SEI Stockholm Environment Institute

Examining wood-energy systems with integrated assessment and landscape models

SEI working paper
May 2019

Rob Bailis

Stockholm Environment Institute
Linnégatan 87D 115 23 Stockholm, Sweden
Tel: +46 8 30 80 44
www.sei.org

Author contact: Rob Bailis
rob.bailis@sei.org
Editing: Emily Yehle
Layout: Richard Clay
Cover photo: Charcoal for sale in Malindi, Africa. © MariusLtu / Getty Images

This publication may be reproduced in whole or in part and in any form for educational or non-profit purposes, without special permission from the copyright holder(s) provided acknowledgement of the source is made. No use of this publication may be made for resale or other commercial purpose, without the written permission of the copyright holder(s).

Copyright © May 2019 by Stockholm Environment Institute

Stockholm Environment Institute is an international non-profit research and policy organization that tackles environment and development challenges.
We connect science and decision-making to develop solutions for a sustainable future for all.
Our approach is highly collaborative: stakeholder involvement is at the heart of our efforts to build capacity, strengthen institutions, and equip partners for the long term.
Our work spans climate, water, air, and land-use issues, and integrates evidence and perspectives on governance, the economy, gender and human health.
Across our eight centres in Europe, Asia, Africa and the Americas, we engage with policy processes, development action and business practice throughout the world.

Contents

Acknowledgments

This work was co-funded by the TRANSrisk project and SEI's "Rapid Response" internal funding mechanism. In addition, the author is thankful for input from reviewers Stefan Boessner and Oliver Johnson, as well as from SEI's Project Leader for TRANSrisk, Francis X. Johnson. Any errors or omissions are the sole responsibility of the author.

Introduction

Fuelwood and charcoal are critical sources of energy throughout sub-Saharan Africa. Heavy reliance on these traditional woodfuels can place a large burden on society and the environment. When wood harvesting is unsustainable, it contributes to land cover change, declines in terrestrial carbon stocks, and loss of biodiversity (Bailis et al. 2015). Woodfuel combustion also results in emissions that expose large portions of the population to health-damaging pollutants, creating a large burden of morbidity and mortality (Smith et al. 2014). Emissions also include a range of climate-forcing pollutants that contribute to climate change (Grieshop et al. 2011). When considering both the emissions and land cover effects, traditional woodfuels probably exceed industrial sources in contributing to climate impacts in many sub-Saharan African nations (Bailis et al. 2015).

Despite their dominant role in the region's energy mix – and the resulting impacts – woodfuels have not been well-incorporated into the integrated assessment models (IAMs) that are used to inform researchers and policy-makers about current and alternative development pathways. While IAMs are useful tools for cross-cutting regional analyses –and have been used for decades to analyse interactions between economy, climate and energy systems – they have several shortcomings when they are applied at national scales. This is particularly true in sub-Saharan Africa, where energy systems are dominated by fuelwood and charcoal.

Nationally determined contributions (NDCs) – and the associated interest in national and regional energy transitions – have resulted in new modelling efforts that explore opportunities and constraints for sustainable energy pathways (Dalla Longa and van der Zwaan 2017; Rodriguez et al. 2017; Sweerts et al. 2019; van der Zwaan et al. 2018).

In that vein, this working paper highlights the need for combining IAMs with other modelling approaches to improve understanding of the interactions between energy, economy, and land use in regions that rely heavily on woodfuels. We examine the strengths and limitations of different modelling approaches and suggest that combining approaches, though challenging, could result in more informative outcomes.

Context

The impact of fuelwood and charcoal demand on forests and woodlands in sub-Saharan Africa is still not fully understood. In fact, researchers, policy-makers and other stakeholders have presented opposing, even contradictory, points of view, which we can classify into two archetypes.

The "negative" archetype considers the pervasive extraction of firewood, used by the majority of the region's rural population, and the steady flow of charcoal into the region's cities, as both being drivers of environmental degradation. Those who ascribe to this view argue that trees simply cannot regenerate quickly enough to satisfy growing demand.

In contrast, the "positive" archetype argues that the environmental impact of fuelwood and charcoal demand is minimal and creates important livelihood opportunities. Adherents to this archetype believe that the region's woodlands are resilient and can usually rebound from woodfuel harvesting, except under extreme exploitation. Importantly, people holding this position do not deny that deforestation and degradation occur; negative impacts can be observed and measured. However, for this archetype, degradation and deforestation are rarely the result of woodfuel extraction alone. Instead they are driven by other socioeconomic and ecological processes, most commonly agricultural expansion.

