

https://dspace.org/

Carbon Footprint Inequality in South Africa

Krinsky, Jezri

2023
University of the Witwatersrand, Johannesburg
https://hdl.handle.net/10539/38711
Krinsky, Jezri. (2023). Carbon Footprint Inequality in South Africa [Master's dissertation, University of the Witwatersrand, Johannesburg]. WireDSpace. WireDSpace. https://hdl.handle.net/10539/38711

Downloaded from a DSpace repository. https://dspace.org/

Carbon Footprint Inequality in South Africa

Jezri Krinsky

2023.02.28

Supervisor: Gilad Isaacs

As the effects of climate change and other ecological crises worsen, numerous attempts have been made to apportion individual responsibility, or ecological footprints, to find effective and just ways to reduce ecological damage. Massive inequalities exist in the responsibility for, and consequence of, ecological damage. So, a just transition must identify how ecologically damaging consumption patterns may be reduced, in ways which do not adversely affect lower-income and other marginalised groups. However, although a significant proportion of carbon emissions may be accounted for in terms of household consumption, these patterns of household consumption are deeply influenced by wider social, political, and economic forces, in larger systems of provisioning. This study estimates and examines the patterns of household carbon footprints within South Africa and explores the link between carbon footprint inequality and income inequality and energy poverty; and how these patterns and links are shaped by systems of provision for carbon intensive consumer goods.

1 Contents

2 Introduction **3**

3 Research Question **3**

4 Literature review **4**

4.1 Carbon inequality 5

4.2 The SoP approach and the limitations of earlier studies 9

4.3 Situating household ecological footprints in the context of wider discourses and paradigms 9

5 Methodology **12**

5.1 Finding the distribution of household emissions based on energy poverty status 13

5.2 Finding the Pseudo-Gini and Kakwani Index 14

5.3 Gini decomposition 15

6 Results **16**

6.1 Carbon inequality and income distribution 17

6.2 Carbon inequality and energy poverty 20

6.3 Carbon inequality and race 22

6.4 Carbon inequality and gender 25

6.5 Spatial distribution of household carbon emission 27

6.6 Carbon inequality and household size 31

6.7 Carbon inequality by product category 32

7 Systems of provisioning **34**

7.1 Electricity SoPs 35

7.2 Road-Based Transport SoPs 37

8 Policy Implications **39**

9 Conclusion **40**

10 References **42**

11 Appendix A **47**

12 Appendix B **52**

2 Introduction

Although developed countries have historically been responsible for the greater proportion of greenhouse gas emissions, developing countries have recently begun to account for a more significant proportion of emissions, particularly driven by industrialisation in East Asian countries (Seriño, 2017).[1] The proportion of emissions from developing countries is expected to grow (Jakob, Haller & Marschinski, 2012). South Africa emits a significant amount of CO_2 per capita for a developing country, although a large portion of the carbon emissions from production in South Africa go to exports. In fact, South Africa produced 44% more carbon emissions than were consumed domestically in 2020 (Our World in Data, 2022). Household consumption accounts for a majority of carbon dioxide emissions for many countries from 1990-2014. For example, in 2014 household final consumption accounted for 54% of carbon emission in India, 77% of emissions in Germany, 85% in the UK and 76% in Vietnam. One notable exception was China, where fixed capital formation accounted for a much larger proportion of total emissions (Duan et al., 2022). Household carbon footprints are therefore an important issue to assess although analysing "carbon footprints" does ignore many other types of unsustainable ecological damage. Despite this, analysing carbon footprints is important for reducing the damage of climate change, arguably the most urgent and potentially destructive environmental crises. Thus, finding ways to reduce the carbon intensity[2] of the South African household consumption economy, without jeopardising poverty reduction, is important for sustainable development and climate justice.

The empirical work within this study can be split into two parts. The first involves estimating the carbon footprints of a sample of South African households. The second involves examining the distributions of these households' carbon footprint and estimating various measures for the carbon footprint inequality of South African households. For these estimates I have used the

[1] Wiegratz et al., (2023) Argue that theoretical understandings of North South inequalities and power relations remain relevant within development economics. While it may be difficult to determine a rigid binary between global North and global South states, the distinction nevertheless highlights an important structural inequality within the global economy, which has resulted from both colonial and neocolonial historical processes. The terms developed and developing countries are often used within research on carbon inequality to understand this division.

[2] The carbon intensity is the amount of tons of carbon dioxide emitted per unit of real GDP

2014/2015 Living Conditions Survey (LCS) (Stats SA, 2015) and estimates of carbon intensities of consumer goods from Arndt et al (2013).

3 Research Question

This study asks the central question: how are South African consumption patterns shaped, creating a society where household needs are met in extremely carbon intensive ways, yet due to inequality many households do not have access to carbon-intensive goods to meet even their most basic needs? I will answer this question through estimating and examining empirical measures of the carbon footprint distribution and inequality among South African households according to income, location, education levels, household size, gender and race of household heads, and incidents of energy poverty. In a later section I will use the systems of provisioning (SoP) framework to examine how this distribution is shaped by the contested systems of provision for carbon-intensives goods such as electricity and transport, drawing together earlier research to examine how these inequalities are linked to wider systems of production and accumulation. Finally, I will examine the policy implications of this research to discuss what consequences it has for paths towards a just transition in South Africa.

In this thesis I will estimate the inequality and distribution of household CO_2 emissions in South Africa. This is important, because it shows directly how carbon emissions are used to meet basic needs, such as lighting and heating, and how carbon emissions are used to provide for luxury consumption. Such research can inform the search for viable ways to significantly reduce national emissions while maintaining or expanding provision of goods and services to meet basic needs.

Introducing the systems of provisioning approach allows the analysis to move beyond a narrow focus on individual household consumption choices and the redistribution of goods currently provided to examine more systemic ways in which household's needs could be met through less carbon-intensive goods. The systems of provisioning approach examines how demand for goods and services is often shaped by contested and contradictory relationships rather than simple neoclassical market interactions between consumers and suppliers.

4 Literature review

Numerous types of inequality form barriers to sustainable development, many of which are closely related to each other. Measures of inequality can focus on different units of analysis, from inequality between households to inequality between nations. They can also differ in terms of the resources that are being allocated, like income inequality, wealth inequality, or inequality in ecological footprints. Historical discussions around the responsibility for carbon emissions have centred on levels of national responsibility related to emissions due to production within the country. However, as emissions may be embodied in traded goods (with wealthy and more powerful nations often importing carbon-intensive goods from global value chains, which results in pollution in the global South) an alternative framework focusing on consumer responsibility has been developed (Starr et al., 2023). This consumer-based framework can also be used to understand the distribution of carbon footprints between households.

Much of the literature on environmental inequality uses the environmental Kuznets curve hypothesis as a framing question, either to prove or disprove. The environmental Kuznets curve emerged as a theory around wealth, modernisation, and environmental degradation. The original theory suggested that up to a certain point national GDP would correlate with increasing environmental degradation, but that beyond that point further GDP growth would in fact be related to reduced environmental degradation. Within the literature on household carbon emissions, an analogous claim is tested: that as household income increases it corresponds to first increasing and then decreasing households carbon emissions. This claim is rejected by the literature on household carbon emissions discussed below. Although Starr et al (2023) show that the elasticity of carbon emissions to income tends to fall with income, as poorer groups often use additional income to purchase carbon intensive essentials. Nevertheless, the environmental Kuznets curve hypothesis provides a convenient narrative for hegemonic groups which echoes many earlier theories linking marginalised groups to environmental degradation.

In this literature review, I will begin with a narrow focus on the limited research which has dealt with household-level carbon footprint inequality. I will discuss the methods used in these papers and the conclusions which emerged from them. After this, I will examine the broader context of research around the intersections of inequality and environmental degradation discussing central themes, and key narratives within historical academic discourses. These include many earlier

theories which overemphasise poor groups' responsibility for environmental destruction and are not generally supported by empirical work on a household level. I believe that this is important to include as it identifies many of the key political and academic narratives which persist and present a distorted understanding of the relationship between inequality and carbon emissions.

4.1 Carbon inequality

While the literature on the links between inequality and CO_2 emissions is extensive, only a handful of studies have focused on household-level CO_2 consumption inequality (Seriño, 2020). This includes studies in the Philippines (Seriño, 2020), Indonesia (Irfany and Klasen, 2016), the United States (US) (Starr et al., 2023), and China (Yang and Liu, 2017). A considerably larger body of literature focuses on emissions inequality between countries, or on the links between national income inequality and national emissions.

The results from previous studies in other countries show that high-income households consume a significantly greater number of carbon-intensive products. This does not support the hypothesis put forward by the environmental Kuznets curve on a household level (that beyond a certain point higher incomes will lead to a decrease in environmental degradation). The theoretical origin of the environmental Kuznets is explored in more detail in the section below. Here I will focus on how it relates to the findings of household level studies on emissions inequality. Seriño (2017) estimated that in the Philippines the wealthiest 20% of the population accounted for approximately half of all household carbon consumption while the poorest 20% accounted for between 5% and 10% of CO_2 emissions. Irfany and Klasen (2016) found similar levels of inequality in Indonesia, and Yang and Liu (2017) also find similar results when studying the income distribution of direct carbon consumption in three Chinese cities. The same is true at a national level. Rises in national income results in increasing national carbon footprints. Even if a turning point exists, it would be at such a high national income level that it is of little relevance to discussions about sustainable development (Seriño, 2017). Starr et al. (2023) pay special attention to very high-income earners, arguing that they are often under-sampled in survey data and, consequently, that they are often under-accounted for in input output(IO)-based models of carbon distribution. They find high levels of carbon footprint inequality among US households focusing on the effects of both income and race on a household's carbon footprint. However,

they find that carbon emissions are significantly less unequally distributed than income, a result similar to my own.

Seriño (2020) finds that urban households have considerably higher emissions than rural ones; that households with a head between 30 and 60 years have much higher emissions than for other age groups; and that high income levels for the household head increase household emissions. However, the degree to which these classifications overlap with classifications of households by income is unclear. Irfany and Klasen (2016) also break down emissions by gender of household head and find that male-headed households have slightly higher consumption. Yang and Liu (2017) examine only direct carbon emissions from energy use. They find that transport is a major component here, along with heating in Northern Chinese cities. In addition, they examine how social factors such as lifestyle, habits, and attitudes effect energy consumption, showing that the belief that household emissions have an effect on the environment does reduce household emissions.

Additionally, Kensett (2021) wrote a short blog post analysing carbon footprint distribution in South Africa using data from the Stats SA 2010/2011 Income and Expenditure of Households survey and research by Arndt, Davies, Makrelov, and Thurlow (2013). Kensett finds high levels of carbon emissions inequality in South Africa similar to my own results, arguing that "households that fall into deciles 9 and 10 will need to reduce their emissions by roughly 50 and 75 per cent, respectively, should they want to reach their 'fair share' amount of emissions. This will involve fundamentally changing consumption patterns and making deliberate choices to reduce wasteful and unnecessary consumption" and that "we should, therefore, not misconstrue increased per capita emissions for poorer households as a failure to meet our climate goals per se. Doing so would be unfair." My research shares this policy conclusion. However, the blog post does not analyse inequality by race, gender, location, or settlement type and does not link this to a more detailed analysis of carbon-intensive systems of provisioning within South Africa.

These studies used IO analysis to estimate ecological footprints. This can be done with carbon emissions, as in the studies above, or with other ecological footprints such as land and water footprints (Ivanova et al., 2016). This method begins with estimating the direct carbon emissions for each industry in the IO table per unit of value produced. However, many goods require processing in long value chains by multiple industries before reaching consumers. This can be

captured through simple linear algebra combining the estimated carbon intensities of the industries with the IO table, to find the carbon intensities of final consumer product categories. This method estimates the household footprint of a sample of households by matching the goods and services they consume with the carbon intensities of various categories of consumer goods found in the previous step.

The IO approach for estimating household ecological footprints has a number of shortcomings, including:

- The IO approach does not consider the quality of items. As wealthier households may purchase fewer, higher-quality items. This may generate systemic bias if higher-quality items are either more or less carbon intensive per unit of currency, within the consumer categories used. Starr et al. (2023) estimate that this may mean that IO analyses overestimate the carbon consumption of high-income households for many goods categories by between 5% and 10%. However, they limit this claim for a wide range of goods purchased by high-income, super-emitter households which purchase very carbon intensive goods such as air and yacht travel, and maintenance and electricity on large homes or multiple homes.
- It frequently does not disaggregate between domestic and foreign production and approximates import carbon intensities using domestic values. The carbon intensity of many goods varies significantly depending on where it was produced, which is not accounted for if only domestic carbon intensity coefficients are used for all consumption. This could be overcome using a multi-regional IO model, but this would require more detailed consumer information (Seriño, 2017).

Despite these limitations, the IO method for estimating household carbon footprints remains a useful and widely used method for analysing carbon footprint distributions. Further, it has benefits over other common methods for estimating household carbon emission, which commonly overestimate household carbon footprint inequality.

Another method for estimating household carbon footprint inequality is using a ‘top-down approach’ based on income data, national levels of carbon consumption, and estimates of the income elasticity of carbon emissions. An example of this method is Chancel and Piketty (2015).

However, Starr et al. (2023) argue that these studies tend to overestimate levels of carbon footprint inequality as they use high estimates of income elasticities for carbon footprints and overlook that income elasticities for carbon footprints may differ substantially over different income ranges.

Additionally, earlier studies on household emissions inequality examined other potential causal variables, as well as disaggregating the inequality by consumption category. Seriño (2020) finds that emissions are driven largely by fuel, lights, transport, and animal agriculture consumption. Expenditure on food tends to have reduced emissions inequality while consumption of fuel, lights, and transports tends to increase it (Irfany and Klasen, 2016).

4.2 The SoP approach and the limitations of earlier studies

These earlier studies generally understand households' carbon consumption and carbon inequality as determined by households spending their income to consume goods and services of various carbon intensities, with a limited amount of social contestation introduced in the idea of a welfare state or a regulatory state being able to curb the excessive inequality and pollution generated by the market. When discussing racial carbon inequality in the US, Starr et al. (2023) argue that "economic inequality spills over into emissions inequality" without any consideration for aspects of racial carbon inequality which may be created through specific contestations over carbon-intensive goods and services such as transport systems. Seriño (2017) writes: "While household consumption is a matter of private choice and imposing restrictions on what households will consume is rather inappropriate, it is, nevertheless, not meaningless to raise households' awareness about consumption choices that are carbon intensive." These examples show that patterns of carbon-intensive consumption are only viewed as a political choice of the state when the focus is on reducing inequality and environmental degradation. They largely overlook how almost every aspect of the economy shaping households' access to carbon-intensive goods is the result of politically and economically contested social relationships both within and outside of the state, determining who has what access to transport and electrical infrastructure, and determining who can displace who to make way for transport and electricity infrastructure.

