Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/59/20240763

Evaluate the potential of electrification to achieve urbanization and carbon neutrality

Zhaohua He

The Australian National University, Canberra 2600, Australia

877380948@qq.com

Abstract: Electrification applications in transport and energy supply can significantly reduce carbon emissions. The impact of electrification on carbon emissions reduction varies across countries with different development profiles. In developed countries, with the increase of renewable resources usage in electricity production, the per capita CO_2 emissions decrease. For example, Germany increased its share of electricity production from renewable sources from 6.2% to 44%, and its per capita CO_2 emissions dropped from 11.2 t to 8.1t. While in developing countries, the per capita CO_2 emissions are still increasing with the increase of electrification level. For example, India increased its degree of electrification from 58% to 99%, and its per capita CO_2 emissions increased from 0.9 t to 1.9 t. This paper first used LCA data to compare the Greenhouse gas (GHG) emissions of electric vehicles and fuel vehicles and GHG emissions of electricity plants from different energy sources. Then, this paper used Linear regression to determine how close between electrification and climate change. This research aims to identify the potential of electrification to achieve urbanization and carbon neutrality, as there are few discussions regarding the combination of these three topics at present. This research can confirm the benefit of electrification in reducing carbon emissions, which can promote the broad application of electrification and its development.

Keywords: Electrification, Climate Change, Electric Vehicles (EV), Carbon Neutrality, Urbanization.

1. Introduction

Nowadays, the development trend of all countries worldwide is to pursue sustainable development and carbon neutrality. Urbanization and climate change have significantly impacted achieving sustainable development and carbon neutrality [1]. The rapid development of urbanization requires highly intensive industrialization and a massive resource and energy supply, which would create obstacles to sustainable development [2, 3]. Environment pollution from urbanization and its impact on climate change now arouse more people's attention. The adverse effects of climate change due to carbon emissions are increasing. As CO_2 emissions increase, the effects of climate change will become more visible because carbon emissions are associated with rising temperatures [4]. Since the 2015 Paris Agreement, world leaders have reached a consensus that stops the global average temperature from increasing more than 1.5°C [5]. Electrification, a new way to develop urbanization, is favored by more people due to its low carbon emission [1, 2]. The convergence of urbanization, climate change, and electrification represents a critical nexus of challenges and opportunities in pursuing sustainable development and carbon neutrality [6, 7].

Driving urbanization means more and more people would gather and live in urban areas. By now, more than 50% of the world's population lives in cities, which is expected to increase to almost 70% by 2050 [8, 9]. The current urbanization has led to significant environmental impacts, including sharply increasing energy consumption, over-exploitation of resources, increasing pollution and emissions, and reducing and degrading the natural landscape due to building construction [10, 11]. Cities account for 80% of global GDP, two-thirds of global energy consumption, and more than 70% of global carbon emissions. Nevertheless, cities account for less than 2% of the Earth's surface area [9]. A report regarding developing sustainable cities from the IEA (International Energy Agency) indicated that climate action in cities is critical for achieving sustainable development and carbon neutrality [9]. Relevant actions could reduce emissions from urban buildings, construction materials, and transport by nearly 85% in 2050, compared to the Coalition for Urban Transition's 2050 business-as-usual reference scenario [8, 12]. Therefore, cities represent an excellent opportunity to accelerate progress towards ambitious climate goals and sustainable development.

