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Financial de-risking to unlock Africa's renewable energy potential

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ABSTRACT

African countries are in a unique position to reap the socio-economic and environmental benefits of renewable resources as a means for meeting increasing energy demand in a sustainable way. A critical obstacle for the deployment of renewable energy technologies in Africa is the difficulty of attracting sufficient and affordable finance. This paper compares the impact of financial conditions on the cost of electricity generation across six renewable and three fossil-based technologies in 46 African countries. The results show large cost variations and highlight the extent to which renewables are disadvantaged by current financial practices. The energy-economy-environment model TIAM-ECN is used to show how lowering financing costs results in a much higher deployment of renewables. For example, solar PV could account for 10–15% of total electricity generation by 2050, even without explicit climate policy, thanks to financial de-risking programmes. The results demonstrate that changes in financing schemes could outweigh the impact of technology learning. This paper also demonstrates that, once ambitious climate policies are in place, reducing financing costs for renewables could be an efficient way to lower greenhouse gas emissions. Financial de-risking is thus a key ingredient for unlocking the renewable energy potential in Africa.

1. Introduction

1.1. Synopsis

African countries are in a unique position to reap the socio-economic and environmental benefits of renewable resources as a means for meeting increasing energy demand in a sustainable way. Implementing sustainable practices proves to be challenging, in developing economies at least as much as in developed countries. A critical obstacle for the deployment of renewable energy technologies in Africa is the difficulty of attracting sufficient and affordable finance. This paper explores the importance of finance for creating the investment levels necessary to support sustainable development objectives, and compares the impact of financial conditions on the cost of electricity generation across six renewable and three fossil fuel technologies and 46 African countries. The results show large cost variations and highlight the extent to which renewables are disadvantaged by current financial practices, but imply significant potential for improvement if financing costs decrease.

These findings are translated into scenarios for the long-term composition of the African energy system and the implications of different financing schemes on renewable energy diffusion are analysed with a technology-rich energy-economy-environment model, TIAM-ECN. This paper shows how lowering financing costs results in a much higher deployment of renewables, at substantially lower total energy system costs. For example, solar PV could account for 10–15% of total electricity generation by 2050, even without explicit climate policy, thanks to financial de-risking programmes. Moreover, this paper demonstrates that the effect of changes in financing costs outweighs the impact of technology learning. Hence, financial de-risking and consistent policy support are key ingredients for unlocking the renewable energy potential in Africa. If integrated assessment models are used to guide the design of energy and climate policies and the choice of renewable energy technologies in Africa, they need to be complemented by financial modelling.

Section 1.2 introduces the subject of this paper, reviews the literature, and explains the steps undertaken in the analysis. Section 2 is dedicated to the analysis of the impact of finance on the cost of producing electricity. Section 3 describes the main mechanisms behind the financing cost scenarios used in this article, with particular focus on country risks, technology premiums, and financial de-risking measures. Section 4 proffers prospects for African energy supply until 2050, both

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in terms of a breakdown of electricity production by technology and regarding additional annual energy system cost requirements. Section 5 provides several conclusions for renewable energy policy makers and project developers, and formulates several recommendations for the energy analysis and finance modelling community.

1.2. Overview

With fast population and income growth across Africa, the continent's demand for energy, one of the essential requirements for socio-economic development, is set to increase significantly and play a progressively larger part in global energy consumption [1–4]. At present, the energy system of especially sub-Saharan Africa is underdeveloped, with only 35% of all people having access to electricity and 80% of the population relying on solid biomass for cooking and heating [5]. Population growth is currently outrunning the rate of electrification [6]. An estimated tenfold increase of the power sector in Africa would be necessary to reach the unlikely target of providing universal access to electricity by 2030 [7].

Increased implementation of renewables in developing countries is of global interest and contributes to reaching the United Nations General Assembly's Sustainable Development Goals (SDGs; see [8,9]). Given the imminence of major developments in the energy sector and the abundance of renewable resources in Africa, as well as the cost reductions realized globally for renewable technologies in recent years, African countries are in a position particularly well suited to gear an expansion in energy production towards the use of sustainable resources instead of fossil fuel alternatives [10–13]. The deployment of renewables in Africa has been relatively limited so far [11], despite their socio-economic and environmental advantages [6,14]. One of the main reasons is that perceived and actual investment risks in Africa make it difficult to identify suitable projects and attract sufficient funding [12,15].