4.3 Situating household ecological footprints in the context of wider discourses and paradigms

Social belief about which consumption production, distribution and accumulation patterns drive environmental degradation is deeply tied to how society collectively responds to threats of environmental destruction. Discourse about environmental degradation is often highly contested, economically and politically motivated, and shaped by hegemonic paradigms within government institutions, academia, corporations, philanthropic organisations, and general social opinion.

Numerous theories have emerged which over emphasise the environmental degradation caused by marginalised groups and distract from the environmental degradation caused by groups with some degree of hegemonic power. When used to advise policy, these theories can worsen inequality by denying poorer communities rights. This results in limited access to essential resources at affordable prices, as efforts to reduce social environmental degradation (as well as their costs) are targeted at marginalised groups (Fakier, 2018). In relation to carbon emissions, this could be seen through increasing energy costs to prohibitive levels or providing lower quality renewable infrastructure to poor households to reduce their energy consumption in a targeted manner. Additionally, load reduction (a policy of cutting power to areas, in excess of load shedding schedules which is justified to counter a number of threats to grid infrastructure such as illegal connections) worsens unequal energy access (although this is not legitimised through environmentalist rhetoric). Pressure on these groups to change their behaviour to reduce their environmental impact often pales in comparison to the significant change needed by more powerful groups that may emit far more (Ojeda, Sasser and Lunstrum, 2020).

These narratives include Malthusianism, Neo-Malthusianism, settler colonial environmentalism, and the Kuznets's curve. In addition, a hyper fixation on the cooking practices of poor and rural communities, while not in itself constituting a complete discourse, has often been criticised as being part of these larger discourses (Simon & Peterson, 2019). In practice, these theories are often intertwined and overlap.

Many of these theories, particularly earlier ones, emerged with a central focus on the conservation or degradation of arable land, for example Malthus (1872) and Ehrlich (1978).

However, partly due to the green revolution, they are now more frequently re-articulated with a focus on other more current types of environmental degradation (Ojeda et al., 2020).

Environmental arguments are often framed around concepts which superficially appear as unbiased, apolitical condemnations of the whole of humanities' interaction with the environment. This is paired with a second layer containing a wide collection of chauvinist characterisations of different groups of people. This is similar to the way wider racial discourses within liberalism are often dependent on an internally contradictory but politically useful set of both race-blind and racialised discourses (Bloch, Taylor, and Martinez, 2020).[3] For example, the concept of the Anthropocene argues that humanity as a whole is responsible for a negative transformation of the global ecosystem (Moore, 2017). However, in parallel, marginalised groups are vilified as uncaring, inconsiderate, wasteful, uninformed, and primitive in their relationship to the environment (Sasser, 2014). By contrast, dominant groups are characterised as rational, innovative, investing in environmental conservation, well-informed, abstaining, and entitled to resources (Erickson, 2020) .

Malthusianism emerged as an early discussion of the way class society was shaped by limited natural resources which focused heavily on the role of population growth. The theory linked poverty and famine, particularly in capitalist peripheries, with natural tendencies for any surplus to result in population growth, particularly among poor classes. However, the theory, as articulated by Malthus, often lacked a clear focus on environmental preservation. Rather than centring marginalised classes' responsibility for environmental degradation, Malthusianism is more worried about marginalised groups' responsibility for their own poverty, malnutrition, and starvation as well as the inevitability of these despite the best intentions of dominant groups. However, it provided a basis for later theories on the interaction between societies and limited natural resources. This either ignored or side-lined inequality and distribution of ecological footprints or suggested that these were frequently inversely to related income and social hierarchy.

Neo-Malthusianism is perhaps the most widely known modern articulation of these theories. This theory places a central concern on population growth as a driver of environmental degradation. The theory again focused heavily on agricultural systems but also included a few

[3] Here race-blind discourses serve to delegitimise claims of racial discrimination and oppression.

other scarce resources. The theory gained significant influence and popularity, leading to numerous violations of reproductive rights in an attempt to control population growth.

Groups who can afford to geographically displace their environmental impact are treated as if they have a lower environmental impact and a greater concern for the environment. People often consume goods with high environmental impacts that are produced in other regions or countries. Further, a wide collection of waste products is systematically removed from wealthy and powerful areas, whereas poor or less powerful areas often cannot afford the same services. Sometimes the waste is actually moved to poorer areas, such as in the case of paying developing countries to import garbage from wealthier countries. Again, this often leads to a false narrative surrounding social values of care for the environment. This is intertwined with a comparison between post-industrial regions in the global North with industrial regions in the global South (although emissions embodied in international trade make up a relatively small portion of national carbon footprints from consumption).

The environmental Kuznets curve represents a more sanitised, abstract mathematical depiction of what are essentially the same beliefs. The environmental Kuznets curve is a hypothesis which argues that environmental quality increases within a country up until a certain income per capita, but then decreases as wealthy countries manage to improve their environmental quality through a collection of possible causal mechanisms(Grossman & Krueger, 1995). Discussion of the environmental Kuznets curve in mainstream economics journals has been quite limited. The hypothesis was initially developed in Grossman & Krueger, (1995), in relation to the expected effects on both economic growth and environmental consequences of NAFTA. Although such studies have included a degree of economic and political complexity contesting simple understandings of economic growth, trade liberalisation, and environmental policy making, they have not included complex models of ecological systems but relied heavily on measurements of a limited range of local air and water pollutants. Further, any positive relations within these limited environmental qualities have been shown to rely heavily on increasing environmental regulation rather than economic liberalisation (Erb, 2018)[4].

[4] This finding acts as a direct critique of Grossman & Krueger, (1995), as their work argued that growth resulting from NAFTA would have positive environmental effects, even though the agreement contained no environmental regulation, and there were concerns it would result in a race to the bottom of national environmental regulations.

Within the Environmental Kuznets Curve literature growth is linked to eventual improvements in environmental quality through changing consumer preferences and technological improvements. However Leal & Marques, (2022) suggest that although technological improvements may play an important role in environmental mitigation particularly in high income countries, the actual pace of technological innovation may be far below the level necessary to ensure sustainable growth, and further that the theory relies on the assumption that degraded ecological systems can be restored after high levels of growth.

In conclusion, IO-based analyses of national household ecological footprint inequality have been widely used to understand the distribution of a wide range of ecologically harmful consumption patterns. While these analyses often link to discussion of inequality, they do not often engage fully with the political discourse analysing and recreating environmental inequality. Further, they often do not engage in a systematic way with the wider systems of provision which drive these ecologically damaging household consumption patterns.

5 Methodology

In this section I will explain how I derived the empirical measures of carbon footprint distribution among South African households. First, I will discuss the data sources which I used. Next I will explain how the carbon footprint for each household in the sample is estimated. After estimating the carbon footprints, I will use the estimate to show how carbon footprints are distributed among the South African households according to income, location, education levels, household size, and gender and race of household heads, and the energy poverty status of the household. Further, I will use this to calculate the pseudo-Gini coefficient of carbon footprints within South African households, which measures the inequality of carbon footprints ranking households by income level. After this, I will find the carbon Gini coefficient and decompose this to show the contribution of different product categories to the overall carbon Gini coefficient.

5.1 Data

To examine the distribution of household carbon footprints among South African households, this study has combined consumer expenditure data from the 2014/2015 Living Conditions

Survey (LCS) (Stats SA, 2015) and estimates of carbon intensities of consumer goods from Arndt et al (2013). The expenditure data is from 2014 to 2015 while the carbon intensity data is from an input-output analysis using data from 2005.

The Data from the 2014/2015 Living Conditions Survey, includes a suggested weighting for each household in the sample, using these I estimated the population level carbon distributions based on the sample used in the sample. These waiting take into account household size.

Arndt et al (2013) estimates, are based on detailed supply and use tables(broken down into 104 products), as well as energy balance tables from statsSA for 2005. The estimates remain useful although the carbon intensity of the South African economy has fallen since 2005, as the energy intensity[5] of GDP has declined from 2.88 Kwh/$ in 2005 to 2.11 Kwh/$ in 2018 while the carbon intensity of energy has remained relatively stable at just over 0.3 Kg of Co2/ Kwh (Our World in Data, 2022). This means that the 2005 estimates will not give an exact picture of the current carbon intensity of different sectors, but will remain useful in approximating more recent distributions of household carbon footprints. Newer estimates of the final carbon intensity of different categories of consumer products for South Africa are not available and I have not calculated these in this study. However, calculating newer estimates from IO tables and estimates of the carbon intensity of different industries in South Africa would form a useful addition to the current study.

5.2 Estimating Household Carbon Footprints

A household's carbon footprint is defined as the sum of both direct carbon consumption from energy use and transport, as well as indirect carbon consumption through buying goods and services which required carbon emissions for their production (Irfany and Klasen, 2016). This is found by multiplying the amount of money spent by a household on different products in the LCS with estimates of the carbon intensity of different industries. Goods were categorised differently in the LCS and the research by Arndt et al (2013). The table in appendix A shows how I assigned carbon intensities to various consumer categories.

[5] Energy intensity is the amount of energy used per real unit of GDP in an economy

5.3 Finding the distribution of household emissions based on energy poverty status

Energy poverty is the condition of not having access to enough clean energy to meet basic household needs. Clean energy commonly refers to electricity as opposed to other energy sources such as firewood, coal, or paraffin, which can result in significant indoor pollution and cause or worsen numerous health conditions (often with a disproportionate effect on women and children). Additionally, fires used to meet basic household needs have resulted in high levels of injury and death within South Africa (Ledger and Rampedi, 2022).

Energy poverty is also tightly linked to other forms of poverty. Energy poverty often reduces a household's ability to engage in income-generating activity. Job searching activities, education, and numerous micro-enterprises require energy access. Further, energy access can significantly reduce the time required for household work and fuel collection, allowing for more time to be spent on income-generating activities within households. Due to the gendered distribution of household work, this may be particularly important for women's ability to engage in income generating activity. Energy poverty is also closely linked to food poverty. This link occurs in two primary ways. The first is the result of substitution, as poor households reduce spending on nutritious foods to afford basic energy requirements. The second link occurs because energy is directly required for the storage and preparation of nutritious and affordable foods. Access to refrigeration allows households to purchase more fresh produce, which is often more affordable and nutritious than alternatives such as tinned foods.

Energy poverty is often defined by examining the percentage of household income used to purchase energy, often set at either 5% or 10%. However, this definition cannot be used to understand energy poverty in households where energy demand is low because household income is largely spent on meeting other basic needs, such as food or housing.

Another option is to determine an absolute level of electricity consumption which households require to alleviate poverty and meaningfully enable development. Such measures do create some difficulties, as household needs differ substantially (for example, the need for climate control for health varies substantially with geography). Numerous measures exist which use unrealistically low measures. These can be the result of using the existing (inadequate) energy

consumption of poor households as a baseline or basing the calculations of a bundle of electrical appliances too small to meaningfully enable households to escape from poverty.

Studies in South Africa show that 200 kilowatt-hours per month is the minimum necessary amount of electricity required. I used this definition in my research to determine the energy poverty of households.

5.4 Finding the Pseudo-Gini and Kakwani Index

The pseudo-Gini coefficient is a measure of how unequally household carbon emissions are distributed when ranked by household income. It can be calculated using the following formula:

$$pG(c) = \left[\frac{2\sum_{i=1}^{N} ic_i}{N\sum_{i=1}^{N} c_i}\right] - \frac{N+1}{N}$$

Where:

- c_i is the carbon footprint from the i_{th} household order by consumption (not ordered by carbon footprint)
- N is the number of households.

The Kakwani index is simply the difference between the pseudo or quasi-Gini coefficient of emissions and the Gini coefficient of income. This can theoretically range between -1 and 1. A positive Kakwani index shows that carbon footprints are less equally distributed than income while a negative result shows that they are more equally distributed.

I will use the pseudo-Gini index for direct comparison with income inequality. However, when I decompose the measure of carbon footprint inequality into product categories, I will use the Gini coefficient of carbon emissions (that is ordered by the carbon emissions of households, rather than household income). This is the approach adopted by previous studies analysing household carbon footprint inequality.

5.5 Gini decomposition

Additionally, I will decompose the Gini coefficient for household carbon consumption to show how inequality in consumption from different product categories contributes to the overall inequality in household consumption according to a method described in Seriño (2020). This allows me to isolate the most important product categories to examine in greater detail which explain the patterns of overall carbon-footprint consumption. The total carbon consumption Gini Coefficient is related to the product-specific carbon consumption Gini Coefficients according to the following formula:

$$G(cf) = \sum_i S_i R_i G(cf)_i$$

Where:

- $G(cf)_i$ is the Gini Coefficient of carbon consumption from the i^{th} product category.
- S_i is the share of total carbon consumption due to the i^{th} product category.
- R_i measures how similar household ordering is for carbon consumption for the i^{th} product category compared to total household carbon consumption. It is defined as $R_i = \frac{Cov(cf_i r)}{Cov(cf_i r_i)}$ where, cf_i is the emissions from the particular source, r is the rank of overall carbon footprints, and r_i is the rank of carbon footprints form the i_{th} product category.

To calculate the Gini coefficient of household carbon footprints (both for individual products and for total footprints) Seriño (2020) and Irfany and Klasen (2016) use the following formula:

$$G(cf) = \frac{2\sum_{i=1}^{n} icf_i}{n\sum_i^n cf_i} - \frac{n}{n+1}$$

However according to Lerman and Yitzhaki (1989) this formula is unsuitable to estimate the Gini coefficients using sample data with weights. Without including suggested waits the results show the Gini coefficient of the Sample, not an estimate of the Gini coefficient of the population.

I, therefore, instead used the formula suggested by Lerman and Yitzhaki (1989):

$$G(cf) = \frac{2\sum_{i=1}^{n} w_i\left(cf_i - \bar{cf}\right)\left(\hat{F}_i - \bar{F}\right)}{\bar{cf}}$$

Where:

- cf_i is the carbon footprint of the i^{th} household and bar.
- $\bar{cf}$ is the mean of cf
- w_i is the weight of the i^{th} household and bar.
- $F(y)$ is the cumulative distribution of cf.
- $\hat{F}_i = \sum_{j=0}^{i-1} \frac{w_j + w_i}{2}$
- w_0 is defined as 0.