Climate change is becoming the most tricky crisis of our time, deteriorating faster than we worried [13, 14]. Carbon dioxide(CO_2) emission produced by human activities is the most significant contributor to climate change, such as burning fossil fuels (coal, oil, and gas) and cutting down trees(deforestation) [15]. By 2022, the CO_2 concentration in the atmosphere had increased to 50% above its pre-industrial level(before 1750) [4]. Those excess emissions would lead to global warming, and in 2022, the global average temperature is 1.1°C above pre-industrial level [16]. Rising temperatures can cause environmental degradation and lead to natural disasters, such as extreme weather, water and food insecurity, rising sea levels, melting the Arctic, coral bleaching, ocean acidification, and deforestation [11, 15]. The rising temperature is still happening, with no sign of slowing down. Therefore, since the 2015 Paris Agreement, the target to stop the global average temperature from increasing by more than 1.5°C has aroused the public's attention and gained broad consensus and strong backing from science [5, 17]. Cities are one of the main contributors to climate change, and some papers also show faster surface warming trends in the urban than in the adjacent rural area [2, 18, 19]. Higher temperatures correlate with higher urbanization rates in the long run, where this relationship is much more pronounced than any short-term linkage [20]. Staying below the 1.5°C threshold means we need massive decarbonization actions of cities, which will require investments and changes in low-carbon energy supply and transport system [5].

In this context, electrification will be essential to sustainable urbanization and carbon neutrality [9]. Electrification has many applications in urbanization but has only generated low or even zero carbon emissions; for example, using electricity as the primary energy supply, electric vehicles replace fuel vehicles [1, 21]. As mentioned before, we need decarbonization actions of cities. Electric power and transport are two main sectors of energy consumption and carbon emission in cities [22, 23]. Electrification in industrial, transportation, and energy supply could reduce significant carbon emissions from using fossil energy, especially if renewable energy sources generate electricity [18, 24]. Therefore, electrification is a win-win strategy to drive urbanization, deal with climate change, and achieve sustainable development and carbon neutrality [1].

Even though urbanization, climate change, and electrification are popular topics, they are rarely discussed together. While it is widely acknowledged that urban areas contribute significantly to greenhouse gas emissions, more research is needed to quantify these contributions' precise extent and explore the underlying drivers and dynamics. On the other hand, examining the potential synergies and trade-offs between urban electrification and climate change mitigation is needed. While electrification is seen as a pathway to decarbonization, there is a need to explore how different electrification strategies and technologies impact greenhouse gas emissions, energy efficiency, and overall sustainability. These can help build a more profound understanding of the specific impacts of urbanization and electrification on climate change and vice versa.

This paper examines the interconnected dynamics of urbanization, climate change, and electrification. Based on different countries' emission and electrification data, we applied Life Cycle Assessment (LCA) and linear regression to examine the feasibility of electrification to achieve urbanization and carbon neutrality. The research also focuses on presenting the correlation between climate change and electrification more intuitively and the specific impacts of electrification on countries at different levels of development.

2. Method

In this paper, we used LCA and linear regression to analyze. LCA is a systematic and comprehensive method used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle. LCA provides a quantitative analysis of the environmental burdens, resource consumption, and potential impacts associated with a product or system. Linear regression is a statistical modeling technique to establish a relationship between a dependent variable and one or more independent variables. Linear regression is widely used for various purposes, including prediction, forecasting, and understanding the direction and strength of relationships between variables.

We used four types of data for analysis. The first is LCA data on battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEVs). We used this LCA data to compare the greenhouse gas (GHG) emissions of the entire life cycle of electric and fuel vehicles. The second one is the LCA data of electricity sources. We used this data to compare the GHG emissions of different electricity sources. Electric power and transport are two main sectors of energy consumption and carbon emission in cities, and they are also two significant applications of electrification to reduce carbon emissions. We used these LCA data to quantify the actual emissions reduction and then determine the effect of electrification on electricity power and transport. The third and fourth are emissions data and electrification data from different countries. Emissions and electrification data visually represent the country's carbon emissions and the spread of electrification. Linear regression can study the inner connection between carbon emission and electrification and then determine the potential of applying electrification to reduce carbon emissions in the future.

