

Future low-carbon electricity in Africa: how much material is needed?

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Short Report

Keywords: material emissions, sep material demand, sep embodied emissions, electricity generation technologies, developing countries, African electricity system, MAT-dp

Posted Date: December 10th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1160025/v1>

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Future low-carbon electricity in Africa: how much material is needed?

Karla Cervantes Barron*¹, Maaïke E Hakker¹, and Jonathan M Cullen¹

Key Messages

- African countries are expected to experience some of the worst climate effects, while trying to provide higher electricity access and increase wellbeing.
- Concrete, steel, and aluminium present the largest opportunities for action, given their high mass or embodied emissions projections.
- Embodied emissions related to material use for electricity plants are evaluated in three scenarios: a reference scenario, and two scenarios related to the Paris Agreement (where renewable energy increases), resulting in higher embodied emissions as renewables are integrated.
- Pursuing strategies to increase the use of renewables should be done along material efficiency strategies to reach the total low-carbon potential.

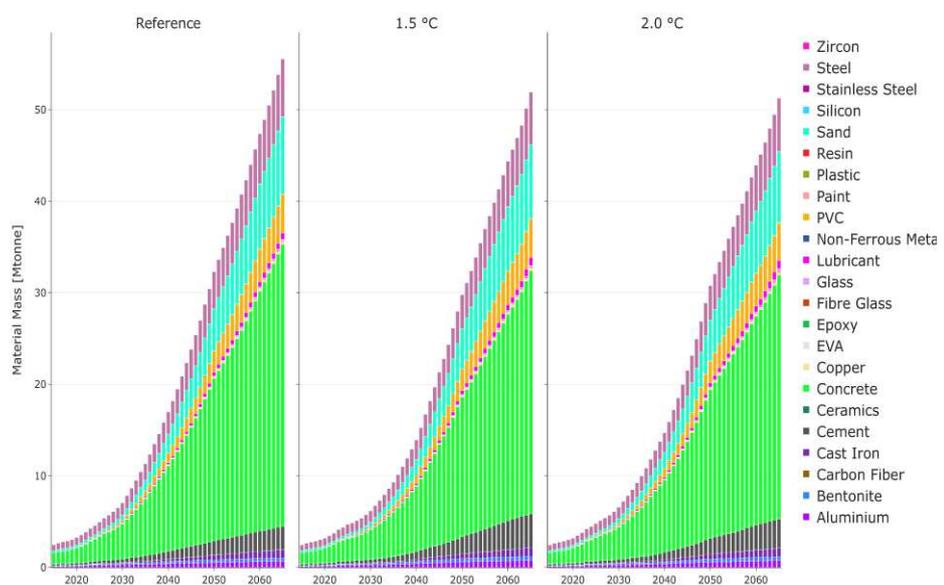


Figure 1 (above) presents materials used to build electricity generation systems in Africa based on scenarios explored in this brief. Large quantities of materials will be needed to build the proposed electricity systems that contribute to increasing wellbeing. However, unless low-carbon technologies are used and material efficiency is considered, the total low-carbon potential will not be reached, worsening the effects of climate change.

Introduction

Deploying low-carbon electricity systems in developing countries is critical for meeting climate targets while increasing wellbeing. Yet, energy-related emissions contribute 73% to global emissions [1]¹. To reduce emissions, electricity planning focuses on low-carbon generation. However, the materials required to build such technologies are frequently overlooked.

Addressing the full lifecycle of systems strengthens climate mitigation strategies. This requires balanc-

ing the upfront investment of emissions required for building electricity systems—called embodied emissions—against the reductions in direct emissions to ascertain how quickly overall emissions can be reduced.

In Africa, the total electricity demand was 613 TWh in 2015 and is projected to increase nine times (5,331 TWh) by 2065 [2]. Then, the total installed capacity projections increase from 183 GW in 2015 to 1,835 GW in 2065. Such increase requires low-

¹ Out of the total of 50 Gt CO₂-eq.

carbon technologies to avoid the worsening of the expected climate effects, considering that seven African countries are already in the top ten most vulnerable countries [3].

