How much can an increased solar power production actually benefit rural, energy-poor areas of Africa?

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Abstract:

There has been a surge in solar power in the last decade which has opened up possibilities for rural, energy poor areas to become electrified. Access to electricity is fundamental for economic growth and human prosperity but still around one billion people lack access to electricity, where the majority is located in Sub-Saharan Africa. Traditional fuels generate toxic emissions which is the cause of approximately 3.5 million premature deaths annually, women and children being the most exposed on a local level. In this thesis we estimate if there is an effect of solar power production on access to electricity and find that an increased solar power production has a significant effect on access to electricity and access to clean fuels and technologies for cooking. We use fixed effects panel data between 2000 and 2014 for all African countries, and we find larger effects in rural areas and underdeveloped countries. In the light of our results we discuss the validity of the Environmental Kuznets curve and find that the relationship between economic growth and environmental degradation could potentially be weaker. Despite renewable energy, most notably solar power, being a widely researched topic, further research is needed to be able to claim causality between solar power production and access to electricity in underdeveloped areas.

List of acronyms

EKC   Environmental Kuznets Curve
FE   Fixed effects
GDP   Gross Domestic Product
HDI   Human Development Index
PV   Photovoltaic
RE   Renewable Energy

Technologies for collecting and distributing solar power:

Large-grids: Exist in urban areas to distribute electricity over large areas. The grid functions as a electricity storage and usually connects to many households which improves the economic viability. Usually financed through subscription services (Kaundinya, Balachandra, & Ravindranath, 2009).

Mini-grids: Usually located outside of the large grids but with relatively high population density. Mini-grids function similarly to large grids but on a smaller scale. In developing countries it's usually run on fossil fuels, but sometimes PV-system (Kaundinya, et al., 2009).

Stand-alone PV-systems: Off grid-solution, more suitable for remote areas. The system has low energy capacity, but most cost-effective for remote areas (Kaundinya, et al., 2009).

Solar Household Systems (SHS): Technology usually installed on the roof of private household providing electricity for that household (Kaundinya, et. al., 2009).

Small pico-systems: Includes for example, solar lanterns and chargers or LED lamps (Kaundinya, et. al., 2009).

Keywords: renewable energy, solar power, access to electricity, rural population, Africa, panel data, fixed effects, Environmental Kuznets curve, Samhällsvetenskapligt miljövetarprogram

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1 Introduction

In 2016 around one billion people lacked access to electricity and half of these were located in Sub-Saharan Africa[1]. The countries with the lowest levels of access to electricity were Burundi, Chad, and South Sudan with an average of only 8.5 percent of their population having access to electricity (World Bank, 2017a). According to a report by the UN Economic Social Council (2017) a major challenge in creating sustainable development is "access to affordable, reliable, sustainable and modern energy for all" (p. 6), which is the seventh UN Sustainable Development Goal[2]. The report identifies the slow progress being made towards meeting the goals set for access to electricity and renewable energy (RE) usage. RE is estimated to be key in improving access to electricity globally, where solar power provides great potential in areas with many hours of intense sunshine. They also describe the urgent actions needed to meet the set targets and identify the many benefits to be made in transitioning from using traditional energy sources to renewables. Benefits are especially high in rural areas currently without access to electricity, but certainly also from a global stance in reducing greenhouse gas emissions generated by traditional energy usage (ibid.).

In this research we examine how the level of solar power production in African countries has improved *access* to electricity. We also estimate that a higher use of solar power has led to increasing access to clean fuels and technology for cooking. By using the theory of the Environmental Kuznets Curve (EKC) we will to discuss how solar power could potentially affect the hypothetical relationship between per capita income and environmental degradation, arguing that an increased use of solar power could help developing countries reduce their emissions at an early stage but still be allowed economic growth. In this thesis we primarily focus on all African countries, since it is the continent with lowest access to electricity and is also estimated to experience high economic growth in the future. For comparison and controlling for differences in development we also exclude South Africa and northern African countries which are generally more developed and have an initial higher access to electricity.

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[1] Sub-Saharan Africa include all African countries, apart from Algeria, Morocco, Tunisia, Libya and Egypt.
[2] The Sustainable Development Goals (SDGs) are 17 social and economic sustainability goals set by the UN. These goals are a part of the 2030 Agenda and the aim is to achieve these goals by then. They cover large, global issues such as hunger, poverty, education, gender equality, water and the energy sector (UN Economic Social Council, 2017).

In this thesis our objective is to answer the following research questions:

- To what extent can an increased production of solar power generate a higher level of access to electricity in African countries?
- Could an increased solar power production generate a higher quality of life, in the form of improved access to clean fuels and technologies for cooking?

We aim to answer these research questions by first introducing the reader to the underlying problems that have shaped our research in chapter 2. We outline what forces have driven the development of solar power and the benefits and challenges of solar power development from different perspectives. We then review relevant research that has been done in this field which examines different factors that affect access to electricity, diffusion[3] of renewable energy, economic and social development and ecological benefits by transitioning to solar power. In chapter 3 we present the theory of the Environmental Kuznets Curve that will serve as the basis for the discussion of our results. In chapter 4 we present the data and which econometric method we have used to process the data, followed by our results in chapter 5. Based on previous research and economic theory we discuss our results in chapter 6. Lastly, we present what conclusions can be drawn from our research and discuss what future research is needed in chapter 7.

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[3] The diffusion theory explains the rate of which ideas and technology spread throughout a social system. It usually follows a pattern over time; innovators, early adopters, early mainstream, late mainstream and laggards. This process usually stretches over a long period of time (Rogers, 2003).

