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Perspective

The need for agricultural productive uses in the national electrification plan of sub-Saharan African countries—a call to action for Ethiopia

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Abstract

Access to electricity is a crucial aspect of sub-Saharan Africa’s path towards development. In light of the potential for electricity access to improve quality of life, the United Nations aims to achieve universal access to ‘clean, reliable, affordable and modern’ electricity as Goal 7 of its Sustainable Development Goals (SDG 7). As such, governments of sub-Saharan African (SSA) countries, such as Ethiopia, have developed national electrification plans to outline their pathway to universal access to electricity. In this paper, we identify why it is essential for the national electrification plans of SSA countries to prioritize electricity access for productive uses in its agricultural sector, using Ethiopia as a case study. Reviewing existing literature and using the authors’ research, we point out that there is 3.04 terawatt-hours of latent demand for small-scale pressurized cereal-crop irrigation alone in Ethiopia. Supplying this electricity demand for small-scale irrigation could lead to a reduction in the levelized cost of electricity of up to 95%. We conclude our paper by recommending the creation of a cross-sector national productive use commission that would be tasked with collecting and sharing relevant data from each sector and collaboratively creating a national productive use program that would ensure that Ethiopia reaps the full benefits and potential for wealth creation from access to electricity.

1. Introduction—the energy gap

There is an energy gap in sub-Saharan Africa (SSA). While the sub-continent is home to 16% of the world’s population, it accounts for less than 3% of the world’s electricity demand (International Energy Agency 2019). The severity of this problem lies in the fact that access to electricity is strongly linked to development and economic growth (Kanagawa and Nakata 2008, Jones et al 2015, Latif 2015). Figure 1 illustrates the correlation between electricity consumption and the human development index (HDI). The HDI is a composite statistic that accounts for education, life expectancy, and the economy of different countries. Here, we see a logarithmic trend where countries with the highest HDI are those with relatively higher levels of electricity consumption (>4000 kWh/person), but there is a saturation effect indicating that there are not continuous returns to scale for increasing electricity consumption. While figure 1 is a correlation, not a causation, it provides a lot of the basis for the UN Sustainable Development Goal 7, to provide ‘access to affordable, reliable, sustainable and modern energy for all’ (United Nations 2015). Hence, if countries in SSA aim to attain self-reliance and stronger economies, their path towards universal electrification needs to be planned to provide each sector (i.e., residential and commercial) with adequate electricity supply (Falchetta et al 2020).

A majority of the electrification work in SSA has focused on electrifying the residential sector ([Ohiare 2015], (Ellman 2015), (Mentis et al 2016), (Azimoh et al 2016), (Afful-Dadzie et al 2017), (Moner-Girona et al 2019]), but to maximize the benefits of electrification, electricity planning in SSA needs to spur economic growth. There is an opportunity for electrification studies to focus on productive uses, such as agriculture, which are activities that can use electricity to generate income, increase productivity, and provide...
economic value. Studies show that an electrified agriculture sector would not only lead to drastic reduction in economic and food poverty, but it would also boost economic growth in SSA (Banerjee et al. 2017, Adela et al. 2019, Phiri et al. 2020). Electrifying the agricultural sector could include activities such as pumped irrigation, electrifying the grain processing, and other hand activities (e.g., peanut shelling). Given that most grid utilities and minigrid companies in SSA are struggling to recover their costs, the electricity load from productive uses could help them improve their profitability (Trimble et al. 2016, Williams et al. 2019, Borgstein et al. 2020). Further, research has shown that electrifying productive uses would increase employment and improve the quality of life in countries within the Global South (Terrapon-Pfaff et al. 2018). In lieu of these benefits of electrifying productive uses, we aim to (1) identify the lack of incorporation of productive uses in the creation of electrification plans in SSA, (2) elaborate on the economic potential of productive uses based on existing literature, (3) delineate barriers to maximizing the benefits of productive uses of energy, and (4) make the case for a national productive use program and how this program can address some of the barriers identified.

