, USA: The World Bank, p. 166.

MWAGENI N, SILAS RS AND KIUNSI R. 2015. Assessment of changes in provision of forest ecosystem goods and services and benefit sharing mechanisms in the Ugalla-Masito Ecosystem: A case of Ilagala and Karago villages in Kigoma Region, Tanzania. International Journal of Biodiversity and Conservation 7: 290–298.

MWAMPAMBA TH. 2007. Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability. Energy Policy 35: 4221–4234.

MWAMPAMBA TH, GHILARDI A, SANDER K AND CHAIX KJ. 2013. Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. Energy for Sustainable Development 17: 75–85.

MWANDOSYA MJ AND LUHANGA ML. 1993. Energy and development in Tanzania: Issues and perspectives. Energy Policy 21: 441–453.

NATHANIELS NQR AND MWIJAGE A 2000. Seed fairs and the case of Marambo village, Nachingwea district, Tanzania: Implications of local informal seed supply and variety development for research and extension. ODI Agricultural research & extension network (AgREN), network paper 101, London, UK: ODI - Overseas Development Institute, p. 12.

NCUBE M. 2012. Urbanization in Africa [Online]. Abidjan, Ivory Coast: African Development Bank

Available: http://www.afdb.org/en/blogs/afdb-championing-inclusive-growth-across-africa/post/urbanization-in-africa-10143/ [Accessed 12.09. 2015].

NEUFELDT H, DOBIE P, IIYAMA M, NJENGA M, MOHAN S AND NEELY C 2015. Developing sustainable tree-based bioenergy systems in sub-Saharan Africa. ICRAF Policy Brief 28, Nairobi, Kenya: ICRAF - World Agroforestry Centre, p. 8.

NONHEBEL S. 2012. Global food supply and the impacts of increased use of biofuels. Energy 37: 115–121.

NYGAARD I. 2010. Institutional options for rural energy access: Exploring the concept of the multifunctional platform in West Africa. Energy Policy 38: 1192–1201.

O'SHAUGHNESSY SM, DEASY MJ, DOYLE JV AND ROBINSON AJ. 2014. Field trial testing of an electricity-producing portable biomass cooking stove in rural Malawi. Energy for Sustainable Development 20: 1–10.

OCHIENG CA, TONNE C AND VARDOULAKIS S. 2013. A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya. Biomass and Bioenergy 58: 258–266.

OKELLO C, PINDOZZI S, FAUGNO S AND BOCCIA L. 2013. Development of bioenergy technologies in Uganda: A review of progress. Renewable and Sustainable Energy Reviews 18: 55–63.

OPENSHAW K. 1983. Wood Fuel Surveys - Annex III - (b) Measuring fuelwood and charcoal [Online]. Rome: Food and Agricultural Organization. Available: http://www.fao.org/docrep/q1085e/q1085e0c.htm [Accessed 12.09. 2015].

OROZCO M, VENTURA I AND SOLOMONS NW. 2006. Household usage of and recipe creation with condiment sauces based on red palm oil: exploring the potential for targeted micronutrient delivery to different family members. Journal of Oil Palm Research 18: 181–188.

OTITI T. 2010. Tanzanian Stoves [Online]. Boiling Point. HEDON Household Energy Network. Available: http://www.hedon.info/View+Article&itemId=10682 [Accessed 12.09. 2015].

OWEN M, DER PLAS RV AND SEPP S. 2013. Can there be energy policy in Sub-Saharan Africa without biomass? Energy for Sustainable Development 17: 146–152.

PALMER C AND MACGREGOR J 2008. Fuelwood Scarcity, Energy Substitution and Rural Livelihoods in Namibia. Proceedings of the German Development Economics Conference, Zürich, Switzerland: Research Committee on Development Economics (AEL), German Economic Association.

PALMULA S AND BEAUDIN M 2007. Greening the charcoal chain - substituting for charcoal as a household cooking fuel in Dar es Salaam. Traineeship Report, ERM Module 5, Amsterdam, The Netherlands: Institute for Environmental Studies. Vrije Universiteit.