In response, this policy brief addresses the question 'what are the material implications for delivering future electricity systems in African countries?'. This question is answered by quantifying the materials needed for building electricity systems in 47 African countries. A purpose-built model, called MAT-dp (Material Demand Projections) is used to assess three scenarios, including business as usual and two scenarios of low-carbon technology options. MAT-dp integrates projected technology deployment from the scenarios with life-cycle analysis tools to produce material budgets and embodied emissions accounts.

Electricity generation considerations and material demand

Low-carbon generation considerations

Building electricity generation has consequences for resource use, the resulting emissions, and grid infra-structure. Globally, fuel-intensive fossil-based electricity systems have been replaced by material-intensive renewable technologies (e.g., using copper for solar photovoltaic (PV) systems and iron for wind power), leading to an increased material demand [4, 5]. Increasing renewable generation also requires electricity storage and grid expansion to guarantee reliable and affordable supply [4]. Further, every kWh of electricity produced using renewable sources requires 0.1–0.25 kWh of non-renewable sources [5]. Fortunately, considering lifecycle implications and comparing renewables with fossil-fuel systems, deploying low-carbon generation can lead to lower overall emissions, lower pollution and higher electricity supply [5]. However, every kWh of electricity produced using renewable sources requires 0.1–0.25 kWh of non-renewable sources [5]. The shift to renewable energy should then reduce material use and non-renewable source dependency.

MAT-dp

MAT-dp uses electricity generation scenarios to calculate material implications of proposed systems divided by type of materials. The resulting embodied emissions depend on the material emissions intensity (shown in **Table 1**) and the mass of

materials used (from the standardized material requirements per technology in Mat-dp).

Table 1 Embodied emissions intensity of different materials. The material footprints were taken from [6] and [7], except for those materials that reference another source.

| Material | CO ₂ footprint [kg CO ₂ /kg material] |
|-------------------|---|
| Aluminium | 12.58 |
| Bentonite [8] | 0.03 |
| Carbon Fibre | 20.30 |
| Cast Iron | 2.20 |
| Cement | 0.87 |
| Ceramics | 1.55 |
| Concrete | 0.10 |
| Copper | 3.63 |
| Epoxy | 7.19 |
| EVA | 2.11 |
| Fibre Glass | 3.00 |
| Glass | 0.79 |
| Lubricant [9] | 1.07 |
| Non-Ferrous Metal | 8.63 |
| Paint [10] | 2.42 |
| Plastic | 2.72 |
| PVC | 2.50 |
| Resin | 3.63 |
| Sand | 0.02 |
| Silicon | 5.34 |
| Steel | 2.46 |
| Stainless Steel | 5.67 |
| Lead | 1.86 |
| Zircon | 0.92 |

Material implications of electricity generation scenarios in Africa

African electricity generation scenarios

Electricity generation scenarios used include 47 African countries between 2015 and 2065 [2]. The scenarios were created considering energy demand and optimising costs. There are three scenarios: the Reference scenario, which considers national

energy policies in place until 2017, and the 1.5°C and 2.0°C scenarios based on the Paris Agreement.

The aggregated capacity in all scenarios is projected to increase. The Reference scenario considers coal and other fossil-fuel generation to be deployed, while the 1.5 and 2.0°C scenarios project a decrease of coal generation by increasing the capacity of nuclear, renewables, biomass, and some fossil fuels with Carbon Capture and Storage. In the 2.0°C scenario, nuclear power ramps up between 2050 and 2065, while in the 1.5°C scenario nuclear power surpasses renewable generation between 2060 and 2065.