2. Case study: Ethiopia and its agricultural sector

With an electricity access rate of 44% and the largest producer of wheat in Africa, Ethiopia stands to benefit immensely from emphasizing agricultural productive uses in its path towards universal electricity access. Various studies have shown that a booming agriculture sector could impact developing countries like Ethiopia by increasing agricultural productivity, increasing exports and foreign exchange revenue, and decreasing food insecurity (Block 1999, Haile 2015, Adela et al. 2019, Phiri et al. 2020). Agriculture accounts for 40% of Ethiopia’s GDP and about 70% of its exports (USAID 2021, Borgstein et al. 2020). Furthermore, studies have shown that the agriculture sector has a growth multiplier greater than unity, which means that its impact on Ethiopia’s economic growth is statistically significant (Block 1999). In global development literature, there are five stages of development for a nation: traditional, preconditions for take-off, take-off, drive to maturity and high mass consumption (Rostow 1959). Most SSA countries, like Ethiopia, are in the second stage characterized by a growing agriculture sector, direct investment, enabling policy environments, and electrification in the sector would be crucial to the economic sustainability of these countries (Phiri et al. 2020). Hence, Ethiopia is laden with opportunities to accelerate its development by prioritizing the electrification of activities in agriculture. As such, we use Ethiopia and its agriculture sector as a case study in this paper.

3. Ethiopia’s national electrification plan

In 2017, Ethiopia’s Ministry of Water, Irrigation and Electricity (MoWIE) released its second version of Ethiopia’s national electrification plan (NEP 2.0, 2019). In NEP 2.0, MoWIE laid out the pathway towards
Since cereal crops are essential for the sustenance of Ethiopians, their cultivation takes up about 75 percent of Ethiopia’s farmland. Hence, their value chain, from irrigation to post-harvest processing, provides opportunities for productive uses of electricity. Data from Borgstein et al. (2020).

In its discussion of the agriculture-energy nexus, NEP 2.0 refers to the agriculture productivity targets set in the second Growth Transformation Plan (GTP II). The targets include almost doubling Ethiopia’s irrigable land by 2020, and providing alternative water sources for 80 percent of smallholder farmers. Additionally, NEP 2.0 points out that the collaboration between the World Bank and the Agricultural Transformation Agency (ATA) in the GTP II project would support efforts to identify commercialization clusters with the highest production potential of crops ‘for which Ethiopia has a comparative advantage’ (NEP 2.0, ATA 2019). Further on in the report, MoWIE emphasizes the need for mechanized irrigation (and its electrification) and discusses some of the benefits of the substitution of diesel-powered systems with solar-powered systems. While the mention of general short-term goals in the agriculture sector is a step in the right direction, the NEP 2.0 lacks a detailed, research-driven action plan regarding the electrification of productive uses in Ethiopia.

First, the NEP 2.0 does not highlight the potential for electrification in the value chain of cereal staples, such as maize and wheat. The Plan appears to emphasize the need to electrify only the irrigation of crops that are of higher global market value, such as coffee and other horticulture crops. In Figure 2 we highlight that despite their relatively low market value, cereals make up about 75 percent of cultivated land in Ethiopia (Borgstein et al. 2020).

Based on these data, it is evident that sustenance farming is the largest component of Ethiopia’s agriculture sector. These findings lead to the following question. If Ethiopia’s agriculture is dominated by sustenance farming, how can increased production from electrified smallholder irrigation be used to improve food security in the country? The dominance of cereal farming in Ethiopia necessitates the electrification of activities in the value chain of cereal crops. For example, research has shown that while Ethiopia is Africa’s largest producer of wheat, Zambia’s wheat farming productivity is more than twice that of Ethiopia’s (Santana et al 2021). Thus, there is a need for Ethiopia’s electrification policy to consider the electrified irrigation of cereal crops on smallholder farms as a productive use of energy. We acknowledge that there are larger scale productive use activities, such as consumer product manufacturing that, if electrified, can yield economic benefit. However,
due to the relative lack of infrastructure in rural parts of SSA countries (Falchetta 2021) and the prevalence of cereal crop cultivation identified, we choose to explore the electrification of productive use activities along the value chain of cereal crops.

