nature climate change

ARTICLES
https://doi.org/10.1038/s41558-019-0649-8

Coal and carbonization in sub-Saharan Africa

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Economic development in sub-Saharan Africa has increased carbon emissions and will continue to do so. However, changes in emissions in the past few decades and their underlying drivers are not well understood. Here we use a Kaya decomposition to show that rising carbon intensity has played an increasingly important role in emission growth in sub-Saharan Africa since 2005. These changes have mainly been driven by the increasing use of oil, especially in the transportation sector. Combining investment data in the power sector with economic and population projections, we find that investments in new coal-fired capacity may become a major driver of future carbonization. Our results highlight the importance of making low-carbon technologies available and financially attractive to sub-Saharan African countries to avoid a lock-in of emission-intensive energy use patterns.

In the past three decades, economic growth has lifted millions of people out of poverty. It has also markedly accelerated the increase of global emissions, especially in Asia[1,2]. The construction of new infrastructure for fossil fuel energy, particularly coal, to cover the energy needs of increasingly industrializing economies has already locked in a sizable amount of emissions for the years to come[3,4]. Emissions in the countries of sub-Saharan Africa (excluding South Africa, hereafter referred to as SSA) are comparatively low, particularly in the energy and industry sectors. However, the continued growth of economic activity and population could turn countries in SSA into major emitters in the future.

Here we find that over the period 2005–2015 emission growth rates in SSA have been among the highest in the world. Carbonization (increasing carbon intensity of energy generation) has been an important driver of emissions. In terms of the percentage change of emissions that can be attributed to increasing carbon intensity (emissions per unit of energy), seven of the top ten carbonizing countries in the world are located in SSA. Although carbonization in the past few decades in SSA can mainly be attributed to oil use in the transportation sector, investments in coal-fired power plants may play a dominant role in the near future.

While previous studies have empirically assessed the drivers of changing energy use and rising GHG emissions from a cross-country perspective[2,5,6], countries in SSA are usually not studied explicitly, arguably owing to the small role they play in current emissions. Some notable exceptions focusing on SSA examine the relationships between economic growth, energy use and fuel prices[7–10], but do not assess the implications of these findings for climate change. Recent integrated assessment model studies that have developed scenarios for African countries, however, hint at the importance of future emission growth. Lucas et al.[11] project that in the absence of climate policy, (continental) Africa's emissions will increase by 7 to 15 times by 2100, such that they will account for 3–23% of global emissions. In a similar vein, Calvin et al.[12] project that by 2100, the continent could account for between 5% and 20% of global emissions (with SSA contributing between 4% and 10%). Van der Zwaan et al.[13] expect a two-fold increase in African emissions by 2050, while Leimbach et al.[14] project a 50% increase in GHG emissions in SSA by 2050.

In light of this, our study provides an in-depth analysis of recent carbonization patterns in SSA and short-term projections of future developments based on planned investments.

Results

Our empirical analysis of the drivers of energy use patterns and carbonization is based on data on population, gross domestic product (GDP), fuel-specific primary energy and CO_2 emissions from the International Energy Agency (IEA)[15]. This includes data for 24 countries in SSA (another 25 are aggregated into Other Africa) for the period 1971–2015. As the main focus of our analysis is on countries that are building up their energy systems, we exclude South Africa from the SSA aggregate.

We then project the development of power sector emissions in the near future, on the basis of the Platts database[16], which provides country-level information on power plant capacities that already exist, are under construction or are in the planning process. Finally, we compare these results with projected emissions in the Shared Socioeconomic Pathways (SSPs)[17] that have been derived from integrated assessment model studies. All data and methods are described in more detail in the Supplementary Information.

Analysis of emission growth for 1971–2015. While emissions from energy and industrial processes are still low, annual growth rates in many countries in SSA have been among the highest globally over the period 2005–2015. With annual emission growth rates of more than 20%, the top three countries in the world are all in SSA (Angola, Congo and Mozambique; ΔCO_2 in Table 1). Overall emissions have increased by 6% annually in SSA. Using the Kaya decomposition[18], this change can be decomposed into changes in population growth (p), per capita economic growth (a), energy intensity of economic activity (e) and carbon intensity of energy production (k). The latter factor, k, can further be subdivided into contributions of individual energy carriers (see the Methods for details). Table 1 provides an overview of the contributions of each factor. Negative values denote a dampening effect on emission growth—for example, due to decreasing energy intensity or an increasing share of low-carbon energy carriers, such as renewables and biomass (both are assumed to be carbon neutral; although some authors have estimated the emissions related to these energy sources[19,20], a detailed consideration of emissions from biomass and renewables would go beyond the scope of this study).