2   Background

Many developing countries are experiencing rapid growth of the economy. Economic growth usually indicates increased living standards such as decreasing poverty and reduced mortality rates. Estimates show that a 10 percent increase in a country's average income could reduce poverty rates by between 20 and 30 percent (Adams, 2002; Ravallion, & Chen, 1997). Even though access to electricity is fundamental for social development and economic growth, approximately one billion people in the world are left without access to electricity and over half of which are located in Sub-Saharan Africa (Bos, Chaplin, & Mamun, 2018). Only 18 percent of the rural population in Sub-Saharan African countries have access to electricity (World Bank, 2015). Based in current connectivity and with the increasing population rate estimates show that it will take around 80 years to electrify Sub-Saharan Africa (Wolde-Rufael, 2006). One key challenge in electrifying rural, energy poor areas currently without access to electricity are the high costs of expanding the large electrical grids already in place. These large electric power distribution systems are usually centralised and uses fossil fuels to produce electricity. Using fossil fuels are problematic due to the greenhouse gas emissions generated from combustion. Although installing off-grid solutions is costly, it is usually more cost-efficient for rural areas far from current grids (Kaundinya, et al., 2009). However, there has been recent development in the renewable energy market, especially within in the solar power sector. Emerging markets such as China, India and South American countries have been leading the investments in renewable technologies in the recent decade and account for 55 percent of global investments (Climatescope, 2017). These developments have led to a 50 percent increased installed solar capacity in developing countries in 2016 compared to the previous year. The opposite happened to wind capacity which decreased by half in the same period. The wind energy sector is also estimated to remain constant in African countries, with a small market share (Mukasa, Mutambatsere, Arvanitis, & Triki, 2015). This surge in solar power is due to various factors; one being the dramatically lowered production costs for solar cells following these large investments. The constant flow of investments during several years has also been an important factor influencing investment flows and security. Further policy development and implementation has also influenced the improved renewable energy production (Climatescope, 2017). Due to these recent events, solar power has opened up the possibility for households to gain access to clean electricity through different technologies that can be implemented outside of the large grids.

The two main solar power systems are thermal systems and photovoltaic (PV) systems. PV-systems are what is usually referred to, and is what we will refer to, when speaking of solar power. PV-systems consist of solar cells that create solar panels which transforms solar power to electricity.

Households without electricity use fossil fuels and solid fuels such as fuelwood and coal for cooking, lighting and heating. The usage of these types of fuels generate indoor air pollution which could lead to increasing risks for asthma, respiratory infections, cardiovascular disease and cancer (Jeuland, Pattanayak, & Bluffstone, 2015). The health risks caused by indoor air pollution are also more common among women and children. The use of solid fuels for indoor combustion is the cause of approximately 3.5 million premature deaths annually, which indicates great benefits for electrified households (Lim et al., 2013). The problem with indoor combustion is predominant in developing countries, in particular with low-income households without access to electricity because of the emissions from traditional energy sources. Long term exposure to the emissions and particles that originate from these fuel sources can be harmful. Because of the intensity of sunlight in the Saharan desert and other parts of the African continent the possibilities for an increased solar power production is very high (Bennet, 2010). Other benefits that can follow by using PV-systems is the possibility of creating household energy independence, thus reducing dependency on purchasing fossil fuels and imports of these. There are also possibilities for local job creation when installing these new PV-technologies in households and villages. This job creation could be followed by spill-over effects such as knowledge spreading and further diffusion of the technology (Karekezi, 2002).

Apart from the major socio-economic benefits, there are also ecological benefits to be gained from transitioning from solid fuels to solar power. Following the previous discussion regarding air pollution, alternatives to solar power also emit high levels of greenhouse gases such as carbon dioxide (CO_2), nitrogen oxide (NO_x) and sulphur dioxide (SO_2) (Tsoutsos, Frantzeskaki, Geka, 2005). There are also other environmental benefits such as improved water and air quality in reduction of particles. Greenhouse gases are the main contributors to global warming and solar power is according to researchers an important step towards reaching climate goals (ibid.). While Tsoutsos et al. (2005) define many positive effects of solar power, there are still some negative aspects such as the energy intensive production of PV-systems which also require some scarce resources such as ruthenium, gallium, indium and toxic cadmium. PV-systems also require batteries to which cobalt is another rare mineral included. Half of the worlds' cobalt production originates from the Democratic Republic of Congo.

This industry and the mining of cobalt has been shown to have negative health benefits in the local population. The mining is often problematic in developing countries due to lacking regulations and in the safety for workers (Banza et al, 2009). Some solar power systems could also involve invasion of the local nature in building large solar plants which could have a negative visual effect. The installation and demolition of these systems could also be a source of sound pollution. However, these negative effects are according to Tsoutsos et al. (2005) usually minor and site specific.

Despite the many benefits of introducing solar power production, the progress in implementing these technologies varies a lot between countries. As mentioned previously, emerging markets have been leading the development in RE technologies, but the transitioning seem to be happening too slowly (UN, 2017). Climatescope (2017) has categorised current developing countries' solar power expansion into three stages: (1) the slow starters, (2) the capacity-builders and (3) the ceiling hitters. The countries in the first category have not yet implemented many changes to improve the transitioning from traditional energy use to solar power, despite most countries in this category having signed the Paris Agreement. The capacity builder in the second category have been developing policies to facilitate transitioning into RE and are showing some successful results. The ceiling-hitters, in the third category have already developed RE policies and attracted investments, but due to lacking infrastructure and issues in their energy sector they have not been able to expand current grids further and are appearing to have 'hit the ceiling'. This last category is due to very recent events in the last few years (Climatescope, 2017). Different aspects influence the speed of which transitioning occurs, such as the technology's financial viability, legal aspects, a country's political stability and trust in the technology and the actors involved influences the diffusion rate. Climatescope (2017) has identified some variables that have facilitated the surge in solar power as falling PV-prices, countries implementation of RE policies, long term investments in solar power and open markets to mention a few.

In our research, we have chosen to focus on solar power because this area has shown the largest development in the recent decade and is expected to rise further in the future. Half of the world's current solar power systems are installed in developing countries and the African continent shows great opportunity for solar power due to the high average hours of sunshine (Bennett, 2010). Solar systems are also generally easier to install outside of current electrical grids, since simple systems can be placed on rooftops or on the ground and generate a high value for households without access to electricity.

2.1 Literature overview

Solar power is a widely researched topic, but there is still research to be done to understand the many possibilities and challenges of the many aspects of the technology that keep evolving from a technical standpoint. The research show different tendencies in explaining the variation within access to electricity and solar power production. In the following chapter we present some of the previous research that has laid the foundation for our research. These sources are first-hand peer reviewed sources and published in the journals Energy Research and Social Science, Energy for Sustainable Development and Energy Economics. To the best of our knowledge, no research has been made to show how RE production affects access to electricity for all African countries, and when also excluding more developed countries. We further estimate what effect RE production has on access to clean fuels and technology for cooking, which neither has been researched in the same area. Our research could provide necessary insights on what role the increasing solar power production can have in the future.