Materials for electricity generation scenarios

Figure 1 shows the required mass of each material by scenario. Generally, the 10-fold power generation capacity increase results in a 21-fold material mass increase. In each scenario, concrete accounts for the highest material mass, tripling in the Reference scenario between 2040-2065. The total mass of concrete in the other two scenarios is 5Mt lower than for the Reference scenario. Specialised material requirements in the Paris Agreement scenarios are the highest, e.g., bentonite, fibre glass or resin require an order of magnitude more materials than in the reference scenario.

Apart from the MAT-dp material projections, transmission and distribution materials require a high mass of aluminium for substations and steel for transformers, while these materials are also required for electricity storage [4].

“ Strategies to increase material production and building efficiency in Africa should be created [...] to further reduce total emissions.

Figure 2 shows the total embodied emissions for each scenario and material. Steel has the highest embodied emissions, being highest in the Paris Agreement scenarios. Aluminium has the second-largest embodied emissions, with similar emissions in all scenarios. The highest embodied emissions by 2065 are in the 2.0°C scenario reaching 47 Mt CO₂ (related to steel and stainless steel) and the lowest are in the Reference scenario reaching 44 Mt CO₂. The higher embodied emissions in the Paris Agreement scenarios show that renewable electricity additions lead to higher material emissions. Thus, a joined-up strategy is needed where renewable additions are done alongside embodied emission reductions and industrial capacity increases.