Successful deployment of sustainable practices in developing economies requires careful long-term planning and informed decision-making [16]. Integrated Assessment Models (IAMs) are tools that can serve policy-making, since they allow for simulating the long-term implications of present efforts to reach climate change mitigation and economic development goals in a combined framework (see e.g. [17]). They can be used to guide medium-term decisions in attempts to achieve a variety of long-term objectives (such as in [18–20]). IAMs also permit assessing the long-term costs of low-carbon electricity generation and the cost reductions achievable in power production, but they usually focus on technology learning and the geographically optimal exploitation of natural conditions as the major drivers for cost improvements (e.g. [19,21,22]). Especially in developing countries the availability and cost of finance play just as important a role in realizing cost-competitiveness of renewables with fossil fuel alternatives [23–26]. Efforts to lower financing costs have thus been identified as a critical way of increasing renewable energy implementation [15,27,28]. The current practice of adopting generalized assumptions in IAMs with regard to financing costs may result in misleading simplifications and consequently uninformed and unjustified conclusions. IAMs are meant to generate internally consistent projections – not predictions – of what the energy system may look like in the future under a wide set of assumptions and conditions such as related to global climate change mitigation. They mostly focus on technical possibilities, while taking into account technically feasible costs, and thus do not take many real-life constraints into account. This article intends to partially compensate for this shortcoming by illustrating how IAMs could be enriched and improved with regard to financing issues.

This article investigates the impact of financial conditions on the cost of electricity production for different technologies and countries, and inspects the long-term implications that different financing mechanisms may have for the evolution of the energy system in Africa. The article follows three steps: 1) calculating and comparing the cost of electricity produced with different technologies under the present-day financing regimes, 2) reviewing the impact of economic development and explicit de-risking efforts on finance costs and formulating three projections for finance cost developments until 2050, and 3) assessing the effects of the findings under the first two steps on scenarios for renewable energy deployment in Africa determined with an IAM. The article ends with several conclusions and recommendations.

2. The impact of finance on the cost of producing electricity

The large size and long lifetime of projects result in financing costs making up a significant portion of the total cost of producing electricity and thus explain the capital-intensive nature of the energy sector [29]. Financing costs are a function of the capital needs from investors and the returns demanded by these investors. The investment requested for a project usually consists of a mix of debt and equity. Debt often makes up the lion's share and is commonly issued by banks, while equity constitutes the remainder and is often provided by private investors or companies. Equity is typically characterized by higher required returns than debt. The weighted average cost of capital (WACC; see Supplementary equation 1) is a measure to express the average financing cost of a project. The high upfront investment cost of renewable energy projects makes them sensitive to variations in required returns [6,28,30]. To illustrate the impact that financing costs have on the cost of generating electricity, the levelized cost of electricity (LCOE; see Supplementary equation 2) is calculated for six renewable and three fossil fuel technologies commonly used in Africa over a range of different WACC values. For cross-comparison reasons a representative set of LCOE input values was chosen for each technology based on project-level estimates by international organizations and national institutions across Africa (Supplementary table 1). The LCOE was disaggregated into debt, equity, fuel and operation & maintenance (O&M), and capital depreciation costs (following [28]).

Fig. 1 shows how high upfront investments that characterize most renewable energy technologies result in debt and equity costs rising quickly and accounting for the majority of the overall electricity production costs as the WACC increases. Fossil fuel options, notably those combusting natural gas and diesel, see much of their power generation costs arising from fuel expenses. As fuel is bought and used on a short time-scale there are no associated financing costs; consequently, the cost of producing electricity using fossil fuels is much less sensitive to changes in the WACC than for renewables. The vertical lines show the WACC values in the plotted range under which a renewable technology has a lower LCOE than the chosen fossil fuel alternative. The lines illustrate that renewable technologies like wind and solar energy may be competitive at low WACC values in comparison to natural gas- and diesel-based electricity generation thanks to the absence of fuel costs, but become more expensive than even diesel generators at a high WACC value. Significant variation exists across the different renewable technologies. While onshore wind power reaches cost-competitiveness with natural gas at a WACC of 13%, solar PV electricity requires a WACC of 6%. Concentrated Solar Power (CSP) only out-competes diesel when WACC values drop below 9%. Geothermal power is relatively cheap and outperforms natural gas and diesel under all WACC values considered. Small hydropower reaches cost-competitiveness with coal and natural gas at WACC values of 2% and 21% respectively. Large hydropower is cost-competitive even with coal until a WACC of 22%. A sensitivity analysis on the LCOE input factors (Supplement Fig. 1) confirms that renewable energy technologies are most sensitive to variations in the WACC and fossil fuel technologies to variations in fuel costs.

The LCOE calculations depicted in Fig. 1 are translated to the African context by analyzing the cost of producing electricity under country-specific estimates for the WACC (see Supplementary table 3). WACC values vary between 8% and 32% across a sample of 46 African countries.