The 20 countries listed in Table 1 are the ones that globally have displayed the highest rate of emission increase that can be attributed to increasing carbon intensity. It is striking that the top five

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Table 1 | Average annual percentage changes in CO_2 emissions and decomposition results for the period 2005–2015

		k (%)	Coal (%)	Oil (%)	NaG (%)	Nuc (%)	RE (%)	Bio (%)	*p* (%)	*a* (%)	*e* (%)	ΔCO_2 (%)
1 (2)	Mozambique*	17.2	−0.5	11.9	8.2	0	−2.2	−0.3	6	8.9	−6.3	25.7
2 (3)	Angola*	12.6	0	13.8	0.3	0	−1.2	−0.2	6.8	9.5	−5	23.8
3 (5)	Niger*	10.1	1.1	12.7	0	0	−3.4	−0.2	7.1	2.9	−0.1	20
4 (1)	Congo*	9.6	0	11.3	3.7	0	−5.4	−0.1	5.9	3.8	9.3	28.6
5 (15)	Cameroon*	9.4	0	7.1	1.6	0	1.1	−0.3	3.8	2.2	−5.1	10.3
6 (9)	Myanmar	8.7	0.3	6.2	2.6	0	0	−0.3	1.3	10.6	−7.5	13
7 (10)	Ethiopia*	8.6	2	9.5	0	0	−2.7	−0.2	4.4	12.1	−12.5	12.7
8 (4)	Cambodia	7.5	5.5	6.3	0	0	−3.7	−0.6	3	9.4	0.9	20.8
9 (21)	Tajikistan	7	5.1	4.3	−3	0	0	0.6	3.2	6.3	−7.8	8.7
10 (8)	Tanzania*	6.8	0.8	7.9	1.3	0	−3.1	0	5	5	−3.6	13.2
11 (28)	Sudan and South Sudan*	6	0	5.4	0	0	1	−0.4	3.7	4.1	−6.9	6.8
12 (12)	Ghana*	4.5	0	3.3	1.7	0	−0.6	0	3.8	6.7	−2.9	12.1
13 (11)	Bangladesh	4.4	1.1	0.7	3	0	−0.4	0	1.9	7.3	−1.5	12.1
14 (24)	Nepal	4.2	3.1	2.9	0	0	−1.6	−0.2	1.5	4.2	−2.4	7.5
15 (14)	Kyrgyzstan	4	2.1	2.3	0	0	0	−0.4	2.1	4.5	−0.2	10.4
16 (29)	Haiti	3.9	0	5.4	0	0	−1.5	0	1.9	0.7	0.4	6.8
17 (19)	Togo*	3.8	0	6.5	0	0	−2.5	−0.2	3.8	1.9	−0.5	9
18 (13)	Georgia	3.6	1.5	1.2	1.3	0	−0.1	−0.2	−1.8	8.9	0	10.8
19 (16)	Bolivia	3.4	0	2.7	1.3	0	−0.6	−0.1	2.4	4.8	−0.4	10.1
20 (20)	Kenya*	2.7	1	5.2	0	0	−1.9	−1.6	3.7	3.4	−0.9	8.9
Regional results	SSA	1.9	0.3	3.3	0.8	0	−0.1	−2.3	3.7	3.8	−3.4	6.0
	Africa	0.2	0.4	0.9	0.3	0	−1.3	−0.1	3	2	−1.9	3.3
	China	0.1	0.8	−0.2	−0.1	−0.1	0.3	−0.5	0.7	11.5	−5.6	6.8
	India	2.1	2.8	0.3	−0.2	−0.1	−0.6	−0.1	2	8.2	−3.2	9.1
	Non-OECD countries	0.4	0.9	0.1	−0.1	−0.1	−0.2	−0.2	1.6	5.3	−2.7	4.7
	OECD countries	−0.4	−0.3	0	0	0.2	−0.2	−0.1	0.6	0.8	−1.9	−0.9
	World	0.1	0.4	0	0	0	−0.2	−0.2	1.3	2.6	−2	1.9

Countries are ranked by *k*. Numbers in brackets indicate rankings in terms of total CO_2 emission changes, ΔCO_2 (see also last column). The value of *k* is determined as the sum of contributions from coal, oil, natural gas (NaG), nuclear power (Nuc), renewable energy and other energy (RE), and biomass (Bio). Total percentage changes in emissions are given by the sum of *k*, *p*, *a* and *e*. Countries in SSA are marked with asterisks.

countries, and seven of the top ten countries, of this list are in SSA. While the growth in population and GDP per capita are important drivers of emission growth in most African countries (see also Fig. 1), increasing carbon intensity has been more pronounced in SSA than in the rest of Africa, resulting in more rapid emission growth. Comparing the entire region on an aggregated level with other countries and regions of the world, such as China and non-Organisation for Economic Co-operation and Development (OECD) countries, it is among the fastest carbonizing regions in the world. Note that the expansion of low-carbon energy, such as renewable energy and hydro, has lowered the growth rate of annual emissions by only about 0.1% on average in the entire region.