It is difficult to say which perspective is more accurate; scientific evidence has been published supporting both positions (for a review, see Masera et al. 2015). What we can conclude is that broad generalizations can be misleading. The landscape-level impact of fuelwood and charcoal production depends on the specific location, as well as the species and volume of wood extracted. When deforestation or forest degradation occurs, policy-makers need more nuanced and accurate assessments of potential drivers and location-specific impacts in order to determine whether and how to intervene (Ghilardi et al. 2016). A model that combines landscape, energy and economic assessment could potentially provide that nuance.

This collaborative work was completed by the Stockholm Environment Institute, the National Autonomous University of Mexico, and the Energy Research Centre of the Netherlands (ECN, now known as TNO, or the Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek). The work was part of TRANSrisk, an EU-funded research project studying the risks and uncertainties associated with low carbon transition pathways in order to understand how transitions can be implemented in technically, economically and sociably feasible ways.

This paper presents insight on the opportunities and challenges around combining spatial analysis of woodfuel supply and demand with integrated assessment models of the economy. Our analysis combined the Times Integrated Assessment (TIAM) and the Modelling Fuelwood Saving Scenarios (MoFuSS) geo-spatial landscape model. The effort focused on Kenya because its woodfuel demand has been studied more than other countries in the region, so that data is accessible. In addition, recent trends show that Kenya sees a greater degree of fuel substitution than other countries in the region, making near-term transitions more likely. The results offer a new way to examine not just the effects of traditional wood energy on land cover, but also the most cost-efficient pathways to meet sustainability targets.

Fuelwood and charcoal are critical sources of energy throughout sub-Saharan Africa. Heavy reliance on these traditional woodfuels can place a large burden on society and the environment.

Modelling biomass energy in the landscape and economy

Integrated Assessment Models – or IAMs – consider both the social and economic factors that drive the emission of greenhouse gases, as well as the biogeochemical cycles and atmospheric chemistry that determines the fate of those emissions; IAMs also analyse the resultant effect of greenhouse gas emissions on climate and society (generally via economic impacts)(SEDAC n.d.). IAMs are designed to have internally consistent inputs and assumptions, including factors like regional diversity; economic and demographic change; energy supply and demand; advances in energy efficiency and other technology; changes to the climate system; and the potential impacts of increased temperature and changed precipitation. Economic and climatic changes create feedbacks in the energy and economic systems, which IAMs also attempt to simulate. IAMs are used to assess the feasibility or cost-effectiveness of climate change mitigation policies, as well as the potential cost of inaction (Hare et al. 2018).

TIAM-ECN (the TIMES Integrated Assessment Model, operated by the former Energy Research Centre of the Netherlands, now known as TNO), is one of many IAMs used as a research and policy tool. It is designed as a partial equilibrium linear optimization model that minimizes energy system costs under a set of user-defined constraints and conditions. It relies on detailed descriptions of different energy resources, processing technologies and end-uses. Modellers input projections for the rest of the economic system. As a partial equilibrium model, TIAM determines prices and consumption by finding the supply–demand equilibrium in energy systems. The production price of a commodity affects demand of that commodity and demand in turn affects the price. The equilibrium is found when consumer and producer surplus, the benefits that each set of actors gain from buying and selling, is maximized (Syri et al. 2008).

Typically, IAMs divide the world into broad regions. Early versions of TIAM combined all of Africa into one of 15 world regions (Loulou and Labriet 2008). Treating Africa as a homogenous unit makes it difficult to examine interactions and impacts that occur at regional or national levels. ECN adapted TIAM so that the African region is disaggregated into 17 regions, including Kenya and other individual countries and a number of multi-country clusters (Figure 1). This disaggregation allows for more nuanced regional models and more detailed country-specific analyses, providing modelling results that are (potentially) more useful for policy-makers (Dalla Longa and van der Zwaan 2017).

Historically IAMs have not been able to accurately model biomass energy and land cover. One recent review of IAMs notes that “the complexity of bioenergy options and their implications means that IAM scenarios need to be supplemented by follow-up analyses on more specific aspects and implications of bioenergy deployment” (Hare et al. 2018 p. 3, emphasis added). This is particularly true in regions that rely heavily on “traditional” biomass like fuelwood and charcoal, which are largely traded in informal markets, making essential IAM inputs like prices, supply and demand unknown. To address this gap and provide the follow-up analyses called for by Hare and colleagues, this project linked TIAM-ECN with a model called MoFuSS, or Modelling Fuelwood Saving Scenarios. MoFuSS was created by researchers at the National Autonomous University of Mexico (UNAM) to spatially model the impacts of woodfuel harvesting on the landscape and analyse the impacts of different interventions or energy pathways. The model uses spatially explicit woodfuel demand scenarios – together with infrastructure, land cover, and woody biomass productivity – to estimate woodfuel sustainability.