Haile (2015) emphasized that improved irrigation techniques will be essential to addressing food security in Ethiopia. Research from Van-Hein Sackey et al (2021) (highlighted in figure 3) has shown that electrifying rural smallholder irrigation for maize and wheat in Ethiopia would result in up to an additional 3.04 terawatt-hour (TWh) of electricity demand (figures 3).
As a result of this additional demand, grid connection would be the least-cost means of meeting 95% of this irrigation demand (compared to electrification via standalone photovoltaic (PV) systems, solar, hydro and wind minigrids, and diesel minigrids). Consequently, such emphasis on grid connection would drive down the levelized cost of electricity by up to 95% in these rural agricultural clusters, which would help utilities with cost recovery (Van-Hein Sackey et al 2021). Regarding productivity, electrified pressurized irrigation of smallholder cereal farms in Ethiopia would almost double the yield of maize and wheat (Izar-Tenorio et al 2021). Assuming that the yield of cereal crops is directly proportional to their production, Ethiopia may be able to double its cereal production to address food insecurity in the nation.

Second, Ethiopia’s existing energy policy in NEP 2.0 only highlights the need to electrify agri-processing (i.e., post-harvest) activities without delving into the necessary steps that may be needed to electrify activities down the agriculture value chain, and the subsequent financial benefits. In their A2EI report, Avila et al (2019) model the economic feasibility of electrifying ten different post-harvest processes in Tanzania. Their study was able to identify that processes, such as maize shelling and rice hulling, had lower earning potential due to the lack of demand in the local areas surrounding these businesses. On the other hand, activities like coffee pulping and peanut shelling were found to have higher productive-use potential regardless of the population density of their locality. Specifically, with regards to Ethiopia, field research from Rocky Mountain Institute (RMI) provided a guide to the prioritization of electrifying productive uses further down the cereal crop value chain. According to their report, activities such as grain milling (i.e., processing of cereal crops) should be the first activities to be electrified as a result of the high existing local capacity for these activities and the high demand for the processed cereal throughout Ethiopia (Santana et al 2021).

4. Economic impact of productive uses of electricity

As stated previously, productive uses of electricity in Ethiopia’s agriculture sector can yield some economic benefits. In their study of post-harvest activities in Tanzania, a study found that electrifying these productive uses, specifically maize milling and maize shelling, could result in an annual profit of $21 per acre and $4 per acre, respectively (Avila et al 2019). In Ethiopia, electrifying grain milling can make a 66% return on investment over a five-year time horizon, and has a net present value of over $4000 over a 15 year time horizon (Santana et al 2021). Further analysis by Santana et al (2021) revealed that over a 15 year time period, although the upfront cost of an electric mill is about $1000 more than the cost of a diesel mill, the net present value of an investment in an electric mill will exceed that of a diesel-fueled grain mill by almost $3000 primarily due to higher operating costs and the cost of transporting diesel. Due to the lack of quality road networks and other infrastructure, the transportation cost of fossil fuels to rural parts of Ethiopia is relatively high compared to the transportation cost to urban centers (Wassie and Adaramola, 2021). As a result, given the current prevalence of diesel mills in rural communities, the lucrative return on capital investment, and the widespread demand for grain milling throughout the country, the displacement of diesel mills by their electric counterparts should be an immediate priority in Ethiopia’s national electrification plan for productive uses.

