On the numerical inevitability of socialism

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Text of abstract

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# Introduction

Decarbonization scenarios that are compatible with the achievement of the Paris Accord to keep global warming well below 2°C above pre-industrial levels consider both the supply and the demand side in the necessary transformation of the energy system. On the supply side, economic and physical upper limits exist due to the assumptions of how much energy can be provided from renewable sources on the one hand, and how much CO2 removal infrastructure is used to compensate for remaining emissions from fossil fuels on the other. On the demand side (Creutzig et al., 2018) there are lower limits to how much energy is minimally required for a decent life (Grubler et al., 2018, pp. @millward–hopkins\_providing\_2020), depending on different assumptions about the available infrastructure of energy services, as well the prevalent social ideas about what constitutes a good life. Maximum possible energy supply and minimum necessary energy demand describe a space in which the simultaneous achievement of climate targets and a decent living for all depends on the distribution of available energy services among the population.

If this dual objective is taken seriously in European climate policy, then there are practical limits to how unequal the society of the future can be, which go beyond the purely political. The European Green Deal already recognizes that inequalities in incomes, energy consumption and greenhouse gas emissions lead to different responsibilities and capacities in achieving the emission savings targets, and includes proposals to increase equity and political acceptance. However, a limited energy supply creates an obvious, if rarely acknowledged, zero-sum game where energetic overconsumption by some has to be compensated by less consumption by others.

The average energy footprint of EU citizens was X GJ per capita in 2011 [oswald\_large\_2020] and the carbon footprint 8.2 tonnes CO2e per capita in 2007 (Ivanova et al., 2016). However, the differences in average energy and carbon footprints are large within and between different regions in the EU. Energy footprints ranged from X to Y GJ per capita in 2011 (Oswald et al., 2020) and carbon footprints from below 2.5 tonnes CO2eq per capita to 55 tonnes CO2eq per capita in 2010 (Ivanova and Wood, 2020). Depending on the assumptions of different global mitigation scenarios, the average footprints need to be reduced to between 15.7 and 100 GJ per capita (Grubler et al., 2018, pp. @millward–hopkins\_providing\_2020) or 0.7 and 2.1 tCO2e per capita (Akenji et al., 2019) by 2050, respectively.

We assess under what conditions European energy inequality is compatible with the achievement of global climate goals and a decent standard of living following these steps. We first construct common European expenditure deciles based on national income stratified household expenditure data from EUROSTAT covering 28 European countries, further stratified by 5 consumption sectors. We then calculate average household energy and carbon footprints per European expenditure decile and consumption sector to explore the current structure of energy and carbon intensities across these categories. Based on these results, we use the current empirical per sector best technology to calculate a homogenized counterfactual European household energy demand distribution (and associated emissions) at current European consumption levels. We report energy and emissions savings per expenditure decile and country and relate the resulting energy demand to available supply across different global 1.5°C scenarios from the literature. Using assumptions on decent living energy demand and available energy supply from different 1.5°C scenarios show how the homogenized European energy demand distribution would need to be transformed (flattened) to conform to these constraints. We report exemplary implications for energy use in different expenditure deciles. We discuss some implications for policy through the paper.

# Materials and methods

We first decomposed national household final demand expenditure in the Environmentally-Extended Multi-Regional Input-Output (EE-MRIO) model EXIOBASE (version3, industry-by-industry) (Stadler et al., 2018), by income quintile, using European household budget survey (HBS) macro-data from EUROSTAT (ref). The EUROSTAT HBS publishes national data on mean consumption expenditure by income quintile (in purchasing power standard (PPS) euro) and the structure of consumption expenditure by income quintile and COICOP consumption category. We mapped the EXIOBASE sectors to one of the COICOP consumption categories (our mapping can be found in the SI), and used the relative shares of each COICOP consumption category between the income quintiles in the HBS to decompose the EXIOBASE national household final demand expenditure per sector by income quintile as well. We then multiplied this income-stratified EXIOBASE national household final demand expenditure by ‘total’ energy use and carbon intensities per EXIOBASE sector, calculated in EXIOBASE using standard input-output calculations, to estimate national household energy and carbon footprints stratified by income quintile.