Figure 1: The African sub-regions included in TIAM-ECN (van der Laan 2015).

The model runs multi-year scenarios by going through a series of steps each year.[1] First, MoFuSS creates a pressure map, showing where woodfuel harvesting is likely to occur based on where people live, where trees are located (forests, woodlands, plantations, trees on farms, etc.), and how easy or difficult it is for people to access those trees by considering roads and other means of transport, topography, and any legal restrictions (e.g. protected areas). Second, MoFuSS uses the pressure map to allocate woodfuel supply from areas with high harvest probability to each centre of demand; areas that are more accessible are more likely to be harvested. MoFuSS then subtracts wood that is harvested in the previous step from the standing stock of trees and estimates the quantity of wood that will regrow in that year based on tree growth functions that are input by the user. If demand exceeds regrowth in a location, then stocks of trees will have declined. This affects growth in that location the following year. MoFuSS then calculates a new pressure map for the next year, accounting for changes in population, woodfuel demand, and wood supply. MoFuSS continues with this cycle until the simulation is complete. At the end of the simulation, users can analyse changes in stock and location of tree cover to estimate land cover change caused by woodfuel consumption.

Many of the parameters needed to run MoFuSS are uncertain. For example, it is difficult to know the growth rates and initial tree stocks in different forests, woodlands, and other land cover categories. MoFuSS users accommodate this uncertainty by defining a continuum of possible values for each key parameter, rather than a single value. The model then runs multiple “Monte Carlo” simulations, selecting key inputs from the range of possible values. Users can select the number of simulations to run and choose from different distributions depending on the available data. The most common choice is the “normal” or Gaussian distribution, with users providing an average and standard deviation.[2]

Running the model this way results in a range of MoFuSS outputs, rather than a single value, and represents the inherent uncertainty in the analysis. MoFuSS has been used to examine the impacts of woodfuel interventions on land cover in Honduras and Haiti, and is used in several ongoing analyses in Central America and Southern Africa (Ghilardi et al. 2016; Ghilardi et al. 2018; Ghilardi 2018).

Combining models to provide more useful insights

Ideally, TIAM and MoFuSS would be fully integrated so that TIAM would use its optimization algorithms to estimate annual woodfuel demand, which would be fed directly into MoFuSS to determine landscape impacts and the potential sustainable supply for the following year. However, the two models are coded in different languages and operate in fundamentally different ways; within the limited scope of this exercise, such a degree of integration was not possible. Instead, the two models were run separately. For TIAM, several scenarios were used that examined the effect of different energy pricing policies on fuelwood and charcoal demand. These demand trajectories were fed manually into MoFuSS to quantify carbon emissions and land cover change.

As an optimization model, TIAM relies on energy prices to determine supply-demand equilibria. The model categorizes biomass fuels into three groups: low-, medium-, and high-priced biomass. In the Kenyan context, low-priced biomass corresponds to unprocessed fuelwood, medium-priced biomass corresponds to charcoal, and high-priced biomass corresponds to pellets or other types of processed biomass fuels. Table 1 describes each category and the prices used in the model in US dollars per gigajoule (USD/GJ).