Research has shown that, alongside standalone solar PV systems, minigrids are one of the least-cost electricity supply option in rural parts of Ethiopia (Mentis et al 2016, 2017, Van-Hein Sackey 2021). As such, it is important for energy policymakers in Ethiopia to consider the impact of productive uses on the economics of minigrids. Studies of the economic impact of grain milling on minigrids in a rural Ethiopian community showed that grain milling could increase annual electricity sales by up to 22% (E4I Report 2020, Santana et al 2021). Furthermore, additional load from productive use activities from the agriculture sector in Ethiopia could increase the income of the utility company by 68% (Santana et al 2021). In spite of the potential for utilities and minigrid companies to increase profitability, Ethiopia’s new minigrid directive published in 2020 does not even mention productive uses in its documentation (Ethiopia Energy Authority 2020). Notably, the directive requires minigrid companies to engage community end-users when setting electricity tariffs for the licensing process. It also delineates steps for cross-subsidization to ensure that electricity is affordable for end-users. However, with the relatively low demand for electricity in the residential sector (Mentis et al 2016, 2017, Van-Hein Sackey, 2021), productive uses of electricity can serve as high-end electricity customers for minigrid companies to increase their profitability while ensuring affordable access to electricity for low-income customers in this cross-subsidization program.

Furthermore, diesel substitution in grain milling could result in a total national savings of US$119 million over a five-year time horizon, stemming from a 51.6 million-liter reduction in annual diesel consumption (Borgstein et al 2020). Thus, electrifying productive uses could substantially reduce Ethiopia’s reliance on petroleum imports. The report (Borgstein et al 2020) estimated that a total capital investment of $380 million would be necessary to acquire the necessary electrical appliances for each of the post-harvest activities described. Importantly, productive uses of electricity in agriculture would increase the revenue of Ethiopia’s
grid utility by US$22 million and reduce cost of supplying electricity for minigrids by over 20 percent (Borgstein et al 2020).

5. Barriers to maximizing benefits of productive uses of electricity

Despite the meaningful benefits of productive uses identified in the previous sections, there are barriers that need to be overcome to reap the optimal benefits of electrifying productive uses. Most importantly, electricity supply must be reliable and affordable to maximize the benefits of electrifying productive uses (Terrapon-Pfaff et al 2018, Santana et al 2021). As discussed earlier, electrifying pumped irrigation on smallholder cereal crop farms may result in a 95% reduction in the cost of electricity supply. However, grid and minigrid tariff structures may have to be adjusted to accommodate these new customers in the agriculture sector. These rural farmers would need to be considered low-end customers until they start to profit from their productive use activities. Thus, Ethiopia’s national electrification plan (NEP 2.0) and minigrid directive need to engage with these farmers to create a timeline in which they progress from low-end to high-end customers in the cross-subsidization program (i.e., when their profitability exceeds a mutually agreed-upon margin). Furthermore, necessary investments in upgrading transmission and distribution infrastructure should be made to ensure that business owners have access to reliable electricity. Additionally, appliance standards need to be issued to ensure that electric agriculture equipment are efficient and available in the appliance market.

Second, the Government of Ethiopia needs to increase the capital of microfinance institutions (MFIs) that support rural farmers, who cultivate low-market-value, sustenance crops like cereals. In an RMI survey 60% of farmers surveyed mentioned that the lack of access to loans and other financial instruments hindered the upgrade of their business (Santana et al 2021). Due to the seasonal nature of agri-businesses and the relatively longer time needed to reach profitability, rural smallholder farmers and cereal processors (i.e., grain milling business owners) would need access to long-term loans to be able to electrify their businesses.

6. Policy recommendations: national productive use program

To overcome the aforementioned barriers to maximizing the benefits of electrifying productive uses, certain policy levers need to be put in place by the Government of Ethiopia. To begin with, we recommend that a cross-sector commission be created that involves representatives of various stakeholders in the energy sector. Specifically, the commission should be housed under the MoWIE, and consist of representatives from research institutions (studying productive uses and other aspects of electrification in Ethiopia), the ATA, (an agency under the Ministry of Agriculture), local farmers and business owners along the value chain of sustenance crops and international development partners, such as the World Bank and African Development Bank. An independent facilitator should be appointed to chair this commission, and this facilitator can use stakeholder engagement methods (such as in Baker et al 2021) to elicit the priorities for each stakeholder represented. This commission would then be responsible for the creation and implementation of a national productive use program, which would be used to update the national electrification plan. The national productive use program would then be used to address the barriers to maximizing the benefits of productive uses of energy.

