Energy Policy 117 (2018) 387–395

Contents lists available at ScienceDirect

Energy Policy

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

An integrated assessment of pathways for low-carbon development in Africa

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ARTICLE INFO

Keywords:
Africa
GHG emissions
Climate change mitigation
Economic growth
Renewable energy

ABSTRACT

In this paper we investigate the prospects for the large-scale use of low-emission energy technologies in Africa. Many African countries have recently experienced substantial economic growth and aim at fulfilling much of the energy needs associated with continuing along paths of economic expansion by exploiting their large domestic potentials of renewable forms of energy. Important benefits of the abundant renewable energy resources in Africa are that they allow for stimulating economic development, increasing energy access and alleviating poverty, while simultaneously avoiding emissions of greenhouse gases. In this study we analyse what the likely energy demand in Africa could be until 2050, and inspect multiple scenarios for the concomitant levels of greenhouse gas emissions and emission intensities. We use the TIAM-ECN model for our study, which enawbbles detailed energy systems research through a technology-rich cost-minimisation procedure. The results from our analysis fully support an Africa-led effort to substantially enhance the use of the continent's renewable energy potential. But they suggest that the current aim of achieving 300 GW of additional renewable electricity generation capacity by 2030 is perhaps unrealistic, even given high GDP and population growth: we find figures that are close to half this level. On the other hand, we find evidence for leap-frogging opportunities, by which renewable energy options rather than fossil fuels could constitute the cost-optimal solution to fulfil most of Africa's growing energy requirements. An important benefit of leap-frogging is that it avoids an ultimately expensive fossil fuels lock-in that would fix the carbon footprint of the continent until at least the middle of the century.

1. Introduction

Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has published a series of reports on global climate change mitigation and the large-scale deployment of renewable forms of energy to achieve deep cuts in greenhouse gas (GHG) emissions (for the latest editions, see IPCC, 2011, 2014). Integrated Assessment Models (IAMs) constitute an important tool of analysis in the studies reviewed in these publications. In recent years increasing attention has been paid by research groups across the world that operate these models to investigating emission reduction options and requirements at the regional level, in view of inspecting the feasibility of reaching the climate change control target to stay well below a 2 °C average global temperature increase as stipulated by the Paris Agreement (COP-21, 2015). For recent studies on Africa, Asia, and Latin America, see for example, respectively, Lucas et al. (2015), Calvin et al. (2012), and van der Zwaan et al. (2016a).

Africa has not yet been studied as extensively with IAMs as other developing parts of the world. Among the reasons are that there are only few research teams on the African continent at present undertaking IAM scenario analysis, and that Africa's energy use to date is limited, which implies that its energy future is more speculative than that of other regions. Yet Africa deserves special consideration, since among all world regions it has the highest population growth, demographic studies expect it to hold around a quarter of the global population in 2050 (UN, 2014), it proffers a large potential for economic growth, it has the most rapidly developing and changing energy system, and it is exceptionally rich in energy resources. Africa, however, is currently particularly poor in energy supply, notably Sub-Saharan

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https://doi.org/10.1016/j.enpol.2018.03.017
Received 11 August 2017; Received in revised form 5 March 2018; Accepted 6 March 2018
Available online 05 April 2018

Africa (IEA-WEO, 2014). According to the International Energy Agency (IEA): "*Making reliable and affordable energy widely available is critical to the development of the [Sub-Saharan] region that accounts for 13% of the world's population, but only 4% of its energy demand*" (IEA-WEO, 2014).

Because the prospects for an increase of energy use in Africa are large, this article contributes to the growing (non-IAM) literature on how modern forms of energy can be supplied to the continent while controlling global climate change through low-emission development strategies (LEDS). Through the Paris Agreement all countries have committed to realizing substantial GHG emission reductions in the short term (COP-21, 2015). Many countries in Africa have ambitions in this context, as formulated in their Nationally Determined Contributions (NDCs), which detail how they intend to reduce their projected business-as-usual emissions in the short to medium term (typically until 2030, but sometimes extending to 2050).

One of the present development queries is whether Africa is capable of "leap-frogging" the use of fossil fuels, that is, launching energy systems that from the outset mostly rely on renewable forms of energy, rather than following the pathways of developed countries that since the industrial revolution built their economies with coal, oil and natural gas as predominant energy resources. We attempt to answer this question because of its environmental importance: if renewable energy (and particularly renewable electricity generation) can be used to drive economic growth, increase energy access and stimulate poverty eradication in Africa, a lock-in into fossil fuels and fossil-based power plants with a lifetime of up to half a century can be precluded.