The energy footprint is the gross total energy use energy extension in EXIOBASE, which converts final energy consumption in the IEA energy balance data from the territorial to residence principle following SEEA energy accounting (ref - Stadler et al.). The carbon footprint includes CO2, CH4, N2O, SF6, HFCs and PFCs, from combustion, non-combustion, agriculture and waste, but not land-use change. For both environmental footprints, direct energy use and carbon emissions from households is included, with the total split between shelter, transport and manufactured goods using further data from EUROSTAT on this split.

Finally, we aggregated the data of 28 European countries with 5 income groups each into 10 European expenditure groups, to decompose the total European household energy and carbon footprint by European expenditure decile, ranking each national income group according to their mean consumption expenditure in PPS. We call these European expenditure deciles, although only countries with EUROSTAT data from 2005 to 2015 are included, which excludes Italy and Luxembourg, but includes the UK, Norway and Turkey. Data on decarbonization scenarios, especially final energy use, is from the IIASA scenario database (Riahi et al., 2017 @gea\_gea\_nodate), and work by Grubler et al. (2018) (Grubler et al., 2018) and Millward-Hopkins et al. (2020) (Millward-Hopkins et al., 2020). (IEA, Boell?)

Our unit of analysis through the paper is households normalized by adult equivalent unit, following the income stratified households expenditure data from EUROSTAT. The adult equivalent units from EUROSTAT adjust for household size in different countries and income groups for comparability purposes. When we discuss our household energy and carbon footprints per European expenditure decile in the context of decarbonization scenarios, we adjust total final energy use per capita output from the scenarios to household final energy use per adult equivalent. As inequality measure through the study, we divide the average value of the population in the top decile by that of the bottom decile, a 10:10 ratio. For example, in expenditure, a 10:10 ratio of 5 means that adult equivalents in the top decile spend 5 times more on average than those in the bottom decile.All data and procedures are described in detail in the supplementary information (SI).

# Results

## Environmental footprints are less unequal than expenditure levels

Consumption-based indicators such as the energy and carbon footprint of households are largely determined by their spending levels. An inequality of household expenditures in a population therefore implies an inequality of their environmental footprints. Figures 1a-c show European households by decile of expenditure and their associated footprints for energy and carbon in 2015. The figures show that increasing expenditure generally translated into larger footprints, but that the inequality decreased from expenditure to energy to carbon, with 10:10 ratios (the top decile divided by the bottom decile) of 7.2, 3.5 and 2.6, respectively. Total expenditure ranged from 0.2 trn€ to 1.3 trn€ (or 5263€ to 3.81110^{4}€ per adult equivalent) across bottom and top decile, the energy footprint from 4.4 EJ to 15.3 EJ (or 132.4 GJ/ae to 457.2 GJ/ae), and the carbon footprint from 232.8 MtCO2eq to 606.5 MtCO2eq (or 7 tCO2eq/ae to 18.1 tCO2eq/ae). The reason for this is evident from figures 1d-f. Both the energy intensity of consumption, measured as energy use per € expenditure (d), and the carbon intensity of energy, measured as carbon per unit of energy use (f), gradually decrease from bottom to top expenditure decile. The weighted average energy intensity of consumption decreased from 25.2 MJ/€ in the bottom decile to less than half (12 MJ/€) in the top decile. Additionally, the carbon intensity of energy was also higher in the bottom decile (52.6 gCO2eq/TJ) compared to the top decile (39.7 gCO2eq/TJ). There is a clear trend of decreasing intensities across expenditure deciles even though the variance in the lower deciles is much higher. The carbon intensity of consumption (figure 1e) combines the effects of the intensities of 1d and 1f. The higher carbon intensity of energy is likely due to a larger share of emission intensive energy carriers in the energy system. The decreasing energy intensity of consumption is due to either inefficient energy technologies or energy subsidies in lower-income areas in Europe.

![Figure 1: Household expenditure and environmental footprints and intensities across European expenditure deciles. Total expenditures (a), energy footprint (b), and carbon footprint (c) per decile. Energy intensity of consumption as energy footprint per expenditure (d), carbon intensity of consumption as carbon footprint per expenditure (e), and carbon intensity of energy as carbon footprint per energy footprint (f).](data:application/pdf;base64,)

Figure 1: Household expenditure and environmental footprints and intensities across European expenditure deciles. Total expenditures (a), energy footprint (b), and carbon footprint (c) per decile. Energy intensity of consumption as energy footprint per expenditure (d), carbon intensity of consumption as carbon footprint per expenditure (e), and carbon intensity of energy as carbon footprint per energy footprint (f).