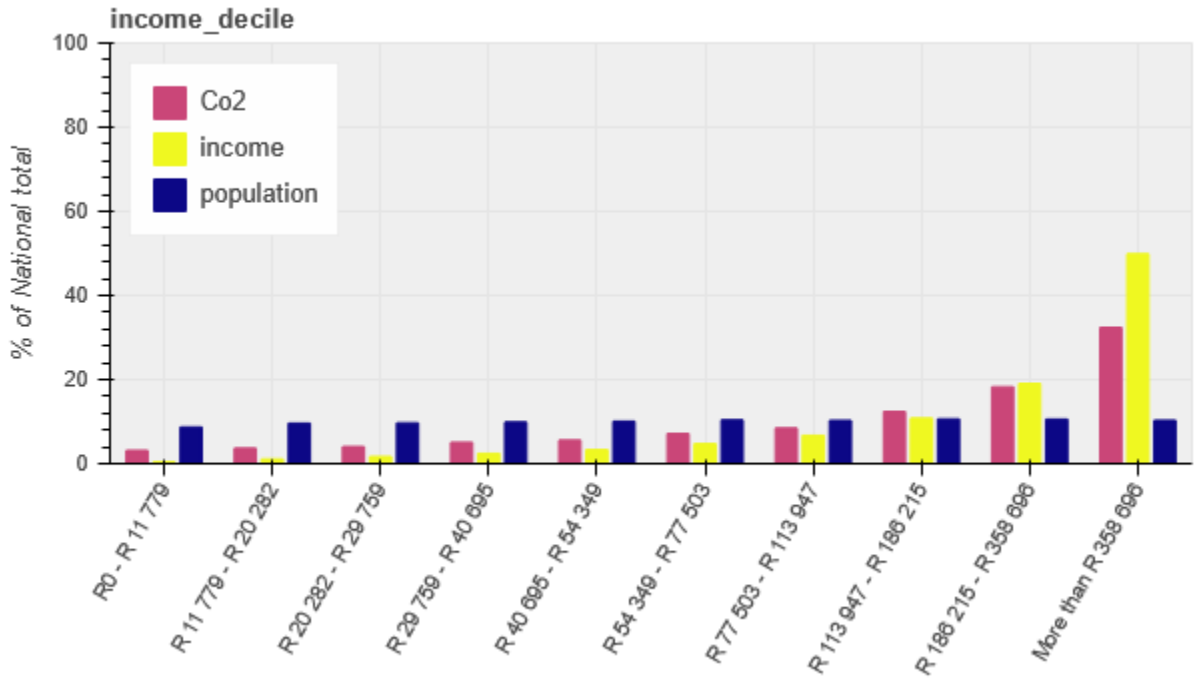
6 Results

I will begin this section by presenting the aggregate statistics for carbon footprint inequality and its relationship to income inequality. These include the pseudo-Gini coefficient of carbon emissions as well as the Kakwani index which measures how tightly linked carbon footprint inequality and income inequality are, and the measure of carbon emissions by income decile. I will also examine how unequal carbon consumption is related to energy poverty as unequal access to carbon intensive goods such as electricity drives widespread energy poverty in South Africa. Following this, I will examine the distribution of carbon emissions and household

income, by a variety of other demographic categories, including sex and race of household head, and energy poverty status of the household. Finally, I will examine how the pseudo-Gini coefficient is disaggregated by consumer product category.

6.1 Carbon inequality and income distribution

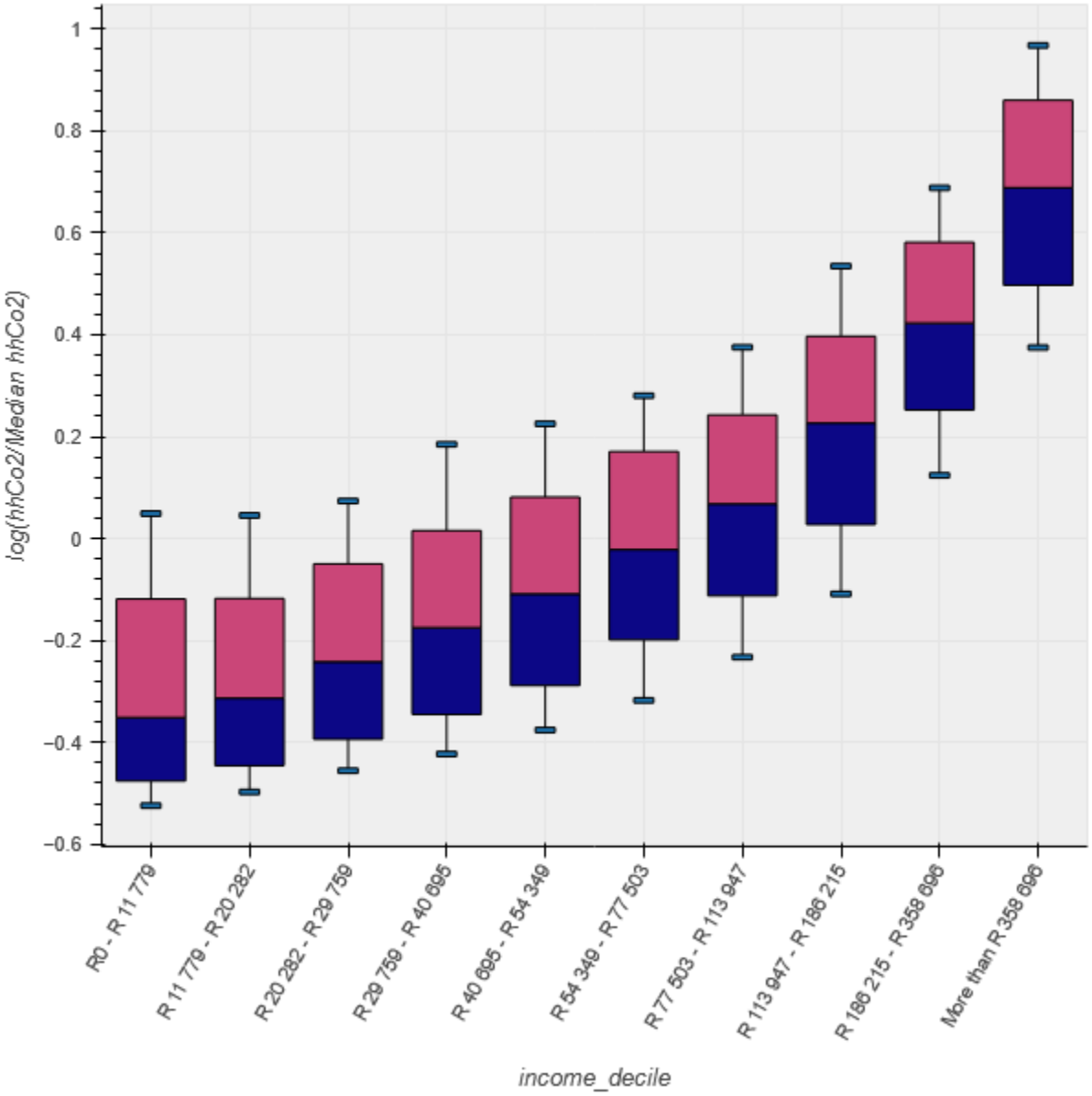
Figure 1a: Percentage of National Consumption Carbon Footprint by Income



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 1a breaks down the unequal distribution of carbon consumption by income deciles. The wealthiest 10% of South Africans account for over 30% of carbon emissions due to domestic household consumption.

Figure 1b: Percentage of National Consumption Carbon Footprint by Income



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 1b shows the distribution of carbon footprints within income categories. I have chosen to use a logarithmic scale (base 10) on the y axis to make it easier to visually compare results with a large range. All boxes and whiskers have similar heights, which should be interpreted as having similar ratios between the upper and lower quartile and between the maximum and minimum household carbon footprints within each income group. Here within each income group households at the 75% percentile consume between 2 and 2.5 times the amount of carbon as

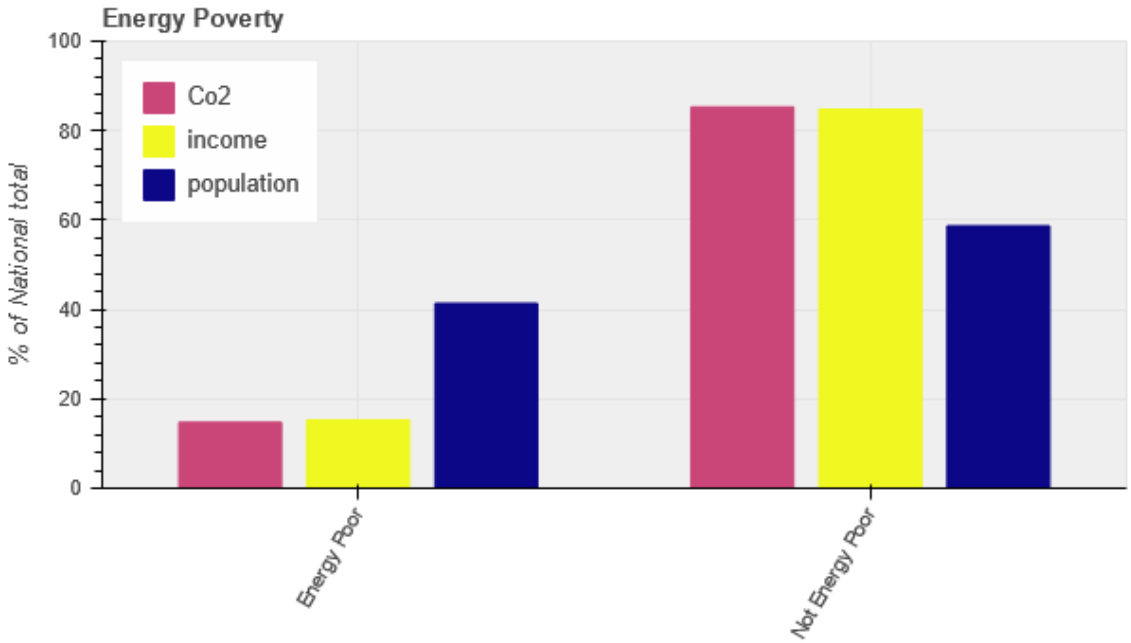
households at the 25% percentile; while the maximum carbon footprints within each group are between three and four times the minimum carbon footprints within the group.

The pseudo-Gini coefficient for the CO_2 consumption of South African households for the 2014 to 2015 period is 0.676.

6.2 Carbon inequality and energy poverty

Additionally, access to carbon-intensive goods and services (particularly electricity and fossil fuels) may drive income inequality, rather than just be affected by it. Energy access can form a vital part of many income generating activities, such as job searching or microenterprises, as well as education. South Africa's long history of unequal access to such goods, and current high levels of energy poverty and unequal access, keep many households trapped at low income levels.

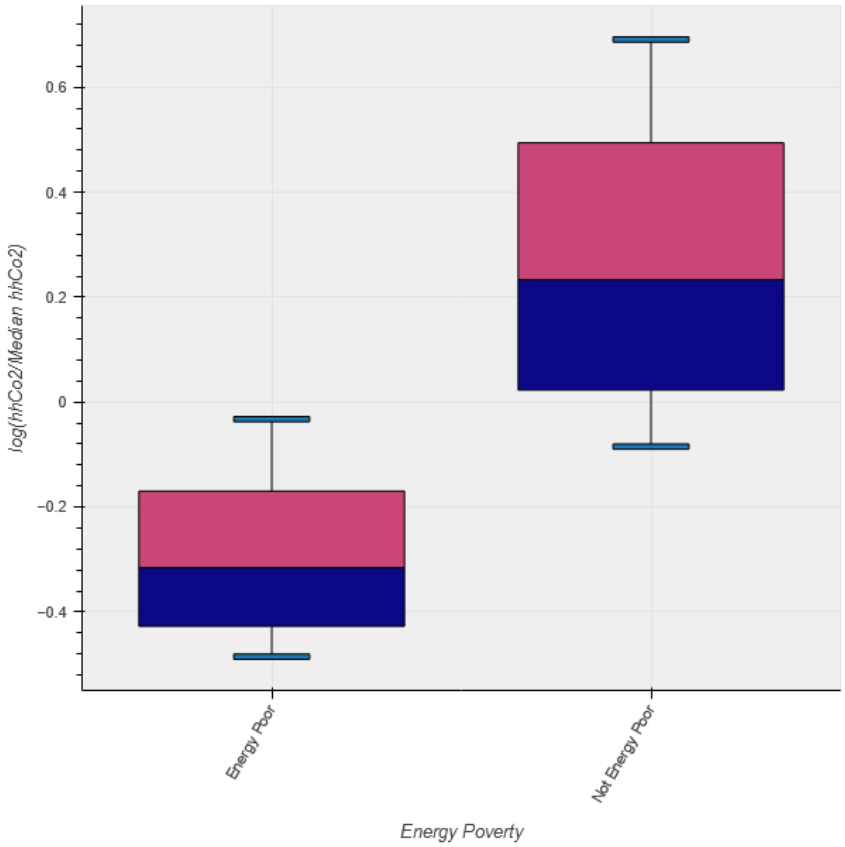
Figure 2a: Carbon Footprint Distribution by Energy Poverty



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

As can be seen in Figure 2a, energy-poor households accounted for 40% of the South African population but less than 20% of South African carbon emissions from consumption.

Figure 2b: Carbon Footprint Distribution by Energy Poverty

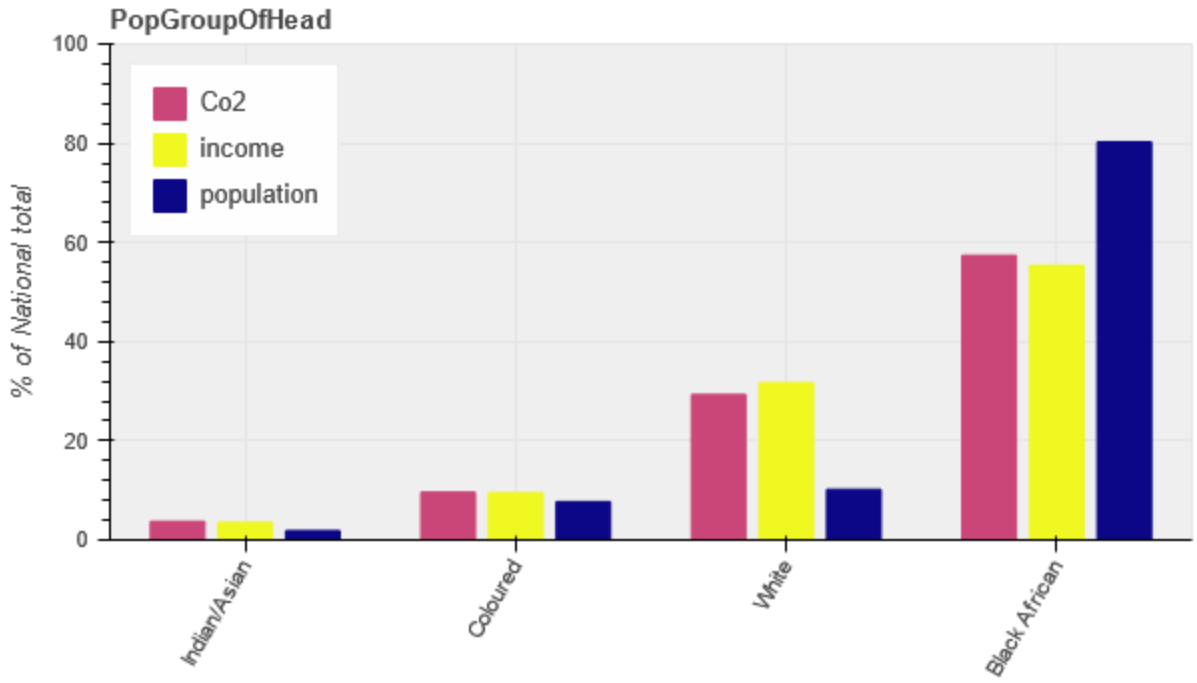


Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 2b shows that non-energy-poor households have a much wider range of carbon footprints than energy-poor households. Non-energy-poor households have an interquartile ratio of 3.0 and a max to min ratio of 6.0, while energy-poor households have an interquartile ratio of 1.8 and a max to min ratio of 2.8. Further, Figure 2b shows that all energy-poor households have below the median household carbon footprint.