Onyeji, Bazilian, Nussbaumer (2012) focus on what has affected access to electricity in Sub-Saharan African countries and why these countries are lagging behind in development. They compared Sub-Saharan Africa with North Africa, China and East Asia, South Asia, Latin America and the Middle East and using data from The World Bank. In their econometric model they use the level of access to electricity in 2009 as dependent variable and control for various variables on the key topics of financing, population and institutional quality and used an average of these on the years between 2000 and 2009. They found that 90 percent of the variation in access to electricity was explained by gross domestic savings, corruption, rural population, poverty levels and population density. They also found that this result differs from the other developing countries located outside Sub-Saharan Africa. This implies that successfully implemented policies in other developing countries might not apply completely in this area. By using an average of the time period introduce the possibility of omitted variable bias by not using panel data. Their results are highly likely to be valid due to their source and they include many aspects of the field of electricity diffusion. The research could however be expanded further with panel data over a longer period of time.

Further research by Pfeiffer and Mulder (2013) show that different aspects could affect the diffusion of non-hydro renewable energy technology in developing countries. They used data from 108 different developing countries during a 30-year period and analysed it by using a two-stage estimation method.

In their research they find that high fossil fuel or hydropower production, increasing electricity consumption, openness, and foreign aid are factors that delay the expansion of renewable technology. The explanations provided to improve diffusion of renewable technology are higher per capita income, education levels, stable democratic regimes, and a mix of energy usage. They also found that countries with RE policies produce on average 1.4 percent more RE than countries without policies. Signing of the Kyoto protocol had a significant positive effect of the adaptation or renewables, which implies the importance of environmental policies. Pfeiffer and Mulder did their research on 108 developing countries, it was not clear which countries they used but we are assuming them to be spread out globally since they compared their results to BRIC countries[4] and claimed not to be OECD countries. By using a sample from different parts of the world, it makes the implications and the conclusions less precise which leaves out effects that would be interesting to learn about. This was of course not their purpose, and is left for further research.

While there are factors that delay the diffusion rate of renewable energy, solar power could improve access to electricity on village level in African countries according to Ulsrud, Winther, Palit, Rohracher, (2015). The research shows that advancements in off-grid solar power technology can lead to economic stability in rural areas of Kenya. Most of the 15 mini-grid solutions in 2009 Kenya are diesel run, but due to high prices of diesel the government and local groups are interested in alternatives. The mini-grids are usually financed by subscriptions similar to the large-grid systems often found in urban areas. Despite the large efforts being made to electrify Kenya, only around 7 percent of rural areas were connected to an electrical grid in 2009. Off-grid solutions can be a cheap solution to cover basic electricity needs, where the cheapest solutions are small pico-systems such as hand held solar lanterns, chargers or LED-lights. On the other hand, research done by A. Jacobson (2007) in Kenya shows that solar electrification mostly benefits the rural middle class living in unsubsidized markets. Further they conclude that an increased solar power production has an increased energy usage for televisions, radio and cellular phone charging and also increase the connection between rural and urban areas. In their research they did not find that solar power improves poverty alleviation or sustainable development. In fact, the arguments are built on research claiming that solar power is not the cheapest way to reduce carbon emissions.

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[4] BRIC countries include Brazil, Russia, India and China (Pfeiffer & Mulder, 2013).

Since their research in 2007, the prices of PV-systems have decreased drastically as we have also explained in the previous chapter, therefore it could be relevant to replicate this study with updated price data. The growing population and future energy usage is expected to increase and should also be taken into consideration. If underdeveloped countries create a dependency on fossil fuels, it will be costlier to transition at a later stage.

3 Theoretical framework

3.1 The Environmental Kuznets Curve

The theory of the Environmental Kuznets Curve (EKC) describes the hypothetical relationship between per capita income and environmental quality (Kuznets, 1955). The theory states a positive correlation between growth and environmental degradation up to a certain point, but that the negative impact on the environment generated by growth should eventually decline and the environment should in turn improve. "This implies that the environmental impact indicator is an inverted U-shaped function of income per capita" (Stern, 2004, p.1), as shown in Figure 1 below, where point B indicates the inflection point where the environment improves.
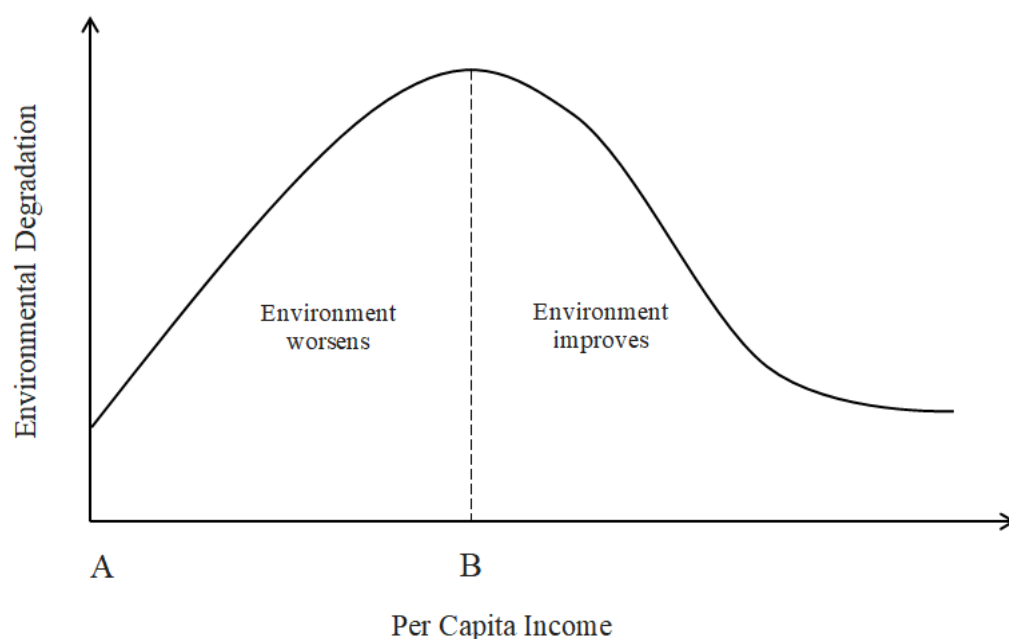
Figure 1 - Environmental Kuznets Curve (Grossman, & Krueger, 1995)

The EKC is based on a theory of inequality developed by Kuznets (1955). The original theory suggested that when a country is experiencing growth, financial inequality first increases and then falls in the same way as shown in Figure 1. Later in the 1990's Grossman and Krueger (1995) developed the theory further and created the Environmental Kuznets Curve by reviewing the development of local water, and air quality.