The findings are summarized in Fig. 2, which shows that the cost of

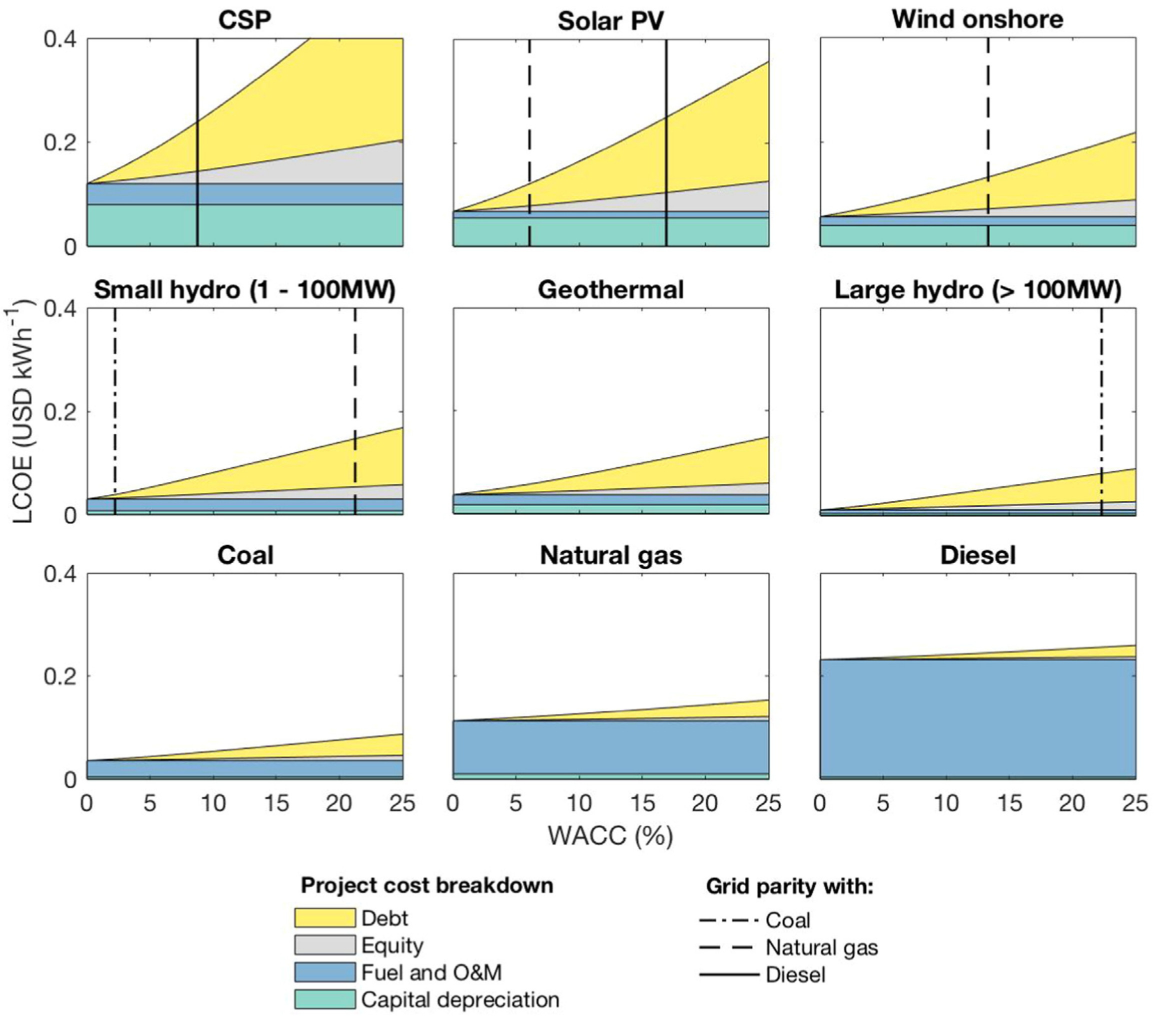

Fig. 1. | The impact of the cost of capital on the cost of power generation. The levelized cost of electricity is plotted against the weighted average cost of capital, with grid parity lines at cost of capital values for which the cost of renewables and fossil fuels is equal (fuel subsidies, grid connection, greenhouse gas emissions and environmental damage costs are not considered). Input tables and calculations are included in Supplementary 1A.

electricity from CSP is over 5 times higher than from coal and nearly 3 times higher than from natural gas. Solar PV is over 3 times more expensive than coal and nearly 2 times more expensive than natural gas. Excluding outliers, diesel generators produce electricity at a cost higher than solar PV in 34 countries; they do so at a cost higher than CSP only in two countries. The cost of electricity from onshore wind is over 2 times higher than that from coal, but it is lower than that from natural gas in 15 countries and lower than that from diesel in all countries. Small hydropower units and geothermal plants produce electricity at lower cost than diesel generators, and, except for two outliers, than natural gas based power production. Large hydropower would be the least-cost option, outcompeting coal plants in all countries except for two outliers. The deployment of hydro, geothermal and wind power is limited to areas with sufficient renewable resources. The hydropower potential is widespread across nearly all regions except Northern Africa, but the potential for large projects is mainly concentrated in the Congo River basin and upper Nile. Geothermal power is by and large limited to East African nations located in the Great African Rift Valley. The