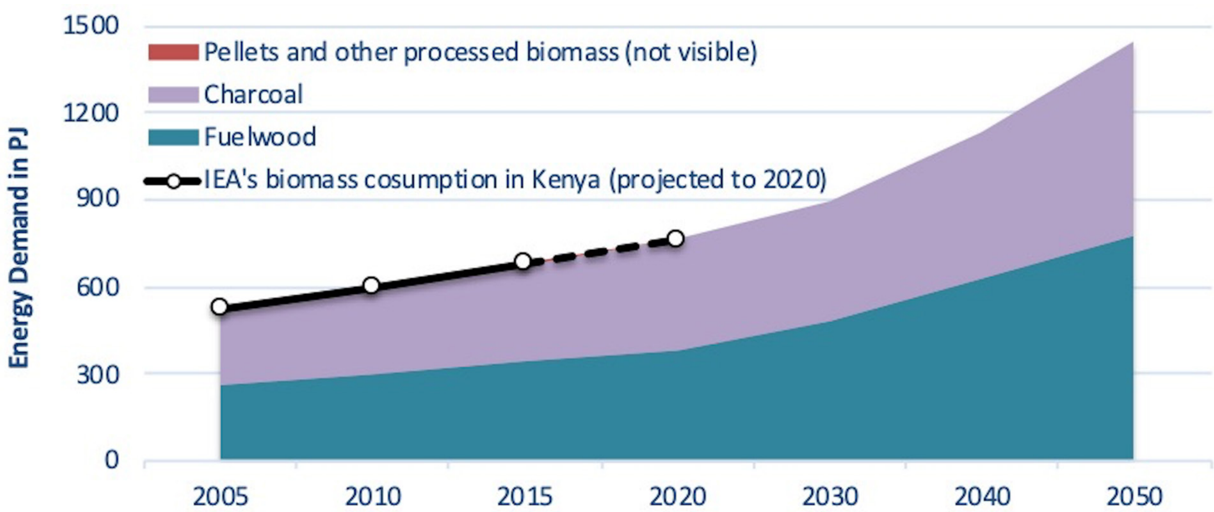
1 This is a simplified description of the processes; for a more detailed overview, see Ghilardi et. al (2016).
2 With a “normal” distribution, as the number of simulations increase, the selected parameters would fall within one standard deviation of the mean ~67% of the time, and would fall within two standard deviations of the mean ~95% of the time.

Table 1: Fuel categories and price assumptions used in TIAM

Category	Description	Cost (USD/GJ)		
		Baseline	Alt. 1	Alt. 2
Unprocessed fuelwood	This is used by the residential sector and some cottage industries, primarily in rural areas. It is either freely collected or purchased at relatively low cost.	0.6	1.2	1.8
Charcoal	This is a commercial fuel supplied almost entirely by informal markets used by the residential and commercial sectors in urban, peri-urban and some rural areas.	1.9	3.8	5.7
Pellets or other processed biomass	These are higher cost options that currently have little to no market presence in Kenya. Typically derived from agricultural waste or timber by-products, they have been proposed as a sustainable alternative to traditional fuelwood and charcoal (Quinn et al. 2018).	3.1	6.2	9.3

Using these categories, the team developed three woodfuel scenarios for Kenya from 2005 to 2050. The first was a business-as-usual (BAU) scenario, which used current woodfuel prices. Alternative scenarios explored the effect of increased fuelwood and charcoal prices, which simulated the effect of regulating traditional woodfuels in order to promote transitions to more sustainable sources of biomass, such as pellets. To be aligned with current sources of data, initial demand for fuelwood and charcoal in each scenario was matched to the International Energy Agency's (IEA's) estimates of Kenya's current woodfuel demand (IEA 2018). Results from the BAU scenario are shown in Figure 2. The solid line shows past IEA data and the dashed line shows an extrapolation of their data through 2020. TIAM was constrained to match IEA data through 2020. After 2020 onwards, constraints are removed, and the output indicates the least-cost pathway to meeting energy demand in woodfuel-dependent sectors.

Figure 2: Projected woodfuel demand in Kenya from 2005-2050 based on the TIAM-ECN BAU scenario



Two alternative scenarios were developed in TIAM in which Kenyan woodfuel prices were doubled and tripled (Table 1). However, the price increases had no discernible effect on demand for fuelwood and charcoal. Each scenario was essentially indistinguishable from the BAU scenario. Modellers from ECN/TNO speculate that the lack of response is due to the fact that biomass users have no cheaper alternatives, therefore they would continue using biomass despite the increasing prices. However, this doesn't reflect the actual situation in Kenya. Earlier research has shown that people do substitute different fuels depending on their relative prices (Nyang 1999). For future work, TIAM will need to be adjusted to more accurately reflect how people respond to changes in fuel prices.

Despite the lack of different outcomes between the TIAM scenarios, we were able to simulate the land cover impacts of projected fuelwood and charcoal demand using MoFuSS. To do this, the annual demand projections shown in Figure 2 were spatially distributed throughout Kenya in proportion to the urban and rural population of each of Kenya's 7,149 sub-locations; this resulted in annual maps that were inputted into MoFuSS, along with the woodfuel supply parameters described above. The supply and demand input maps for 2005 are shown in Figure 3. Supply is highest around Kenya's highland forests (dark green in Figure 3a) and demand is greatest in areas with high population densities, particularly in urban centres where charcoal is most popular. Demand is also high in some of the more productive agricultural areas in Kenya's central and western districts (orange and red shading in Figure 3b). However, biomass supply and population density are not the only factors driving wood extraction. Wood removals and the resulting impacts are affected by accessibility, as explained above.