The LCA data on electricity sources are from the United Nations Economic Commission For Europe (UNECE) report. LCA data on electric and fuel vehicles is from the World Bank and International Council on Clean Transportation (ICCT) 's report. The emission data are from the World Bank, Our World in Data, and the Global Carbon Project. The UNECE and ICCT's reports are integrated reports used for international reference, ensuring the data sources are objective and credible. The emission data provides estimates for major countries from 1990 onwards, and the methodology is laid out by Peters et al. (2012). The consumption-based emissions data does not include land use change and only includes energy production (coal, oil, gas, and flaring) plus direct industrial emissions from cement and steel production. The electrification data and electricity consumption data are from the International Energy Agency (IEA) and the World Bank. IEA is an intergovernmental organization that provides energy data and statistics for national energy policies and long-term planning investment in the energy sector, which means IEA provides a comprehensive, accurate, and timely source of global energy data.

Regarding the emissions and electrification analysis of different countries, we divided the study subjects into two groups: developed countries, including the UK, Germany, France, Australia, and the USA, and developing countries, including China and India. Because these two groups of countries are at different levels of development, the degree of electrification is also very different. Hence, the impact of electrification on emission reduction needs to be studied separately. Developed countries are at a high level of electrification (nearly 100% electrified), so we will study the decarbonization of electricity sources and its impacts on carbon emissions. Developing countries are still in the construction phase and implementing electrification, so we will focus on the direct impact of electrification on carbon emissions and construction. Figure 1 is the flow chart of this paper.

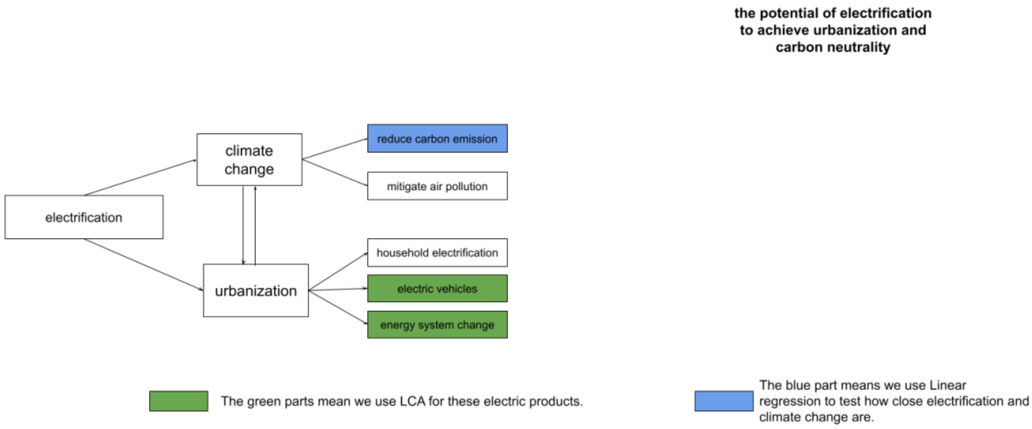

Figure 1. The flow chart of this paper.

3. Results

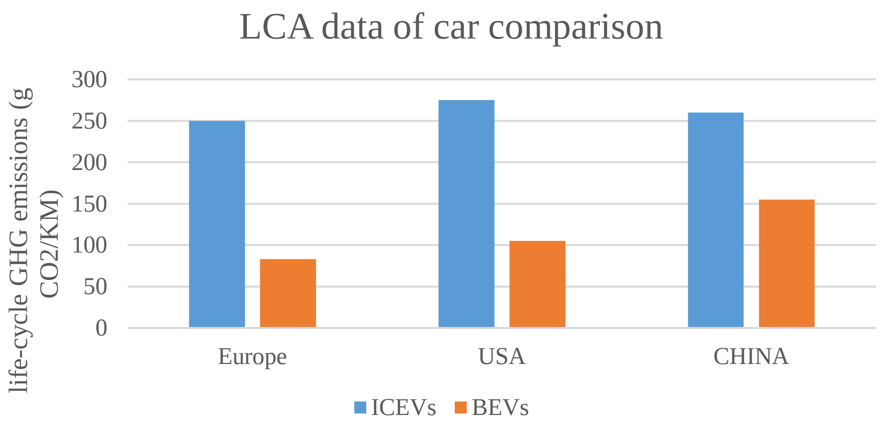

Figure 2. The Green House Gas (GHG) emissions in g CO_2 eq./km of internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs) in Europe, the United States, and China in 2021.