The EKC has since been globally acknowledged as a valid theory in economics and has been the dominant approach to model emissions and has been shown to hold in some cases related to depletion of natural resources and local environmental improvements (Grossman, & Kreuger, 1991; Shafik, & Bandyopadhyay, 1992; Beckerman, 1992; Selden & Song, 1994). Despite the theory's acknowledgement, it was criticised early after its publication (Stern, 2017). A problem that has been shown to arise when a country becomes richer and the local environment improves is that the pollution generated by dirty industries is outsourced (Sterner, & Segnestam, 2001). This is found to hold in most developed countries which import goods from developing countries, thus reducing the domestic pollution. By also assuming, as the theory implies, that these are somewhat naturally occurring events, it suggests that no intervention is needed. It is not clear what drives this empirical change (Stern, 2017). The theory is mostly based on empirical evidence and has in many studies shown to not be statistically significant, especially in fast growing economies where pollution increases from a global perspective (Stern et al., 1996; Arrow, Bolin, Costanza, & Dasgupta, 1995).

The theory could be problematic since it strengthens arguments such as only the assumption that rich countries can afford environmental quality and that growth is actually beneficial for the environment. This would indicate that pollution is justified and will lessen at a later, more developed state. In Figure 1 the interval between point A and point B shows that the environmental degradation is increasing with growth. However, the severity of the environmental degradation is not specified in the theory. Considering the stress human activity has put on the environment, with the aspects of biodiversity, climate change, natural resources, and biochemical flows[5], the turning point shown in the Kuznets Curve is likely to have surpassed the ecological threshold. Assuming the EKC has some validity, Figure 2 presents an alternative scenario with a different kind of development. If developing countries can reduce their emissions at an early stage and not be dependent on environmentally degrading technologies but still be allowed economic growth a more sustainable development will follow.

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[5] In 2009 the concept of planetary boundaries was introduced to estimate the limits of which human activity can function without pushing the planet into an uncertain future. The boundaries have been divided up into nine categories, four of which; climate change, biospheric integrity, biochemical flows, such as high emissions of nitrogen and phosphorous, and land system change are estimated to currently exceed the planetary boundaries (Steffen et al., 2015).
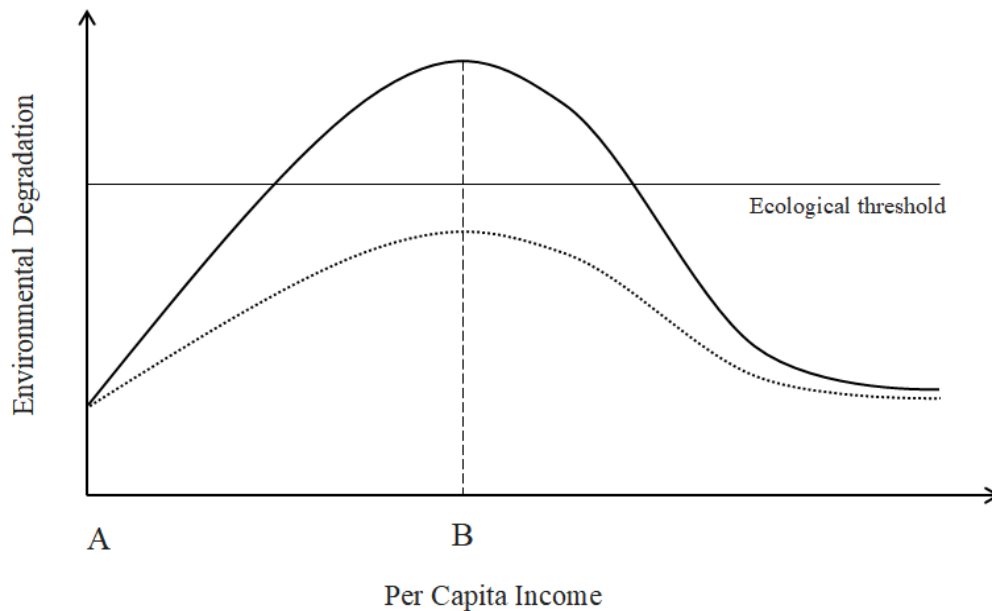
Figure 2 - An adjusted Environmental Kuznets Curve

The critiques of the EKC identify the need of separation of economic growth and negative ecological impact. This is also called decoupling. An economy is considered decoupled if it experiences GDP growth without environmental degradation. Decoupling has become widely researched and by many, seen as the best way to create a more sustainable development. Decoupling has also been the focus of the OECD countries' Environmental Directorate (OECD, 2017). While economic growth is unstable due to the pressure on the environment and issues with inequality, decoupling could also be considered unstable. According to Jackson (2009) decoupling in the current economic system could lead to instability due to the need of consumer demand to decline, thus leading to unemployment and eventually recession. The theory is combined with ideas of changing the current way of growth, being highly dependent on material output, goods and services and production processes. If changes occur, economies should be able grow without the negative impact on the environment.

The EKC has, as mentioned, shown various results for its validity depending on what variables have been measured. A study by Zoundi (2017) tests the short- and long-run impacts of renewable energy and CO_2 emissions in 25 African countries between 1980 and 2012. By doing a robustness test using their data, they find "no evidence of a total validation of EKC predictions" (Zoundi, 2017, p. 1). Two other studies done in African countries find disparity in support of the EKC. Wesseh and Lin (2016) estimated data between 1970 and 2011 find support of the EKC and show an inverted U-shaped curve.

However, Ben Jebli, Ben Youssef, and Ozturk (2015) researched 24 sub-Saharan African countries between 1980 and 2010 and found that the EKC does not hold.

Due to the ambiguous results by previous research, we want to further discuss whether this hypothetical relationship between per capita income and environmental degradation seem to hold for our study. We estimate to what extent solar power could affect access to electricity and thus spur development in African countries. Though we do not empirically test the validity of the EKC, we discuss how substituting traditional fuels for RE sources could influence the current validity of the EKC for developing countries in Africa.