The reasons for carbonization differ between countries. Most African countries start from an energy mix that is largely dominated by (traditional) biomass, which still supplied roughly 50% of Africa's energy in 2015 (78% in SSA)[15]. In 2015, sources of energy-related CO_2 emissions in Africa as a whole were dominated by oil (46%) and coal (34%), followed by natural gas (20%)[15]. Most of the coal-based emissions come from African countries that are not part of SSA, including South Africa and North African countries. Most energy-related CO_2 emissions in SSA stem from oil (75% in 2015), while those from natural gas (17%) and coal (8%) have played a minor role so far[15].

Figure 2 displays the contributions of different energy sources to changes in carbon intensity (see the Supplementary Information for details). Increasing shares of energy carriers with a carbon intensity above (below) the average amount to a positive (negative) contribution. For SSA, oil was the largest contributor to carbonization (Fig. 2a), as emission growth has mainly been driven by the transportation sector (around 60% of oil supplied in Africa is consumed in transportation sector[15]). However, in Africa as a whole, increasing carbon intensity was mostly due to increased coal use (Fig. 2a, mainly driven by South Africa). This poses the question of whether countries in SSA that are currently building up their energy systems can be expected to converge with the African average by also turning towards increasing coal use. To shed some light on this issue, we analysed to what extent coal-fired power plants can be expected to be constructed in countries in SSA in the next several years.

The role of coal in emission growth to 2025. While many projects in the electricity sector target large-scale hydro projects, natural gas and increasing oil consumption have already been important determinants of increasing carbonization. Some comparably rich countries in SSA, such as Botswana, Kenya or Senegal, have already seen rising emissions due mainly to increased coal use, contributing to emission growth of 0.7%–1% yr^{-1} (in addition to the other

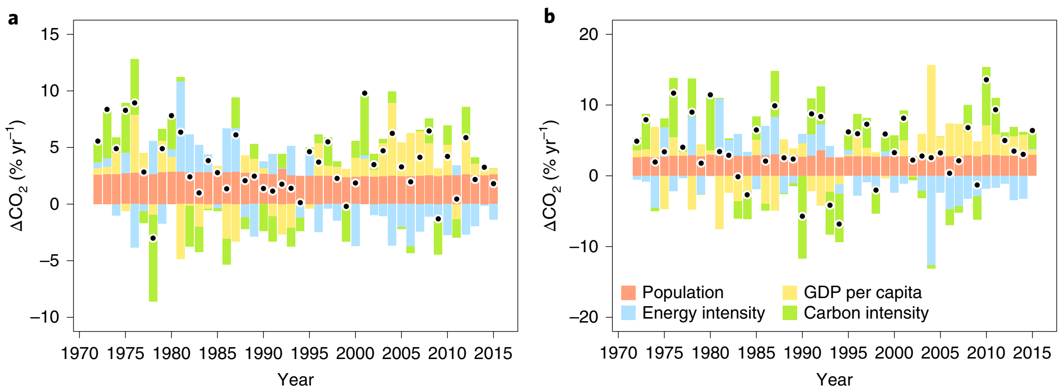

Fig. 1 | Kaya decomposition of emission drivers. a, Emission drivers in continental Africa. **b**, Emission drivers in SSA excluding South Africa. The black dots show the total emission growth. Note the different *y* axis scales.

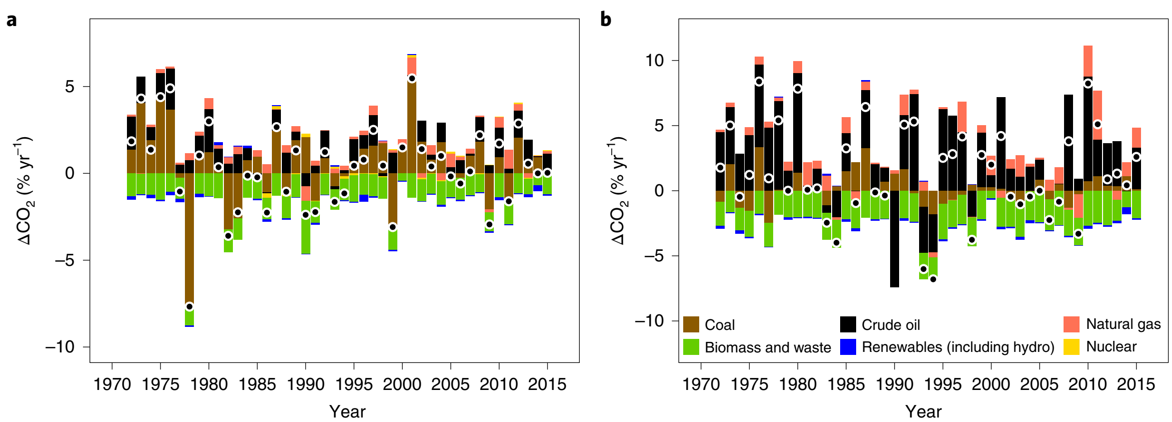

Fig. 2 | Effect of carbon intensity on total emission growth decomposed into effects of different energy carriers. a, Effects in continental Africa. **b**, Effects in countries in SSA excluding South Africa. The black dots indicate changes in aggregated *k*. Note the different *y* axis scales.