Figure 3: Above-ground tree stocks (left) and woodfuel demand (right) in 2005

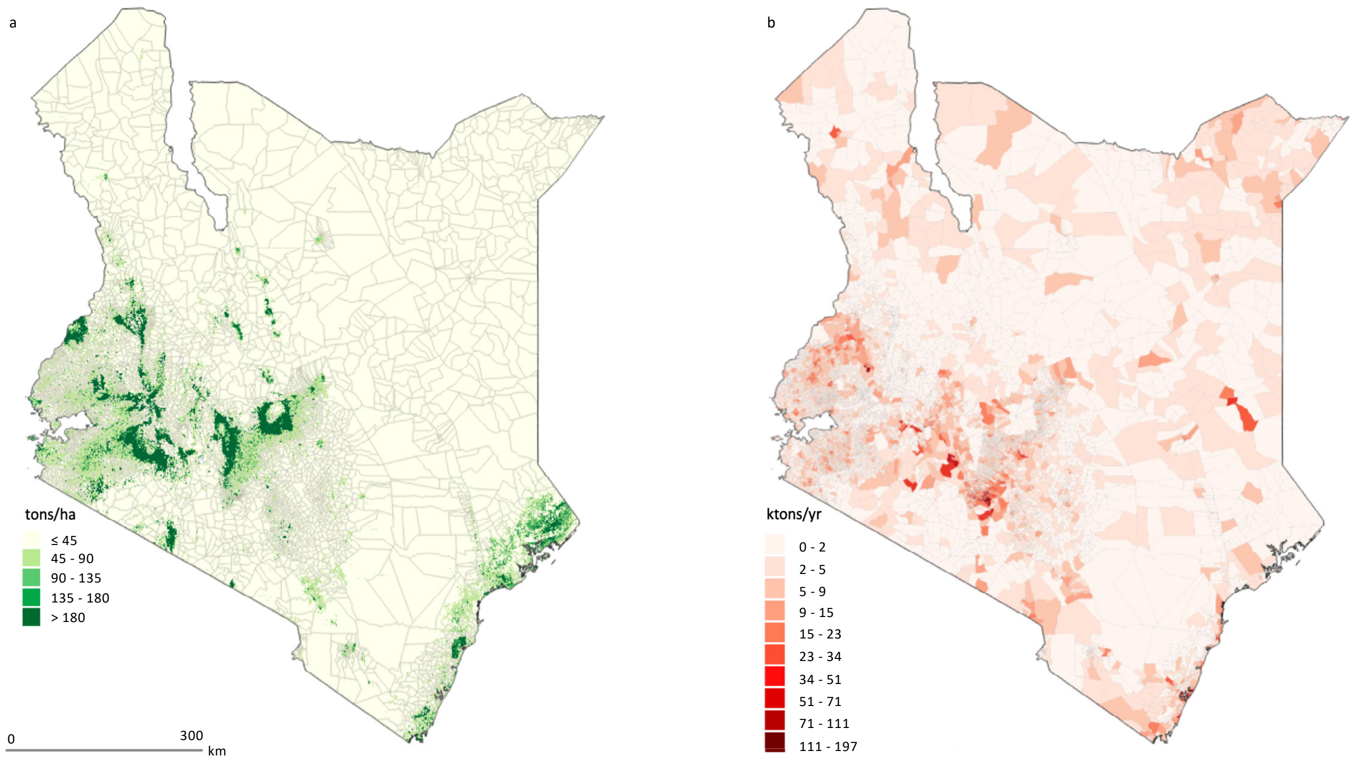
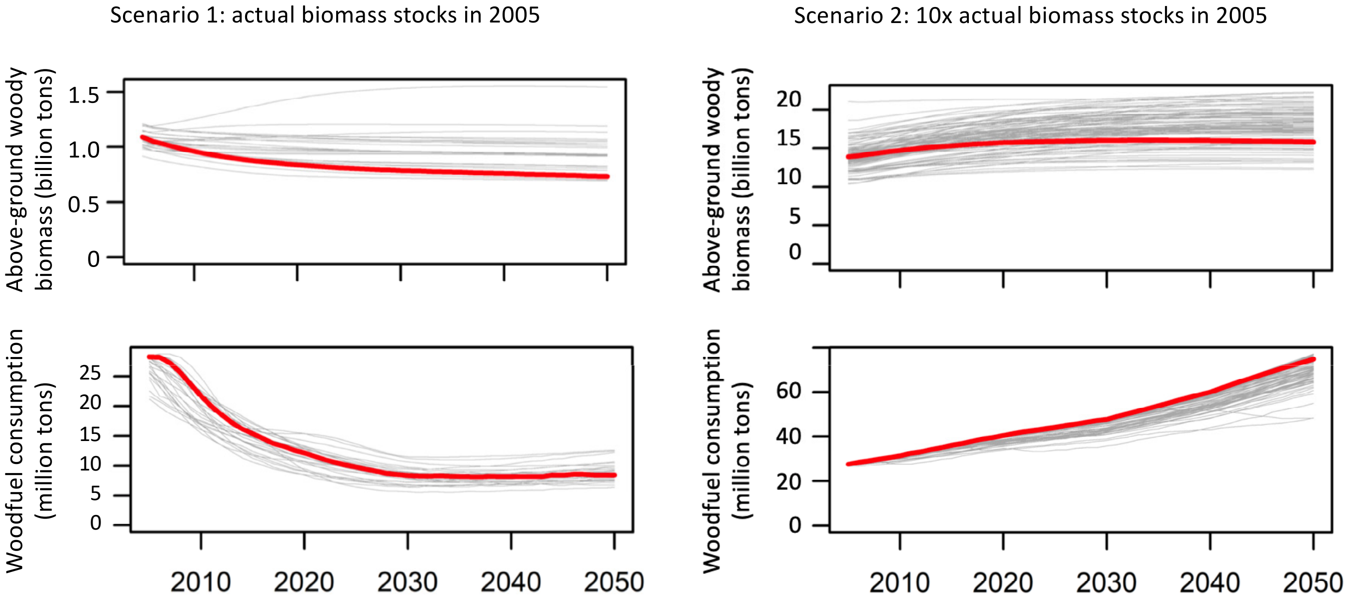