6.3 Carbon inequality and race

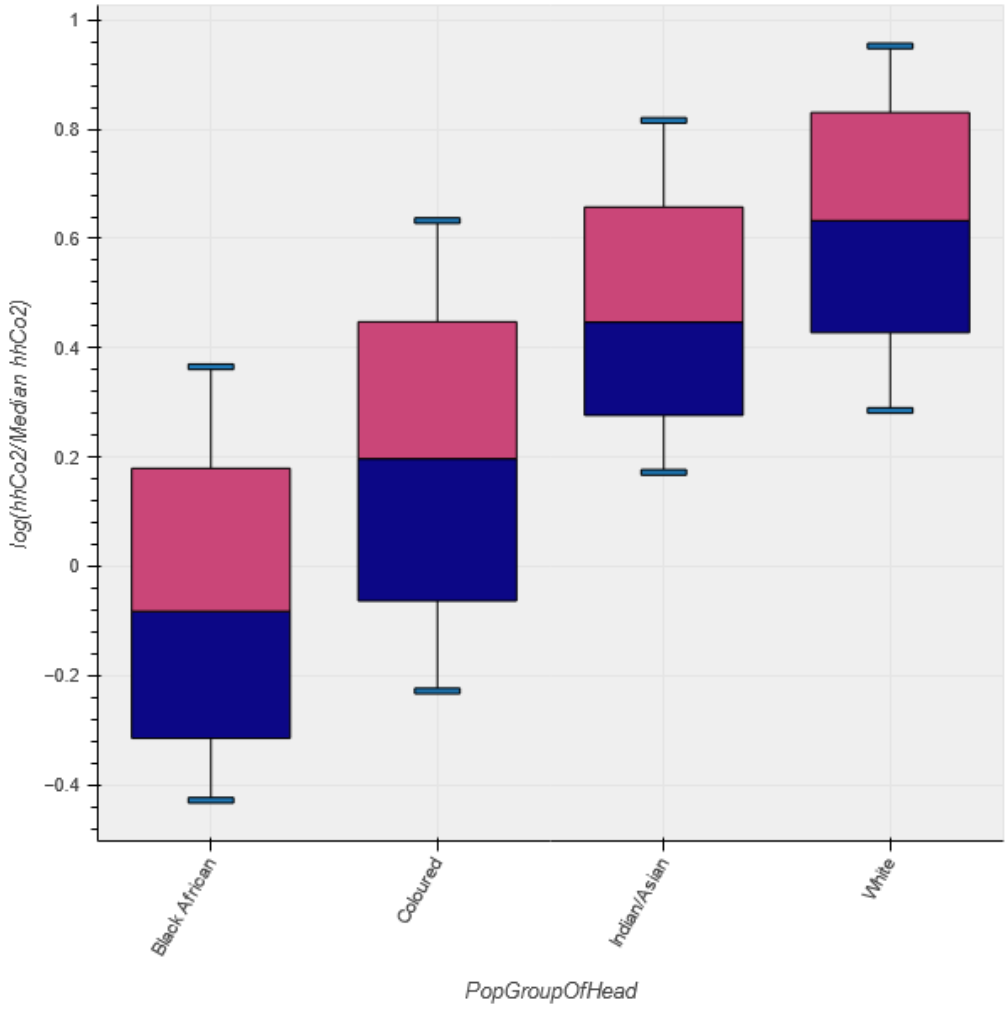
Figure 3a: Percentage of National Consumption Carbon Footprint by Race of Household Head



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

As we can see in Figure 3a, household carbon footprints are distributed highly disproportionately by race of household head for South Africa and appear closely linked to income distribution by race of household head. On aggregate, households with an Indian, Asian, or Coloured head have a slightly higher share of income and carbon emissions than their population share, households with white heads have a much larger share of both income and carbon emissions than their population share, and households with Black heads have a significantly lower amount of emissions and income compared to their population share.

Figure 3b: Percentage of National Consumption Carbon Footprint by Race of Household Head

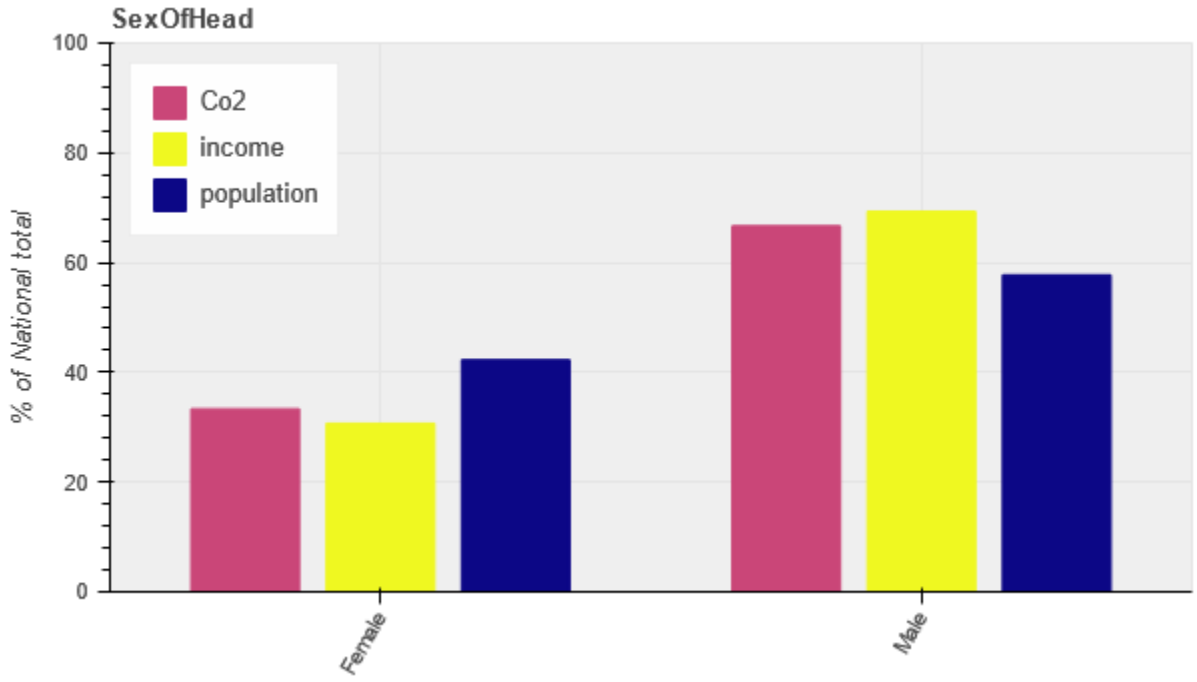


Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 3b shows that Black and Coloured households have much larger within-group carbon footprint inequality than white or Asian households. Black and coloured households have interquartile ratios of 3.1 and 3.2 respectively and a max to min ratios of 7.3 and 6.2. In comparison white and Asian households have interquartile ratios of 2.4 and 2.5 and max to min ratios of 4.4 and 4.6 respectively.

6.4 Carbon inequality and gender

Figure 4a: CO_2 Emission Disaggregated by Gender of Household Head

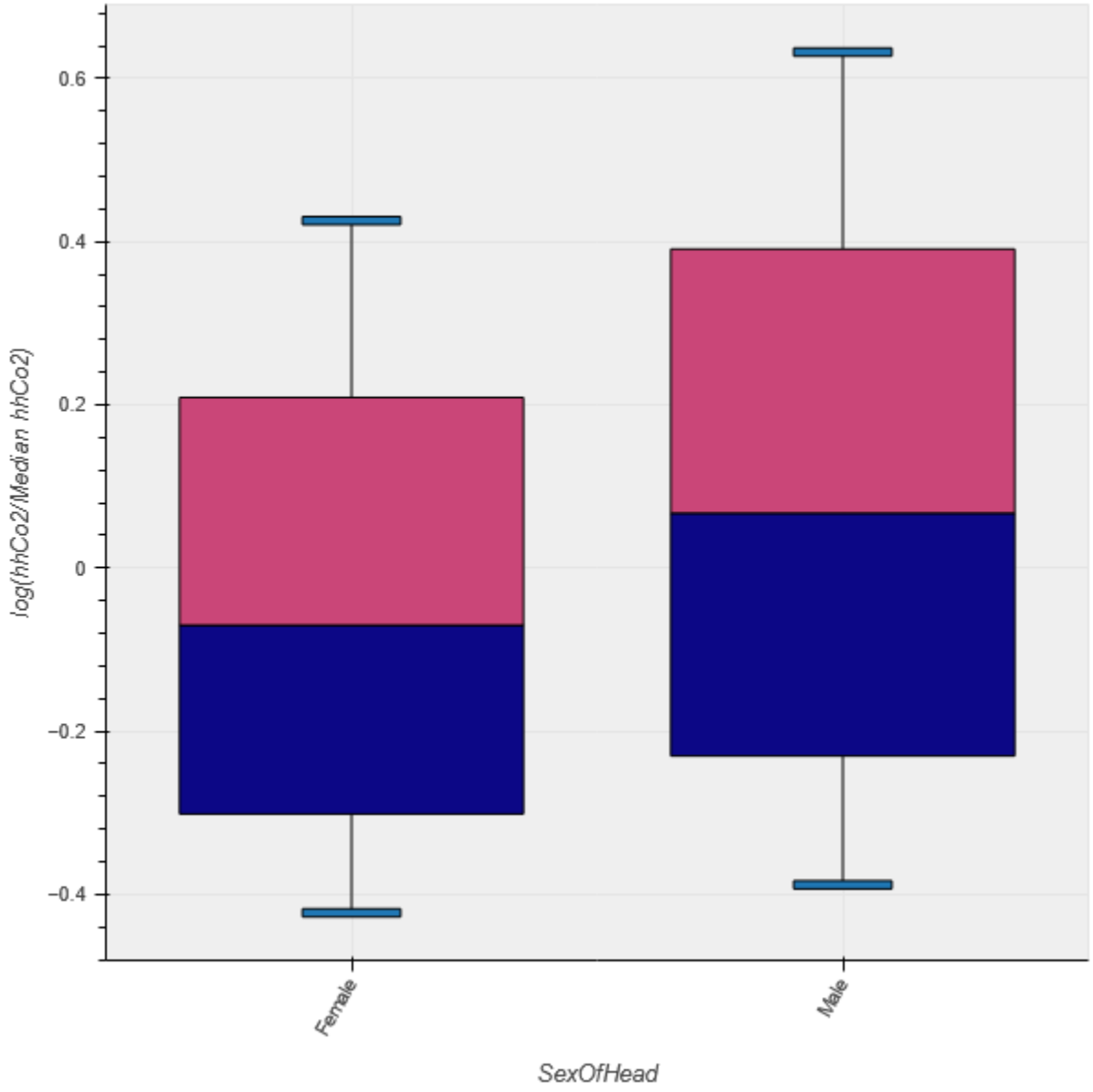


Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

As Figure 4a shows, female-headed households consume substantially less carbon on average than male-headed households, although this is closely tied to differences in income.[6]

[6] Here I have examined data on a household level, rather than on an individual level. This was due to the structure of the consumption data used. This does indicate the high levels on inequality in access to carbon-intensive goods and services. Further, consumption patterns are often shaped by household characteristics and consumption cultures rather than purely individual ones, where activities such as transport and cooking are done at a household level. However, it does not examine inequality in access to carbon-intensive goods within households, which may further worsen levels of energy, poverty, and inequality. For example, the use of the gender of the household head has been criticised as a tool for understanding gender inequality in access to resources, as it directs attention away from gendered inequality and poverty within male headed households, which appear to be better off on a household level.

Figure 4b: CO_2 Emission Disaggregated by Gender of Household Head

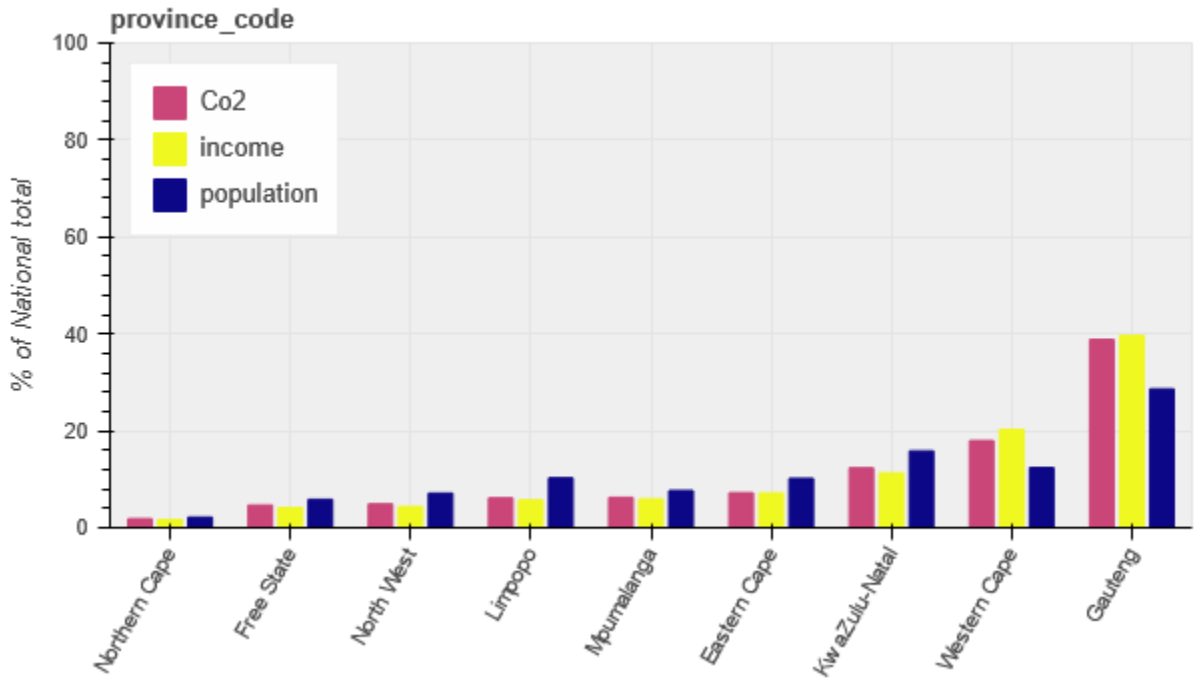


Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 4b shows high levels of within-group inequality for both female-headed and male-headed households, though the inequality is greater among male headed households. Female and male headed households have interquartile ratios of 3.2 and 4.2 respectively, and max to min ratios of 7.0 and 10.5.