factors, such as population growth and economic growth). In general, many countries in SSA envisage increasing investments in coal-fired capacity in the electricity sector today, often with the help of Chinese companies[17]. Many African countries have plans to build (or have already started building) coal-fired capacity, led by Egypt (13,240 MW) and South Africa (12,744 MW), followed by the sub-Saharan African countries Zimbabwe (4,260 MW), Nigeria (2,400 MW), Botswana (2,082 MW) and Kenya (2,010 MW)[21]. Some countries, such as Mozambique and Tanzania, also show increasing interest in starting or expanding coal mining activities. For these countries, coal is probably an attractive option because of its low price and the fact that it can be operated with proven, readily available technologies. Ramping-up of Chinese and Indian investments after the domestic market for coal-fired plants becomes increasingly saturated is also likely to play an important role[4].

In total, countries in SSA are developing approximately 16 GW of new coal-fired capacity, of which 802 MW is already under construction. Another 15.2 GW is currently shelved (that is, there has been no significant development activity in a certain time span). The reasons can be very different, including local resistance (which appears to be the case in Ghana) and changing priorities towards a different energy mix (such as in Tanzania). Whether plants will come back into the pipeline or ultimately be cancelled is difficult to say. Note that beyond SSA, South Africa, Egypt and Morocco plan to add another 27.3 GW, of which 7 GW is built. The effects of all plans (including natural gas and renewables) in terms of short-term emission growth that can be attributed to changes in carbon intensity are displayed in Fig. 3. Hence, in the years to come, carbonization in SSA may be largely driven by coal (see brown areas) rather than oil or natural gas, depending on how much coal capacity is built and how much of it is used. At the same time, the resulting increase in carbon intensity can be expected to be, at least to some extent, counterbalanced by the growing use of non-fossil fuel energy sources (large hydro and renewable energy, blue area in Fig. 3). For this reason, the power sector in SSA is at a critical junction, experiencing simultaneous deployment of additional high- and low-carbon energy sources. How these developments may play out is illustrated in two scenarios (Fig. 3, see Methods and Supplementary Information for details). Our lower bound scenario, 30%, assumes that only 30% of the pre-construction coal power plant projects will be successful, while all shelved projects will not. This is consistent with the average rate of implemented projects between 2010 and 2017, which was 27% in the Africa and Middle East region and 34% worldwide[22]. We also consider all coal power plants to run at 30% of their capacities, which is close to the average capacity factor of 35% in the SSA region over the period 2000–2015 (see also Supplementary Fig. 2b). In this scenario, the emission growth that can be attributed to changes in carbon intensity would actually slow down during the period 2015–2025, with oil and natural gas as the major driving forces, which are almost entirely counterbalanced by the low-carbon energy supply. In contrast, the carbonization of the energy system would rapidly increase and positive effects of low-carbon energy additions would be dwarfed if we assume that all planned coal plants (pre-construction and shelved) will successfully