Figures 1d-e show that energy and carbon intensities of consumption are particularly high in the lower four deciles, while the higher deciles do not show large differences in weighted average energy and carbon intensity. The different intensities of household consumption across European expenditure deciles can be attributed to a combination of two plausible causes: first, if the composition of consumption baskets systematically differs according to the level of household expenditure. Second, if energy and carbon intensity within individual consumption sectors systematically differs according to the level of household expenditure.

![Figure 2: Sectoral expenditure shares and carbon intensities of European expenditure deciles. Share of expenditure per final demand sector of total spending per decile in percent (a) and carbon intensity per final demand sector in kgCO2eq/€.](data:application/pdf;base64,)

Figure 2: Sectoral expenditure shares and carbon intensities of European expenditure deciles. Share of expenditure per final demand sector of total spending per decile in percent (a) and carbon intensity per final demand sector in kgCO2eq/€.

Our data show that both of these factors play a role 2. Lower-income households, on average, spend larger shares of their expenditure in the shelter sector. The bottom and top deciles spend an average of 10.6% and 5.4% of their household expenditure on shelter, respectively (our aggregated ‘shelter’ sector does not include rental payments. We have included the EXIOBASE production sector ‘real estate services’, which includes rental payments, in our aggregated ‘services’ sector, not the aggregated ‘shelter’ sector - see SI Table 4). Overall, with increasing expenditure decile, the shares of transport and services expenditures increase and the shares of shelter, food and manufactured goods decrease. At the same time, shelter is by far the most carbon intensive sector with the highest variance between expenditure deciles. In our sample, the intensity of all sectors decreases with expenditure level but the shelter sector stands out with a carbon intensity of consumption more than 3 times higher in the bottom decile (7.5 kgCO2eq/€) than in the top decile (2 kgCO2eq/€). Households in the top decile spend about 55.2% in the service sector, which has the lowest carbon intensity, compared to 38.4% in the bottom decile. Single country studies using EE-MRIO models with national resolution can pick up on differences in consumption baskets, but due to the homogeneous technology assumption in EE-MRIOs, cannot represent differences in technology between expenditure deciles.

The tendency for energy and carbon intensity to decrease with increasing affluence can be observed at the global level (XXX) between countries and also applies within Europe. In some of the Eastern European countries, between 80% and 100% of the population belong to the four lowest European expenditure deciles. This compares to less than 20% of the population in the higher-income European countries (Scandinavia, Germany, France, Austria, the Netherlands, Belgium, the UK, and Ireland). Note here that our analysis is based on average expenditure data from five income groups at the national level. This aggregation cuts off the lower and higher ends of the respective national expenditure distributions (see SI - Supplementary Note and Map).

The high intensities in the bottom four European expenditure deciles can be attributed in large part to more inefficient and dirtier domestic energy supplies for heating and electricity generation in Poland, Bulgaria, the Czech Republic, and Romania. Poland alone was responsible for about 40% of total coal combustion for heat production in Europe in 2015 (Eurostat, n.d.), and had a higher average intensity of carbon per MJ of heat delivered than both Europe and the world (Werner, 2017). These differences in energy and carbon intensities in basic, non-luxury sectors (especially shelter) account for the smaller inequality between expenditure deciles, in terms of environmental footprints compared to raw expenditures.

## Inequality across final consumption sectors

In absolute terms, the final consumption sectors contribute very differently to the total environmental footprint of households (Figure 3). On average, shelter and transport are the two largest sectors, accounting for nearly two thirds of both footprints. However, there are big differences between the sectors when looking at the respective contributions of each expenditure decile. For shelter there is very little difference, in both the energy and carbon footprint, between deciles. The lowest four deciles even have higher carbon footprints from shelter than most higher deciles, which can be explained by the extreme differences in intensity shown in Figure 2. Transport was the most unequal sector, with footprints in the top decile 10 times higher than the bottom decile (corroborating findings in (Ivanova et al., 2020) and (Oswald et al., 2020)). Manufactured goods was the second most unequal final consumption sector (10:10 ratios around 5 for both footprints), followed by services (10:10 ratios of 4.9 for energy and 4.4 for carbon) and then food (10:10 ratios of 2.1 for both footprints).