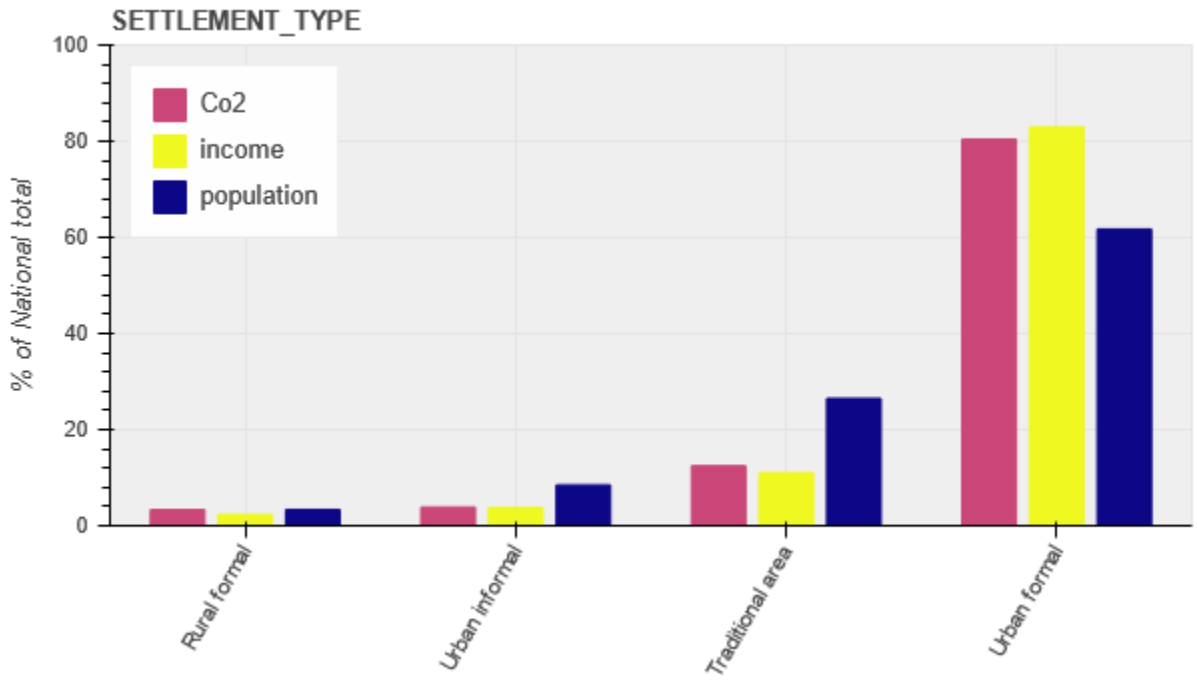
6.5 Spatial distribution of household carbon emission

Figure 5a: CO_2 Emissions by Province



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

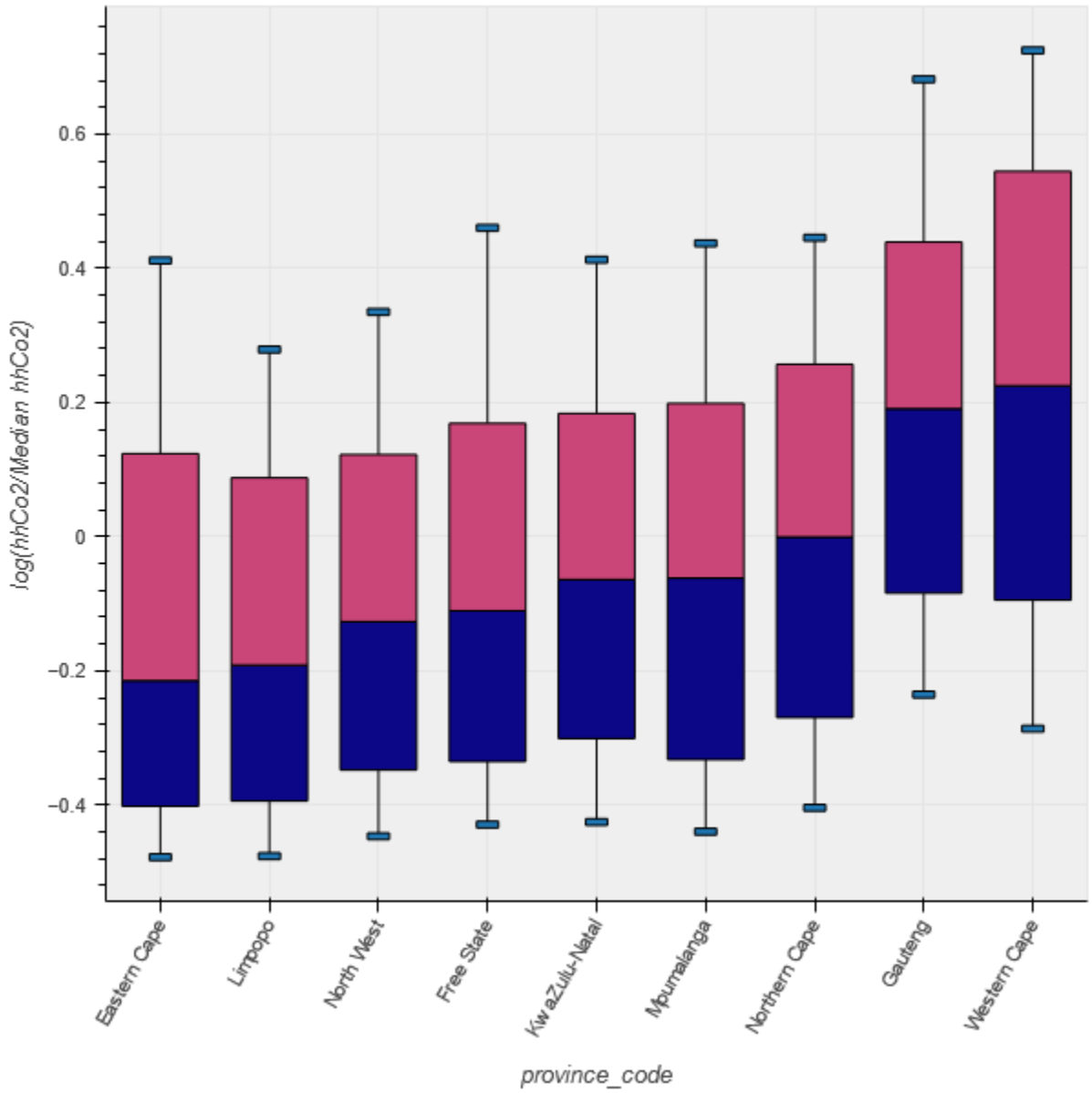
Figure 6a: CO_2 Emissions by Settlement Type



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Looking at the spatial distribution of households, we can see in Figure 6a that urbanisation results in much higher levels of carbon consumption with formal urban households accounting for roughly 60% of the South African population but just over 80% of household carbon footprints. Additionally, as shown in Figure 5a, carbon consumption is concentrated heavily in wealthier provinces.

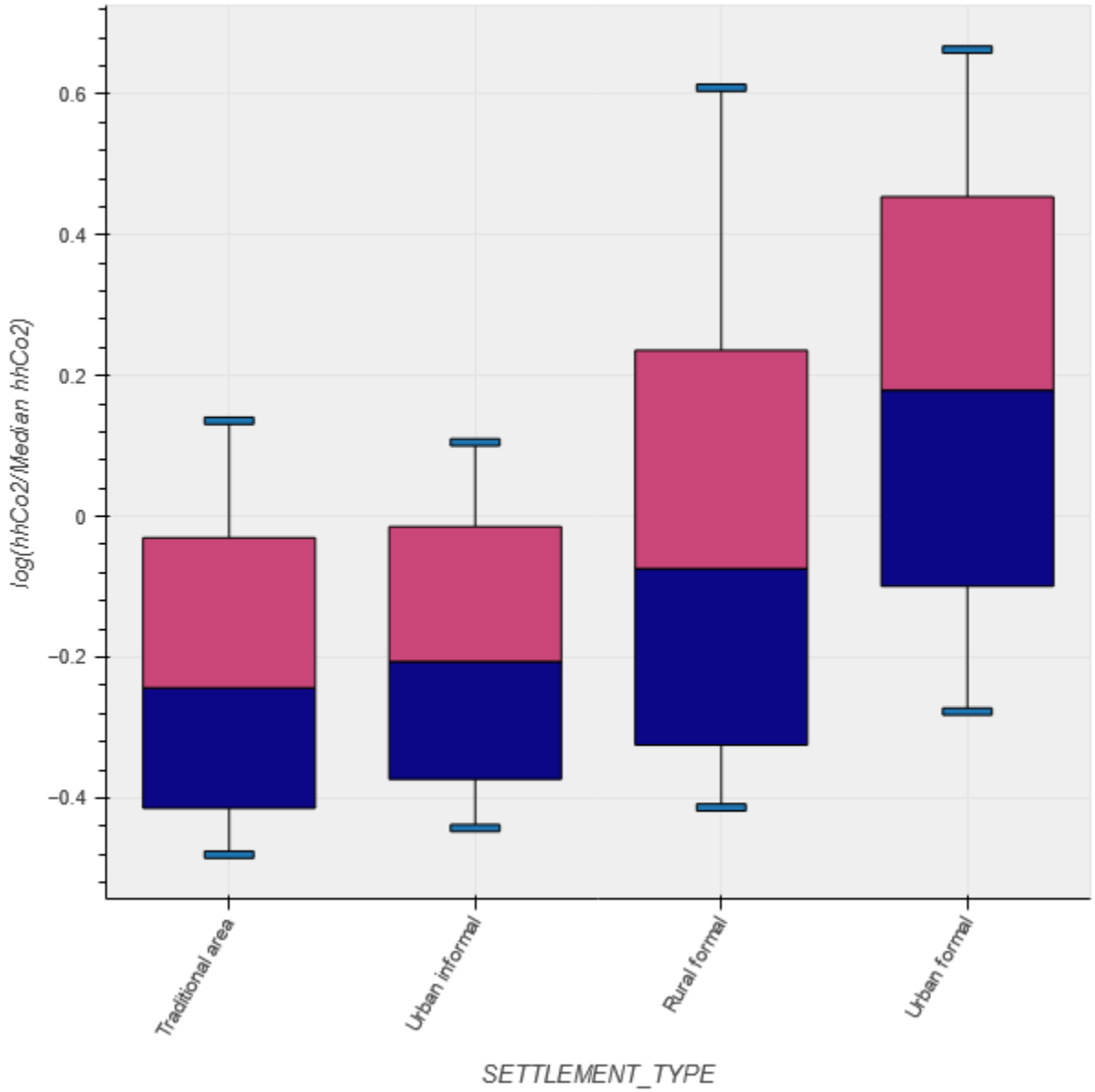
Figure 5b: CO_2 Emissions by Province



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

We can see from Figure 5b that the median household carbon footprint in Gauteng and the Western Cape is roughly two and half times the median household carbon footprint in the Eastern Cape or Limpopo. Further, it shows high levels of inequality within each province, with interquartile ratios of between 3.0 and 4.5 and min max ratios of between 5.7 and 10.3.

Figure 6b: CO_2 Emissions by Settlement Type



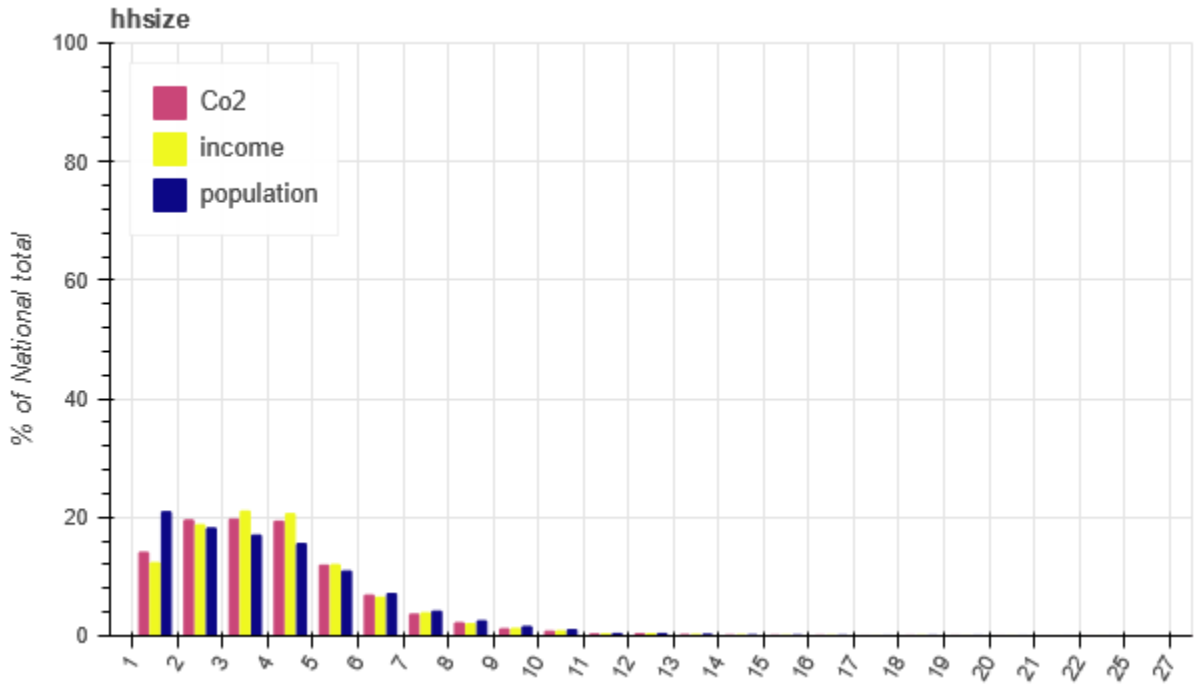
Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 6b shows a large within-group inequality for households in rural formal households and urban formal households with lower levels of within-group inequality for urban informal households and households in traditional areas.