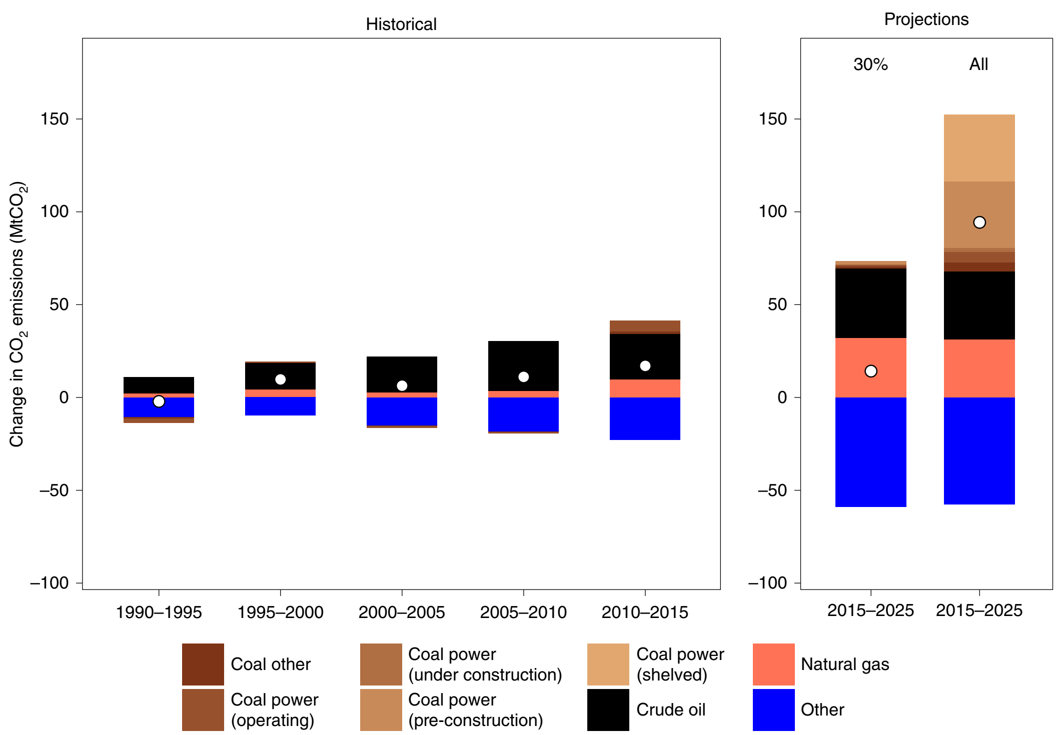

Fig. 3 | Historical (1995–2015) and projected (2015–2025) short-term effects of changes in the carbon intensity on absolute emission growth. The effect is decomposed into different energy carriers, and the projections are computed for two scenarios. See text for definitions of the scenarios. White dots correspond to the total change in CO_2 emissions that can be attributed to changes in the overall carbon intensity.

come online by 2025. If they operate with their historical load factor of 48% (scenario All; for further assumptions, see Methods and Supplementary Information), coal-fired power plants in the pipeline (assuming they were all built) would lock in approximately an additional 118 $MtCO_2$ that would be emitted year after year in SSA. Although this amount is relatively small in absolute numbers, this needs to be seen in terms of the entire energy-industry emissions in SSA, which were 245 $MtCO_2$ in 2015. The 30% scenario not only features lower emissions, but also corresponds to a lower level of electricity production, which could raise concerns related to electricity access and industrial development.

Comparison with model scenarios. To understand and interpret the observed carbonization patterns, we compared our results with previous modelling efforts on future emissions. Riahi et al.[17] developed scenarios on SSPs based on various narratives for future socioeconomic development with different energy, land-use and GHG emission implications[23–28]; their scenarios therefore include various complex challenges for climate change mitigation. For example, SSP1 uses a baseline where resource efficiency is already very high and countries develop fast, while SSP5 projects high rates of economic growth achieved with resource- and fossil fuel-intensive development, which would be challenging for climate mitigation. Using the SSPs allows us to abstract from the assumptions of one single scenario, while covering a wide range of possible future developments. SSPs depict how emissions can be expected to develop without policy intervention, and what changes would need to occur for successful climate change mitigation. To gauge to what extent the developments projected for SSA in the previous section approximate SSP baseline (Ref) or climate stabilization (2.6 and 3.4) scenarios, we also applied our decomposition of carbon-intensity changes to the SSP scenarios (Fig. 4).

Whereas in the SSP baseline scenarios, which assume no additional policies, continued carbonization is mainly due to an increasing share of coal, most stabilization scenarios exhibit declining carbon intensity driven by a decreasing share of coal and increased use of low-carbon energy sources. Even those stabilization scenarios that feature continued carbonization have a lower share of coal than the baseline scenarios.

Comparing the results of this study with the SSP results, we find that our upper-bound estimates (All) are closely aligned with the projections of the reference scenarios (except the extreme case of SSP5) with regard to the changes in emissions that can be attributed to changes in carbon intensity resulting from additional coal use. Our lower-bound estimates (30%) come close to, and in some cases even fall below, stabilization scenarios. That is, to achieve the rate of carbonization in the SSP stabilization scenarios, it is not necessary to shelve all the power plants that are currently in the pipeline in SSA, as long as the completion rate and capacity factors are sufficiently constricted.

Discussion and conclusion

The current trend towards carbonization in SSA is largely ignored in international climate negotiations. Although the absolute levels are still relatively low and the growth of CO_2 emissions in the past few decades has mainly been driven by the increased use of oil, investment dynamics in the energy sector hint towards an increasing role for carbon-intensive coal and hence accelerated emission growth in the future. The Chinese example should remind us that economic growth and carbonization are tightly interwoven and can materialize relatively quickly. For example, in 1990 the poverty headcount rate at the US$1.25 level in mainland China was higher than in SSA (ref. [29]); in only 20 years China managed to lift hundreds of millions of people out of poverty, while its coal-based carbonization has been