4 Data and econometric methods

4.1 Data

The majority of our data is collected from the World Bank Development Index (2017b), due to its validity and large amount of data. The World Bank is one of five international organizations that together make the World Bank Group. The World Bank is also an observer of the United Nations Development Group (United Nations Development Group, 2016). The World Bank provides an abundance of variables measuring development, but many developing countries appear to lack registered data. We chose to estimate panel data between the years 2000 and 2014 for all 54 African countries. Due to solar power production having recent development, earlier measurements would be useless and data later than 2014 is not available.

The dependent variables we have used in our study are access to electricity per country and year on a population level and on a rural level, and access to clean fuels and technology for cooking. We control for annual GDP growth for each country and for Human Development Index (HDI). HDI is a measurement of human development, such as life expectancy and quality, access to knowledge and a decent standard of living (United Nations Development Programme, 2016). Using the HDI is a common way of controlling for various development factors that can have an effect on the dependent variable. We also include GDP growth to control for economic development between years. We use GDP growth as a variable instead of GDP per capita, because GNI[6] per capita is already included in the HDI. Since we want to estimate differences in tendencies, GDP growth is a sufficient estimate to highlight the variation between years.

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[6] GNI is an abbreviation of Gross National Income

A summary of the statistics of our variables is presented in Table 1, which provides the number of observations, the mean values, the standard deviations and also the minimum and maximum value of the data for each variable. Firstly the values of all African countries are presented, followed by the values of our subsample which exclude Northern African countries and South Africa.

Table 1. Summary statistics of our variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Access to electricity - % of population |	786	40.16	30.06	0.01	100
Access to electricity - % of rural population |	788	24.72	30.06	0.01	100
Production of RE excluding large hydro - % of total |	438	1.91	5.39	0	45.73
Access to clean technology for cooking - % of total |	780	24.66	30.93	2	99.99
HDI |	816	0.49	0.119	0.255	0.782
GDP growth annual % |	862	4.48	6.12	-62.08	63.38
Access to electricity - % of population, excluding North Africa and South Africa |	711	34.75	26.10	0.01	99.8
Access to electricity - % of rural population excluding North Africa and South Africa |	713	18.61	23.76	0.01	99.64
Access to clean technology for cooking % of total excluding North Africa and South Africa |	705	17.62	22.96	2	99.94

The average access to electricity of all African countries was 40.16 percent during the 14-year time period while the average for the rural population was 24.72 percent for the same time period. We also find a large variation between the highest and the lowest values, where the country with the highest access to electricity is estimated to be 100 percent, and the lowest 0.01 percent. A value of 0.01 percent is unlikely to be accurate. After examining the data, we find a few countries that show a yearly value of around 0 or 1 percent. Since the seemingly incorrect individual data points concern a small number of countries such as Guinea Bissau and Lesotho which have no renewable energy production it will likely not affect our results. When we exclude North Africa and South Africa we find the average access to electricity is 34.75 percent of the population and for the rural population access to electricity is 26.10 percent. The total average for access to clean fuels and technology for cooking all African countries during the time period was 24.67 percent. This means that on average 75 percent did not have access to clean fuels and technology for cooking.

In Figure 3 we present the large variation in access to electricity across all African countries derived from our data. This highlights the heterogeneity in access to electricity in Africa. The graph shows years on the horizontal axis and the percentage of the total population's access to electricity on the vertical axis. The crossing line depicts the average access to electricity for all African countries and the top and bottom of the bars are one standard deviation from the average. Detailed data for all African countries can be found in Appendix A.
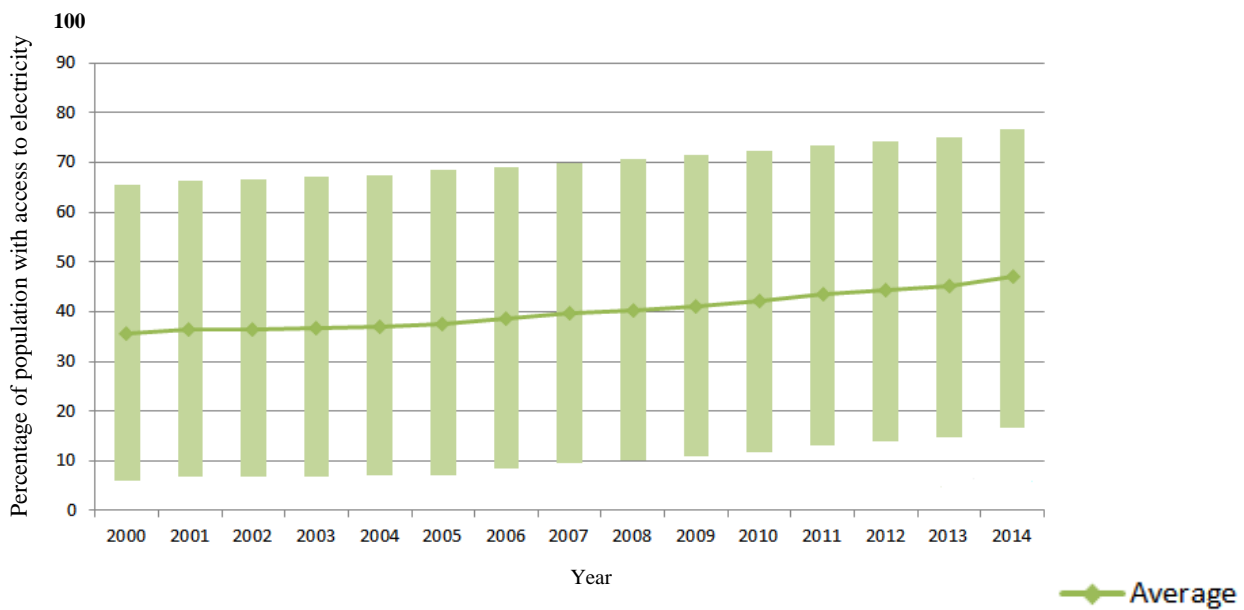

Figure 3 - variation in access to electricity for all African countries between 2000 and 2014.