![Figure 3: Energy and carbon footprints by final consumption sector and European expenditure decile in 2015, further broken down by emission source location.](data:application/pdf;base64,)

Figure 3: Energy and carbon footprints by final consumption sector and European expenditure decile in 2015, further broken down by emission source location.

Figure 3 also shows the inequality in geographical source of the household energy and carbon footprints across final consumption sector. The shelter footprint was almost entirely domestic, with 26/30% coming from direct household emissions/energy use for heating and cooling, and the rest embedded primarily along the domestic supply chain. The transport footprint was just under 2/3rds domestic. The majority of the transport footprint, above 60%, came from vehicle fuel, either burned directly or indirectly embedded along its supply chain. More than half of the transport footprint’s foreign 1/3rd came from outside Europe. The manufactured goods footprint was mostly non-European, while services and food were both around half domestic. These results suggest that proposed future carbon border-adjustment mechanisms will especially impact the manufactured goods and transport footprints of the higher deciles, and to a lesser extent the food and services footprints, depending on mechanism design.

# Counterfactual: a 1.5°C compatible Europe

Global 1.5°C compatible decarbonisation scenarios achieve a similar climate outcome with different assumptions about the transformation of energy supply and demand, from renewable capacity, deployment of carbon-capture-and-storage (CCS), and socio-technological demand transformation.

| scenario | fe\_gj\_aeu | ccs\_required | description |
| --- | --- | --- | --- |
| DLE | 16 | 0 | full stock replacement\nalso |
| LED | 53 | 0 | Global 27 GJ/cap |
| GEA efficiency | 64 | 5 |  |
| IEA ETP B2DS | 84 | 0 | missing CCS |
| SSP1-1.9 | 87 | 45 | CSS: 44 EJ |
| SSP2-1.9 | 94 | 38 | CSS: 38 EJ |

The various global supply side scenarios (SSP1-1.9, SSP2-1.9, GEA efficiency) envisage total EU (*or our sample*) energy consumption falling from the current X EJ to X-Y EJ by 2030 (or 2050), equivalent to a per household reduction from a current average of 250 GJ to X-Y GJ per adult equivalent. The differences in energy consumption in 2050 in the scenarios reflect different model assumptions about the rate of expansion of renewable energy and CCS capacity. Most/all of these scenarios rely on substantial amounts of CCS (*starting from when?*) which is still a fairly speculative technology and we therefore interpret them as ranges for the upper limits of 1.5°C-compatible energy supply.

It is even more difficult to determine a lower limit for the minimum amount of energy needed for a decent life. This depends strongly on the one hand on the prevalent socio-cultural idea of what constitutes a decent life, and on the other hand, perhaps even more strongly, on the physical infrastructure available to deliver this life. The two global demand side scenarios (LED, DLE) that attempt to define such a limit conclude that, in principle, a very low energy footprint (between 16-53 GJ per household adult equivalent) could be sufficient. However, these scenarios rely on socio-technological transformations on a scale that, especially at the lower end, far exceeds the current political discourse on the subject. All two/three scenarios are 1.5°C compatible without resorting to any CCS but they all implicitly (LED) or explicitly (DLE) assume near complete equality of consumption across the population. To put these low energy demand numbers in perspective, the average energy footprint in our sample is about a factor 5 above the high estimate (250 MJ/aeq). Households in the first European expenditure decile had an energy footprint of 130 GJ per adult equivalent in 2015 even though they fell almost entirely within the Eurostat definition of severe material deprivation.

Based on these two constraints, the upper limit on the supply side and the lower limit on the demand side, it is possible to make a generalized estimate of how much inequality in the distribution of energy consumption is numerically possible, if at the same time global warming is to be kept below 1.5°C above pre-industrial levels and a good life for all is to be made possible. Before we can make this evaluation, we must take into account the existing large differences in the technological efficiency of energy provision (Figure 2). Since the European expenditure deciles discussed here include large population groups (~X persons/households) with different demand structures for energy services (urban/rural, demographic, climatic), we assume that the variation in energy intensity across deciles is largely due to technological efficiency. These differences will be adjusted in the next step.