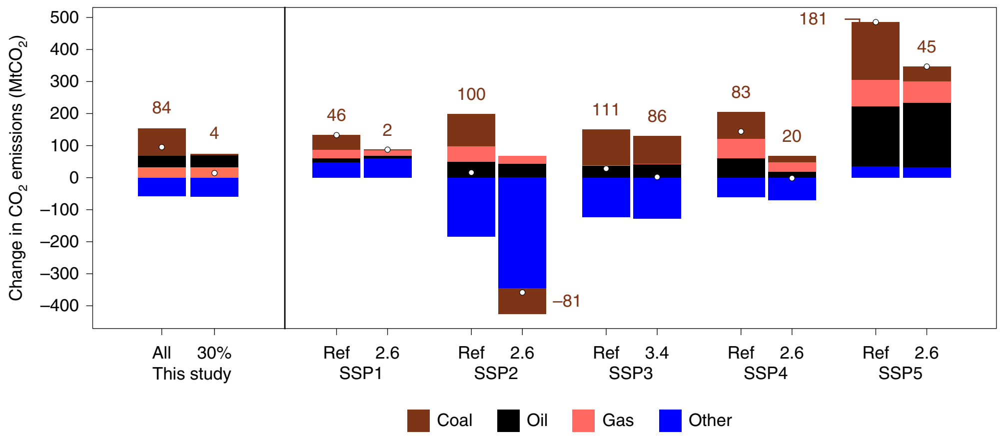

Fig. 4 | Kaya decomposition of projected carbon intensity in 2015–2025 in the SSA region under various socio-economic and climate policy assumptions. The baseline scenario without climate policy is labelled Ref; 2.6 and 3.4 denote climate policy scenarios that keep radiative forcing in 2100 below 2.6 W m^{-2} and 3.4 W m^{-2}, respectively (see the Supplementary Information for details). The brown numbers show the changes in emissions that can be attributed to changes in carbon intensity resulting from increasing or decreasing coal use. White dots show changes in aggregated emissions.

unprecedented. With growing incomes, African countries will see a lot of pressure to provide cheap and reliable energy sources. In the past decade, poor but fast-growing countries have predominantly invested in coal-fired capacity because coal is cheaper than other forms of energy[2,4]. Our analysis suggests that Africa is no exception to this pattern. Without dedicated policies, African countries seem likely to undergo a sharp increase in coal consumption and GHG emissions.

At present, climate change mitigation measures in the energy sector are not necessarily a priority for African governments. The National Determined Commitments (NDCs) that countries submitted to the UNFCCC (see Supplementary Table 5 for a more detailed list of planned mitigation actions in the energy sector following the NDCs) indicate that countries in SSA put forward their development needs in the energy sector. While most countries envisage building additional large hydro and/or renewable energy capacity, they remain generally silent (with some exceptions, such as Namibia) on how the overall energy mix shall look like in the future. No country, however, explicitly envisages an energy mix free of fossil fuels. Whereas one country, Malawi, makes explicit reference to planned coal capacity needed to cover the energy demand, the others more generally rely on thermal capacity to meet their future energy supply. Most countries do not publish specific plans for policy instruments to slow down carbonization. If they do, announcements remain relatively vague. For example, Nigeria has announced a "fiscal reform" to provide mitigation and budgetary benefits, without describing explicitly what such a reform should look like (see Supplementary Information).

The planned expansion of renewable energy use that is about to occur in SSA in parallel with increasing coal consumption suggests that there are viable alternatives to carbon-intensive energy technologies based on fossil fuels. The international community needs to find practical ways to make such substitutes for coal attractive to countries in SSA, while at the same time ensuring that efforts to reduce poverty and improve human well-being can be sustained. The United Nations' Sustainable Development Goals could serve as a frame of reference for pro-poor sustainability energy policy[30]. To design policies that set the scene for a clean energy future, it is important to keep in mind that SSA constitutes a set of very heterogeneous countries with large differences regarding potentials for renewable energy generation, fossil fuel endowments, and legal and political systems. Proposed solutions, such as targeting international climate finance to facilitate access to modern technologies, will be effective only if they take into account such country-specific challenges and opportunities.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-019-0649-8.

Received: 20 August 2018; Accepted: 5 November 2019;
Published online: 09 December 2019

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Methods

Kaya decomposition. We decomposed CO_2 emissions in SSA along the Kaya factors p, a, e and k. Using the Laspeyres index method[31], changes in emissions over time can be decomposed into contributions from changes in each of these four factors. Note that the literature on index decomposition analyses usually recommends using logarithmic mean divisia index decomposition[32]. In our case, both methods hold identical results for the decomposition of Kaya factors as the residuals are sufficiently small. We still used Laspeyres because it can be used to further decompose carbon intensity.

We also applied an extended decomposition of carbon intensity following Steckel et al.[33]. This method decomposes k into the effects of changes in the energy system (that is, changing shares of natural gas, coal, oil, renewables, and so on in the primary energy supply). In this decomposition, an increasing share of an energy carrier with a carbon intensity above (below) average leads to a positive (negative) contribution to economy-wide k and hence total emissions. We further enhance the Kaya decomposition in the period 2015–2025 by splitting coal into five categories that correspond to the status of power plant projects (that is, operational, permitted, pre-permitted, announced and shelved) as reported by Shearer et al.[22].

