Energy Policy 86 (2015) 705–717

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy and the environment

Future energy system challenges for Africa: Insights from Integrated Assessment Models

Paul L. Lucas [a,*], Jens Nielsen [a], Katherine Calvin [b], David L. McCollum [c], Giacomo Marangoni [d], Jessica Strefler [e], Bob C.C. van der Zwaan [f,g,h], Detlef P. van Vuuren [a,i]

[a] PBL Netherlands Environment Assessment Agency, PO Box 303, 3720 BA Bilthoven, The Netherlands
[b] Joint Global Change Research Institute/PNNL, College Park, MD, USA
[c] International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, 2361 Laxenburg, Austria
[d] Fondazione Eni Enrico Mattei (FEEM) and Centro Mediterraneo sui Cambiamenti Climatici (CMCC), Corso Magenta 63, Milan, Italy
[e] Potsdam Institute for Climate Impact Research, PO Box 601203, 14412 Potsdam, Germany
[f] Energy research Centre of the Netherlands (ECN), Policy Studies, Amsterdam, The Netherlands
[g] Johns Hopkins University, School of Advanced International Studies, Bologna, Italy
[h] University of Amsterdam, Faculty of Science, Amsterdam, The Netherlands
[i] Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

HIGHLIGHTS

- We assess long-term energy developments in Africa using results of six models.
- Africa's share in global CO_2 emissions is projected to increase to 3–23% by 2100.
- The period before 2050 is critical for the transition towards a low carbon future.
- Without additional policy no universal access to modern energy services by 2030.
- Africa's role as a net fossil fuel exporter is projected to diminish over time.

ARTICLE INFO

Article history:
Received 18 February 2015
Received in revised form
12 August 2015
Accepted 13 August 2015

Keywords:
Africa
Integrated Assessment Modelling
Energy
Climate policy
Energy access
Energy trade

ABSTRACT

Although Africa's share in the global energy system is only small today, ongoing population growth and economic development imply that this can change significantly. Here, we discuss long-term energy-system developments in Africa using results of a recent model inter-comparison study on global climate policy. We focus on Africa's role in the wider global energy system and in global climate mitigation. The results show a considerable spread in model outcomes, emphasizing the large uncertainty regarding Africa's energy future. Without climate policy, Africa's share in global energy-related CO_2 emissions is projected to increase to 3–23% by 2100. Emissions become significant on a global scale only after 2050. In none of the model projections the international ambition to provide universal modern energy access by 2030 is achieved. Furthermore, although the continent is currently a large net exporter of oil and natural gas, towards 2050 the model projections emphasize that Africa needs most of its resources for its rapidly growing domestic demand. However, the projected rapid expansion of their energy system also implies that Africa gains importance in global mitigation action. An important challenge is to align the increasing investments in the energy system with climate policy and potential revenues from international carbon trading.

1. Introduction

Africa's shares in global energy use and related CO_2 emissions are currently relatively small. In 2009, the continent was responsible for around 5.9% of total global energy use (including modern and traditional energy sources) and 3.2% of the related

* Corresponding author.
E-mail addresses: paul.lucas@pbl.nl (P.L. Lucas), jens.jielsen@pbl.nl (J. Nielsen), katherine.calvin@pnnl.gov (K. Calvin), mccollum@iiasa.ac.at (D. L. McCollum), giacomo.marangoni@feem.it (G. Marangoni), strefler@pik-potsdam.de (J. Strefler), vanderzwaan@ecn.nl (B.C.C. van der Zwaan), detlef.vanvuuren@pbl.nl (D.P. van Vuuren).

http://dx.doi.org/10.1016/j.enpol.2015.08.017
0301-4215/

CO_2 emissions (IEA, 2010; UNCTAD, 2012). Furthermore, in 2008, only a small number of nations accounted for the majority of CO_2 emissions (South Africa and the North African nations together were responsible for 84% of the total energy-related CO_2 emissions) and only 4 out of the 54 African nations had per capita emissions higher than the global average (Boden et al., 2011). The small shares in global energy use and CO_2 emissions are related to relatively low levels of economic activity and low levels of access to modern sources of energy, especially in Sub-Saharan Africa (Mandelli et al., 2014). In fact, Africa's share of the population without access to electricity and modern fuels for cooking and heating is the largest in the world (Pachauri et al., 2013). Furthermore, where several countries in Africa, including Nigeria, Libya and Algeria, are endowed with large fossil fuel resources and are net exporters of oil and natural gas (UNECA, 2011), most other countries are net importers, having serious energy security issues (Bacon and Mattar, 2005). Driven by ongoing population growth, urbanisation and economic development, Africa's energy situation is likely to change significantly (Canadell et al., 2009; Bazilian et al., 2012; Calvin et al., 2013; IEA, 2014; Panos et al., 2015). Expanding their energy system and increasing access to modern sources of energy provides great opportunities to reduce poverty and accelerate economic growth. However, depending on the fuel choice this could also have environmental impacts at the local, regional and global scale, including an increasing regional contribution to global greenhouse gas emissions (Calvin et al., 2013) and air pollution (Liousse et al., 2014).