## Current empirical best technology per sector

![Figure 4: Energy savings through sectoral best current technology by expenditure deciles a) and country b).](data:application/pdf;base64,)

Figure 4: Energy savings through sectoral best current technology by expenditure deciles a) and country b).

Our results show that in 2015, rich people in rich countries had access to the most energy-efficient energy services across all final demand sectors (Figure 2). Since we are interested in the numerically possible inequality in the distribution of actual consumption of goods and services in the next section, these efficiency differences must first be adjusted. In practice, this corresponds, for example, to the need for large-scale investments in the technical efficiency of heat, electricity and hot water supply, especially in Eastern Europe. Figure 4 shows the energy footprint savings per decile (Fig. 4a) that would have occurred in 2015 if all deciles had the same efficiency per final demand sector as the 10th decile. Around 17 EJ would have been saved in total, and the energy footprint of the first decile would have been nearly half its 2015 value. Fig. 4b shows saved energy per country, with Eastern European countries especially saving large proportions of their 2015 footprint, over 60% for Bulgaria and Estonia for example.

Points to hit: - Improving energy efficiency is the most politically uncontroversial step towards mitigation targets. The EU has a bunch of policies for that, old and new. The GD has a transition fund to pay for this for poorer countries, sort of.

## Inequality in a 1.5°C compatible Europe

Based on this counterfactual distribution of the energy footprint using homogeneous supply technologies, we can now scale down energy consumption across European expenditure deciles to meet supply constraints and, where necessary, “squeeze” the distribution to not undershoot minimum demand constraints in any decile. This means that, based on the current empirical distribution, for each value combination of supply and minimum necessary demand, the maximum permissible inequality can be calculated as a 10:10 ratio (Figure 5. [*Ref to formula*]

Starting at the low end of energy supply, both (or all three with Boell) the DLE and LED scenarios satisfy energy demand without resorting to CCS technologies. The DLE scenario explicitly envisions absolute global equality (10:10 ratio of 1) in consumption, except for small differences in required energy consumption based on climatic and demographic factors, as well as differences in population density. The LED scenario does not explicitly discuss distributional aspects beyond giving different final energy consumption values for the Global North (53GJ/cap) and the Global South (27GJ/cap). However, due to the bottom-up construction of this demand scenario, these values can be interpreted as estimates for the minimum required energy demand.

The descriptions of the energy supply scenarios do not include specific details about how the energy footprints are distributed within the population. The energy savings here are achieved primarily through efficiency improvements, and perhaps also generally assumed demand reductions. However, Figure 5 makes it clear that even with ambitious demand reductions, as in the LED scenario, a large reduction in inequality between the European expenditure quantiles is required.

At current inequality levels, only the two scenarios with heavy CCS deployment and GEA efficiency are possible if we assume extremely low minimum energy requirements (below 27 GJ/cap). This 27 GJ/capita is the value the low-energy demand (LED) scenario gives for the global South in 2050. If we use the value given for the global North at 53 GJ/cap (with strong demand side measures) then inequality would need to be drastically reduced, the 10:10 ratio more than halved, in all scenarios (including those with CCS deployment).

![Figure 5: Dings. in Figure 5, all deciles have ‘best technology’ already](data:application/pdf;base64,)

Figure 5: Dings. in Figure 5, all deciles have ‘best technology’ already

# Conclusions

Estimates of energy and carbon footprint inequality are increasingly being used to assign responsibility for climate change. At a global, regional, and within-country level, energy use and carbon emissions are often highly unequal (Piketty and Chancel, 2015, pp. @kartha\_carbon\_2020 @gore\_extreme\_2015 @hubacek\_global\_2017–1 @ivanova\_unequal\_2020 @wiedenhofer\_unequal\_2017 @golley\_income\_2012 @steenolsen\_carbon\_2016 @weber\_quantifying\_2008 @hardadi\_implications\_2020 @oswald\_large\_2020). The proposed solution is often a call to reduce the carbon or energy inequality by reducing over-consumption, especially by the richest at the top of the economic distribution, which would then also reduce the energy and carbon footprints, everything else held equal. Complicating this picture, however, is the fact that energy and carbon intensities of consumption usually differ between economic groups. This is due to different consumption baskets and different access to technology. That lower-income groups tend to have higher energy and carbon intensities is an important finding from the environmental Kuznet’s curve literature (Berthe and Elie, 2015, p. @scruggs\_political\_1998). This finding has not yet been well integrated with the current carbon and energy footprint inequality literature, that focuses more on assigning responsibility based on aggregate energy and carbon footprint inequality.