Figure 4: Two simulations of above-ground woody biomass (top) and woodfuel demand (bottom). Scenario 1 simulates how tree cover could evolve under TIAM's BAU woodfuel demand, assuming actual stocks of woody biomass in 2005. Scenario 2 simulates how tree cover would evolve if it was increased by a factor of 10 in the base year. Red lines show the results when average values of each input are used. Gray lines show the results of 100 Monte Carlo simulations, which select key inputs randomly from a user-defined distribution of possible values.



We found that fuelwood and charcoal demand projected by TIAM exceeds Kenya's sustainable supply of wood, assuming current management conditions and biomass stocks. As a result, stocks of woody biomass decline by about 15% and woodfuel demand cannot be met. Rather than along the trajectory projected in Figure 2, it declines by 50%, leading to millions of tons of unmet demand each year (Figure 4, left panels). To illustrate a situation in which demand projected by TIAM could be met, we ran a simulation in which Kenya's initial biomass stocks were inflated by a factor of 10. Under these unrealistic conditions, the demand projected by TIAM can be satisfied while biomass stocks remain relatively constant (Figure 4, right panels).

An improved charcoal kiln in Thika, near Nairobi, Kenya. Kilns like this efficiently convert wood from Eucalyptus grown in sustainable plantations into charcoal; however, only a tiny fraction of Kenya's charcoal is currently produced in this way. © ROB BAILIS / SEI

Discussion

Fuelwood and charcoal are likely to remain crucial components of the energy mix in sub-Saharan Africa for the foreseeable future. Utilizing IAMs to analyse energy scenarios in this region will require nuanced treatment of land cover and land use change. This analysis represents a preliminary attempt to use two models together in a single analysis: MoFuSS, a spatial model designed to simulate land cover change at a landscape scale, and TIAM, an IAM designed to optimize energy systems at a regional or global scale. By simulating energy-landscape interactions in Kenya, a medium-sized country, both models may have extended outside the respective "comfort zones" in which their developers typically operate. The analysis, though not conclusive, provides us with an indication of how to proceed in order to improve links between the two models and, ultimately, obtain meaningful results.