The explanatory variable of interest is the total percentage of the country's electricity production derived from renewable energy sources, excluding electricity from large hydroelectric power plants. The data for renewable energy production is collected for the World Bank by the International Energy Agency (IEA) and is a combination of solar photovoltaic, geothermal, tide, wind and various biofuels. As stated in the background (chapter 2), solar power energy production has had the most development compared to other RE sources in the last decade. We describe the factors that have led up to this development and since solar power has been an attractive investment followed by reduced prices of PV-systems, it is likely that most of the variation in the variable of interest is explained by the change in solar power energy production.

We have not found references showing drastic changes in other RE sources such as geothermal or biofuels. The sources we've found and reference to in the background show that wind power is estimated to remain constant. We therefore assume that the other energy sources included in the variable should be roughly constant and assume that solar power will account for most of the variation in the variable of renewable energy production. Solar power is likely to serve as the most important renewable energy source in the African continent due to the geographical conditions given the amount of sunshine (Bennett, 2010). The total average of renewable energy production is only 1.95 percent, due to many smaller countries having 0 percent renewable energy production during this period. The countries that have renewable energy production have seen development during this time period. Renewable energy has accounted for a minor part of many African countries' energy production. The data is based on national energy reports and when key data is missing estimations of energy sources and their extent are made with help from national statistical offices, oil companies, electric utilities, and national energy experts (World Bank, 2014).

4.2   Econometric method

By using ordinary least squares and fixed effects models we estimate the effect of produced renewable electricity on access to electricity on a population level and a rural level, and access to clean fuels and technologies for cooking. As a robustness check we use a subsample where we exclude more developed countries, i.e. North African countries and South Africa, we observe the coefficient and we can draw conclusions about how it changes. Since access to electricity has a large variation between countries, notably comparing less developed areas to more developed areas, we expect to see a higher effect on access to electricity in Sub-Saharan Africa. The same logic applies for differences in size of the coefficient of produced renewable energy comparing the rural population to the total population where we expect to see a larger effect on the rural population.

In the results we include regression models with and without the control variables to see how the variable of interest changes in order to determine how much of the effect on access to electricity is shared. The explanatory variables are lagged with one year to control for the time between the implementation of more renewable energy and generic development, and when households actually access the electricity. We use a fixed effects model to account for country specific factors that can affect access to electricity beyond the variables included in our analysis.

We believe that there are institutional differences between the countries and that they are unique for each country. We also want to control for differences between years, for example meteorological factors and fluctuation in fuel prices. Using FE we control for these differences *within* each country and year since it uses time variation in each cross section, while the OLS estimates *between* variations in each cross section, thus avoiding bias of the predicted coefficient on access to electricity (Wooldridge, 2010).

We aim to estimate the following equations with the use of an ordinary least squares model and a fixed effects model:

(1) $\quad Access\ to\ electricity\ Population = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + u$

(2) $\quad Access\ to\ electricity\ Population = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + \beta_4 * FE_{country} + \beta_5 * FE_{year} + u$

(3) $\quad Access\ to\ electricity\ Rural = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + u$

(4) $\quad Access\ to\ electricity\ Rural = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + \beta_4 * FE_{country} + \beta_5 * FE_{year} + u$

(5) $\quad Access\ to\ clean\ fuels\ and\ technology\ for\ cooking = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + u$

(6) $\quad Access\ to\ clean\ fuels\ and\ technology\ for\ cooking = \beta_0 + \beta_1 * Renewables_{t-1} + \beta_2 * GDP_{t-1} + \beta_3 * HDI_{t-1} + \beta_4 * FE_{country} + \beta_5 * FE_{year} + u$

4.3   Limitations

Due to limited data and not being able to collect data ourselves we have restricted our use of other control variables than GDP growth and HDI. Instead we have used subsamples for rural population, where there is less likely to exist large variation in infrastructure for example, which should reduce the risk of omitted variable bias that affect our result. Our variable of interest, renewable energy production, contains energy sources other than solar power. Ideally, we would like to have data on only solar power but since we believe that solar power accounts for most of the variation in the renewable energy production variable we find it is sufficient to use in this thesis.

We have also used a subsample where we exclude northern African countries and South Africa where most of the population has access to electricity and a higher GDP per capita. This is to further strengthen our results. Countries with high access to electricity outside the North African countries and South Africa are mostly small island states with little relevance to our analysis. By using FE models we try to correct for the variation within countries to further minimise potential bias. There are other factors that could influence the results since our estimates will not take into consideration all factors of institutional functionality, political differences or attitudes to renewable energy for example.

5 Results

The results are divided into three parts with six different regressions. The first part (5.1) presents the effect on access to electricity for all African countries and for the subsample when Northern African countries and South Africa is excluded. The second part (5.2) presents the effect on a rural population. The last part (5.3) presents the effects on access to clean fuels and technology for cooking. For all regressions we also control for fixed effects for countries and years of the model to check whether our variables of interest stay significant.

5.1 Access to electricity on population level

Table 2 presents the regression models specified in equations (1) and (2) for all African countries and Table 3 presents the regression models specified in equations (1) and (2) for the subsample.

Table 2. Access to electricity on a population level with all African countries.

	(1)	(2)	(3)	(4)	(5)
	Access to electricity	Access to electricity	Access to electricity	Access to electricity	Access to electricity
Renew. electricity	0.750^{**}	1.163^{***}	0.715^{***}	1.165^{***}	0.456^{***}
GDP growth		-0.516^{**}	0.0293	-0.535^{*}	0.0332
HDI		56.04^{***}	95.06^{***}	55.88^{***}	-17.33
Constant	48.38^{***}	23.44^{***}			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	408	391	391	391	391

$^{*} p < 0.1, ^{**} p < 0.05, ^{***} p < 0.01$

Table 3. Access to electricity on a population level excluding North African countries and South Africa

	(1)	(2)	(3)	(4)	(5)
	Access to electricity	Access to electricity	Access to electricity	Access to electricity	Access to electricity
Renew. electricity	1.187***	1.404***	0.649***	1.332***	0.394**
GDP growth		-0.318*	0.0255	-0.372**	0.0235
HDI		-94.15***	98.24***	-110.2***	-20.59
Constant	38.55***	83.24***			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	338	321	321	321	321