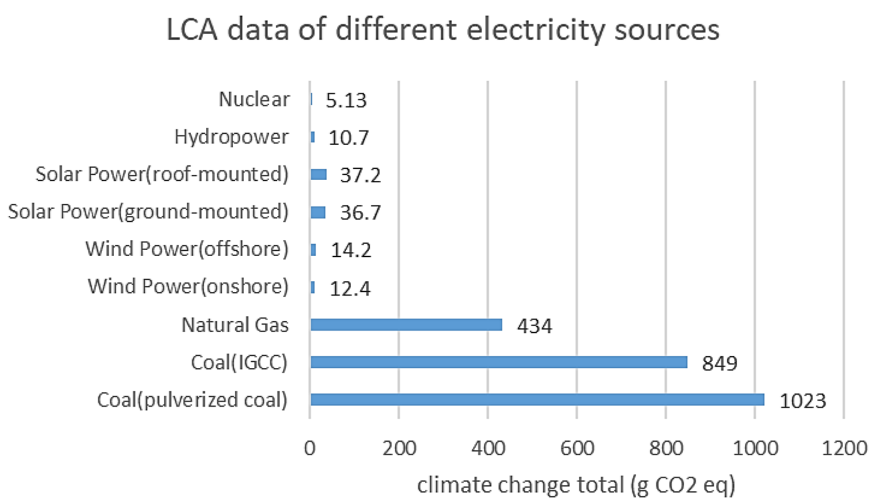

Figure 3. The total Greenhouse gas (GHG) emissions in g CO_2 eq of electricity plants from different energy sources.

Figure 1 shows that the average GHG emissions of ICEVs in different areas are very similar and range from 250-275 g CO2eq./km in China, Europe, and USA. The BEVs today already produce significantly lower average life-cycle GHG emissions, and the average GHG emissions of BEVs in different areas range from 83-155 g CO2eq./km. Now, the BEVs have 42%-67% lower life-cycle GHG emissions than ICEVs. Therefore, the electrification of vehicles can effectively reduce carbon emissions. As the number of electric vehicles continues to increase, there will be a significant reduction in transport-related carbon emissions in the future, which is crucial to achieving the Paris Agreement and carbon neutrality.

Figure 2 shows the average life-cycle GHG emissions of different electricity sources worldwide [23]. The electricity sources include coal (Pulverized coal and IGCC (Integrated gasification combined cycle)), natural gas (NGCC), hydropower, nuclear power, solar power (roof and ground mounted), and wind power. Coal power shows the highest GHG emissions, a minimum value of 849g CO_2 eq./kWh and a maximum value of 1023g CO_2 eq./kWh. They were then followed by natural gas power, emitting about 434 g CO_2 eq./kWh. However, the values of renewable resources range from 5.13-37.2 g CO_2 eq./kWh. Applying them as electricity resources can also significantly reduce carbon emissions. Therefore, using renewable energy as electricity resources can produce low and even zero carbon emissions, which means their carbon intensity value is much lower and even zero.

By now, electrification can significantly reduce the carbon emissions in the major sectors of cities - transportation and energy supply. Considering the increased usage of electric vehicles and a continuously decreasing carbon intensity of electricity (using more renewable energy as electricity resources) in the coming years, the reduction of carbon emissions by electrification will continue to increase. Therefore, the potential of electrification to achieve carbon neutrality is enormous.