Following Kaya[18], we express carbon emissions (F) as a product of the underlying factors GDP (G), primary energy (E) and p:

$$F = p\left(\frac{G}{p}\right)\left(\frac{E}{G}\right)\left(\frac{F}{E}\right) = p\,a\,e\,k \tag{1}$$

The right side refers to the relative variables $a=G/p$, $e=E/G$ and $k=F/E$. Using the Laspeyres index method[31], a change over time in emissions (ΔF) can be expressed as the joint contribution of the four underlying effects (indicated by f):

$$F(t+\Delta t) - F(t) = \Delta F = p_f + a_f + e_f + k_f \tag{2}$$

where each effect can be derived from multiplication, as done here, for example, for the contribution of a change in population to changes in emissions, labelled p_f:

$$\begin{aligned} p_f &= \Delta p a_t e_t k_t \\ &+\tfrac{1}{2}(\Delta p)[(\Delta a)e_t k_t + a_t(\Delta e)k_t + a_t e_t(\Delta k)] \\ &+\tfrac{1}{3}(\Delta p)[(\Delta a)(\Delta e)k_t + (\Delta a)e_t(\Delta k) + a_t(\Delta e)(\Delta k)] \\ &+\tfrac{1}{4}(\Delta p)(\Delta a)(\Delta e)(\Delta k) \end{aligned} \tag{3}$$

The first part of equation (3) ($\Delta p a_t e_t k_t$) can be interpreted as the partial effect of the population component on the change in CO_2 emissions between time step t' and the preceding step t. The following parts capture the interactions between the remaining variables and form the residual term.

We further decomposed k into the effects of changes in the energy system. Carbon intensity $k_{t'}$ at time t' can be expressed relative to a preceding time step t as

$$k_{t'} = k_t\frac{E_t}{E_{t'}} + \sum\nolimits_j \left(\frac{k_{jt'}E_{jt'} - k_{jt}E_{jt}}{E_{t'}}\right) \tag{4}$$

where j indexes the different energy carriers (for example, natural gas and coal), and k_{jt} represents the specific carbon intensity of energy carrier j at time t, which supplies carrier-specific energy E_{jt}. Note that while changing specific carbon intensity over time might be confusing at first sight, the composition of energy carriers, such as coal, changes over time, as, for example, lignite is replaced by hard coal or vice versa. Given that by definition we have

$$E_t = E_{t'} - \sum\nolimits_j (\Delta E_j) \tag{5}$$

where ΔE_j denotes the change between t and t' in energy supply E_j, one can write

$$k_{t'} = k_t\frac{E_{t'} - \sum(\Delta E_j)}{E_{t'}} + \sum\nolimits_j \left(\frac{k_{jt'}E_{jt'} - k_{jtE_{jt'}}}{E_{t'}}\right) \tag{6}$$

The first part of the expression can be interpreted as the energy carrier's changing contribution to the overall energy mix, while the second term of the expression indicates the change of the energy carrier's specific carbon intensity. This can be reformulated to express Δk between t and t' as a sum over the contributions from all energy carriers:

$$\Delta k = \frac{1}{E_{t'}}\sum\nolimits_j \left(k_{jt'}E_{jt'} - k_{jt}E - \Delta E_j k_t\right) \tag{7}$$

So far, Δk only captures the partial effect. In a complete (Laspeyres) decomposition, all residuals are taken into account, implying that the effect of k_f can be written as $k_f = \Delta k \cdot R$, where R represents the residual (compare also equation (3)). R can then be written as

$$\begin{aligned} R &= (p_t a_t e_t) + \tfrac{1}{2}(\Delta p a_t e_t + \Delta a p_t e_t + \Delta e p_t a_t) \\ &+\tfrac{1}{3}(\Delta p \Delta a e_t + \Delta p \Delta e a_t + \Delta e \Delta a p_t) + \tfrac{1}{4}\Delta p \Delta a \Delta e \end{aligned} \tag{8}$$

To adapt the decomposition of carbon intensity (that is, the effect k_f of carbon intensity on the change of emissions), we need to multiply Δk (equation 7) by R on both sides. This allows us to directly observe the influence of specific changes in the energy mix on emissions.

Projected data. The projected data for 2025 result from combining three data sources by the IEA[15], Platts[16] and Shearer et al., with a set of assumptions. A summary diagram of the methodology used to compute the Kaya factors is provided in Supplementary Fig. 1. For instance, GDP and population data over 2005–2015 were taken from the IEA[15] and were linearly extrapolated to 2025.

Primary energy production in the period 2015–2025 was estimated separately for power plant capacities and other activities. Current and planned power plant capacities were taken from Shearer et al.[22] for coal and from Platts[16] for other energy types (for example, oil, gas, nuclear, hydro, geothermal, solar and wind, biomass and waste). Capacities planned for retirement between 2015 and 2025 were removed. Supplementary Fig. 2 shows the current and planned capacities by energy type and status (that is, operating, in construction, pre-construction and shelved). The large numbers of hydro, natural gas and coal power plant projects can be seen. Regarding the categories of plant statuses, we adopted the classification of Shearer et al.[22]. The plant statuses in Platts were modified to match those of Shearer et al. Planned power plants were set to pre-construction, while delayed, deferred and unknown types were set to shelved (see Supplementary Table 3). The efficiency and load factors (that is, utilization rates) of power plants can vary significantly across power plants. In this analysis, we assumed average efficiency and load factors for each energy type (Supplementary Table 4). The efficiency factors were taken from Wirth[34] while load factors stemmed from dividing electricity production[15] by the theoretical maximum electricity production estimated from nameplate capacities[16].