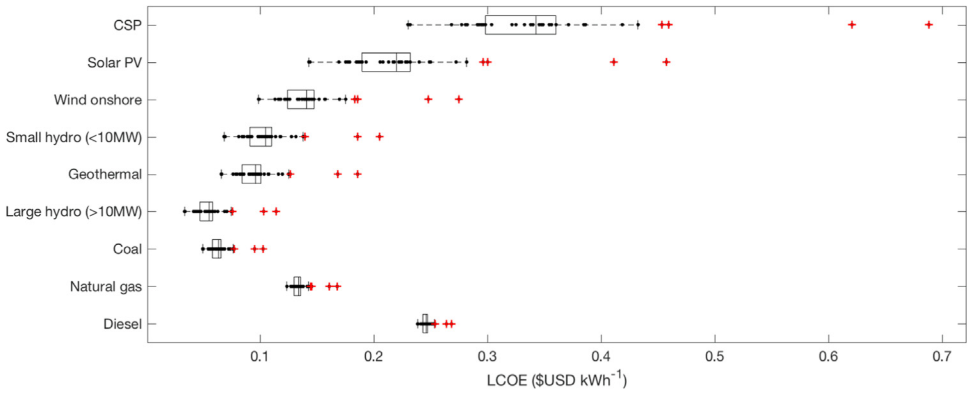

Fig. 2. | Levelized cost of electricity for renewable and fossil fuel technologies in 46 African countries. Black dots represent different countries. Each dot is calculated with the WACC value estimated for the power sector in the corresponding country. Boxes show the lower and upper quartiles and whiskers the 5th and 95th percentiles. Red crosses show statistical outliers (denoting four countries for which the WACC value is exceptionally high).

majority of high-quality wind resources are located in the northern, eastern and southern coastal zones. CSP and solar PV have the largest and most evenly distributed technical potential but they come at a higher cost. As can be observed in Fig. 2, renewables (notably solar and wind energy) display a larger spread in the LCOE than their fossil fuel counterparts. Larger spreads here imply higher costs under a large spectrum of WACC values, but also illustrate the opportunity for cost reductions by reducing the cost of finance. The results for the LCOE of renewables relative to fossil fuels in Africa depicted in Fig. 2 are less optimistic than those reported in e.g. Walwyn and Brent [31] and by IRENA [32], because empirical data was used for essentially all countries in Africa, while these two publications only consider countries with low perceived risks and strong support mechanisms.

3. Mechanisms behind financing cost scenarios

Having investigated the size of the variations in electricity generation costs across technologies and countries in Africa, the prospects for change in the financial situation of these countries are explored, and the effects on (renewable) energy technologies deployment thereof. To accomplish this, a stylistic model that allows for generating technology and country specific WACC values until 2050 is introduced (for details see Supplementary Fig. 4). The idea behind this model is to provide an estimate of the effects that actual and perceived risks have on the WACC. The model consists of three main components: country risk, technology premium and financial de-risking. Then, three scenarios are built to explore the effects that variations in these components induce on the WACC.

3.1. Country risk

The realization of energy projects is tied to country-specific risks. Perceived and actual investment risks are higher in Africa than in developed countries. Consequently, investors demand a higher rate of return to accommodate for these risks (see e.g. [27]). Risks are often related to concerns over political and financial stability, as well as regulatory and institutional conditions [33]. Several studies report on the links between political, financial and economic risk, or the interconnection between economic development and political stability (e.g. [34,35]). Weak democratic institutions, associated risks and, consequently, high-interest rates often characterize low-income, high growth countries. To illustrate this, in Fig. 3 current estimated WACC values are plotted against GDP per capita for 130 countries worldwide [25,36].

Fig. 3 shows that there exists a correlation between WACC and the average per capita GDP, the trend being highlighted by the fitted dashed line (see Supplement equation 3). African countries (filled circles) are generally characterized by low GDP per capita and high WACC. African economies have shown significant growth in the last decade and GDP per capita is projected to increase 3- to 16-fold by 2050 depending on the region [37,38]. As economies and financial markets on the continent mature, country-specific risks are set to decrease. African countries are likely to progress towards better country risk ratings issued by international credit rating agencies. This will lead to higher foreign investments at progressively lower interest rates. To capture these dynamics, the relation between WACC and GDP per capita is used, expressed by the dashed line in Fig. 3 (see Supplement equation 3), as a first order approximation for the effect of economic development on the cost of finance.

3.2. Technology premium

In emerging markets, substantial risks may arise from technology specific concerns over the availability of specialized workers, building materials and infrastructure, or over technical know-how [39,40]. These multiple types of risk add up to form what in this article is referred to as the technology premium. As the deployment of a given technology increases, local technology learning leads to a higher level of domestic capabilities [41]. As the technical, financial and legal skills concerning the deployment of a technology improve, the risks associated with investing in this technology decrease. Domestic installed capacity of a technology is used as proxy for estimating the technology premium and projecting it into the future.