In this particular case, the simulations show that the supply of woody biomass from Kenya's current stock of trees would be insufficient to meet future demand under the BAU scenario created by TIAM: stocks decline, and demand is only partially satisfied. This raises questions about the realism of several key assumptions in one or both models. For example, in Figure 2, TIAM defines "optimal" demand trajectories for fuelwood and charcoal using certain assumptions about energy prices and other input parameters. However, MoFuSS determines that the Kenyan landscape does not have sufficient accessible wood to meet TIAM's demand. If this situation were to arise in reality, several things could occur, which are not reflected in either model.

For example:

- If supply cannot meet growing demand, wood and charcoal prices would likely increase rapidly.
- Higher prices could induce wood and charcoal suppliers to increase production. They might plant trees or invest in more efficient production processes like improved charcoal kilns (see photo on page 10). To accurately simulate this, MoFuSS would need different assumptions about future land cover, biomass productivity, and wood-to-charcoal conversion rates.
- In the face of higher prices, consumers might also change their behaviour by switching to alternative cooking fuels and/or investing in efficient stoves.
- In either case, price increases and the resulting response among consumers and suppliers, would shift TIAM's equilibrium, leading to less demand for wood and charcoal than was originally forecast.

It is possible to modify the models to accommodate these changes, but additional research would be required. In contrast to electricity and petroleum markets, which are closely tracked and regulated, woodfuel markets are informal and unregulated. Although we use the best available data, it is spotty and uncertain. In addition, we know little about how consumers and suppliers respond to price changes.

Nevertheless, models can accommodate a degree of uncertainty and still deliver useful information. For example, MoFuSS works with uncertainty in key input parameters by running "Monte Carlo" simulations, which yield a distribution of possible outcomes, rather than a single value. Such distributions can inform decision-makers about which impacts are more or less likely to occur given a range of reasonable inputs. TIAM or other IAMs could also work with uncertain inputs and deliver a range of possible outputs. In addition, the spatial nature of MoFuSS allows users to identify potential "hotspots" – specific locations where negative impacts are likely to be concentrated. The challenge will lie in interpreting the results and communicating them to decision-makers.

Keeping these challenges and limitations in mind, we should pursue further linkages between IAMs and landscape models in order to gain deeper insights into the implications of different household energy pathways. The former offers insights into relationships between energy and economic systems but does not provide information about environmental conditions; the latter simulates environmental impacts and constraints but does not account for market forces and other economic drivers. With additional work, the two could be combined to better analyse traditional household energy systems, which could positively impact economic and environmental conditions throughout sub-Saharan Africa.

References

Bailis, R., Drigo, R., Ghilardi, A. and Masera, O. (2015). The Carbon Footprint of Traditional Woodfuels. *Nature Climate Change*, 5. 266–72. DOI: 10.1038/nclimate2491

Dalla Longa, F. and van der Zwaan, B. (2017). Do Kenya's climate change mitigation ambitions necessitate large-scale renewable energy deployment and dedicated low-carbon energy policy? *Renewable Energy*, 113. 1559–68. DOI: 10.1016/j.renene.2017.06.026

Ghilardi, A. (2018). Modelling Fuelwood Savings Scenarios (MoFuSS). Wood-Energy Geospatial Portal. 2018. http://www.mofuss.unam.mx/#models

Ghilardi, A., Bailis, R., Mas, J.-F., Skutsch, M., Elvir, J. A., et al. (2016). Spatiotemporal modeling of fuelwood environmental impacts: Towards improved accounting for non-renewable biomass. *Environmental Modelling & Software*, 82. 241–54. DOI: 10.1016/j.envsoft.2016.04.023

Ghilardi, A., Tarter, A. and Bailis, R. (2018). Potential environmental benefits from woodfuel transitions in Haiti: Geospatial scenarios to 2027. *Environmental Research Letters*, 13(3). 035007. DOI: 10.1088/1748-9326/aaa846

Grieshop, A. P., Marshall, J. D. and Kandlikar, M. (2011). Health and climate benefits of cookstove replacement options. *Energy Policy*, 39. 7530–42. DOI: 10.1016/j.enpol.2011.03.024

Hare, B., Brecha, R. and Schaeffer, M. (2018). *Integrated Assessment Models: What Are They and How Do They Arrive at Their Conclusions?* Climate Analytics. https://climateanalytics.org/publications/2018/integrated-assessment-models-what-are-they-and-how-do-they-arrive-at-their-conclusions/

IEA (n.d.). Kenya - Energy Balance (2016). International Energy Agency. https://www.iea.org/Sankey/#?c=Kenya&s=Balance [Accessed 5 December, 2018.]