6.6 Carbon inequality and household size

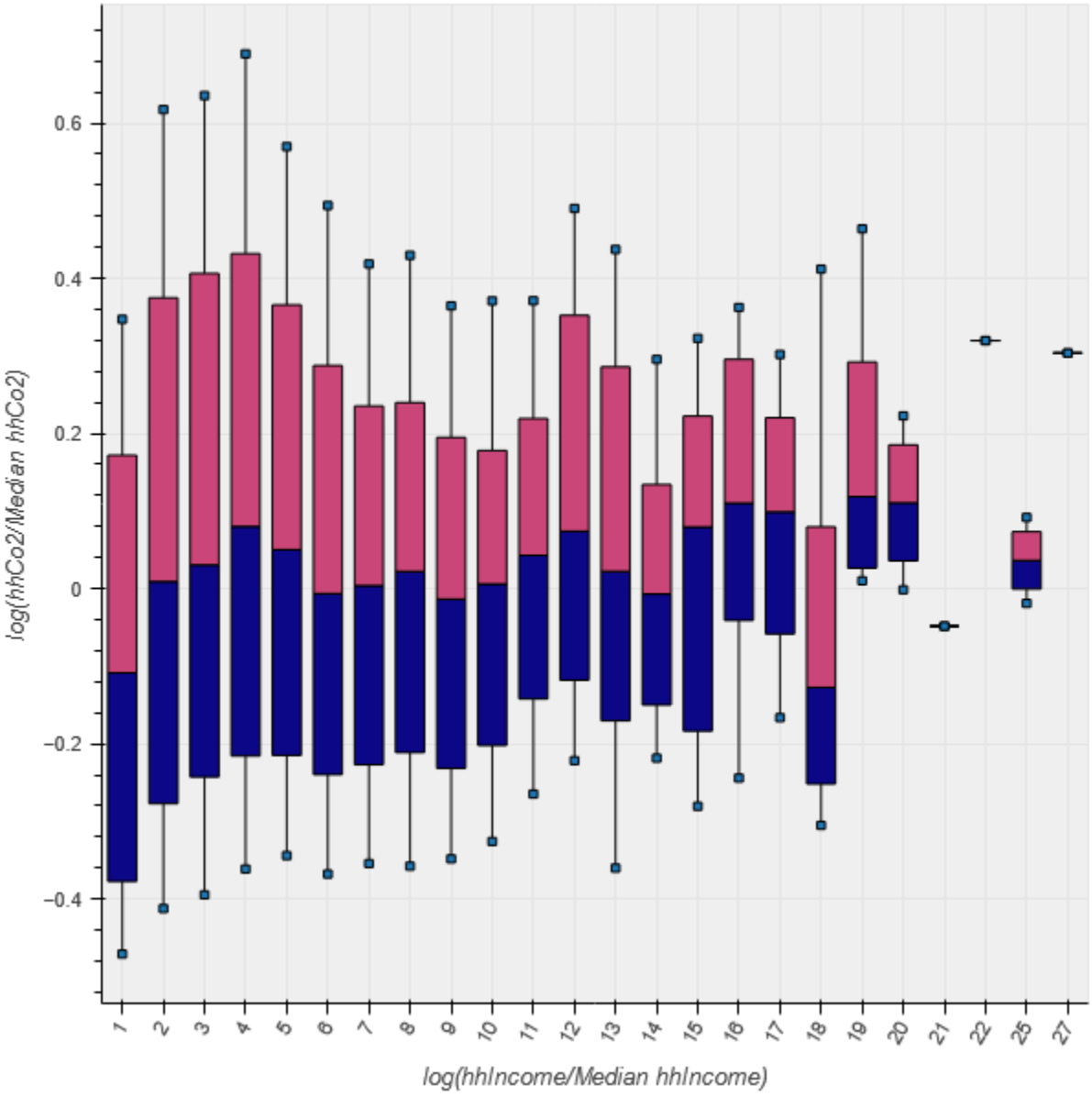
Looking at household size, we see in Figure 7a that cumulative household earnings and carbon footprints rise with household size until five members, after which they decline. Though as the number of people increases, the proportion of the general population represented in households of that size rapidly decreases. Figure 7b shows that median household CO_2 emissions, however, remain relatively stable as household size increases, though it is important to note that there is a very small sample size for larger households, so the results are less reliable as household size increases. This suggests that household carbon footprints do not rise with household size beyond a certain point. This is likely due to the variation of income with household size but may also indicate that the consumption of some carbon-intensive goods, such as electricity, do not scale with household size beyond that point. Additionally, the sample size for larger households is quite small, so the data is only reliable for relatively small household sizes.

Figure 7a: CO_2 Emissions by Household Size



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

Figure 7b: CO_2 Emissions by Household Size

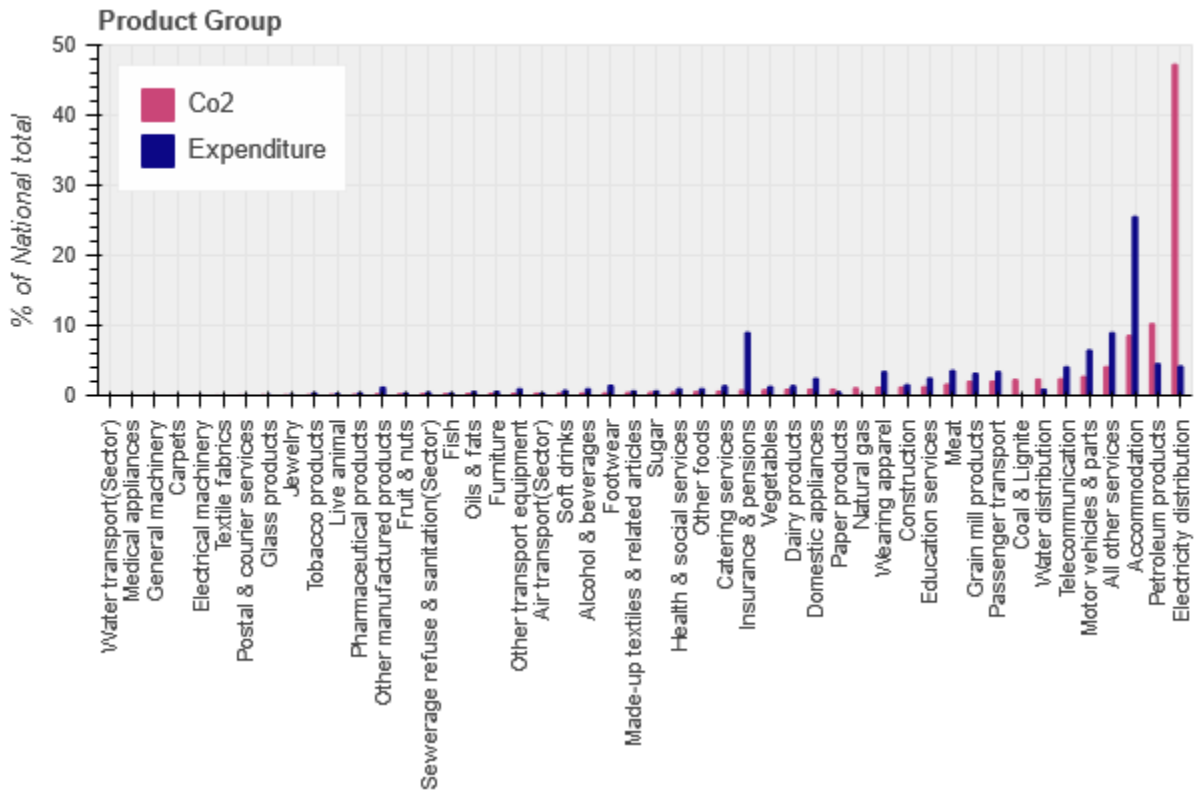


Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

6.7 Carbon inequality by product category

Household carbon footprints can be broken down into product categories as shown in the Figure 8 below. Electricity and fossil fuels account for the largest proportions of household carbon emissions, while these only account for a small fraction of household expenditure.

Figure 8: (Percentage of National Consumption Carbon Footprint by Product Category)



Source: Authors' calculations using Stats SA (2015) and Arndt et al (2013).

The decomposition of the carbon footprint Gini Coefficient by product category is shown in Table 1 in Appendix B. Although electricity consumption is relatively more evenly distributed than many other carbon-intense products with a Gini coefficient of 5.8, its large share of household carbon footprints (accounting for 47% of households total carbon footprints) means that it results in the most significant contribution to household emissions inequality. Petrochemicals contribute 10% to household carbon emissions while accommodation contributes another 8%.

In conclusion, the results show a wide range of intersecting inequality shaping South African household carbon footprints. These carbon footprints are dominated by electricity provision and products associated with road-based transport. South Africa has a high level of carbon footprint inequality in relation to income, race, and gender in comparison with other countries. This means

that the national carbon consumption is extremely high and unsustainable which means many houses cannot access carbon intensive necessities and face energy and transport poverty.

7 Discussion

In this section I will discuss the results presented above. I compare the results to the results of studies of carbon footprint inequality in other countries, as well as drawing on wider literature on South African inequality and consumption patterns to interpret and contextualise the results.

The results from Figure 1a show a much higher level of inequality than Starr et al. (2023) find for the US, with the top 10% of South Africans responsible for over 32% of national emissions as opposed to 23% in the US, and the bottom 50% of South Africans responsible for only 21% as opposed to 31% in the US.

South Africa has high levels of income inequality, which have been reproduced over a collection of intersecting forms of power imbalances in post-apartheid South Africa. Policies have been an important part of poverty reduction through expanded grant systems and expanded basic service provision. However, poverty and inequality reduction remain constrained by the constitutional protection of property rights established during apartheid as well as macroeconomic policies aimed primarily at creating a stable environment for domestic and foreign private investment (Francis & Webster, 2019). Nevertheless, significant extensions of access to electricity mean that despite the high levels of inequality and poverty, many poor South African households still have some access to electricity (Sarkodie and Adams, 2020). This results in carbon footprint inequality being lower than income inequality.

The pseudo-Gini coefficient for South African CO_2 shows a much higher inequality in the levels of carbon consumption than for other developing countries studied. For example, Irfany and Klasen (2016) found a pseudo-Gini coefficient of 0.409 for Indonesia in 2009, and Seriño (2020) found a carbon pseudo-Gini coefficient of 0.475 in 2006 for the Philippines.

This shows a similar pattern to measures of income inequality for the three countries. This can be seen through the relatively small Kakwani indexes of carbon footprint inequality relative to income inequality. (Within this context, the Kakwani index measures the differences between carbon footprint inequality and income inequality and is found by subtracting the household Gini

coefficient from the carbon footprint pseudo-Gini coefficient). Within my study I found a Kakwani index of 0.015. While Kakwani indexes reported by Irfany and Klasen (2016) and Seriño (2020) vary between −0.023 and 0.028 showing that there is very little variation between income inequality and carbon footprint inequality and that carbon emissions may be more or less equally distributed than income.[7]

The results in Figure 3a on carbon footprints by race of household head follows similar patterns to Starr et al.'s (2023) results in the US, which find that white US households have emissions that are on average 13% higher than Hispanic households and 33% higher than for Black households. However, the racial inequality in South Africa is much larger, as households with white heads have carbon footprints 302% greater than households with Black heads, 103% greater than households with Coloured heads, and 43% greater than households with Indian or Asian heads.

In comparison to Irfany and Klasen (2016) and Seriño (2020), there is a much lower significance around food, particularly animal agriculture in Figure 8. This is because the estimates of industry carbon intensity I have used are derived from the South African energy balance and account for carbon emissions only (not carbon equivalent emissions, which include emissions of other greenhouse gases such as methane). Additionally, it is difficult to theoretically attribute the emissions related to investments (as the investment goes into further production of other consumer goods) (Chancel & Piketty 2015). However, Starr et al. (2023), appear to have attributed a much greater carbon intensity to investment than I have. Because of the large differences in weighting for different product categories, direct comparison to see differences in consumption patterns between the various countries studied in earlier articles cannot be meaningfully done.

[7] To contextualise these Kakwani coefficients, it may be useful to compare them to the common range of Kakwani coefficients found in tax systems. This is a strained comparison but helps to emphasise how small the Kakwani coefficients of carbon emissions are. Kakwani indexes for tax measure how progressive tax systems are with larger negative numbers showing that income is more unequally distributed than tax. For example, in 2010, South Africa's Kakwani index for direct tax was -0.13 while Mexico's Kakwani index for direct tax was -0.30 (World Bank ., 2014). These are about an order of magnitude larger than the Kakwani indexes of carbon emissions.

8 Systems of provisioning

In Section 7.7 and Appendix B, I identified electricity and transport as the product categories most relevant to household carbon consumption and inequality. I will now examine the systems of provisioning for these carbon intensive goods within South Africa. This will give a deeper understanding of the complex political and economic systems driving carbon intensity and inequality within South Africa.

The systems of provisioning approach examines how consumption is shaped by wider social, economic, and political relations (Fine, 2013). It is a theoretical approach used to understand consumption focusing on its relationship to larger systems of production, accumulation, social reproduction, and dispossession. Typically, this approach is used to examine smaller vertically integrated systems of provisioning such as food, clothing, or housing systems of provisioning, and such an approach may not be useful when considering the consumption of emission-intensive goods as a whole. However, considering how forces outside of direct consumer preferences shape consumption of such carbon-intensive categories of consumer goods, such as energy and transport, is important. These have been shown above to be the key sources of carbon footprint inequality in the results section above.

The SoP approach is also important to understand policy solutions to reducing household emissions by envisioning more systemic ways to reduce household carbon consumption and reduce inequality within carbon-intensive systems of provisioning.

SoP for transport and electricity in South Africa are socially contested based on: concerns about access to cheap energy and transport; concerns for local environmental quality in terms of air, water, and soil pollution associated with heavy fossil fuel usage and struggles for land rights; and more recent contestation based on reducing greenhouse gas emissions (Schaffartzik et al ., 2021).

In the next subsections I will examine existing literature on how the systems of provisioning approach can help analyse household consumption of transport and energy, both in South Africa and internationally. This shows how consumption of these goods is shaped by contestations of access to state infrastructure and large concentrated systems of production demanding and supplying electricity.

Figure 4a shows a significantly larger gap carbon footprint based on gender of household head than Irfany and Klasen (2016) found in their study on Indonesian households where they found that the mean for male-headed households' footprint was only 2% higher than for female headed households in 2005, and that this had reversed by 2009. Ngarava et al. (2022) suggest that patterns of electricity usage in South Africa vary with the gender of head of household. As many energy-intensive household tasks, such as cleaning and cooking, are treated as gendered, female-headed households are more likely to prioritise electricity spending which makes these tasks easier or faster.