3.3. Financial de-risking

In this article “financial de-risking” refers to any form of external financial support that reduces the risks involved with investments, whether from financial institutions or in the form of national or international policy. Financial de-risking lowers the perceived risks and required returns, and thus reduces investment costs. At an international level, bilateral and multilateral development banks play an important role in supporting development across Africa by providing financial and technical assistance. These Development Finance Institutions (DFIs) are usually majority-owned by national governments, which ensures their high credit-worthiness and enables them to raise large amounts of capital on the international market. Consequently, they are able to offer grants or supply debt and equity at lower interest rates than domestic providers of capital. Funding low-carbon energy access is becoming an increasingly larger part of overall DFI activity ([42]; see Supplementary Fig. 3). Continued involvement of DFIs is seen as crucial to the diffusion of renewable energy technologies in developing countries [27,43]. Climate funds, set up specifically to support climate change mitigation and adaptation projects, constitute another source of international financial support for low-carbon energy generation. The UNFCCC Green Climate Fund (GCF) in particular, with a target value of 100 $USD billion/yr by 2020, is expected to play an essential role in delivering the

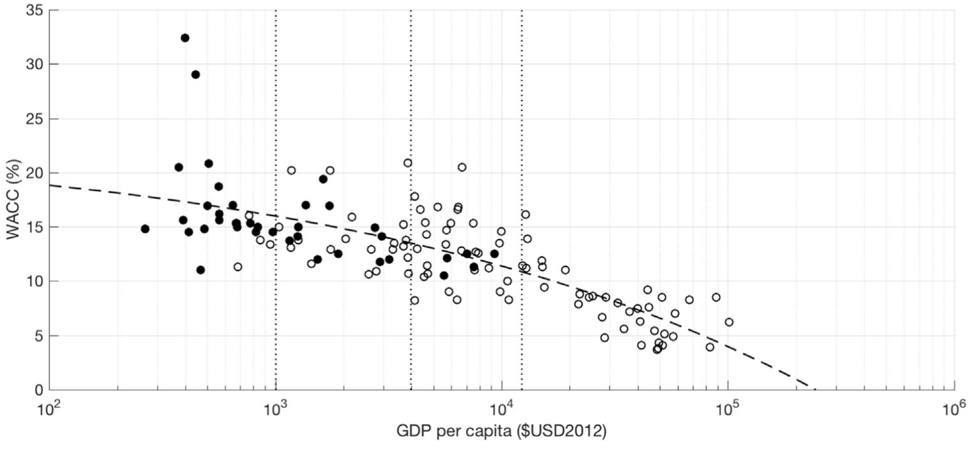

Fig. 3. | Weighted average cost of capital against GDP per capita. Each circle represents one country. African countries are plotted as filled circles. The dashed line denotes a fitted trend, vertical lines show the boundaries of UN income classifications (low, lower middle, upper middle and high).

investment levels required for the large-scale deployment of renewable energy technologies in developing countries, in view of global efforts to meet the 2 °C target of the Paris Agreement [44]. The GCF explicitly states as one of its main goals to address the needs of least-developed countries. By late 2017, the GCF has approved climate change mitigation projects totalling 1.1 $USD billion, with African states forming the largest group of beneficiaries [45]. At a national level, financial de-risking consists of support policies like feed-in-tariffs, subsidies or low-carbon promotion tools such as carbon pricing. These efforts increase investor confidence, lower perceived risks and attract additional finance for sectors or technologies [46,47]. In the analysis international financial de-risking is investigated by estimating the fraction of total investment needs for renewable energy in a given country that DFIs and the GCF can provide on a yearly basis. The expected interest rate is based (market-rate, concessional or mixed) on the UN income classification of a country, and the WACC is recalculated accordingly. National financial de-risking efforts are included by evaluating the Nationally Determined Contributions (NDCs) of African countries to the Paris Agreement (see the summary in Supplementary table 5).

3.4. Scenarios

To illustrate the effects of risks and financial de-risking on the value of the WACC, three scenarios are developed that represent different possible pathways for its evolution in Africa. The starting point is a reference assumption that involves a WACC value of 15% that is constant in time and uniform across both technologies and countries: this scenario is called Uniform. Three alternative scenarios with time-dependent and technology- and country-specific WACC values – named Diverse, Concessional and De-risked – explore the effects of different levels of economic development and financial de-risking. These four scenarios assume no climate policies are implemented in Africa or elsewhere, i.e. this paper is solely interested in the effect different financial conditions have on the electricity generation mix. Fig. 4 summarizes the main assumptions behind each of these three scenarios and the resulting WACC projections, at an aggregated level for the whole of Africa. Tables 3 and 4 in the Supplement give a more detailed description of the assumptions used in the scenarios. As indicated by the percentages in Fig. 4, the Diverse, Concessional and De-risked scenarios project between today and 2050 an overall reduction in WACC values of respectively 4%, 2% and 5% points. The Diverse scenario assumes no financial de-risking now or in the future. Hence, the starting point WACC values are higher than for the other two alternative scenarios. In the Concessional scenario financial de-risking remains constant in absolute US$ terms between 2015 and 2050. Growing investment needs of the renewable energy sector in Africa mean that the corresponding percentage point impact of financial de-risking becomes smaller. The time evolution of the financial de-risking component in the De-risked scenario is due to the interplay between monotonically increasing de-risking contributions and overall investment needs.