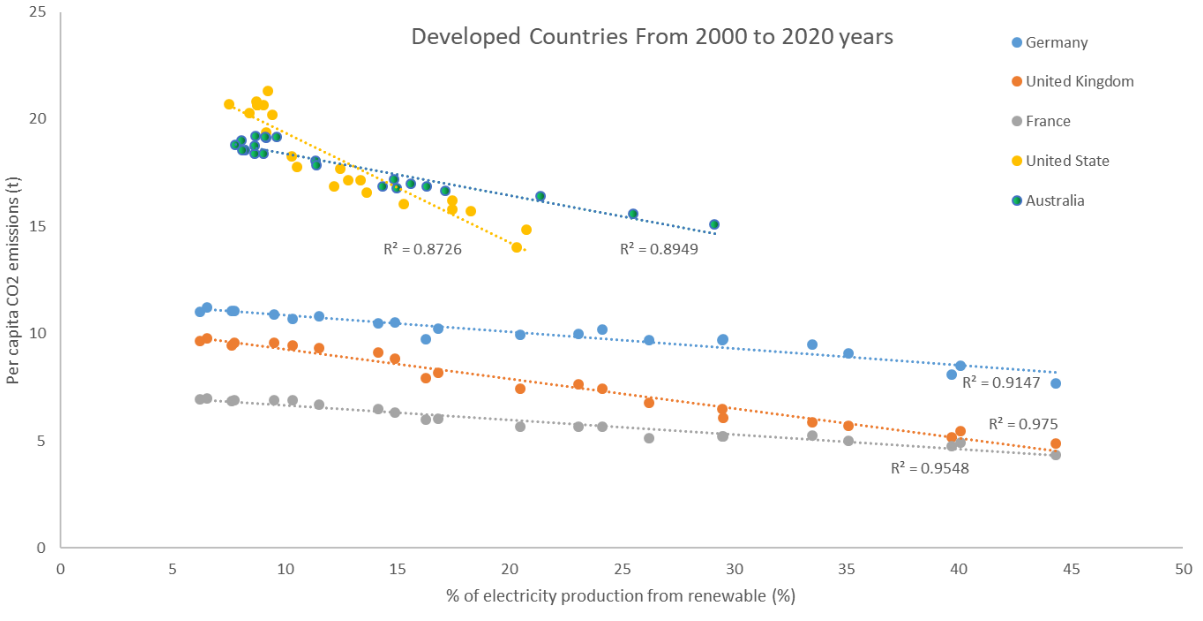

Figure 4. The per capita CO_2 emissions (t) and share of electricity production from renewable resources of developed countries in 2000-2021 (Germany, UK, France, United State, and Australia).

The selected developed countries have a high degree of electrification (nearly 100%), so these countries' focus is applying more renewable resources to electricity resources. Table 1 shows during the period 2000-2021 years, with the increased usage of renewable resources in electricity production, the per capita carbon emissions are decreasing, and all the selected developed countries have the same tendency. Through the linear regression analysis, the R2 value of Germany is 0.92, the United Kingdom is 0.98, France is 0.95, the United States is 0.87, and Australia is 0.89. All the R2 values are higher than 0.5, which shows a very close relationship between carbon emissions and the share of electricity production from renewable resources.

DOI: 10.54254/2755-2721/59/20240763

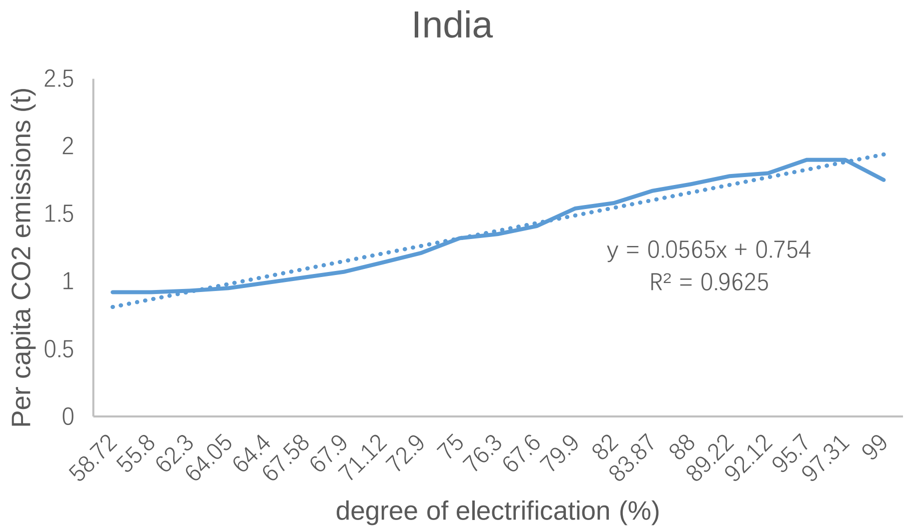

Figure 5. The electrification level and per capita CO_2 emissions of India in 2000 to 2020.