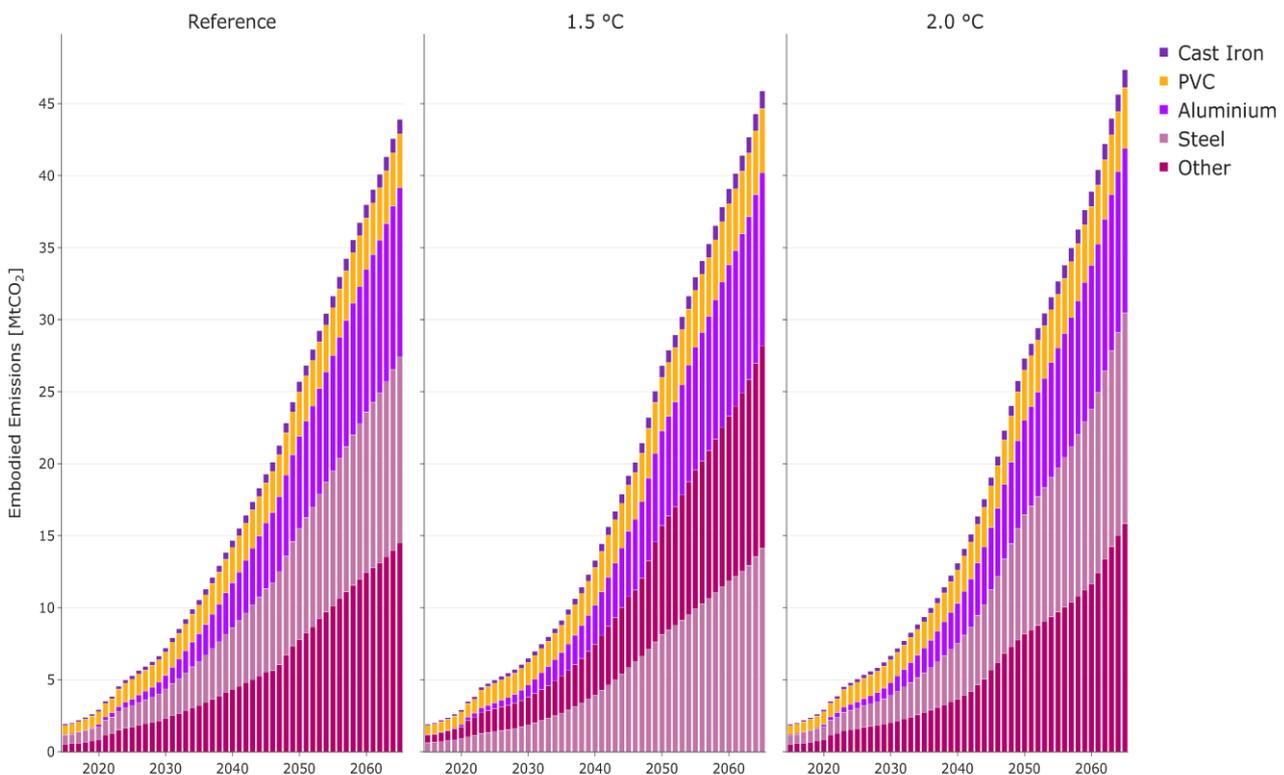


Figure 2: Total embodied emission by material (ordered according to emissions) for different electricity generation scenarios in Africa between 2015 and 2065. PVC means polyvinyl chloride.

The total African emissions were 1,185 MtCO₂ in 2017, i.e. 4% of global emissions [11]. Then, cumulative embodied emissions for electricity account for less than 5% of the total 2017 emissions. Although this fraction is low, considering material provision has strategic importance since material production and use influences systems beyond electricity generation.

Figure 3 shows the total embodied emissions divided by regional power pool. The total embodied emissions in each scenario are similar by 2065. The Reference scenario presents a more linear increase

compared to the others. Most regions are expected to reach similar embodied emissions in the 2.0°C scenario by 2065, bar Central Africa, whose emissions increase at a lower rate. In each region, a handful of countries are responsible for over 50% of electricity demand and embodied emissions, having the highest increases. The Western African demand and embodied emissions are driven by Nigeria; in the East, they are driven by Egypt, Ethiopia, Sudan, Tanzania and Kenya; in the South by South Africa; and in the Central by the Democratic Republic of Congo.