4. Prospects for the African energy system

The four scenarios yield technology- and country-specific WACC projection series for Africa. This paper uses the technology-rich TIAM-ECN model to investigate the impact of financial conditions on the development of the energy system in Africa under the four WACC scenarios. TIAM-ECN is the TIMES Integrated Assessment Model operated at ECN-TNO, and is a well-established version of the global TIAM model developed under the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA; see Supplementary Note 3 for more details on this IAM, which is based on the general principle of overall energy system cost minimisation). TIAM-ECN has recently been updated, refined and expanded to better reflect energy system developments across the African continent (for a full description hereof, see [48–50]).

Fig. 5 presents projected electricity generation in the four scenarios, disaggregated into several technology classes. Up to 2020 there is little difference in the power supply mix across scenarios: a sizeable increase materializes in the share of gas as replacement of oil for electricity generation in all scenarios with respect to 2010. In 2030 the role of natural gas (and coal) further increases, but the three alternative WACC scenarios display a lower electricity production from natural gas and an increase from coal relative to the Uniform scenario. This is the consequence of slightly lower WACC values that favour coal over natural gas electricity generation (see Supplementary table 5). This substitution

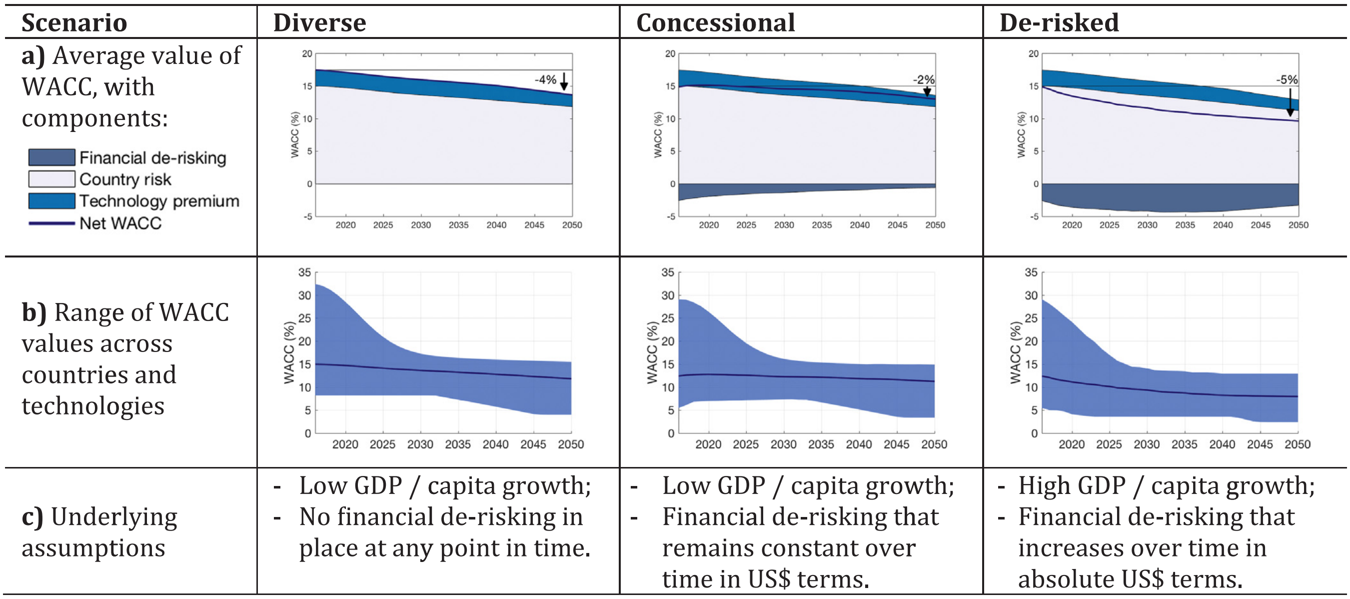

Fig. 4. | Summary of the three alternative WACC scenarios. Row **a:** WACC values averaged over technologies and countries in Africa; the area under the x-axis depicts the amount by which the WACC value is lowered by means of financial de-risking. Row **b:** spread in WACC values across countries and technologies in Africa; the dark blue line shows the average across countries and technologies. Row **c:** underlying assumptions regarding economic development and financial de-risking.