First, the national productive use program would prioritize productive uses that can be electrified in the agriculture sector. Based on the research cited in this paper, activities throughout the value chain of cereal crops, especially irrigation and grain milling should be classified as activities in need of immediate electrification (Santana et al 2021). The program should also increase funding for smallholder farmers to access resources, such as fertilizers and improved cultivars of cereal crops, which can increase their productivity. Additionally, the program should allocate funding to MFIs in need of longer-term funding to provide agribusiness owners with credit to sustain their businesses.

Second, the program should contain equipment standards for productive uses in the energy sector. Without these standards, agri-entrepreneurs and farmers may incur expensive maintenance and repair costs and suffer inefficiencies that may cripple their businesses. These appliances should then be made import tax-exempt to increase the accessibility of these equipment to farmers and business owners. Furthermore, the program should provide meaningful incentives to local equipment retailers and manufacturers to create long-term, customer-curtailed (i.e., customers should be consulted), appliance financing options that make these appliances accessible to rural farms and business owners.

Third, the commission would identify opportunities for infrastructure investment in Ethiopia’s electrification to MoWIE and international investors. With an enabling policy environment (i.e., a national electrification plan and minigrid directive focused on productive uses), investors would be more willing to fund Ethiopia’s electrification, due to the substantial return on investment of these productive use activities and their consequent increase of electricity revenue for utility companies. Furthermore, the commission should recommend...
the restructuring of the nation’s cross-subsidization program to allow new, low-income farmers and agriculture business owners to collaborate with the Ethiopian Energy Authority to develop a more impactful cross-subsidization scheme. Such a new scheme should allow these new customers to be supplied with electricity as low-end customers until their productive use businesses attain a mutually agreed-upon margin of profit that would make them high-end customers, who in turn would subsidize electricity costs for other low-income customers.

Given that the cost of electricity may still be prohibitive for some smallholder farmers, a collaboration between MoWIE, the A TA, local farmers and researchers from development partners would identify the need for a study (survey-based, perhaps) to determine the affordability-reliability tradeoff between grid-connected pumps and solar water pumps, which would provide the take-up rate of grid electricity by these local farmers. Although grid connection may be the least cost option for electrifying irrigation for some of these farmers, the reliability of the existing grid is relatively low (NEP 2.0). As such, end-users in the agriculture sector would face a reliability cost in the event of power outages and the consequent inability to irrigate their farms. Ethiopia has already mandated the Lighting Global quality standards for standalone systems (e.g., solar water pumps), meaning the quality and reliability of grid electricity being supplied to farmers would need to be at least equivalent to that of solar water pumps to incentivize farmers living in areas optimized for grid connection to connect to the grid. Furthermore, access to electricity is only one input necessary for productive uses of electricity to yield growth in employment and the economy (Terrapon-Pfaff et al 2018). Information provision, awareness-raising and market accessibility will be crucial to the success of any productive use program (Terrapon-Pfaff et al 2018). To accomplish these goals, involving the Ministry of Information and media houses in the cross-sector collaboration would enable the dissemination of information about the benefits of a national productive use program to farmers and post-harvest entrepreneurs.

Based on these findings, the cross-sector commission can institute farmer education programs that encourage farmers to prioritize post-harvest processes accordingly. Hence, the cross-sector collaborative effort (described earlier) among stakeholders in Ethiopia can conduct a similar study and make corresponding recommendations to local farmers. Further, the commission can also allocate funding for the training community members and business owners, which would equip them with the knowledge and skills necessary to efficiently use and maintain newly purchased electric appliances. The education program should use success stories of farmers and business owners whose profitability increased significantly as a result of electrification to promote the national productive use program.