There are ample studies that have assessed developments in the energy system at the global scale, many focussing on climate change (recent examples include Kriegler et al. (2013a, 2014) and Riahi et al. (2014)). Recent studies have also focussed on specific regions, including Europe (Knopf et al., 2013), Asia (Calvin et al., 2012; Gambhir et al., 2013; Johansson et al., 2014), Latin America (Calvin, 2013; van der Zwaan et al., forthcoming) and large economies (Van Sluisveld et al., 2013). At the same time, few studies have focussed on projections for the African continent. A study by Calvin et al. (2013) forms an important exception. This study addresses how population and economic growth, as well as climate policy, could potentially transform Africa's energy system, including energy access and CO_2 emissions. Furthermore, IEA (2014) provides a comprehensive study of future developments in the Sub-Saharan African energy sector and Panos et al. (2015) discuss two alternative scenarios of Sub-Sahara Africa's energy future with a focus on the power sector and grid extension. There are also several studies that address specific elements of Africa's future energy development, including the power sector (IRENA, 2012), renewable energy (IRENA, 2011) and energy access (Brew-Hammond, 2010; Bazilian et al., 2012). Finally, some national scenario studies exist, including for South Africa (Winkler et al., 2011; Alton et al., 2014) and Nigeria (Gujba et al., 2011). None of these studies, however, specifically focusses on Africa's long-term role in the global energy system and global climate change mitigation.

In this context, the current paper analyses long-term developments in Africa's energy system using the results of a recent multi-model scenario study (LIMITS; Kriegler et al., 2013a). The analysis looks specifically at the position of Africa in the wider global energy system and in global climate mitigation. The paper addresses the following questions:

- How does Africa's energy system evolve assuming a continuation of current policies and trends and what does that mean for its shares in global energy use and CO_2 emissions?
- How does Africa's future energy system change under globally coordinated climate policy that aims at limiting global mean temperature increase to a maximum of 2 °C compared to pre-industrial levels?
- What do these trends imply for Africa's international trade in energy resources and for household access to modern sources of energy?

The use of multiple models – that differ in model structure, data sources and basic assumptions – allow us to assess the robustness of the projected developments.

The paper is structured as follows. Section 2 describes the methodology, including the two scenarios, and gives a brief description of the models used. Section 3 discusses long-term developments in Africa's energy system, with and without climate policy, including energy supply, energy-related CO_2 emissions, energy poverty and trade in primary energy resources. Additionally, this section compares African developments with global developments. Section 4 then discusses some major uncertainties in the model projections and missing issues in the models used. Finally, Section 5 draws some policy and modelling conclusions from the analysis.

2. Methodology

For our analysis, we use the model results of the recent LIMITS model inter-comparison study (Kriegler et al., 2013a; Tavoni et al., 2013). The LIMITS study assesses post-2020 climate policies that are broadly consistent with the objective of keeping global mean warming below 2 °C since preindustrial levels. The study reported on a range of topics relevant in this context, including distributional impacts of climate mitigation, the role of investments and financing, energy security, regional mitigation effort, technology diffusion and bioenergy (Kriegler et al., 2013b). However, no special attention was paid to Africa. Nevertheless, all models used describe future energy system developments for different world regions, together covering the whole world. Here, we only use the results for Africa for a selection of indicators and compare them, where relevant, to the global results.[1] We mainly discuss model ranges to address the uncertainties and trends with respect to Africa's long-term energy-system developments and only go into individual model results where relevant for drawing conclusions.

The LIMITS projects uses seven energy–economy and Integrated Assessment Models for their analysis. We use the model results of six of them: GCAM (Calvin, 2011), IMAGE (van Vuuren, 2007; Stehfest et al., 2014), MESSAGE (Riahi et al., 2007, 2012), REMIND (Luderer et al., 2011), TIAM-ECN (Keppo and van der Zwaan, 2012, 2013; Rösler et al., 2014) and WITCH (Bosetti et al., 2006, 2009).[2] Table 1 provides some key model characteristics as a summary. The diversity in model structure and assumptions allows us to take into account several relevant uncertainties related to energy projections as well as drawing more robust conclusions on potential future developments. The models describe future emissions in energy and land use on the basis of expected trends over time for population, income, lifestyle, technology development and resource depletion. Although applied differently across the models, in principle they assume that low cost energy options are used more than high costs options. Climate policy is implemented by forcing the model to limit total greenhouse gas emissions, leading to an implicit or explicit 'greenhouse gas price'. As our intention is not to go into individual model outcomes, we do not give an in-depth description of the models here. For an overview of model details see the overview paper of the LIMITS

[1] All scenario results discussed in this paper can be found in the publicly available LIMITS Scenario Database: https://secure.iiasa.ac.at/web-apps/ene/LIMITSDB/.

[2] Results for AIM-Enduse, which was also part of the LIMITS project, are excluded in our analysis as the model does not run up to 2100.