8.1 Electricity SoPs

Schaffartzik et al. (2021) use the SoP approach to examine fossil fuel energy provisioning systems using examples from a wide range of countries. This is central to understanding the distribution of household carbon footprints in South Africa because, as shown above in the results section, electricity consumption is the largest contribution to households' carbon emissions and is relatively evenly distributed in comparison with income. They argue that large-scale infrastructure and political economic and social factors lock in to dominate these SoPs which heavily shape the consumption patterns and carbon footprints of consumers.

In South Africa, household energy access and consumption historically developed in tight coordination with a set of mining and mineral beneficiation industries known as the Minerals-Energy Complex (MEC) (Essex, & de Groot, 2019) .These industries benefited significantly from large amounts of cheap electricity from coal-fired power stations. This was paired with very unequal patterns of household electrification under apartheid.

After apartheid, significant policy focus was put in place to expand electricity access and use. A widespread programme of electrification was implemented, increasing the rate of households with electricity access to 85.9% in 2014 (World Health Organization, 2022). In addition, a subsidy program, Free Basic Electricity (FBE), was implemented to provide indigent households with 50 Megawatt hours per month. This programme was managed at a municipal level and hence resulted in substantial geographical variation (Ye et al., 2018). Additionally, some policy attempts have been made at giving poor households access to small-scale renewable energy

(particularly for water heating which accounts for roughly 50% of households' electricity usage) (Ngarava et al., 2022).

Parallel to this expansion in grid access, South Africa has shifted towards prepaid meters. Such a shift may result in more conscious energy use practices within households. However, this will likely place an excessive burden on poorer households for two reasons. First, it is often seen as a solution to non-payment either by providers or landlords (which is more likely to affect more financially precarious households). Some municipalities require prepaid meters for households to be recipients of FBE (this is important because, as discussed later, FBE falls substantially below households' basic needs). Second, the rates on pre-paid electricity are higher than the other forms of household electricity tariffs (Ye et al., 2018).

The post-apartheid government planned to privatise significant amounts of energy generation in line with a general neoliberal policy agenda. While the full realisation of this has been contested and delayed, it prevented Eskom from investing in new generation capacity from 2001-2004, particularly in renewables. Additionally, maintenance was reduced. After 2004, a new build project was planned for Eskom including two massive new, state-owned coal power stations (Medupi and Kusile). These projects were mismanaged and significantly delayed, and they substantially increased the debt burden of Eskom (Phalatse, S. and Isaacs, G, 2020).

In addition to this, several renewable energy stations were set up as Independent Power Producers (IPPs). While such programmes decreased the coal intensity of the South African electricity supply, they form part of a contested shift towards privatisation (Bowman, 2020), and increasing financialisation. Both Eskom's substantial debt and private interests from IPPs have resulted in calls to increase electricity tariffs to be more "cost reflective" (Eskom, 2022).

Additionally, load shedding has played a significant role in shaping households' energy access within South Africa, as Eskom has not been able to provide consistent energy access. This is worsened by load reduction in poor areas, which often leads to much longer outages.

Thus, the inequality and intensity of energy consumption within South Africa is shaped by the dominance of the MEC and entrenched but contested systems of racial and spatial inequality, as well as attempts to push the costs of emission reduction onto poorer households.

This shows that household electricity consumption is not a simple result of individual behavioural responses to either changes in electricity use, or propaganda encouraging socially responsible electricity use, but of complex social forces both inside and outside the household.

8.2 Road-Based Transport SoPs

As shown in Appendix B, road-based transport is responsible for a large amount of South African carbon emission and highly unequal consumption patterns. Petroleum products account for 10.2 percent of carbon emissions from South African households; these are extremely unequally consumed with a Gini coefficient of 0.838 and highly correlated with income inequality with a correlation score R of 0.907. Motor vehicles and parts also contribute a small but significant amount of emission making up 2.7% of household emissions which are also highly unequal with a Gini coefficient of 0.997 and tightly linked to income inequality with a correlation score of 0.889. In comparison, passenger transport accounts for only 2% of household emissions and is much more evenly distributed with a Gini coefficient of 0.63 and a correlation score of 0.183 (Considering the low correlation score this Gini coefficient still represent a highly unequal use of passenger transport, but likely due to consumer choice rather than budget constraints). This shows systems of transport provisioning may reveal important underlying force shaping households carbon consumption.

Shaw (2006) argues that South Africa's post-apartheid transport system is constrained by many of the same challenges as other middle-income developing countries: rising private car ownership and use, insufficient funding for public transport, poor coordination of public transport, a large informal low-capacity passenger transport industry, and high amounts of transport poverty. This interlinks with a complex system of accommodation provisioning which shapes the high and unequal demand for transport in South Africa. Legacies of apartheid planning persist, with a large poor population living in the peripheries of cities and requiring long commutes to access work and services. Additionally, policy such as single-use zoning creates an urban pattern which makes pedestrianism more difficult. Further, recent investment in public transport has focused on projects aimed at higher income groups (while also being

subsidised), been poorly coordinated with land development, and had limited effects on reducing congestion (McKay, 2020).

Mattioli et al. (2020) argue that the SoP approach can be used to draw a more unified understanding from existing research on car dependence. Further, they argue that although existing literature on car dependence includes detailed understandings of social attitudes, built environments, and social practices, they often overlook political and economic factors, suggesting solutions in a technical or apolitical manner. They draw from a wide range of literature on car dependency in both developed and developing countries. They use this to provide a relatively abstract model of the global and national political economy forces which shape transport systems in many countries.

This can form a useful complement to existing research on transport systems in South Africa which often engage with such political economic systems in a relatively limited manner. For example, Shaw (2006) and McKay (2020) examine the effects economics of a few, more visible groups on the supply side such as taxi drivers in detail, but the potential political sway of the auto-industry, both locally and globally, remains unexamined.

Mattioli et al. (2020) argue that production and state systems promote car-based transport, which leads to a consumer culture that reinforces this pattern. Car production is limited by capital intensity and economies of scale, and car manufacturing is often highly concentrated. This increases the capacity for political organising and lobbying for state policy to support the auto industry. State support for the auto industry is seen in subsidies and spatial development patterns that prioritise car ownership. Alternative public transport systems suffer due to neoliberal reforms, and subsidies for car-based systems have become naturalised over time, fostering car dependence. This system leads to an unequal and carbon-intensive way of meeting basic household needs in many countries, including South Africa.

9 Policy Implications

This study shows that in South Africa carbon footprints are dominated by electricity and road-based transport, so that consumer goods categories associated only with luxury consumption are not sources of significant pollution. Instead, progressive reforms in both

electricity and transport systems of provisioning appear to be more promising avenues to reduce both total emissions and inequality. Policies could still aim to curtail the excessive use of these resources by wealthier groups, while ensuring workers are protected where demand is reduced. However, attempts to reduce the carbon intensive consumption of poor households must ensure that they do not undermine basic needs and should ensure that affordable and high-quality renewable technologies are allocated to these groups. This would ensure poor and low-income households are not being made to bear the burden of a transition away from a fossil fuel-based system they are least responsible for.

However, designing viable policies which achieve a just transition is still a significant challenge, because:

- Wealthy income groups hold a lot of political power and may oppose policies designed to significantly reduce their high CO_2 consumption.
- Many high CO_2 goods are consumed both by rich and poor income groups, so placing increased production costs for transitioning only on wealthier groups is difficult.
- Employment is highly dependent on value chains producing consumer goods for wealthy income groups both domestically and in the form of exports. While domestically income could be transferred through progressive taxation and social grants rather than through purchasing carbon-intensive goods, for higher-income groups, internationally this is not possible. Further, even domestically the degree to which transfers can reduce inequality without creating an industrial structure with many high-paying jobs may be limited.

Looking at how different policy options for reducing carbon emissions may affect the distribution and inequality of household carbon footprints, as well as the total levels of carbon emissions, is important.

A common policy tool, carbon pricing, does not offer an effective solution for reducing carbon emissions and threatens to worsen carbon inequality. Carbon pricing relies on market-based mechanisms to incentivise consumers and producers to align their carbon emissions optimally given their true social cost. Apart from the political challenges in implementing a large enough

price to increase private costs to social costs, such a price-based mechanism allocates permission to pollute to those who can pay. Starr et al. (2023) find that lower-income households would face drastic reductions in their overall consumption (52% for the lowest income decile in the US) while wealthy households' consumption patterns would be largely unaffected. Additionally, the idea of high carbon pricing alongside redistribution (a Pareto optimal solution in a simplistic neoclassical model) is also unlikely to be effective as powerful groups who shape policy are unlikely to accept such a degree of redistributive policies necessary to ensure lower-income groups are not adversely affected by high carbon prices.

Instead, as carbon-intensive consumption is currently required to meet many basic needs, considering whether such rights to polluting goods and services should not be allocated on a more equitable basis, essentially carbon rationing rather than carbon pricing, is important. Wood et al., (2023) argue that non-tradable carbon rationing has been widely ignored in the literature on climate policy and argues that this policy would enable states to reduce carbon emissions both rapidly and equitably. Here they draw on inspiration from world war two rationing in Britain. Further, many authors have argued that market responses to price increases may in fact be insufficient and argue that more interventionist policy (loosely modelled on industrial policy) should be used to reshape industries to reduce carbon emissions in a more just and significant way. This would entail large scale interventionist reshaping of core carbon intensive systems of provisioning. A significant state role in provisioning systems for affordable renewable energy and public transport must play a pivotal role in allowing households to maintain their quality of life while reducing their carbon emissions.

10 Conclusion

In this study I have used a common method to estimate levels of national carbon footprint inequality, by pairing industrial carbon intensity with an IO table and data on household consumption. I have paired household consumption data from the Stats SA Living Conditions Survey, with estimates of consumer goods carbon intensity calculated from using the input-output method by Arndt et al. (2013). The data presented here could be expanded in many ways, including with more detailed and recent estimates of product carbon intensity, and

including additional household surveys. However, this initial analysis is highly revealing and the first of its kind in South Africa.

The results show large class, gender, and racial disparities in carbon footprints. These levels of inequality show higher levels of national carbon footprint inequality than exists in other developing countries studied. This result mirrors South Africa's high income and wealth inequality. This stems from South Africa's apartheid history of unequal racially and spatially divided access to major carbon intensive products, as well as a more recent history of limited progressive social policy combined with a broader neoliberal policy focus.

Electricity and transport represent the largest drivers of household carbon footprints in South Africa and thus represent clear focus areas for decarbonisation developed in tight coordination with the MEC. Electricity is both heavily carbon intensive and highly unequally distributed in South Africa. Many households live in energy poverty, and attempts to reduce South Africa's carbon footprint must improve and not exacerbate this. Transport systems of provision are unnecessarily dominated by road-based transport, which results in much higher emissions, and more unequal access, than more public transport systems.

In conclusion, it is vital to consider inequality when considering how to reduce the carbon footprint of South African households. There is little room to reduce carbon footprints for low-income households, without substantial increases in access to affordable low carbon energy and transport systems. Instead, attempts to contain South Africa's carbon footprints should focus on high-income groups' consumption. Sustainable development and a just transition will require prioritising energy to meet the basic needs of the South African population as well as reshaping larger systems of provisioning to allow for needs to be met in less energy intensive (or carbon intensive) ways.

11 References

Arndt, C., Davies, R., Makrelov, K., Thurlow, J. (2013) *Measuring the Carbon Intensity of the South African Economy*, South African Journal of Economics, 81(3), pp. 393–415. Available at: https://doi.org/10.1111/j.1813-6982.2012.01324.x.

Baiocchi, G., Minx, J. and Hubacek, K. (2010*) The impact of social factors and consumer behavior on carbon dioxide emissions in the United Kingdom: A regression based on input- output and geodemographic consumer segmentation data,* Journal of Industrial Ecology, 14(1), pp. 50–72.

Bell, S., Judson, E., Bulkeley, H., Powells, G., Capova, K. A., Lynch, D. (2015) *'Sociality and electricity in the United Kingdom: The influence of household dynamics on everyday consumption', Energy Research & Social Science*, 9, pp. 98–106. Available at: https://doi.org/10.1016/j.erss.2015.08.027.

Bloch, K. R., Taylor, T., & Martinez, K. (2020). Playing the race card: White injury, White victimhood and the paradox of colour-blind ideology in anti-immigrant discourse. *Ethnic and Racial Studies*, *43*(7), 1130-1148.

Bowman, A. (2020) 'Parastatals and economic transformation in South Africa: The political economy of the Eskom crisis', *African Affairs*, 119(476), pp. 395–431. Available at: https://doi.org/10.1093/afraf/adaa013.

Chancel, L., & Piketty, T. (2015). Carbon and inequality: From Kyoto to Paris Trends in the global inequality of carbon emissions (1998-2013) & prospects for an equitable adaptation fund World Inequality Lab.

Cole, M., (2015*.) Is South Africa operating in a safe and just space. Using the doughnut model to explore environmental sustainability and social justice.* London: Oxfam

Ehrlich, P. R. (1978). The population bomb.

Eskom., *2022 Holdings Summary Submission MYPD5* Available at: https://www.eskom.co.za/wp-content/uploads/2021/12/Eskom-Holdings-Summary-Submission_MYPD5.pdf (Accessed: 25 August 2022).

Erb, P. (2018). *The Environmental Kuznets Curve Hypothesis as a Problematic: Beyond" Falsificationism"*.

Fakier, K. (2018). Women and renewable energy in a South African community: Exploring energy poverty and environmental racism. *Journal of International Women's Studies*, *19*(5), 165-176.

Fine, B. (2013) *'Consumption Matters'*, Ephemera, 13(2), pp. 217–248.

Francis, D. and Webster, E., (2019). *Poverty and inequality in South Africa: critical reflections*. Development Southern Africa, 36(6), pp.788-802.

Grunewald, N. et al., (2017) *The trade-off between income inequality and carbon dioxide emissions, Ecological Economics,* 142, pp. 249–256.

Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment*. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443

Irfany, M.I. and Klasen, S., (2016) *Inequality in emissions: evidence from Indonesian household*, Environmental Economics and Policy Studies, 18(4), pp. 459–483.

Ivanova, D., Stadler, K., Steen‐Olsen, K., Wood, R., Vita, G., Tukker, A. and Hertwich, E.G., (2016). *Environmental impact assessment of household consumption*. Journal of Industrial Ecology, 20(3), pp.526-536.

Kensett M, (2021) 'The Distribution Of Carbon Emissions Across South African Households.' DNA Economics Available at: https://www.dnaeconomics.com/pages/climate_change/?zDispID=NewsArtThe_Distribution_of_Carbon_Emissions_Across_South_African_Households

Erickson, B. (2020) 'Anthropocene futures: Linking colonialism and environmentalism in an age of crisis', *Environment and Planning D: Society and Space*, 38(1), pp. 111–128. Available at: https://doi.org/10.1177/0263775818806514.