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As shown in Table 2, production of renewable energy, excluding hydroelectric sources, has a significant effect on access to electricity on a population level. This means that on average, one percentage point increase in produced renewable electricity would, on average, increase the access to electricity by 0.75 percentage point on a 95-percent confidence level. To check whether the effect on access to electricity is robust we control for annual GDP growth and the human development index. When including the control variables in the regression the variable of interest keeps its explanatory power while we can see that HDI has a large coefficient of 56 percentage points. Thus, HDI has an expected large effect on access to electricity. Since the effect of produced renewable electricity is not rendered insignificant when controlling for HDI we believe that they are sufficiently uncorrelated. The correlation between the independent variables is presented in (Appendix B). The same interpretation can be made for the second control variable, GDP growth, even though the effect of GDP growth is much smaller on access to electricity. Lastly, we control for fixed effects across years and countries. The results show that the fixed effects estimator of produced renewable electricity is smaller than when we do not control for fixed effects but still holds explanatory power and is still significant. Some of the variation within countries and years in access to electricity explained by produced renewable electricity is accounted for when the effects are fixed, hence a lower coefficient of produced RE. Furthermore, much of the variation in GDP growth and HDI can be attributed to the fixed effects, hence lower and insignificant coefficients.

When we exclude the North African countries and the country of South Africa in Table 3 we have a larger coefficient of produced renewable energy on access to electricity. This is due to the already high access to electricity in the North African countries and the country of South Africa. Naturally, if the access to electricity in a given country is already close to a hundred percent, the impact of more renewable energy production on access to electricity is negligible. The result implies that the effect of more renewable electricity production on access to electricity is greater in less developed countries in Africa. This is in line with our expectations that renewable electricity production benefit less developed countries to a higher extent since the initial access to electricity is lower and there is a greater need for a higher access to spur development in less developed areas.

5.2   Access to electricity on a rural population level

Table 4 presents the regression models specified in equations (3) and (4) for all African countries and Table 5 presents the regression models specified in (3) and (4) for the subsample.

Table 4. Access to electricity on rural population level with all African countries.

	(1)	(2)	(3)	(4)	(5)
	Access to electricity rural	Access to electricity rural	Access to electricity rural	Access to electricity rural	Access to electricity Rural
Renew. electricity	0.988***	1.460***	1.503***	1.493***	1.289***
GDP growth		-0.517**	0.0412	-0.521*	0.0453
HDI		87.33***	71.96***	90.18***	-26.95
Constant	30.47***	-9.912			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	408	391	391	391	391

$^{*} p < 0.1$, $^{**} p < 0.05$, $^{***} p < 0.01$

Table 5. Access to electricity on rural population level, excluding North African countries and South Africa

	(1)	(2)	(3)	(4)	(5)
	Access to electricity rural	Access to electricity rural	Access to electricity rural	Access to electricity rural	Access to electricity Rural
Renew. electricity	1.522^{***}	1.757^{***}	1.223^{***}	1.720^{***}	1.068^{***}
GDP growth		-0.302*	0.0528	-0.337^{*}	0.0505
HDI		-68.21^{***}	61.59^{***}	-77.01^{***}	-15.39
Constant	18.53^{***}	51.10^{***}			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	338	321	321	321	321

$^{*}\ p < 0.1,\ ^{**}\ p < 0.05,\ ^{***}\ p < 0.01$

In Table 3 and 4 we only include households that are considered to be living in a rural area. The average effect of production of renewable electricity on access to electricity is greater on the rural population compared to the population as a whole. As previously stated, we expected a greater effect on the rural population due to a lower access to electricity because rural areas are not included in the electrical grid thus there is greater opportunities for off-grid energy supplies. The estimated coefficients of the model with the average access to electricity on a rural level and a population level have a noteworthy difference in size of coefficients when we control for fixed effects. On a population level the coefficient of produced renewable energy changes from 0.75 to 0.46 with all African countries and from 1.19 to 0.39 with the subsample of countries. In comparison, the coefficients on a rural population level changes from 0.99 to 1.29 with all African countries and from 1.52 to 1.07 with the subsample of countries.

5.3   Access to clean fuels and technology for cooking

Table 6 presents the regression models specified in equations (5) and (6) for all African countries and Table 7 presents the regression models specified in equations (5) and (6) for the subsample.

Table 6. Access to clean fuels and technology for cooking for all African countries

	(1)	(2)	(3)	(4)	(5)
	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.
Renew. electricity	0.997**	1.618***	-0.0493	1.687***	-0.126
GDP growth		-0.542*	0.0108	0.485	-0.0142
HDI		145.9***	70.76***	152.2***	33.45**
Constant	31.87***	-37.28***			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	394	379	379	379	379

$^{*} p < 0.1, ^{**} p < 0.05, ^{***} p < 0.01$

Table 7. Access to clean fuels and technology for cooking, excluding North African countries and South Africa

	(1)	(2)	(3)	(4)	(5)
	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.	Access to clean fuel and tech.
Renew. electricity	1.604***	1.881***	-0.0937	1.880***	-0.0854
GDP growth		-0.248	0.00459	-0.263	0.00264
HDI		1.447	64.00***	-0.157	66.46***
Constant	17.83***	18.73**			
Fixed effects country	NO	NO	YES	NO	YES
Fixed effects year	NO	NO	NO	YES	YES
Observations	324	309	309	309	309

$^{*} p < 0.1, ^{**} p < 0.05, ^{***} p < 0.01$

When using access to clean fuels and technologies for cooking as the dependent variable we show a significant effect of produced renewable energy without controlling for fixed effects. We have a larger effect using the subsample which follows the trend seen in access to electricity and can this be explained by a high correlation between access to electricity and access to clean fuels and technology for cooking that is presented in Appendix B. When we control for fixed effects across countries the coefficient of produced renewable energy loses its significance and becomes considerably smaller. This could be explained by having access to clean electricity is not equivalent to using it for cooking. For example cultural variation within the country or having a preference of cooking on an open fire could affect the continuing use of firewood.

6.   Discussion

The results show a relatively large significant positive effect on access to electricity when increasing production output of RE, excluding hydroelectric sources. As previously stated, we interpret the produced RE variable as that solar power accounts for most of the variation over time. This answers the first research question "To what extent can increased production of solar power generate a higher level of access to electricity in African countries?". The effect on access to electricity is larger when we only include rural areas in the regression. This is in line with the study by Onyeji et al. (2012) who found that rural population explained much of the variation in access to electricity. In their study they compared the results from Sub-Saharan Africa with other developing countries in South America and Asia which implied that possible successful policies in Asia are not applicable in Sub-Saharan Africa. Their findings showed that Sub-Saharan African countries differed between other developing countries. The combined results confirm the hypothesis that the rural population is mostly to benefit from the expansion of solar power technologies.