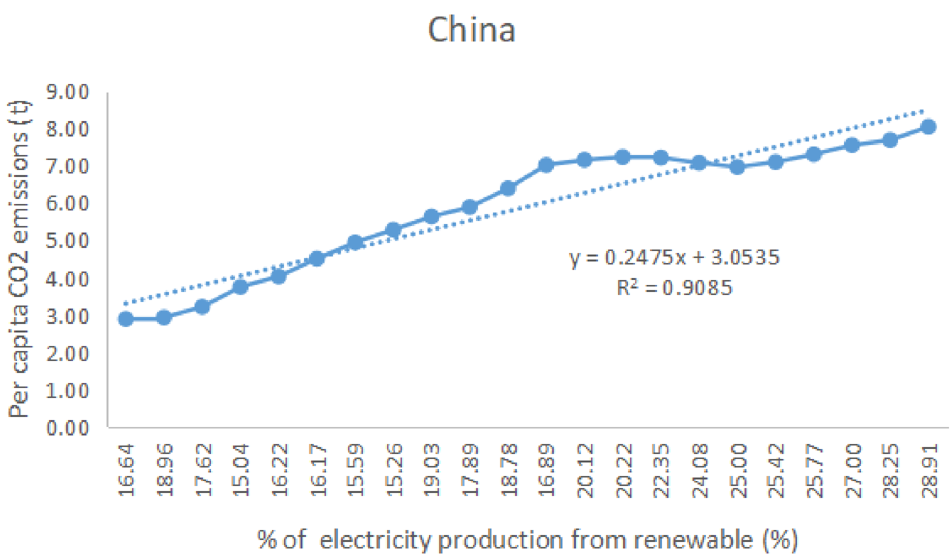

Figure 6. The share of electricity production for renewable resources and per capita CO_2 emissions of China in 2000 to 2021.

In this paper, the degree of electrification refers to the share of people with access to electricity.

However, the selected developing countries show a different tendency. India has promoted its level of electrification from 58% to 99% from 2000 to 2020, significantly improving its urban development and construction. With the increase in electrification, India also increases its per capita CO_2 emissions. China has already achieved a high level of electrification. However, with the increased usage of renewable resources in electricity production, China's per capita CO_2 emissions are still growing, which differs from developed countries' conditions. The difference in development level and industrial structure makes the selected developing countries (China and India) show a different tendency compared to selected developed countries (Germany, UK, France, United States, and Australia). Those developed countries have completed modernization, so their energy efficiency is much higher than that of developing countries. Besides, developed countries' tertiary industry has significantly been developed, so the proportion of industry output has steadily declined. On the contrary, developing countries are still in the stage of industrialization and development. Industrial development is an indispensable driving force for overall development, so the proportion of their industrial output will continue to rise. The increase in industrial output comes with the increased carbon emissions. Therefore, promoting industrial development and maintaining social development will inevitably be accompanied by a significant increase in carbon emissions.

Moreover, the effect of electrification on carbon emission reduction has a time lag effect. Applying electrification will not affect carbon emissions at once but gradually affect it. Although electrification has already been implemented in developing countries, it will still take more time to have an effect on carbon reduction than in developed countries. Therefore, the benefits of electrification in reducing carbon emissions cannot be directly seen in the examples of these developing countries at present.

Therefore, even though electrification can improve developing countries' construction efficiency, it may not directly reduce carbon emissions at present.