Loulou, R. and Labriet, M. (2008). ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. *Computational Management Science*, 5(1). 7–40. DOI: 10.1007/s10287-007-0046-z

Masera, O. R., Bailis, R., Drigo, R., Ghilardi, A. and Ruiz-Mercado, I. (2015). Environmental Burden of Traditional Bioenergy Use. *Annual Review of Environment and Resources*, 40. 121–50. DOI:10.1146/annurev-environ-102014-021318

Nyang, F. (1999). *Household Energy Demand and Environmental Management in Kenya*. Thela Thesis, Amsterdam

Quinn, A. K., Bruce, N., Puzzolo, E., Dickinson, K., Sturke, R., et al. (2018). An analysis of efforts to scale up clean household energy for cooking around the world. *Energy for Sustainable Development*, 46. 1–10. DOI: 10.1016/j.esd.2018.06.011

Rodriguez, D., Delgado, A., Bazilian, M., Ahjum, F., DeLaquil, P., et al. (2017). Water Constrains South Africa's Energy Future: A Case Study on Integrated Energy-Water Nexus Modeling and Analysis. *The International Journal of Engineering and Science*, 6(10). 01–25.

SEDAC (n.d.). Integrated Assessment Modeling - Ten Things to Know. Socioeconomic Data and Applications Center. http://sedac.ciesin.columbia.edu/mva/iamcc.tg/mva-questions.html [Accessed 15 November, 2018.]

Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., et al. (2014). Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution. *Annual Review of Public Health*, 35. 185–206. DOI:10.1146/annurev-publhealth-032013-182356

Sweerts, B., Longa, F. D. and van der Zwaan, B. (2019). Financial de-risking to unlock Africa's renewable energy potential. *Renewable and Sustainable Energy Reviews*, 102. 75–82. DOI: 10.1016/j.rser.2018.11.039

Syri, S., Lehtilä, A., Ekholm, T., Savolainen, I., Holttinen, H. and Peltola, E. (2008). Global energy and emissions scenarios for effective climate change mitigation - Deterministic and stochastic scenarios with the TIAM model. *International Journal of Greenhouse Gas Control*, 2. 274–85. DOI:10.1016/j.ijggc.2008.01.001

van der Zwaan, B., Kober, T., Longa, F. D., van der Laan, A. and Jan Kramer, G. (2018). An integrated assessment of pathways for low-carbon development in Africa. *Energy Policy*, 117. 387–95. DOI: 10.1016/j.enpol.2018.03.017

SEI Headquarters
Linnégatan 87D Box 24218
104 51 Stockholm Sweden
Tel: +46 8 30 80 44
info@sei.org

Måns Nilsson
Executive Director

SEI Africa
World Agroforestry Centre
United Nations Avenue
Gigiri P.O. Box 30677
Nairobi 00100 Kenya
Tel: +254 20 722 4886
info-Africa@sei.org

Philip Osano
Centre Director

SEI Asia
15th Floor Witthyakit Building
254 Chulalongkorn University
Chulalongkorn Soi 64 Phyathai Road
Pathumwan Bangkok 10330 Thailand
Tel: +66 2 251 4415
info-Asia@sei.org

Niall O'Connor
Centre Director

SEI Tallinn
Arsenal Centre
Erika 14, 10416
Tallinn, Estonia
info-Tallinn@sei.org

Lauri Tammiste
Centre Director

SEI Oxford
Florence House 29 Grove Street
Summertown Oxford
OX2 7JT UK
Tel: +44 1865 42 6316
info-Oxford@sei.org

Ruth Butterfield
Centre Director

SEI US Main Office
11 Curtis Avenue
Somerville MA 02144-1224 USA
Tel: +1 617 627 3786
info-US@sei.org

Michael Lazarus
Centre Director

SEI US Davis Office
400 F Street
Davis CA 95616 USA
Tel: +1 530 753 3035

SEI US Seattle Office
1402 Third Avenue Suite 900
Seattle WA 98101 USA
Tel: +1 206 547 4000

SEI York
University of York
Heslington York
YO10 5DD UK
Tel: +44 1904 32 2897
info-York@sei.org

Lisa Emberson
Centre Director

SEI Latin America
Calle 71 # 11–10
Oficina 801
Bogota Colombia
Tel: +57 1 6355319
info-LatinAmerica@sei.org

David Purkey
Centre Director

SEI Stockholm Environment Institute

sei.org
@SEIresearch @SEIclimate