In this paper we investigate the large-scale use of renewable energy options in Africa from a cost-optimality perspective through a well-established IAM, the TIAM-ECN model, so as to bridge a present gap in the literature in which IAMs have so far rarely been applied to Africa. One of the merits of this work is the novelty of our approach. We connect with our study to recent publications with a global focus on the challenges of renewable energy deployment (see e.g. GEA, 2012; REN21, 2016; IEA-ETP, 2016). We also contribute to work undertaken internationally to address the question how to provide "sustainable energy for all", by assessing the energy requirements associated with this goal in Africa (UN, 2012). By focusing on the use of renewables and some of its ramifications in Africa we also briefly touch upon an important aspect of the water-energy-food nexus (IRENA, 2015): the possible water and food (price) implications of traditional and modern biomass-based renewable energy. Finally, with this research we attempt to provide a reality check for the ambitions put forward by the Africa Renewable Energy Initiative (AREI), an Africa-led effort to substantially enhance the use of the continent's renewable energy potential, aiming to achieve 10 GW of additional renewable electricity generation capacity by 2020, and 300 GW by 2030 (AREI, 2015).

Section 2 of this article summarizes our methodology by concisely presenting the model used for our study and listing the references in which more details can be found describing it. In Section 3 we report the results from our scenario runs, in terms of possible evolutions of Africa's energy system until 2050. In Section 4 we discuss these results and draw our main conclusions based on the insights that derive from our simulations, as well as attempt to provide recommendations for policy makers as well as the private sector in Africa.

2. Methodology

TIAM-ECN (the TIMES Integrated Assessment Model operated at ECN) is an energy systems model that can be employed for finding cost-minimal energy mixes based on a number of techno- and socio-economic conditions. It models energy demand and supply at the global, regional, and – in some cases – national level. In the following subsections a description is provided of the most important features of this scenario development tool, its inputs and outputs as well as the scenarios we ran with it, and the values that we adopted for some of its main parameters.

2.1. TIAM-ECN

TIAM-ECN is a version of the well-established TIAM model developed in the context of the IEA Implementing Agreement IEA-ETSAP, the Energy Technology Systems Analysis Program of the International Energy Agency (the energy analysis branch of the Organization for Economic Cooperation and Development (OECD) in Paris). TIAM is a member of the family of technology-rich energy systems models based on the TIMES software platform and is described in detail in Loulou and Labriet (2008) and Loulou (2008). As bottom-up model it is characterized by achieving a partial equilibrium in which energy production meets an essentially exogenously determined demand for energy services, unlike top-down models that calculate endogenously a general equilibrium between supply and demand (see, for example, van der Zwaan et al., 2002). TIAM is a linear optimization model simulating the development of the global energy economy from resource extraction to final energy use over a period of over 100 years. Its regional disaggregation separates the world in a number of distinct geographical areas, 15 in its original format and refined to 20 a few years ago for TIAM-ECN (see Kober et al., 2016). The objective function of TIAM-ECN consists of the total discounted aggregated energy system costs calculated over the full time horizon summed across all 20 regions. Running scenarios with TIAM-ECN involves minimizing this objective function.

The main cost components included in the objective function are investment costs, fuel costs and fixed plus variable operation and maintenance (O&M) costs. Other cost components such as decommissioning and infrastructure costs are also included, albeit in a simplified way. TIAM-ECN is based on a partial equilibrium approach with demand for energy services responding to changes in their respective prices through end-use price elasticities. Savings of energy demand and corresponding cost variations are thus accounted for in the objective function as well. The database associated with TIAM-ECN includes hundreds of technologies for a broad set of different sectors: for a general description of the reference energy system of TIAM-ECN see Syri et al. (2008). Since it encompasses all main sectors (electricity generation, industry, residences and commerce, transport), TIAM-ECN has been used for analysis of subjects in several domains, including transportation (see van der Zwaan et al., 2013a; Rösler et al., 2014), power supply (Keppo and van der Zwaan, 2012; Kober et al., 2016), and burden-sharing among countries for global climate change control (Kober et al., 2014). Other examples of studies with TIAM-ECN – that also provide more detailed description of parts of the TIAM-ECN model – include work on global and regional technology diffusion (see for instance van der Zwaan et al., 2013b; van der Zwaan et al., 2016b).

In order to provide more insight into the African energy system, we have recently replaced the global disaggregation of TIAM-ECN in 20 regions by one with 36 regions, by sub-dividing the former single Africa region into 17 different geographical areas (which we will refer to as regions, even while some of them are actually countries: see Fig. 1 and Lvan der Laan, 2015). Replacing the original representation of Africa as one entity by a specification of 17 distinct regions allows for a more accurate simulation of both developments that relate to the entire continent and its interactions with the rest of the world. It also enables inspecting in greater detail the energy systems of individual regions within Africa. We can thus more closely connect to the large diversity across different geographical areas in Africa, in terms of, for instance, their economy, energy infrastructure, as well as political system and preparedness to address environmental challenges such as climate change. With this breakdown of Africa we can also better analyse resource potentials, which diverge substantially across regions in Africa, both for fossil fuels and renewable energy options. This article is dedicated to Africa as a whole, and for our present purposes we have ensured that the continent's current and likely near-term energy system is represented in its entirety as realistically as possible, including the energy systems of our 17 African regions as well as the main energy-consuming sectors and energy-providing technologies therein. This