PETER C AND SANDER K 2009. Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. A policy note. Washington DC, USA: The World Bank, p. 54.

PINSTRUP-ANDERSEN P AND PANDYA-LORCH R. 1998. Food security and sustainable use of natural resources: a 2020 Vision. Ecological Economics 26: 1–10.

PÖPPL M. 2014. Strom für Afrika – dank einer Idee aus Friedrichshain [Online]. Berlin, Germany. Available: http://www.tagesspiegel.de/wirtschaft/energieversorgung-strom-fuer-afrika-dank-einer-idee-aus-friedrichshain/11050386.html [Accessed 12.09. 2015].

POTTS D. 2009. The slowing of sub-Saharan Africa's urbanization: evidence and implications for urban livelihoods. Environment and Urbanization 21: 253–259.

POUDEL BN, PAUDEL KP, TIMILSINA G AND ZILBERMAN D. 2012. Providing Numbers for a Food versus Fuel Debate: An Analysis of a Future Biofuel Production Scenario. Applied Economic Perspectives and Policy 34: 637–668.

PURSNANI P. 2011. Shell Foundation and the Breathing Space Programme. Innovations: Technology, Governance, Globalization 6: 103–106.

RAMAN P, MURALI J, SAKTHIVADIVEL D AND VIGNESWARAN VS. 2013. Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut shell. Biomass and Bioenergy 49: 333–340.

RAMIREZ S, DWIVEDI P, GHILARDI A AND BAILIS R. 2014. Diffusion of non-traditional cookstoves across western Honduras: A social network analysis. Energy Policy 66: 379–389.

RATHMANN R, SZKLO A AND SCHAEFFER R. 2010. Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate. Renewable Energy 35: 14–22.

REINHARDT G, RETTENMAIER N, GÄRTNER S AND PASTOWSKI A 2007. Rain forest for biodiesel? Ecological effects of using palm oil as a source of energy. Berlin, Germany: WWF - World Wildlife Fund Germany, p. 52.

REYES - MORENO C, PAREDES - LÓPEZ O AND GONZALEZ E. 1993. Hard - to - cook phenomenon in common beans — A review. Critical Reviews in Food Science and Nutrition 33: 227–286.

RIEDJIK A 2011. Desk-study: The household improved cook stoves sector in Tanzania. Arusha, Tanzania: SNV - Netherlands Development Organisation Tanzania and Round Table Africa, p. 62.

RLDC 2008. Sunflower sector: Market development strategy. Arusha, Tanzania: RLDC - Rural Livelihood Development Company, p. 30.

ROMIJN HA AND CANIËLS MCJ. 2011. The Jatropha biofuels sector in Tanzania 2005–2009: Evolution towards sustainability? Research Policy 40: 618–636.

ROWHANI P, LOBELL D, LINDERMAN M AND RAMANKUTTY 2011. Climate variability and crop production in Tanzania. Agricultural and Forest Meteorology 151: 449-460.

SANDER K, GROS C AND PETER C. 2013. Enabling reforms: Analyzing the political economy of the charcoal sector in Tanzania. Energy for Sustainable Development 17: 116-126.

SANGA GA AND MEENA SB 2008. Bio-fuel powered energy service platforms for rural energy services. Design, installation, operation, maintenance and mangement. Dar es Salaam, Tanzania: TaTEDO - Tanzania Traditional Energy Development Organization.

SCHENKEL Y, BERTAUX P, VANWIJNBSERGHE S AND CARRE J. 1998. An evaluation of the mound kiln carbonization technique. Biomass and Bioenergy 14: 505–516.

SCHURE J, INGRAM V, SAKHO-JIMBIRA MS, LEVANG P AND WIERSUM KF. 2013. Formalisation of charcoal value chains and livelihood outcomes in Central- and West Africa. Energy for Sustainable Development 17: 95–105.

SCHURICHT W 2009. Der Obstbau Mitteldeutschlands vom Mittelalter bis zum Jahre 1945. Erfurt, Germany: Förderverein Deutsches Gartenbaumuseum Erfurt.