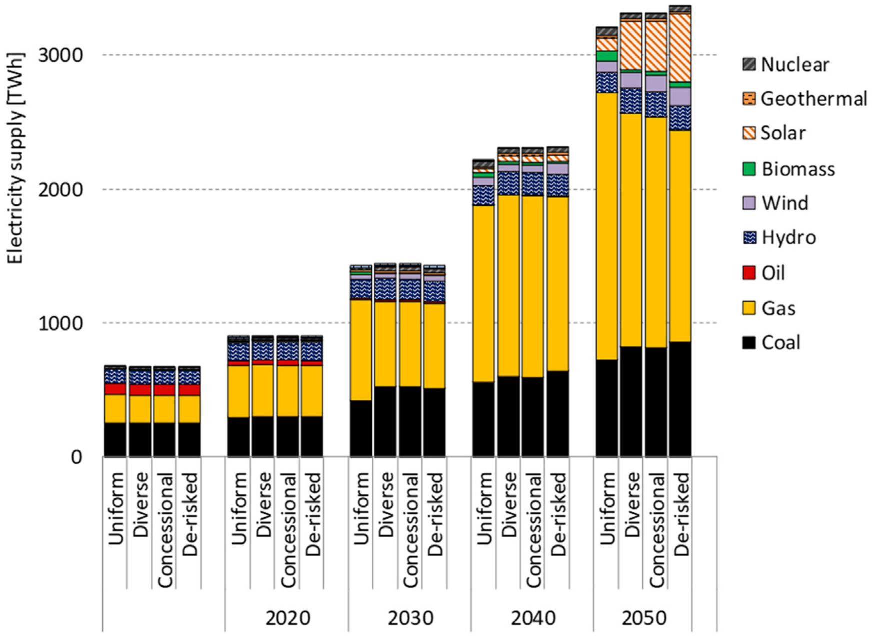

Fig. 5. | Electricity production projections for Africa until 2050. Each bar represents the breakdown of electricity supply in a given scenario and simulation year. No global climate policy is assumed so as to most clearly show the effects of financial de-risking measures only.

effect continues after 2030. Starting from 2040, the three alternative WACC scenarios display a slightly larger overall level of electricity supply in comparison to Uniform, with solar PV and wind gaining shares of several percentages. This trend continues in the following decade, in which solar PV (displacing natural gas) accounts for 10–15% of total electricity supply in the three alternative WACC scenarios. This rapid growth follows a substantial decrease in the costs of PV, driven by technology learning at a higher rate than for most other – more mature – technologies. Supplementary Fig. 6 shows that total emissions are only slightly reduced across scenarios. The higher share of coal in the energy mix observed in lower WACC scenarios offsets the emission reduction as a result of gas being displaced by renewables.

Contrasting the large role of solar PV in 2050 in the three alternative WACC scenarios – while its presence remains limited in Uniform – reveals that a suitable financial climate is essential to fully unlock the potential impact of renewable technology cost reductions on the composition of the energy system. The projections for 2050 also show that the lower the WACC, the higher the total level of electricity generation. This suggests that favourable financial conditions are not only necessary to materialize the deployment of emerging low-carbon technologies, but also conducive for increasing the overall degree of electrification of the energy system. Note that several recent publications yield much higher shares of renewable electricity generation in 2050 than presented in this paper in Fig. 5 (including work by the authors; see e.g. [49,51]). This is the result of the imposition of stringent climate policy in these studies, from which this paper abstains in order to more clearly elucidate the role of finance in stimulating renewable energy deployment. See Supplementary Fig. 7 for the electricity production breakdown calculated with TIAM-ECN under stringent (2DC) global climate policy.

Fig. 6 shows projected additional annual system cost developments (excluding costs associated with interregional trading) in the four scenarios, relative to Uniform. In each period the composition of costs changes, depending on the values of WACC. Capital expenditures in the three alternative WACC scenarios are somewhat lower than in Uniform up to 2040, as a result of a slightly lower average WACC and similar installed electricity production capacities. In 2040, however, variable cost increases outweigh these reductions in capital expenditures, resulting in a net increase in total annual energy system costs. The increase in variable operational costs in 2040 is mainly due to the larger

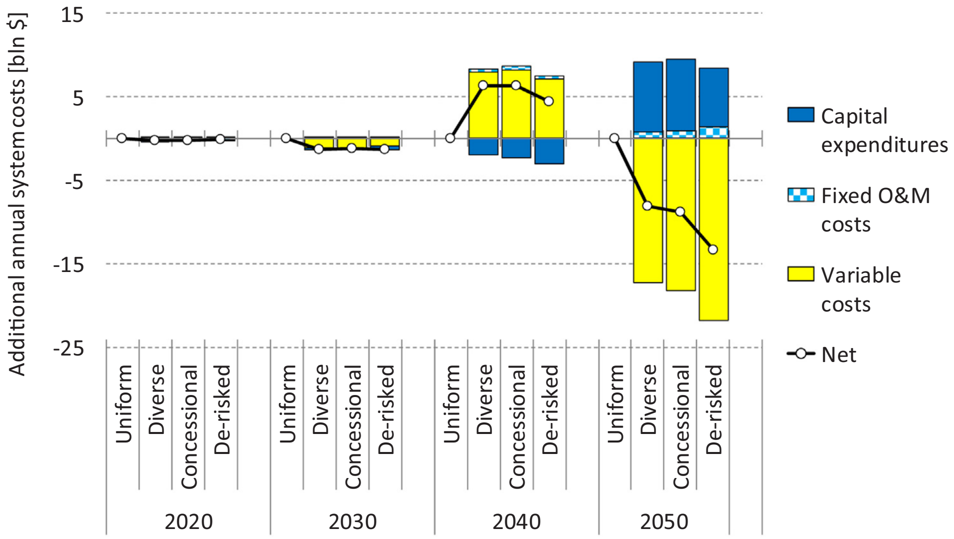

Fig. 6. | Additional annual energy system costs relative to the Uniform scenario. Overall costs are broken down in capital expenditures, fixed O&M costs and variable costs (the latter including fuel costs). Net additional costs are indicated by white dots.