The primary energy production required by other activities (for example, activities in the transportation, buildings and industry sectors) was linearly extrapolated using information from the period 2000–2015 (Supplementary Fig. 4 and Supplementary Table 2; note that for some variables, the starting point can be later if a trend starts later (for example, PE other starts in 2010)). This assumption appears realistic considering the relative stability of past dynamics and the short time frame considered in this analysis.

The associated CO_2 emissions were estimated using carbon intensities from the previous periods for all fossil fuels. More specifically, the carbon intensities of coal, oil and gas power plants are about 950, 850 and 400 g CO_2 kWh^{-1}, respectively. These were computed using IEA data[15] and were relatively constant between 2000 and 2015. They are in good agreement with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[35]. In other words, CO_2 emissions in 2025 are calculated using the projected energy consumption in the power sector and other sectors multiplied by the relevant CO_2 emission factors.

On the basis of these data and assumptions, we generated two polar scenarios: 30% and All. In 30%, we assumed that only 30% of the pre-construction coal power plant projects will be successful while all shelved projects will not. This assumption reflects historical rates as indicated in Shearer et al.[22] (Africa and the Middle East: 27%, World: 34%; see Table 2 in the report). We also considered all coal power plants to run at 30% of their capacities, which is also in line with historical data (Supplementary Fig. 3). In All, we assumed that all planned coal plants (pre-construction and shelved) will successfully come online by 2025 and that all coal plants have a load factor of 48% (Supplementary Fig. 3). In both scenarios we also assumed that all coal power plants existing in the previous period are still operating and that all plants in construction will be fully operating in 2025. The assumptions underlying these two scenarios cover a broad range of highly disputed values. The future will probably lie somewhere between the two scenarios. We emphasize, however, that our results indicate an influence on short-term emission growth in general; that is, they do not necessarily depend on the year 2025 specifically but rather sometime around this year.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The data used in this study are not publically available (except Shearer et al.[22] and Wirth[34]). Data on emissions and energy are available from the IEA[15], and data on power plants are available from Platts[16], but fees and restrictions apply to the availability of both databases that we used under license for the current study. Data are available from the authors on reasonable request and with permission of the IEA and Platts, respectively. Data on SSP scenarios rely on peer reviewed publications and are available from the respective modelling teams[23–28].

Code availability

All code and figures and their underlying data are available at https://github.com/jhilaire/ssawosacarb.git

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Acknowledgements

The authors acknowledge funding from the German Federal Ministry of Education and Research (BMBF), funding code 011A1807A (DECADE). We also thank K. Calvin (PNNL), N. Bauer (PIK), D. van Vuuren and M. Hamsen (PBL), S. Fujimori (NIES) and O. Fricko (IIASA) for sharing IAM data with us. We thank L. Montrone and L. M. Puerto Chaves for excellent research assistance.

Author contributions

All authors conceived and planned the project. J.C.S., J.H. and M.J. analysed the data. J.H., J.C.S. and M.J. designed the simulations. J.H. and J.C.S. developed the code and ran the simulations. J.C.S, M.J. and J.H. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41558-019-0649-8.

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Peer review information *Nature Climate Change* thanks Fadiel Ahjum, Heli Arminen, Paul Lucas and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Last updated by author(s): Oct 16, 2019

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Software and code

Policy information about availability of computer code

Data collection	We used the "Professional Browser" provided by IEA to extract data from the "World Energy Balances 2017" and "CO2 emissions from Fuel Combustion 2017" databases.
Data analysis	We developed R scripts to analyse the data. All scripts are publicly available on GitHub: https://github.com/jhilaire/ssawosacarb.git

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• Bauer et al (2017) Shared Socio-Economic Pathways of the Energy Sector – Quantifying the Narratives. Global Environmental Change, 42, pp 316-330. doi.org/10.1016/j.gloenvcha.2016.07.006
• Calvin et al (2017) The SSP4: A world of deepening inequality. Global Environmental Change, 42, pp 284-296. doi.org/10.1016/j.gloenvcha.2016.06.010
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All code and figures and their underlying data are available at https://github.com/jhilaire/ssawosacarb.git

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Study description	We perform a data decomposition analysis of carbonization patterns in Sub-Saharan Africa (without South Africa) using Kaya decomposition methods. We also generate near-term projections until 2025 and compare them to recent scenario data (Shared Socio-economic Pathways) from the IAM community.
Research sample	N/A
Sampling strategy	N/A
Data collection	We gathered data on CO2 emissions by fossil fuel, primary energy consumption by energy carrier, GDP and population for each Sub-Saharan African country from 1970 until 2015 (IEA 2017), current data on operating and planned power plant capacities (PLATTS 2017, Shearer et la 2018) for all Sub-Saharan African countries. We collected data for SSP scenarios from the respective modeling teams when not publically available.
Timing and spatial scale	Sub-Saharan Africa without South Africa
Data exclusions	No data were excluded
Reproducibility	N/A
Randomization	N/A
Blinding	N/A

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