SEGERSTEDT A AND BOBERT J. 2013. Revising the potential of large-scale Jatropha oil production in Tanzania: An economic land evaluation assessment. Energy Policy 57: 491–505.

SÈNE EH. 2000. Forests and food security in Africa: the place of forestry in FAO's Special Programme for Food Security [Online]. Rome, Italy: FAO. Available: http://www.fao.org/docrep/x7273e/x7273e03.htm [Accessed 12.09. 2015].

SEPP C 2014. Meeting of the „Bonner Netzwerks „Bioenergie für Entwicklung" – Holzenergie – zurück in die Zukunft?"; 22.10.2014. Bonn, Germany.

SHRIMALI G, SLASKI X, THURBER MC AND ZERRIFFI H. 2011. Improved stoves in India: A study of sustainable business models. Energy Policy 39: 7543–7556.

SIDIBÉ SS, BLIN J, VAITILINGOM G AND AZOUMAH Y. 2010. Use of crude filtered vegetable oil as a fuel in diesel engines state of the art: Literature review. Renewable and Sustainable Energy Reviews 14: 2748–2759.

SIMON GL, BAILIS R, BAUMGARTNER J, HYMAN J AND LAURENT A. 2014. Current debates and future research needs in the clean cookstove sector. Energy for Sustainable Development 20: 49–57.

SIMON GL, BUMPUS AG AND MANN P. 2012. Win-win scenarios at the climate–development interface: Challenges and opportunities for stove replacement programs through carbon finance. Global Environmental Change 22: 275–287.

SMITH K.R., MEHTA S. AND MAEUSEZAHL-FEUZ M. 2004. Indoor smoke from household solid fuels. In: EZZATI M., RODGERS A., LOPEZ A.D., HOORN S.V. AND MURRAY C.J.L (Eds.) Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors, Geneva, Switzerland: WHO - The World Health Organization, p. 1435–1493.

SOKONA Y, MULUGETTA Y AND GUJBA H. 2012. Widening energy access in Africa: Towards energy transition. Energy Policy 47, Supplement 1: 3–10.

SOSOVELE H. 2010. Policy challenges related to biofuel development in Tanzania. Africa Spectrum 45: 117–129.

STEIERER F 2011. Highlights on wood charcoal: 2004–2009. Rome, Italy: FAO - Food and Agriculture Organization of the United Nations, p. 3.

SUTAR KB, KOHLI S, RAVI MR AND RAY A. 2015. Biomass cookstoves: A review of technical aspects. Renewable and Sustainable Energy Reviews 41: 1128–1166.

TABUTI JRS, DHILLION SS AND LYE KA. 2003. Firewood use in Bulamogi County, Uganda: species selection, harvesting and consumption patterns. Biomass and Bioenergy 25: 581–596.

TAN KT, LEE KT, MOHAMED AR AND BHATIA S. 2009. Palm oil: Addressing issues and towards sustainable development. Renewable and Sustainable Energy Reviews 13: 420–427.

TANSANIA INFORMATION. 2014. Tanseco-Treuhand-Skandal [Online]. Available: http://www.tansania-information.de/index.php?title=Tanesco-Treuhand-Skandal_-_12/2014 [Accessed 10.07. 2015].

THE GUARDIAN. 2014. Cookstove designs are failing the poorest communities [Online]. London, UK: Guardian News & Media Ltd. Available: http://www.theguardian.com/sustainable-business/cookstoves-design-poor-communities-refugees-unhcr-ikea [Accessed 12.09. 2015].

THE WORLD BANK 2007. Growth Prospects for Rukwa Region: Constraints and Opportunities. Washington DC, USA: The World Bank, p. 57.

THE WORLD BANK 2009. Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. A policy note.: Sustainable Development, African region, The World Bank, p. 54.

THE WORLD BANK 2011a. Household cookstoves, environment, health and climate change: a new look on an old problem. Washington DC, USA: The World Bank.

THE WORLD BANK 2011b. Wood-Based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches. Washington DC, USA: The World Bank, p. 64.

THOMPSON P. 2012. The Agricultural Ethics of Biofuels: The Food vs. Fuel Debate. Agriculture 2: 339.