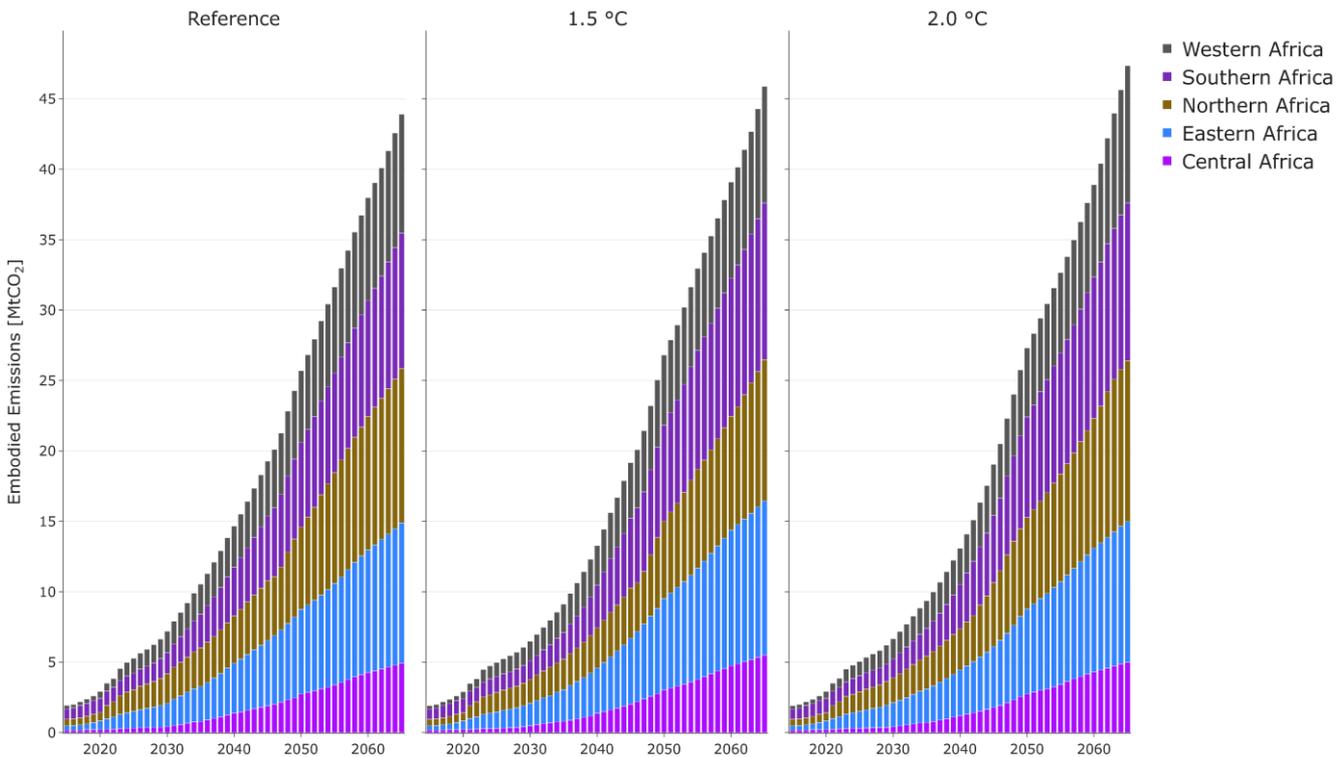


Figure 3: Embodied emissions for different electricity generation scenarios and regions in Africa between 2015 and 2065.

Implications for African countries

Reaching a global carbon-neutral system by 2060 requires rapid deployment of clean energy technologies [12], avoiding locking in high-carbon systems. Africa has high carbon lock-in risks [13], unless rapid decarbonization occurs.

Embodied emissions are projected to grow most in Nigeria, South Africa, Egypt, Ethiopia, the Democratic Republic of Congo, Sudan, and Mozambique. Of these countries, Nigeria is on the list of the ten most-threatened countries by climate

change, along with six other African countries² [3]. Further, six countries accounted for 80% of the total direct emissions in Africa in 2017³ [11]. Thus, emission reduction strategies that include material efficiency to benefit the most vulnerable countries need to be considered.

Conclusions and Recommendations

² Central African Republic, Chad, Eritrea, Ethiopia, Sierra Leone, and South Sudan

³ South Africa, Egypt, Algeria, Nigeria, Morocco, and Libya.

- Introduce material efficiency techniques for concrete, steel, and aluminium, as these three materials are projected to have the highest mass or embodied emissions by 2065.
- Creating material pools that trade key materials, encouraging efficient manufacturing, managing scrap material, and considering material lifecycles in design stages are possible material efficiency strategies in electricity generation.
- Promote the use of low-carbon materials, designs that optimize emission reductions,

and material production efficiency so material efficiency strategies can spill over to the buildings, transport, and industrial sectors.

- Investigate the potential embodied emission savings by evaluating regional material producers and suppliers.
- Material efficiency is estimated to contribute 30% of the combined emissions reduction for concrete, steel, and aluminium globally in 2060 [14], highlighting similar opportunities for Africa.

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Notes

Climate Compatible Growth (CCG) programme:

CCG is funded by the UK's Foreign Development and Commonwealth Office (FCDO) to support investment in sustainable energy and transport systems to meet development priorities in the Global South.

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Credit author statement: Karla Cervantes Barron: Conceptualization, Methodology, Software, Data Curation, Writing – Original Draft, Visualization. Maaïke E. Hakker: Conceptualization, Methodology, Data Curation, Writing – Review & Editing. Jonathan M. Cullen: Conceptualization, Writing – Review & Editing, Supervision.