Essex, S. and de Groot, J. (2019) *'Understanding energy transitions: The changing versions of the modern infrastructure ideal and the "energy underclass" in South Africa, 1860–2019*', Energy Policy, 133, p. 110937. Available at: https://doi.org/10.1016/j.enpol.2019.110937.

Jakob, M., Haller, M. and Marschinski, R., (2012). *Will history repeat itself? Economic convergence and convergence in energy use patterns.* Energy Economics, 34(1), pp.95-104

Leal, P. H., & Marques, A. C. (2022). *The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective.* Heliyon.

Ledger, T. and Rampedi, M., (2022) *Hungry for Electricity*

Lerman, R.I. and Yitzhaki, S., (1989). *Improving the accuracy of estimates of Gini coefficients.* Journal of econometrics, *42*(1), pp.43-47.

McKay, T., 2020. South Africa's key urban transport challenges. *Urban geography in South Africa: perspectives and theory*, pp.189-207.

Malthus, T. R. (1872). *An Essay on the Principle of Population.*.

Mattioli, G., Roberts, C., Steinberger, J., and Brown, A. 2020 *'The political economy of car dependence: A systems of provision approach'*, Energy Research & Social Science, 66, p. 101486. Available at: https://doi.org/10.1016/j.erss.2020.101486.

Minx, J.C., Wiedmann, T., Wood, R., Peters, G.P., Lenzen, M., Owen, A., Scott, K., Barrett, J., Hubacek, K., Baiocchi, G. and Paul, A., (2009). *Input–output analysis and carbon footprinting: an overview of applications. Economic systems research, 21(3), pp.187-216.*

Moore, J.W. (2017) *'The Capitalocene, Part I: on the nature and origins of our ecological crisis'*, The Journal of Peasant Studies, 44(3), pp. 594–630. Available at: https://doi.org/10.1080/03066150.2016.1235036.

Ngarava, S., Zhou, L., Ningi, T., Chari, M., and Mdiya, L. (2022) 'Gender and ethnic disparities in energy poverty: The case of South Africa', Energy Policy, 161, p. 112755. Available at: https://doi.org/10.1016/j.enpol.2021.112755.

Seriño, M.N.V., (2017). *Is decoupling possible? Association between affluence and household carbon emissions in the Philippines.* Asian Economic Journal, 31(2), pp.165-185.

Seriño, M.N.V., (2020). *Rising carbon footprint inequality in the Philippines*, Environmental Economics and Policy Studies, 22(2), pp. 173–195.

Sarkodie, S.A. and Adams, S., (2020). *Electricity access and income inequality in South Africa: evidence from Bayesian and NARDL analyses.* Energy Strategy Reviews, 29, p.100480.

Sasser, J. (2014) 'From Darkness into Light: Race, Population, and Environmental Advocacy: From Darkness Into Light', *Antipode*, 46(5), pp. 1240–1257. Available at: https://doi.org/10.1111/anti.12029.

Schaffartzik, A., Pichler, M., Pineault, E., Wiedenhofer, D., Gross, R., and Haberl, H. 2021 *'The transformation of provisioning systems from an integrated perspective of social metabolism and political economy: a conceptual framework'*, Sustainability Science, 16(5), pp. 1405–1421. Available at: https://doi.org/10.1007/s11625-021-00952-9.

Shaw, A. (2006) 'Achieving a pro-public transport agenda in South Africa — the challenge for middle income countries', in *Urban Transport XII: Urban Transport and the Environment in the 21st Century*. *URBAN TRANSPORT 2006*, Prague, Czech Republic: WIT Press, pp. 805–815. Available at: https://doi.org/10.2495/UT060781.

Simon, G.L. and Peterson, C., 2019. Disingenuous forests: A historical political ecology of fuelwood collection in South India. *Journal of Historical Geography*, *63*, pp.34-47.

Stats SA. 2015. *Living Conditions Survey 2014/2015* Statistic Release P0310

Starr, J., Nicolson, C., Ash, M., Markowitz, E. & Moran, D. (2023) *'Assessing U.S. consumers' carbon footprints reveals outsized impact of the top 1%',* Ecological Economics, 205, p. 107698. Available at: https://doi.org/10.1016/j.ecolecon.2022.107698.

Raworth, K., (2017). *Doughnut economics: seven ways to think like a 21st-century economist.* Chelsea Green Publishing.

Ojeda, D., Sasser, J. S., & Lunstrum, E. (2020). Malthus's specter and the anthropocene. *Gender, Place & Culture*, *27*(3), 316-332.

Our World in Data based on Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., Le Quéré, C., Luijkx, I. T., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Alkama, R., Arneth, A., Arora, V. K., Bates, N. R., Becker, M., Bellouin, N., Bittig, H. C., Bopp, L., Chevallier, F., Chini, L. P., Cronin, M., Evans, W., Falk, S., Feely, R. A.,

Gasser, T., Gehlen, M., Gkritzalis, T., Gloege, L., Grassi, G., Gruber, N., Gürses, Ö., Harris, I., Hefner, M., Houghton, R. A., Hurtt, G. C., Iida, Y., Ilyina, T., Jain, A. K., Jersild, A., Kadono, K., Kato, E., Kennedy, D., Klein Goldewijk, K., Knauer, J., Korsbakken, J. I., Landschützer, P., Lefèvre, N., Lindsay, K., Liu, J., Liu, Z., Marland, G., Mayot, N., McGrath, M. J., Metzl, N., Monacci, N. M., Munro, D. R., Nakaoka, S.-I., Niwa, Y., O'Brien, K., Ono, T., Palmer, P. I., Pan, N., Pierrot, D., Pocock, K., Poulter, B., Resplandy, L., Robertson, E., Rödenbeck, C., Rodriguez, C., Rosan, T. M., Schwinger, J., Séférian, R., Shutler, J. D., Skjelvan, I., Steinhoff, T., Sun, Q., Sutton, A. J., Sweeney, C., Takao, S., Tanhua, T., Tans, P. P., Tian, X., Tian, H., Tilbrook, B., Tsujino, H., Tubiello, F., van der Werf, G. R., Walker, A. P., Wanninkhof, R., Whitehead, C., Willstrand Wranne, A., Wright, R., Yuan, W., Yue, C., Yue, X., Zaehle, S., Zeng, J., and Zheng, B (2022).: *Global Carbon Budget 2022*, Earth Syst. Sci. Data, 14, 4811-4900, https://doi.org/10.5194/essd-14-4811-2022,

Yang, T. and Liu, W. (2017) *Inequality of household carbon emissions and its influencing factors: case study of urban China*, Habitat International, 70, pp. 61–71.

Ye, Y., Koch, S.F. and Zhang, J. (2018). *'Determinants of household electricity consumption in South Africa'*, Energy Economics, 75, pp. 120–133. Available at: https://doi.org/10.1016/j.eneco.2018.08.005.

Wiegratz, J., Behuria, P., Laskaridis, C., Pheko, L. L., Radley, B., & Stevano, S. (2023). Common Challenges for All? A Critical Engagement with the Emerging Vision for Post‐pandemic Development Studies. Development and Change.

World Health Organization. (2022). *Tracking SDG 7: The Energy Progress Report 2022*.

World Bank, (2014) South Africa economic update: Fiscal policy and redistribution in an unequal society.

12 Appendix A

Table 1: Consumer Category to IO category

Consumer Category (LCS)	**IO category (as assigned by author)**
Accommodation services	Accommodation
Actual rentals paid by tenants	Accommodation
Imputed rentals of owner-occupiers	Accommodation
Interest on mortgage bonds	Accommodation
Beer	Alcohol & beverages
Beverages in restaurants, cafes, canteens, and the likes	Alcohol & beverages
Coffee, tea, and cocoa	Alcohol & beverages
Spirits	Alcohol & beverages
Wine	Alcohol & beverages
Cultural services	All other services
Domestics services and household articles	All other services
Games of chances	All other services
Hairdressing salons and personal grooming establishment	All other services
Other services	All other services
Other services relating to the dwelling	All other services
Recreational and sporting services	All other services
Veterinary and other services	All other services
Fuels and lubricants	Petroleum products

Carpets and other floor covering	Carpets
Meals in restaurants, cafes, canteens, and the likes	Catering services
Solid fuels	Coal & Lignite
Service of the maintenance and repair of the dwelling_(431)	Construction
Service of the maintenance and repair of the dwelling_(432)	Construction
Consumption Unclassified Diary Items	Dairy products
Milk, cheese, and eggs	Dairy products
Electrical appliances for personal care	Domestic appliances
Major household appliances whether or no electrical	Domestic appliances
Other appliances, articles, and products for personal care	Domestic appliances
Repair of household appliance	Domestic appliances
Small electrical household appliance	Domestic appliances
Small tools and miscellaneous accessories	Domestic appliances
Spare parts and accessories	Domestic appliances
Higher education	Education services
Pre-primary and primary education	Education services
Secondary education public paid by means of loans	Education services
Tertiary education	Education services
Photographic and cinematographic equipment and optical instruments	Electrical machinery
Electricity	Electricity distribution
Water and Electricity	Electricity distribution

Fish	Fish
Repair and hire of footwear	Footwear
Shoes and other footwear	Footwear
Fruits	Fruit & nuts
Furniture and furnishings	Furniture
Repair of furniture, furnishings, and floor covering	Furniture
Major tools and equipment	General machinery
Glassware, tableware, and household utensils	Glass products
Bread and cereals	Grain mill products
Dental services	Health & social services
Hospital services	Health & social services
Medical services	Health & social services
Paramedic services	Health & social services
Social protection services	Health & social services
Insurance connected with the dwelling	Insurance & pensions
Insurance connected with the health	Insurance & pensions
Insurance connected with the transport	Insurance & pensions
Life insurance	Insurance & pensions
Other insurance	Insurance & pensions
Jewellery, clocks, and watches	Jewellery
Pets and related products	Live animal

Household textile	Made-up textiles & related articles
Meat	Meat
Therapeutic appliances and equipment	Medical appliances
Motorcars	Motor vehicles & parts
Gas	Natural gas
Oils and fats	Oils & fats
Food products n.e.c.	Other foods
Unclassified food items	Other foods
Equipment for sport, camping, and open-air recreation	Other manufactured products
Games, toys, and hobbies	Other manufactured products
Gardens, plants, and flowers	Other manufactured products
Non-durable household goods	Other manufactured products
Other personal effects	Other manufactured products
Stationery and drawing materials	Other manufactured products
Maintenance and repairs of personal transport equipment	Other transport equipment
Other services in respect of personal transport equipment	Other transport equipment
Books	Paper products
Miscellaneous printed matter	Paper products
Newspaper and periodicals	Paper products
Passenger transport by air	Air transport (Sector)
Passenger transport by railway	Passenger transport

Passenger transport by road	Passenger transport
Passenger transport by sea and inland waterway	Water transport (Sector)
Other medical products	Pharmaceutical products
Pharmaceutical products	Pharmaceutical products
Postal services	Postal & courier services
Refuse collection	Sewerage refuse & sanitation (Sector)
Sewerage collection	Sewerage refuse & sanitation (Sector)
Mineral waters, soft drinks, fruit, and vegetable juices	Soft drinks
Sugar, jam, honey, chocolate, and confectionery	Sugar
Equipment for the reception, recording, and reproduction of sound and pictures	Telecommunication
Information processing equipment	Telecommunication
Recording media	Telecommunication
Telephone and telefax equipment	Telecommunication
Telephone and telefax services	Telecommunication
Clothing materials	Textile fabrics
Tobacco	Tobacco products
Vegetables	Vegetables
Water supply	Water distribution
Cleaning, repair, and hire of clothing	Wearing apparel
Garments	Wearing apparel

Other articles of clothing and clothing accessories	Wearing apparel

13 Appendix B

Table 1: Decomposition of pseudo-Gini by product category

Industry	Contribution to CO_2 Gini	Product Gini	CO_2 R	Product CO_2 Share
Electricity distribution	0.25	0.579	0.913	0.472
Petroleum products	0.078	0.838	0.907	0.102
Accommodation	0.029	0.816	0.412	0.085
Motor vehicles & parts	0.023	0.977	0.889	0.027
Water distribution	0.016	0.899	0.776	0.023
All other services	0.012	0.761	0.382	0.041
Coal & Lignite	0.01	0.964	0.444	0.022
Construction	0.008	0.96	0.733	0.012
Natural gas	0.008	0.992	0.792	0.01
Education services	0.008	0.911	0.693	0.012
Telecommunication	0.007	0.665	0.434	0.024
Paper products	0.006	0.923	0.719	0.009
Meat	0.005	0.622	0.504	0.016
Wearing apparel	0.003	0.65	0.398	0.012
Catering services	0.003	0.869	0.568	0.006
Air transport (Sector)	0.003	0.993	0.924	0.003
Insurance & pensions	0.003	0.773	0.485	0.007

Industry	Contribution to CO_2 Gini	Product Gini	CO_2 R	Product Share	CO_2
Dairy products	0.003	0.63	0.505	0.008	
Health & social services	0.002	0.899	0.579	0.005	
Passenger transport	0.002	0.63	0.185	0.02	
Grain mill products	0.002	0.469	0.24	0.02	
Domestic appliances	0.002	0.734	0.305	0.009	
Other transport equipment	0.002	0.886	0.687	0.003	
Vegetables	0.002	0.578	0.397	0.008	
Made-up textiles & related articles	0.002	0.871	0.475	0.004	
Other foods	0.002	0.847	0.387	0.005	
Furniture	0.001	0.965	0.515	0.003	
Fruit & nuts	0.001	0.845	0.629	0.002	
Sewerage refuse & sanitation (Sector)	0.001	0.844	0.597	0.002	
Footwear	0.001	0.655	0.439	0.004	
Soft drinks	0.001	0.674	0.466	0.003	
Sugar	0.001	0.726	0.305	0.004	
Live animals	0.001	0.956	0.818	0.001	
Alcohol & beverages	0.001	0.796	0.324	0.003	
Pharmaceutical products	0.001	0.868	0.58	0.001	
Fish	0.001	0.846	0.356	0.002	
Jewellery	0.001	0.972	0.761	0.001	
Oils & fats	0.001	0.718	0.289	0.003	
Other manufactured products	0.0	0.71	0.325	0.002	
Glass products	0.0	0.933	0.495	0.001	

Industry	Contribution to CO_2 Gini	Product CO_2 Gini	CO_2 R	Product CO_2 Share
Tobacco products	0.0	0.923	0.297	0.001
Postal & courier services	0.0	0.954	0.593	0.0
Electrical machinery	0.0	0.997	0.823	0.0
Textile fabrics	0.0	0.987	0.519	0.0
General machinery	0.0	0.994	0.876	0.0
Carpets	0.0	0.986	0.53	0.0
Medical appliances	0.0	0.996	0.854	0.0
Water transport (Sector)	0.0	1.0	0.867	0.0