TILMAN D ET AL. 2009. Beneficial biofuels – The food, energy, and environment trilemma. Science 325: 270–271.

TIMILSINA GR AND SHRESTHA A. 2011. How much hope should we have for biofuels? Energy 36: 2055–2069.

TIRADO MC, COHEN MJ, ABERMAN N, MEERMAN J AND THOMPSON B. 2010. Addressing the challenges of climate change and biofuel production for food and nutrition security. Food Research International 43: 1729–1744.

TRÖGER S 2004. Handeln zur Ernährungssicherung im Zeichen gesellschaftlichen Umbruchs. Untersuchungen auf dem Ufipa-Plateau im Südwesten Tansanias. In: BOHLE, H-G AND KRINGS, T (Eds.) Studien zur Geographischen Entwicklungsforschung 27, Saarbrücken, Germany: Verlag für Entwicklungspolitik.

TURNER AG 2003. Sampling strategies. New York, USA: UN secretariat - Statistics Division, p. 45.

UNFPA TANZANIA. 2013. More people move to urban areas as Tanzanian population gallops. What does the results of population and census 2012 tell us about the state of Tanzania today. [Online]. UNFPA - United Nation Population Fund. Available: http://countryoffice.unfpa.org/tanzania/2013/04/19/6599/more_people_move_to_urban_areas_as_tanzanian_population_gallops/ [Accessed 12.09. 2015].

UNITED NATIONS 2005. Designing Household Survey Samples: Practical Guidelines. In: DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, SD (Ed.) Series F New York, USA.

UNITED NATIONS 2013a. Human Development Report 2013. The Rise of the South: Human Progress in a Diverse World – Explanatory note on 2013 HDR composite indices Tanzania (United Republic of). Nairobi, Kenya: United Nations.

UNITED NATIONS 2013b. World Population Prospects: The 2012 Revision; Highlights and Advanced Tables. Working paper No ESA/P/WP228, New York, USA: Department of Economic and Social Affairs Population Division.

UNITED NATIONS. 2015. Open Working Group proposal for Sustainable Development Goals [Online]. New York. Available: https://sustainabledevelopment.un.org/sdgsproposal.html [Accessed 12.09. 2015].

URASSA JK 2010. Rural household livelihoods, crop production and well-being after a period of trade reforms: a case study of Rukwa, Tanzania; PhD Thesis University of Sussex. Sussex, UK: University of Sussex.

URMEE T AND GYAMFI S. 2014. A review of improved Cookstove technologies and programs. Renewable and Sustainable Energy Reviews 33: 625–635.

VAN DER KROON B, BROUWER R AND VAN BEUKERING PJH. 2013. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. Renewable and Sustainable Energy Reviews 20: 504–513.

VAN EIJCK J AND ROMIJN H. 2008. Prospects for Jatropha biofuels in Tanzania: An analysis with Strategic Niche Management. Energy Policy 36: 311–325.

VAN EIJCK J, ROMIJN H, SMEETS E, BAILIS R, ROOIJAKKERS M, HOOIJKAAS N, VERWEIJ P AND FAAIJ A. 2014. Comparative analysis of key socio-economic and environmental impacts of smallholder and plantation based jatropha biofuel production systems in Tanzania. Biomass and Bioenergy 61: 25–45.

VERMEULEN S AND COTULA L. 2010. Over the heads of local people: Consultation, consent, and recompense in large-scale land deals for biofuels projects in Africa. Journal of Peasant Studies 37: 899–916.

VON FREYHOLD M 1979. Ujamaa Villages in Tanzania: Analysis of a Social Experiment. London, UK: Heinemann.

VOS J AND VIS M 2010. Making charcoal production in sub-Saharan Africa sustainable. Utrecht, The Netherlands: NL Agency; Netherlands Programmes Sustainable Biomass p. 59.

WAHL N ET AL. 2012. Insights into Jatropha projects worldwide. Key facts & figures from a global survey. Lüneburg, Germany: Leuphana University of Lüneburg, Centre for Sustainability Management (CSM), p. 72.

WALLMO K AND JACOBSON SK. 1998. A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda. Environmental Conservation 25: 99–108.