Figures

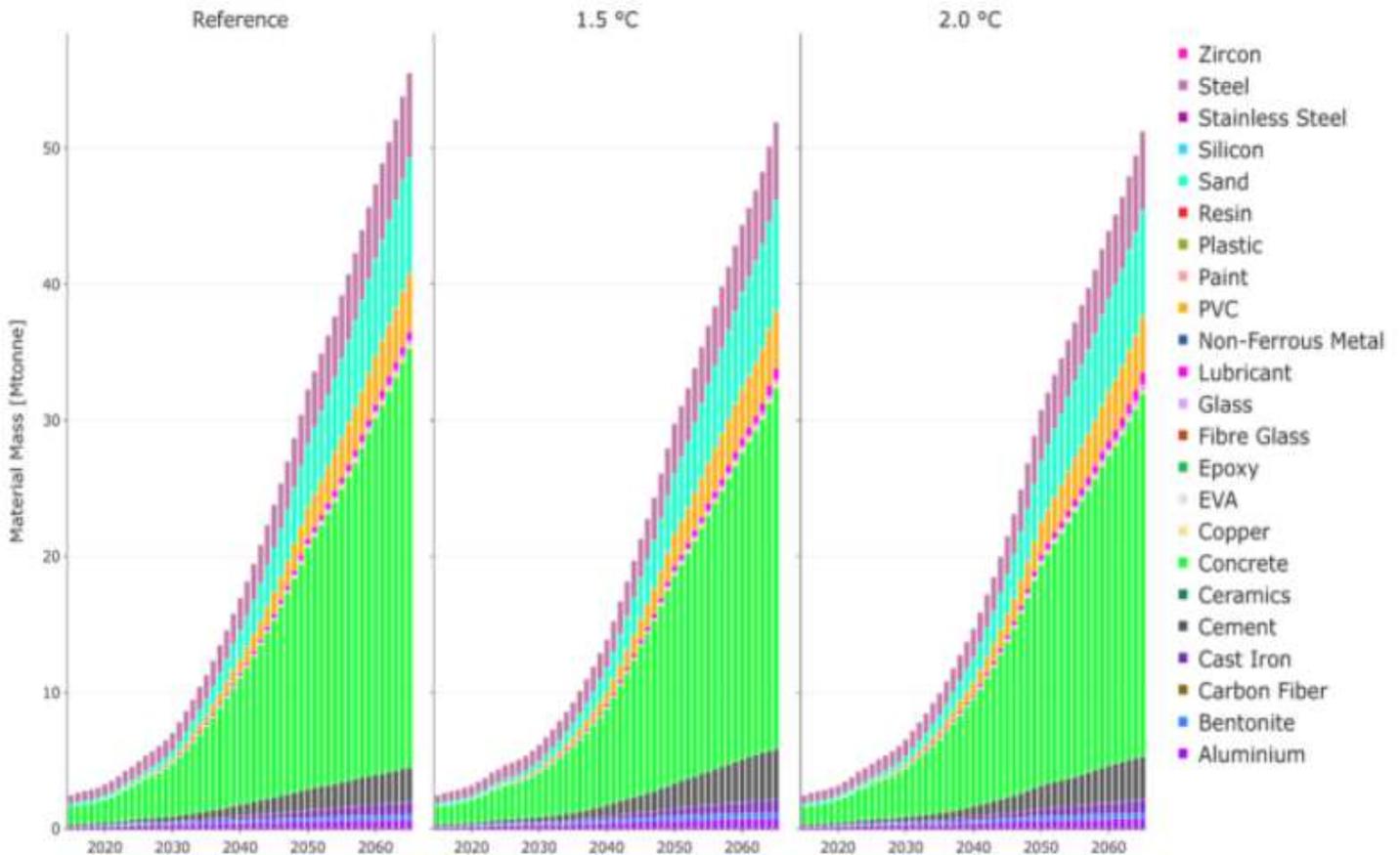


Figure 1

Materials used to build electricity generation systems for different electricity generation scenarios in Africa between 2015 and 2065. Large quantities of materials will be needed to build the proposed electricity systems that contribute to increasing wellbeing. However, unless low-carbon technologies are used and material efficiency is considered, the total low-carbon potential will not be reached, worsening the effects of climate change.