In this study, we have found that, for Europe as a whole, lower-economic groups have higher energy and carbon intensities of consumption (although this is not necessarily true within each European country) (Sommer and Kratena, 2017, p. @kerkhof\_determinants\_2009). These higher intensities come almost entirely from domestic electricity production and heating/cooling for shelter, in a handful of Central and Eastern European countries. This is already an important focus of European climate policy, but reducing these intensities should be a major priority for investment fund allocation going forward, especially within a framework such as the EU’s European Green Deal (Bianco et al., 2019). Efforts to break consumer lock-in to these high intensities must be occurring alongside policies that seek to reduce aggregate consumption and intensities higher up in the economic distribution. Bringing intensities of consumption for all economic groups in line with those of higher-economic groups in Europe with access to the cleanest and most efficient available technologies, would substantially reduce the European household energy and carbon footprints, everything else held equal. The unequal intensity structure hinders clear conclusions on footprint inequality. We have shown that in an important sector such as shelter, lower-economic groups have almost the same level of footprint as higher-economic groups despite a fraction of the expenditure, because of their higher intensities. This can then be misleading in terms of assigning responsibility for climate change. Bringing energy and carbon intensities of all economic groups in line with the top group, and thus removing the inequality in intensity structure, would reduce the footprint, all else held equal, but *increase* energy and carbon inequality. The reduction of energy and carbon inequality is not a meaningful goal by itself.

Current consumption inequality, however, is a barrier to achieving both scenario targets *and* providing minimum energy use (and minimum carbon in the short-term) for decent living to every European. At a global level, there is concern that achieving extreme poverty eradication may put global climate targets at risk (Hubacek, Baiocchi, Feng, and Patwardhan, 2017, p. @woodward\_incrementum\_2015). In the European context, although less unequal than the globe as a whole, if/as lower-consumption groups increase their income and consumption, energy use and carbon emissions will increase if more efficient and cleaner technology is not adopted at a fast enough rate. Achieving an average per capita/adult equivalent energy and carbon footprint in Europe, in scenarios that reach the Paris agreement goals, means either doing so at current consumption inequality levels and keeping lower-economic groups near or below minimum energy use levels for decent living, or reducing consumption inequality.

# refs to add

demand side solution:

Royston, S., Selby, J. & Shove, E. Invisible energy policies: A new agenda for energy demand reduction. *Energy Policy* **123**, 127–135 (2018).

reduction in demand

Alfredsson, E. *et al.* Why achieving the Paris Agreement requires reduced overall consumption and production. *Sustainability: Science, Practice and Policy* **14**, 1–5 (2018).

# Acknowledgements

# References

Akenji, L., Lettenmeier, M., Koide, R., Toivio, V., Amellina, A., 2019. 1.5-Degree Lifestyles: Targets and options for reducing lifestyle carbon footprints. Institute for Global Environmental Strategies, Aalto University,; D-mat ltd.

Berthe, A., Elie, L., 2015. Mechanisms explaining the impact of economic inequality on environmental deterioration. Ecological Economics 116, 191–200. <https://doi.org/10.1016/j.ecolecon.2015.04.026>

Bianco, V., Cascetta, F., Marino, A., Nardini, S., 2019. Understanding energy consumption and carbon emissions in Europe: A focus on inequality issues. Energy 170, 120–130. <https://doi.org/10.1016/j.energy.2018.12.120>

Creutzig, F., Roy, J., Lamb, W.F., Azevedo, I.M.L., Bruine de Bruin, W., Dalkmann, H., Edelenbosch, O.Y., Geels, F.W., Grubler, A., Hepburn, C., Hertwich, E.G., Khosla, R., Mattauch, L., Minx, J.C., Ramakrishnan, A., Rao, N.D., Steinberger, J.K., Tavoni, M., Ürge-Vorsatz, D., Weber, E.U., 2018. Towards demand-side solutions for mitigating climate change. Nature Climate Change 8, 260–263. <https://doi.org/10.1038/s41558-018-0121-1>

Eurostat, n.d. Eurostat - Data Explorer - Production of electricity and derived heat by type of fuel.