WANDEL M AND HOLMBOE-OTTESEN G. 1992. Food availability and nutrition in a seasonal perspective: A study from the Rukwa region in Tanzania. Human Ecology 20: 89–107.

WANDEL M, HOLMBOE-OTTESEN G AND MANU A. 1992. Seasonal work, energy intake and nutritional stress: A case study from Tanzania. Nutrition Research 12: 1–16.

WHO 2006. Fuel for Life: Household Energy and Health. Geneva, Switzerland: WHO - The World Health Organization.

WILLIAMS M. 2009. Energy neglect hurting poverty fight: U.N. climate chief [Online]. Reuters. Available: http://in.reuters.com/article/2009/01/21/us-india-energy-idINTRE50K36G20090121 [Accessed 12.09. 2015].

WILLIS R 1981. A State in the Making. Myth, History and Social Transformation in Pre-colonial Ufipa. Bloomington, USA.

WISKERKE WT, DORNBURG V, RUBANZA CDK, MALIMBWI RE AND FAAIJ APC. 2010. Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania. Renewable and Sustainable Energy Reviews 14: 148–165.

ZANCHI G, FRIEDEN D, PUCKER J, BIRD DN, BUCHHOLZ T AND WINDHORST K. 2013. Climate benefits from alternative energy uses of biomass plantations in Uganda. Biomass and Bioenergy 59: 128–136.

ZORYA S AND MAHDI S 2009. High marketing costs and ineffcient policies in Tanzania’s Maize market. Washington DC, USA: The World Bank Poverty Reduction and Economic Management Africa Region, p. 24.

ZULU LC AND RICHARDSON RB. 2013. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development 17: 127–137.

10 Annex

Annex 1: Different weights, heating values and traditional kiln efficiencies as extracted from literature

Charcoal						Firewood				Charcoal kiln efficiency	
Bag	kg	Bucket	kg	Heating value (MJ/kg)		Headload	kg	Heating value (MJ/kg)			%
Applied factor	28	Applied factor	5.6	Applied factor	30.8	Applied factor	15	Applied factor	18	Applied factor	8
The World Bank (2009)[a]	28	Butz (2013)[m]	5.6	Menéndez and Curt(2013)	30.8	Bwalya (no date)[n]	10-15	Maes and Verbist (2012)[t]	20-22; 19-21	Mwampamba (2007)[u]	8-23
Johnsen (1999)[b]	28			Maes and Verbist (2012)	28	Johnson and Bryden (2012)[o]	3-11; 14-22	Wiskerke et al. (2010)	19.8	The World Bank (2009)[v]	8-12
Openshaw (1983)[c]	23-36			Openshaw (1983)	33	Wiskerke (2010)[p]	16	Openshaw (1983)	16.5	Malimbwi and Zahabu (2008)[w]	11-30
Mwampamba (2007)[d]	30			Malimbwi and Zahabu (2008)	31.8	Tabuti (2003)[q]	17.5	Malimbwi and Zahabu (2008)	16	Menéndez and Curt (2013)[x]	5-30
Wiskerke et al. (2010)[e]	29					IEA(2006)[r]	20			Felix and Gheewala (2011)[y]	11-25
Luoga et al. (2000)[f]	29					Openshaw (1983)[s]	26			Tabuti et al. (2003)[z]	8
Kimaryo and Ngereza (1989)[g]	34										
Kimaryo and Ngereza (1988)[h]	34										
Adballah and Monela (2007)[i]	40-55										
Malimbwi and Zahabu (2008)[j]	56										
Menéndez and Curt (2013)[k]	60-70										
Kaale (2012)[l]	70										