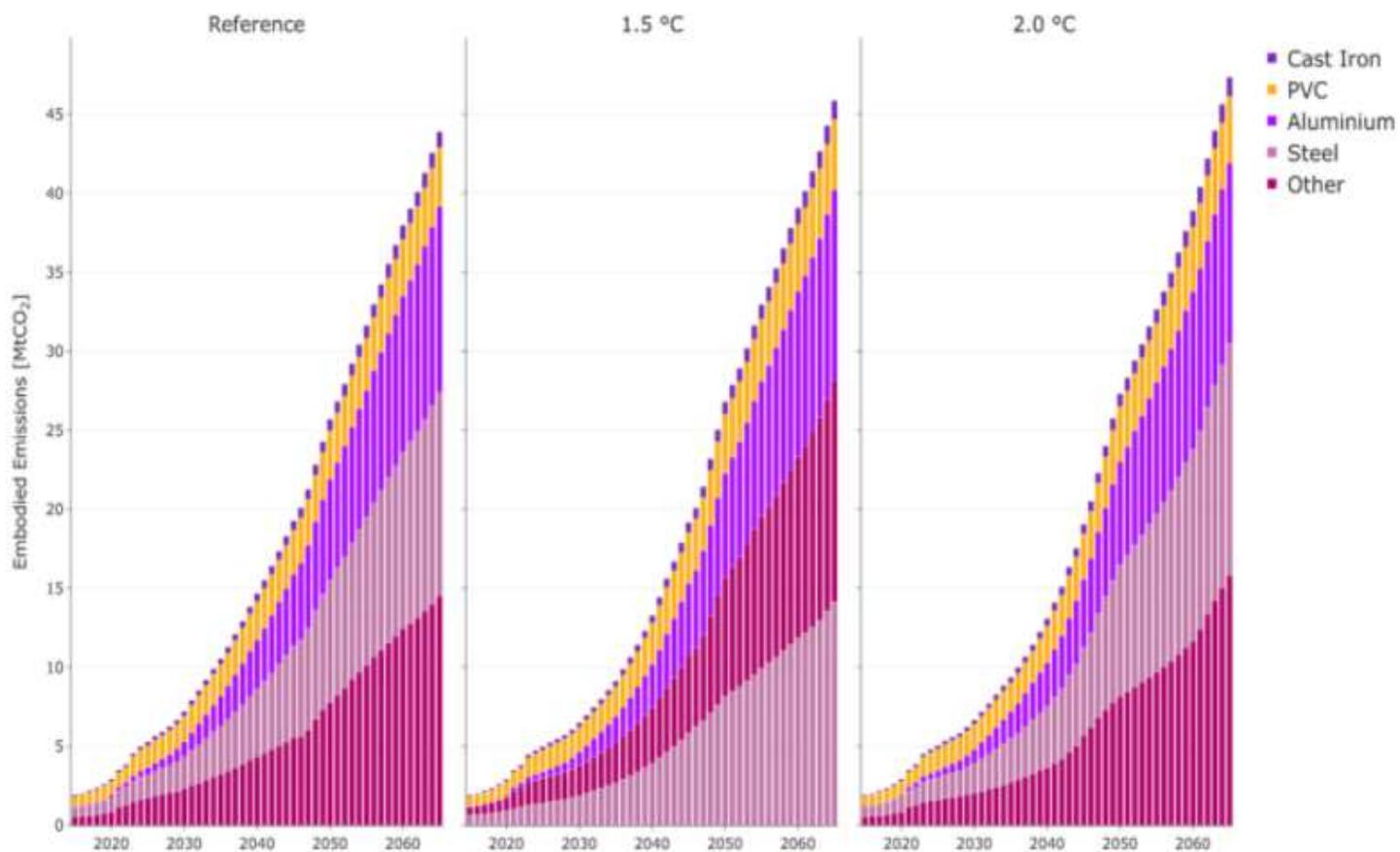


Figure 2

Total embodied emission by material (ordered according to emissions) for different electricity generation scenarios in Africa between 2015 and 2065. PVC means polyvinyl chloride.