Additionally, the commission would fund/ideate research efforts to identify key barriers to the economic feasibility of productive uses and the take-up of electrical appliances by stakeholders in the agriculture sector, and incentivize data collection from productive use business owners and farmers across Ethiopia. The research findings of this Commission on productive uses could be used to inform future work on electricity system planning. A review of existing electricity planning literature from Trotter et al (2017) showed that majority of electricity planning models are focused on minimizing system cost. As such, collaboration between the Commission and researchers could encourage more socially driven electrification planning. For example, the goal of many countries electrification planning efforts is to maximize social benefit within their region. Findings from the Commission about the value derived from electrifying productive uses in agriculture could inform electricity system planning research by providing different objective functions for electricity planning models such as in Nock et al (2020).

The Commission would hold frequent (monthly, perhaps) public fora to engage local farmers and community members in the policy-making process. Additionally, based on the findings of research studies such as Terrapon-Pfaff et al (2018), education programs can be established by the Commission to help farmers understand how to maximize the benefits (i.e., profits and reduced risk) of adopting electrical appliances for productive uses. The Commission would then be able to contribute to the next national electrification plan (NEP 3.0) by providing a detailed analysis (including optimal electrification pathways for rural agricultural clusters) and discussion of the challenges and potential of and the solutions to creating a productive use ecosystem in the agriculture sector. When Ethiopia is able to prioritize the electrification of its agriculture sector, the nation would be able to accelerate its development and become a beacon of hope to other developing countries in Africa and around the world.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