a) 28 kg is the legal weight of charcoal bags in Tanzania
b) Study from Hai district/Kilimanjaro region/Tanzania
c) 23 kg for "softwood", 33 kg for "normal tropical hardwoods" and 36 kg for "preferred charcoal species"; no location
d) Applying a "sack-to-kg" conversion rate of 30 kg; nation-wide study/Tanzania
e) Own measurements, "Average weight of bag"; study site Shinyanga region/Tanzania
f) Kilns having a "mean production of 1.28 +/-0.26 t/charcoal (1280 kg), the equivalent of 44.2 +/- 8.67 bags of charcoal", study site in Morogoro region/Tanzania
g) Own trials, average weight derived from four Basic Earth Kilns; study site in Mwanga district/Kilimanjaro region/Tanzania
h) Own trials, Acacia xabthophloea, average weight from 13 Casamance Earth Kilns; study site in Moshi rural district/Kilimanjaro region/Tanzania
i) Study site in Tabora region/Tanzania
j) Study concerning charcoal consumption in Dar es Salaam/Tanzania
k) Own observation; study site in Iringa region/Tanzania
l) Newspaper article, Focus on Dar es Salaam/Tanzania
m) Derived from given volume comparison between "sack" (100 l) and "bucket" (20 l); study site in Arusha region/Tanzania
n) "Standard headload", Zambia (bordering country of Rukwa region)
o) 3-11 kg: children; 14-22 kg: adult women; Mali
p) Own measurements and various sources; study site in Shinyanga region/Tanzania
q) Own measurements, range 15-20; study site in Bulamogi County/Uganda
r) 20 kg: "average"; 36 kg:" maximum"; Sub-Saharan Africa
s) Average headload, nation-wide surveys/Tanzania
t) 20-22 kg: "tropical softwood", 19-21 kg: "tropical hardwood", no location
u) Kiln efficiency from various sources (no details), study site in Morogoro region/Tanzania
v) 8-12% for traditional kilns; 12-18% for improved ones; nation-wide study/Tanzania
w) Sub-Saharan Africa: 10-20%; Tanzania: 11-30%, various sources
x) Literature data ranges from 5-30%, 17.5% is assumed in this study; study site in Iringa region/Tanzania
y) 11-25% for "traditional way of making charcoal", nation-wide study/Tanzania
z) 8% assumed in this study, nationwide ranges of 10-15% reported; study site in Bulamogi County/Uganda

Annex 2: Key variables determining the affiliation to income classes

Total value of assets per HH member (in Tanzanian Shilling (TSh))					
	n	average	SD	min	max
IC1	30	459,452	1,157,396	13,375	6,472,400
IC2	27	93,003	134,979	1,167	605,250
IC3	59	28,722	33,134	0	143,333
IC4	32	7,240	11,960	0	45,000
Total	148	123,114	545,624	0	6,472,400

Total savings per HH member (in TSh)					
	n	average	SD	min	max
IC1	29	326,566	829,903	222	4,380,000
IC2	25	63,610	123,951	250	500,000
IC3	62	12,963	21,336	0	111,111
IC4	33	2,001	2,908	0	14,000
Total	149	80,070	384,941	0	4,380,000

Total previous year school expenditures per HH member (in TSh)					
	n	average	SD	min	max
IC1	33	59,367	74,795	0	247,500
IC2	28	19,727	30,108	0	133,333
IC3	61	14,394	24,400	0	116,250
IC4	35	5,260	17,214	0	102,000
Total	157	22,762	44,488	0	247,500

Total value livestock per HH member (in TSh)					
	n	average	SD	min	max
IC1	32	607,668	1,099,732	1.667	5,505,000
IC2	28	231,917	292,414	667	1,495,000
IC3	62	130,554	177,301	0	704,444
IC4	35	48,493	88,789	0	339,625
Total	157	227,584	556,521	0	5,505,000

Total previous year off-farm income per HH member (in TSh)					
	n	average	SD	min	max
IC1	27	656,036	644,518	80,000	2,468,571
IC2	17	190,629	241,153	8667	900,000
IC3	36	88,495	84,166	0	428,571
IC4	19	36,815	24,369	750	96,000
Total	99	250,899	432,167	0	2,468,571

Total plot size per HH member (in acre)					
	n	average	SD	min	max
IC1	33	2.2	1.6	0.22	7.5
IC2	28	1.4	0.8	0.33	3.5
IC3	63	1.2	1.0	0.28	4.8
IC4	34	0.7	0.6	0.17	3.0
Total	158	1.4	1.2	0.17	7.5