Though we cannot claim causality, we interpret the results of our analysis as outlining a relationship between an increased solar power output and access to electricity. Since claiming causality of the relationship requires a more exhaustive econometric analysis to be able to solve the endogeneity problem, i.e. there are omitted variables that also explain the variation in access to electricity that we are unable to control for. As mentioned, there are still more factors that could explain the variation in access to electricity, such as the attitudes towards solar power and traditional fuels, local entrepreneurs' ability to install these PV-systems and infrastructure that can affect the accessibility of the technologies, the effectiveness of current RE policies to name a few. One could expect that there are obstacles for the implementation of the PV-systems, such as financial hindrance for the relative large fees of installation. This implies that there is a need for governmental support for rural electrification. When using the subsample, we see a larger effect on access to electricity compared to the full sample. This is in line with our expectations because of initially lower electricity access in the subsample. A larger effect is expected in less developed areas.

Building on the theory of the Environmental Kuznets curve, our findings suggest that an increased amount of solar power output increase the access to electricity, which according to previous research could lead to a higher economic standard. This indicates that human prosperity, would increase while emissions, such as air pollutants and greenhouse gases, would be far less than what would have been emitted to accomplish the same growth with fossil fuels. Substituting the energy supply which is needed to increase wealth and raise individuals out of poverty with clean, renewable energy instead of fossil fuels would then push the left-hand side of the EKC down (see Figure 2, p. 13). In this case, GDP would grow at the expected rate while environmental degradation would still increase but with a reduced rate. This would render the EKC obsolete for some developing countries, especially in Sub-Saharan Africa where many countries currently have a low energy production but will see rapid development in the coming decades. Zoundi (2016) concludes in their article that that renewable energy has a clear negative effect on CO_2 emissions, while an increased economic activity still contributes to environmental degradation they cannot fully confirm the validity of the EKC for a sample of African countries. In light of these results, an increased solar power output would decrease environmental degradation while our results suggest that it also leads to a higher access to electricity and with that a higher economic standard.

Following our main research question we examined if an increased output in RE could lead to a higher usage of clean fuels and technology for cooking. Previous research suggests that access to electricity can improve life expectancy and spur economic growth. Studies show large negative impacts of indoor household pollution due to the usage of firewood and fossil fuels, the health implications are especially apparent for women and children. This suggests that further actions are needed in improving the life expectancy for the almost one billion people in the world without access to electricity (World Bank, 2017a). Our results show that an increased RE production has a significant effect on access to clean fuel and technology for cooking, but when we control for fixed effects across countries the coefficient loses its explanatory power. This suggests that some countries could have implemented different tools to ease the transitioning from traditional energy usage to solar energy for clean fuel and technology for cooking. Following the previous discussion about fixed effects, possible implementation of environmental policies such as feed in tariffs, subsidies for clean technology or other financial policies could have been introduced by different countries to facilitate the implementation of clean fuel and technology for cooking. Other possible factors that could explain the variation are whether countries have more developed infrastructure or whether their domestic markets are open to import these technologies.

As previously mentioned in chapter 1 the benefits of clean fuel and technology are especially large for women and children that are subjected to higher amounts of indoor air pollution. This makes access to clean fuel and technology for cooking a gender equality issue as well, which connects to the fifth UN Sustainable Development Goal: "Achieve gender equality and empower all women and girls" (United Nations, 2017, p. 5). Women are to a higher extent submitted to gender discrimination and are often provided with fewer opportunities in life. Improving access to clean fuels and technology for cooking could therefore increase life expectancy and grant women with better opportunities in life.

Even if there are great benefits in using solar power, we expect that there could be situations where the transition to solar power could be hindered. The recipients of these PV-systems might not see the same value in these systems as intended by the policy makers or aid agencies. Populations under large stress induced by poverty could choose to sell these PV-systems in order to use the money for other purposes. The technology also changes the everyday way of living and cooking, habits that could be tied to cultural heritage. If cooking has been done in a certain way for centuries, it is not necessarily easy to transition to a new technology. This imposes the need of potential policies to be made in dialogue with the rural population to identify the actual needs and abilities.

7   Conclusion

In this thesis we conclude that there is a significant positive effect of solar power production on access to electricity including when controlling for fixed effects. We use data from all 54 African countries, and subsamples where we exclude North African countries and South Africa. We find that the effect is larger in rural and underdeveloped areas. We also see a significant positive effect of an increasing solar power production on access to clean fuels and technology for cooking.

Many African countries have especially great possibilities to increase their output of solar power following recent development. These possibilities have opened up due to various factors such as high investment flows, price drop of these technologies, and an increasing implementation of RE policies. There are many possible benefits in transitioning to solar power, especially for African countries with high poverty rates and low development. If these countries would transition to solar power at an early stage of their development, they could reduce their emissions but still be allowed economic growth, thus going against the theory of the EKC. The results suggest that the validity of the EKC should be questioned because of a proposed weaker positive relationship between income per capita and environmental degradation. We further discuss other large sustainability challenges, namely indoor air pollution, health implications, and gender equality in relation to an increased access to clean fuels and technology for cooking due to an increased solar power production. We conclude that in addition to a reduced environmental degradation, an increase of solar power production in Africa could also raise life expectancy and provide other health benefits, especially for women and children.

Future research should include recent development in off-grid solar power and evaluation of current RE policies and programmes for an increased solar power production. When adequate data exists a difference-in-difference analysis could be implemented in order to claim causality of solar power production on access to electricity and access to clean fuels and technology for cooking.

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Appendices

Appendix A

Access to electricity of all African countries between 2000 and 2014:

Graphs by Country

Appendix B

Correlation between the explanatory variables:

	Produced renewable energy, excl hydro.	HDI	GDP growth
Produced renewable energy, excl hydro.	1		
HDI	-0.0864	1	
GDP growth	0.0106	0.0133	1

Correlation between access to electricity and access to clean fuels and technologies for cooking:

	Access to electricity	Access to clean fuels and technology for cooking
Access to electricity	1	
Access to clean fuels and technology for cooking	0.8547	1