use of coal and natural gas in power production (see Fig. 5), which induces higher fuel expenditures. The increase in capital expenditures in 2050 is triggered by a large deployment of capital-intensive renewable energy technologies – mostly solar PV. The large presence of solar PV in the electricity supply mix (displacing natural gas), however, induces substantial savings in variable fuel costs. This yields net energy system benefits between 8 and 13 $USD billion annually. The benefits of renewables are most pronounced in the De-risked scenario, which displays the highest installed electricity generation capacity at significantly lower total system costs.

5. Conclusions

The difficulty of attracting sufficient investments is a major obstruction for the deployment of renewable energy in developing countries. This paper therefore explores the impact of the cost of finance on the prospects for renewable electricity generation in Africa. In this paper a comprehensive analysis of 46 African countries, six renewable energy and three fossil fuel based electricity production technologies is performed. This paper provides novel insights by incorporating different scenarios for the evolution of energy financing in Africa into a technology-rich IAM, and by assessing the system-level implications thereof until 2050.

Consistent with past work [24,28], renewable energy technologies are found to be more sensitive to rising financing cost than their fossil fuel based counterparts. For example, under current financial conditions, the cost of producing electricity with solar PV is higher than for technologies based on coal, natural gas and, in a few cases, diesel. Yet, this paper's analysis reveals a potential for substantial cost-reductions if financing costs decrease. This supports the argument for financial de-risking as a promising way for decreasing the cost of renewable electricity generation, and thereby increasing the deployment of renewables.

The analysis of the power generation system in Africa presented in this paper shows large variations for the deployment of renewables across different WACC scenarios. The Uniform scenario results in a much lower penetration of renewables, especially solar PV, than the other three scenarios. In the former WACC values are assumed that are constant in time and uniform across countries and technologies, as is common practice in essentially all conventional IAMs. The latter allows for time evolution and geographical variation of WACC values. The three alternative scenarios used in this paper show that solar PV can account for 10–15% of total electricity generation by 2050, thanks to financial de-risking programmes. This indicates that suitable financial conditions are pivotal for fully taking advantage of expected PV cost reductions from technology learning.

The limited emission reductions observed in the WACC scenarios with higher shares of renewables show that low financing costs alone are not sufficient to achieve lower emissions. To effectively reduce emissions, climate policies must be in place that incentivise the displacement of high-carbon energy generation, especially from coal. Hence, this paper argues that once ambitious climate policies are in place, lowering financing costs is an efficient method for reducing emissions in Africa.

The results show that early deployment of renewables pays off in the long-term thanks to fuel-cost savings that eventually outweigh higher annual capital expenditures. The strongest cost savings realized in the De-risked scenario show that ambitious financial de-risking schemes are necessary to reap the maximum benefits from a renewable-based energy system.

The work presented in this paper reveals that lower financing costs result in a larger deployment of renewable energy technologies and a higher overall electrification level. This provides an additional argument for the findings of Creutzig et al. [52], who show that the underlying assumptions of most IAM studies are overly pessimistic towards the implementation of solar power. However, while Creutzig and co-authors attribute the effect to the use of insufficiently steep technology learning curves for PV, the exclusion of climate policy impacts and too optimistic assumptions regarding the costs of other low-carbon energy generation technologies, the results in this paper indicate that an important driver behind pessimistic outlooks for PV in developing countries is an over-simplification and unrealistic representation of financing costs in IAMs. This is a critical message for the energy modelling community. This paper illustrates that detailed financial modelling should inform IAM-based studies of the prospects for electricity generation in developing countries.

Several lines of research can further improve financial studies of renewable energy deployment potentials. A first step would be the construction of a comprehensive and freely available database containing financial parameters, like finance costs, to allow for model validation. Current studies usually lack validation based on empirical data. While some databases exist, they often contain only few observations and typically are poor in covering developing countries. Global expert elicitation surveys on the techno-economic perspective of different renewable energy technologies, like the one performed by Wiser et al. [53], could complement these databases by developing estimates for the future value of financial parameters. Second, building on the work presented in this paper, efforts can be undertaken to construct more extensive financing cost models that untangle the different risk components and their separate contributions to the value of WACC. Third, the efficiency of de-risking mechanisms can be better assessed, both across countries and regions. Fourth, bottom-up and top-down energy-economy-environment models as used by an expanding IAM community for climate change policy research must account for insights derived from financial analyses. Advancing this research agenda is necessary to develop concrete recommendations for development banks and the GCF on how to effectively and efficiently deliver financial support for low-carbon development.

CRediT authorship contribution statement

Bart Sweerts: Conceptualization, Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Francesco Dalla Longa:** Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Bob van der Zwaan:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing.

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Competing interests

The authors declare no competing financial interests.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rser.2018.11.039.

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