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References

Adela F A, Aurbacher J and Abebe G K 2019 Small-scale irrigation scheme governance—poverty nexus: evidence from Ethiopia Food Sec. 11 897–913
Afful-Dadzie A, Afful-Dadzie E, Awudu I and Banuro J K 2017 Power generation capacity planning under budget constraint in developing countries Appl. Energy 188 71–82
Avila E, Garties A, Mohamed B and Lin J 2019 Productive Use Report: Evaluation of Solar Powered Agricultural Technologies for Productive-Use Applications—A Modeling Approach (Access to Energy Institute)
Azimoh C L, Klintenberg P, Wallin F, Karlsson B, Mbohwa C and Mbohwa C 2016 Electricity for development: mini-grid solution for rural electrification in South Africa Energy Convers. Manage. 110 268–77
Baker E et al 2021 Who is marginalized in energy justice? Amplifying community leader perspectives of energy transitions in Ghana Energy Res. Social Sci. 73 101933
Banerjee S G, Malik K, Tipping A, Besnard J and Nash J 2017 Double Dividend: Power and Agriculture Nexus in Sub-Saharan Africa p 250 Block S A 1999 Agriculture and economic growth in Ethiopia: growth multipliers from a four-sector simulation model Agric. Econ. 20 241–52
Borgstein E, Wade K and Mekonnen D 2020 Capturing the Productive Use Dividend: Valuing the Synergies between Rural Electrification and Smallholder Agriculture in Ethiopia (Rocky Mountain Institute) http://rmi.org/insight/ethiopia-productive-use/
Efficiency for Access 2020 Solar Milling: Exploring Market Requirements to Close the Commercial Viability Gap (Efficiency for Access Coalition)
Ellman D 2015 The Reference Electrification Model: A Computer Model for Planning Rural Electricity Access p 109
Ethiopia Energy Authority 2020 Directive For Mini Grid p 80
Ethiopian Agricultural Transformation Agency 2019 Quarterly Report: October–December 2019 (Agricultural Transformation Agency—ATA)
Falchetta G 2021 Energy access investment, agricultural profitability, and rural development: time for an integrated approach Environ. Res.: Infrastruct. Sustain. 1 103002
Falchetta G, Stevanato N, Moner-Girona M, Mazzoni D, Colombo E and Hafner M 2020 M-LED: multi-sectoral latent electricity demand assessment for energy access planning SSRN Scholarly Paper (Rochester, NY:Social Science Research Network)
Haile G G 2015 Irrigation in Ethiopia, A Review p 8
International Energy Agency 2019 Africa Energy Outlook p 288
International Energy Agency 2020 Energy Atlas http://energyatlas.iea.org/#/tellmap/-1118783123/1 (accessed 19 September 2020)
Izar-Tenorio J L, Jaramillo P and Williams N 2021 Techno-economic feasibility of small-scale pressurized irrigation in Ethiopia, Rwanda, and Uganda through an integrated modeling approach Environ. Res. Lett. 16 104048
Jones R V, Fuertes A and Lomas K J 2015 The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings Renew. Sustain. Energy Rev. 43 901–17
Kanagawa M and Nakata T 2008 Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries Energy Policy 36 2016–20
Latif E 2015 A panel data analysis of the demand for electricity in Canada Econ. Pop. 34 192–205
Mentis D et al 2017 Lighting the world: the first application of an open source, spatial electrification tool (OnSSET) on sub-Saharan Africa Environ. Res. Lett. 12 085003
Mentis D, Andersson M, Howells M, Rogner H, Siyal S, Broad O, Korkovelos A and Bazilian M 2016 The benefits of geospatial planning in energy access—a case study in Ethiopia Appl. Geogr. 72 1–13
Ministry of Water, Irrigation and Electricity 2019 National Electrification Program 2.0: Integrated Planning for Universal Access (Lighting to All) (Government of Ethiopia)
Moner-Girona M, Bódis K, Morrissey J, Kougias I, Hankins M, Huld T and Szabó S 2019 Decentralized rural electrification in Kenya: Speeding up universal energy access Energy for Sustainable Development 52 128
Nock D, Levin T and Baker E 2020 Changing the policy paradigm: a benefit maximization approach to electricity planning in developing countries Appl. Energy 264 114583
Ohiare S 2015 Expanding electricity access to all in Nigeria: a spatial planning and cost analysis Energy Sustain. Soc. 5 8
Phiri J, Malee K, Majume S K, Appiah-Kubi S N K, Gebeltová Z, Maitah M, Maitah K and Abdullahi K T 2020 Agriculture as a determinant of Zambian economic sustainability Sustainability 12 4559
Rostow W W 1959 The stages of economic growth Econ. Hist. Rev. 12 1–16
Sananta S, Meng Z, Wade K and Bukwira P 2021 Productive Uses of Energy in Ethiopia (RMI) https://rmi.org/insight/productive-uses-of-energy-in-ethiopia/
Terrapon-Pfaff J, Gröne M-C, Dienst C and Ortiz W 2018 Productive use of energy—pathway to development? Reviewing the outcomes and impacts of small-scale energy projects in the global south Renew. Sustain. Energy Rev. 96 198–209
Trimbles C, Kojima M, Perez Arroyo I and Mohammadzadeh F 2016 Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs (Washington, DC: World Bank)
Trotter P A, McManus M C and Maconachie R 2017 Electricity planning and implementation in sub-Saharan Africa: a systematic review, *Renew. Sustain. Energy Rev.* 74 1189–209

United Nations Development Programme 2019 *Human Development Data Center* https://hdr.undp.org/en/data (accessed 19 September 2020)

United Nations 2015 *Goal 7 Department of Economic and Social Affairs* https://sdgs.un.org/goals/goal7 (accessed 17 November 2021)

United States Agency for International Development (USAID) 2021 *Ethiopia: Agriculture and Food Security* https://usaid.gov/ethiopia/agriculture-and-food-security (accessed 10 October 2021)

Van-Hein Sackey C, Nock D, Wamalwa F, Izar J, Williams N and Jaramillo P 2021 Incorporating electricity demand for small-scale pumped irrigation as a productive use for electricity in system planning for sub-Saharan African countries *MIT A + B Applied Energy Symp.* https://youtube.com/watch?v=6q2o65Y4gqA

Wassie Y T and Adaramola M S 2021 Analysis of potential fuel savings, economic and environmental effects of improved biomass cookstoves in rural Ethiopia *J. Clean. Prod.* 280 124700

Nathan W, Booth S and Baring-Gould E I 2019 *Survey Use in Micro-Grid Load Prediction, Project Development, and Operations: Review and Best Practices* (United States)