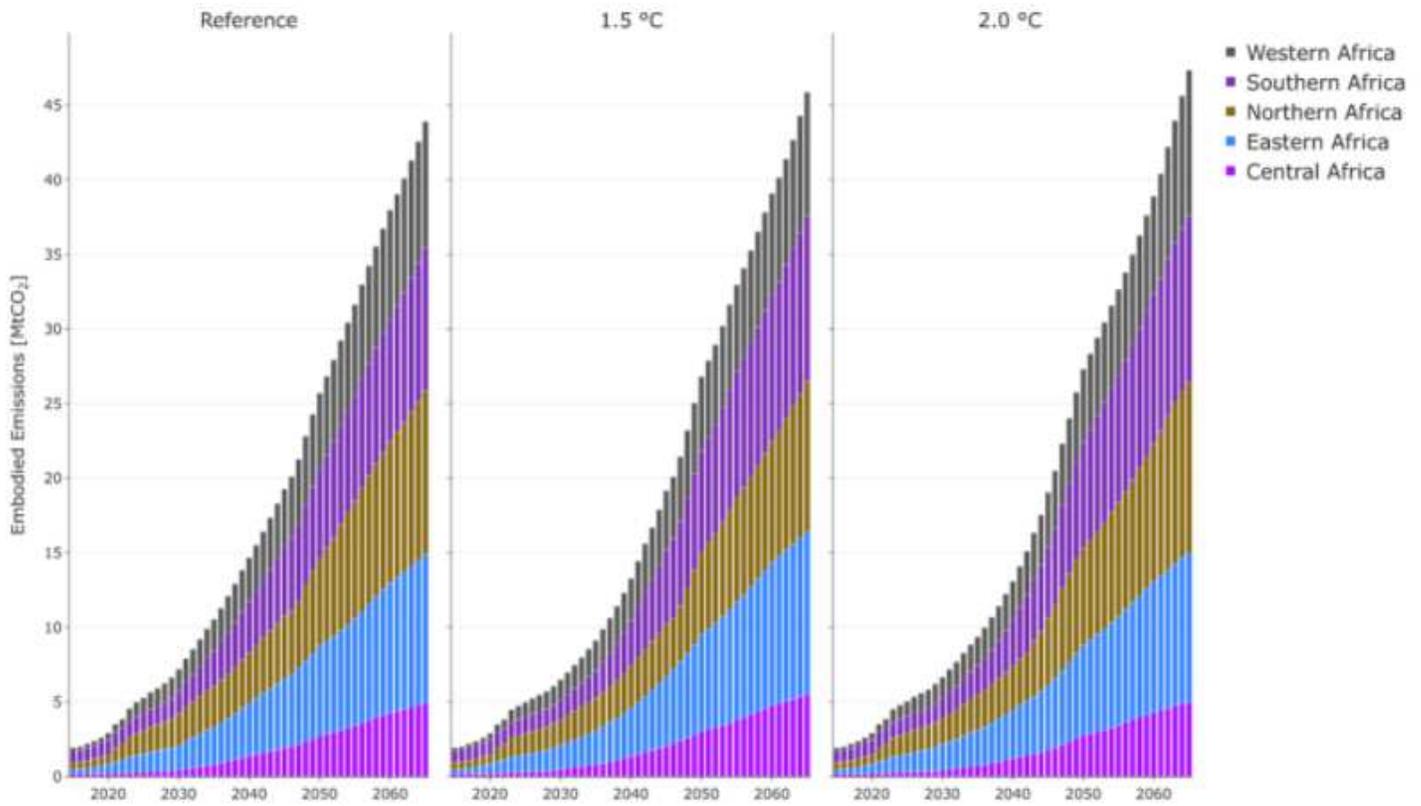


Figure 3

Embodied emissions for different electricity generation scenarios and regions in Africa between 2015 and 2065.