4. Conclusion

The LCA analysis shows that renewable energy power plants can significantly reduce carbon emissions while ensuring sufficient energy. Besides, electric vehicles can also considerably reduce carbon emissions compared to fuel vehicles. Therefore, this study indicates that electrification can significantly reduce carbon emissions in cities' transport and energy supply, two significant emissions of cities. Besides, this study shows that the impact of electrification varies across countries with different development profiles. In developed countries, per capita carbon emissions have declined over the past two decades as the share of sustainable energy in power generation has risen. However, in developing countries, because these countries are still in the stage of construction and development, per capita carbon emissions are at a high level in the short term, so the benefits of electrification in reducing carbon emissions cannot be directly seen in the examples of these countries.

There are some limitations in this study. Due to the impact of carbon emission on temperature and the lag of carbon emission data, more relevant data are needed for analysis in the future. Moreover, different countries have different directions and emphases for urbanization construction, but these differences have not been taken into account, so further analysis is still needed.

Based on the results, it is clear that as developing countries become more electrified, their urbanization process is also accelerating. The rate of construction is increasing, which will significantly reduce the time required for construction (i.e., the time needed to reduce high levels of carbon emissions). The growth rate of carbon emissions per capita in these countries will also slow down. In other words, increasing electrification could also help reduce carbon emissions in developing countries. LCA analysis also points out that the two most significant products in electrification, electric vehicles and power plants, have varying degrees of help in reducing carbon emissions. Therefore, electrification can help drive urbanization in the future while ensuring sustainable development and carbon neutrality. This study confirms that electrification is closely related to urbanization and climate change, and electrification can positively affect developing urbanization and mitigating climate change.

References

[1] L. Chandra Voumik and T. Sultana, "Impact of urbanization, industrialization, electrification and renewable energy on the environment in BRICS: fresh evidence from novel CS-ARDL model," *Heliyon*, vol. 8, no. 11, p. e11457, Nov. 2022, doi: 10.1016/j.heliyon.2022.e11457.

[2] Z. Ahmed, M. W. Zafar, S. Ali, and Danish, "Linking urbanization, human capital, and the ecological footprint in G7 countries: An empirical analysis," *Sustainable Cities and Society*, vol. 55, p. 102064, Apr. 2020, doi: 10.1016/j.scs.2020.102064.

[3] H. Liu, W. Cui, and M. Zhang, "Exploring the causal relationship between urbanization and air pollution: Evidence from China," *Sustainable Cities and Society*, vol. 80, p. 103783, May 2022, doi: 10.1016/j.scs.2022.103783.

[4] NOAA logo and National Oceanic and Atmospheric Administration, "Carbon dioxide now more than 50% higher than pre-industrial levels." Accessed: Jul. 22, 2023. [Online]. Available:

https://www.noaa.gov/news-release/carbon-dioxide-now-more-than-50-higher-than-pre-industrial-levels
[5] Alex A., "Why 1.5°C? The crucial climate target explained," Tearfund Australia. Accessed: Jul. 20, 2023. [Online]. Available: https://www.tearfund.org.au/stories/why-1-5-c-the-crucial-climate-target-explained?token=6xzZzAI5CNnWDoUpUcx_8FgMXjxi-d_h
[6] M. Ali, "Urbanisation and energy consumption in Sub-Saharan Africa," *The Electricity Journal*, vol. 34, no. 10, p. 107045, Dec. 2021, doi: 10.1016/j.tej.2021.107045.
[7] H. Xu, T. Zhong, Y. Chen, and J. Zhang, "How to simulate future scenarios of urban stormwater management? A novel framework coupling climate change, urbanization, and green stormwater infrastructure development," *Science of The Total Environment*, vol. 874, p. 162399, May 2023, doi: 10.1016/j.scitotenv.2023.162399.
[8] DASGUPTA S., Lall S., and Wheeler D., "Cutting global carbon emissions: where do cities stand?" Accessed: Jul. 13, 2023. [Online]. Available: https://blogs.worldbank.org/sustainablecities/cutting-global-carbon-emissions-where-do-cities-stand
[9] IEA, "Empowering Cities for a Net Zero Future," 2021.
[10] M. Helbling and D. Meierrieks, "Global warming and urbanization," *J Popul Econ*, vol. 36, no. 3, pp. 1187–1223, Jul. 2023, doi: 10.1007/s00148-022-00924-y.
[11] Y. D. Wei and X. Ye, "Urbanization, urban land expansion and environmental change in China," *Stoch Environ Res Risk Assess*, vol. 28, no. 4, pp. 757–765, May 2014, doi: 10.1007/s00477-013-0840-9.
[12] G. He, J. Lin, F. Sifuentes, X. Liu, N. Abhyankar, and A. Phadke, "Rapid cost decrease of renewables and storage accelerates the decarbonization of China's power system," *Nat Commun*, vol. 11, no. 1, p. 2486, May 2020, doi: 10.1038/s41467-020-16184-x.
[13] R. de B. Ruas, L. M. S. Costa, and F. Bered, "Urbanization driving changes in plant species and communities – A global view," *Global Ecology and Conservation*, vol. 38, p. e02243, Oct. 2022, doi: 10.1016/j.gecco.2022.e02243.
[14] B. Szabó, D. Korányi, R. Gallé, G. L. Lövei, G. Bakonyi, and P. Batáry, "Urbanization decreases species richness, and increases abundance in dry climates whereas decreases in wet climates: A global meta-analysis," *Science of The Total Environment*, vol. 859, p. 160145, Feb. 2023, doi: 10.1016/j.scitotenv.2022.160145.
[15] Nations U., "The Climate Crisis – A Race We Can Win," United Nations. Accessed: Jul. 21, 2023. [Online]. Available: https://www.un.org/en/un75/climate-crisis-race-we-can-win
[16] "ESSD - Global Carbon Budget 2022." Accessed: Jul. 23, 2023. [Online]. Available: https://essd.copernicus.org/articles/14/4811/2022/
[17] J. Rogelj *et al.*, "Energy system transformations for limiting end-of-century warming to below 1.5 °C," *Nature Clim Change*, vol. 5, no. 6, Art. no. 6, Jun. 2015, doi: 10.1038/nclimate2572.
[18] H. Liu, W.-K. Wong, P. The Cong, A. A. Nassani, M. Haffar, and A. Abu-Rumman, "Linkage among Urbanization, energy Consumption, economic growth and carbon Emissions. Panel data analysis for China using ARDL model," *Fuel*, vol. 332, p. 126122, Jan. 2023, doi: 10.1016/j.fuel.2022.126122.
[19] T. Gutu Sakketa, "Urbanisation and rural development in sub-Saharan Africa: A review of pathways and impacts," *Research in Globalization*, vol. 6, p. 100133, Jun. 2023, doi: 10.1016/j.resglo.2023.100133.
[20] Z. Liu *et al.*, "Surface warming in global cities is substantially more rapid than in rural background areas," *Commun Earth Environ*, vol. 3, no. 1, Art. no. 1, Sep. 2022, doi: 10.1038/s43247-022-00539-x.
[21] Z. Yin *et al.*, "Implication of electrification and power decarbonization in low-carbon transition pathways for China, the U.S. and the EU," *Renewable and Sustainable Energy Reviews*, vol. 183, p. 113493, Sep. 2023, doi: 10.1016/j.rser.2023.113493.
[22] G. Bieker, "A GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF COMBUSTION ENGINE AND ELECTRIC PASSENGER CARS," 2021.

[23] United Nations Economic Commission for Europe, *Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources*. in ECE Energy Series. United Nations, 2022. doi: 10.18356/9789210014854.
[24] M. Arbabzadeh, R. Sioshansi, J. X. Johnson, and G. A. Keoleian, “The role of energy storage in deep decarbonization of electricity production,” *Nat Commun*, vol. 10, no. 1, p. 3413, Jul. 2019, doi: 10.1038/s41467-019-11161-5.