GEA, n.d. GEA Scenario database (public).

Golley, J., Meng, X., 2012. Income inequality and carbon dioxide emissions: The case of Chinese urban households. Energy Economics 34, 1864–1872. <https://doi.org/10.1016/j.eneco.2012.07.025>

Gore, T., 2015. Extreme Carbon Inequality: Why the Paris climate deal must put the poorest, lowest emitting and most vulnerable people first.

Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D., Rao, N., Riahi, K., Rogelj, J., De Stercke, S., Cullen, J., Frank, S., Fricko, O., Guo, F., Gidden, M., Havlik, P., Huppmann, D., Kiesewetter, G., Rafaj, P., Schöpp, W., Valin, H., 2018. A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nature Energy 3, 517–525. [https://doi.org/Grubler A <http://pure.iiasa.ac.at/view/iiasa/112.html>, Wilson C <http://pure.iiasa.ac.at/view/iiasa/333.html>, Bento N <http://pure.iiasa.ac.at/view/iiasa/2833.html>, Boza-Kiss B <http://pure.iiasa.ac.at/view/iiasa/2913.html>, Krey V <http://pure.iiasa.ac.at/view/iiasa/166.html>, McCollum D <http://pure.iiasa.ac.at/view/iiasa/203.html>, Rao N <http://pure.iiasa.ac.at/view/iiasa/243.html>, Riahi K <http://pure.iiasa.ac.at/view/iiasa/250.html>, et al. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nature Energy 3: 517-525. DOI:10.1038/s41560-018-0172-6 <https://doi.org/10.1038/s41560-018-0172-6>.](https://doi.org/Grubler%20A%20%3Chttp://pure.iiasa.ac.at/view/iiasa/112.html%3E,%20Wilson%20C%20%3Chttp://pure.iiasa.ac.at/view/iiasa/333.html%3E,%20Bento%20N%20%3Chttp://pure.iiasa.ac.at/view/iiasa/2833.html%3E,%20Boza-Kiss%20B%20%3Chttp://pure.iiasa.ac.at/view/iiasa/2913.html%3E,%20Krey%20V%20%3Chttp://pure.iiasa.ac.at/view/iiasa/166.html%3E,%20McCollum%20D%20%3Chttp://pure.iiasa.ac.at/view/iiasa/203.html%3E,%20Rao%20N%20%3Chttp://pure.iiasa.ac.at/view/iiasa/243.html%3E,%20Riahi%20K%20%3Chttp://pure.iiasa.ac.at/view/iiasa/250.html%3E,%20et%20al.%20%20(2018).%20%20A%20low%20energy%20demand%20scenario%20for%20meeting%20the%201.5%20°C%20target%20and%20sustainable%20development%20goals%20without%20negative%20emission%20technologies.%20%20%20Nature%20Energy%203:%20517-525.%20DOI:10.1038/s41560-018-0172-6%20%3Chttps://doi.org/10.1038/s41560-018-0172-6%3E.)

Hardadi, G., Buchholz, A., Pauliuk, S., 2020. Implications of the distribution of German household environmental footprints across income groups for integrating environmental and social policy design. Journal of Industrial Ecology n/a. <https://doi.org/10.1111/jiec.13045>

Hubacek, K., Baiocchi, G., Feng, K., Muñoz Castillo, R., Sun, L., Xue, J., 2017. Global carbon inequality. Energy, Ecology and Environment 2, 361–369. <https://doi.org/10.1007/s40974-017-0072-9>

Hubacek, K., Baiocchi, G., Feng, K., Patwardhan, A., 2017. Poverty eradication in a carbon constrained world. Nature Communications 8, 1–9. <https://doi.org/10.1038/s41467-017-00919-4>

Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M.W., Creutzig, F., 2020. Quantifying the potential for climate change mitigation of consumption options. Environmental Research Letters. <https://doi.org/10.1088/1748-9326/ab8589>

Ivanova, D., Stadler, K., Steen‐Olsen, K., Wood, R., Vita, G., Tukker, A., Hertwich, E.G., 2016. Environmental Impact Assessment of Household Consumption. Journal of Industrial Ecology 20, 526–536. <https://doi.org/10.1111/jiec.12371>

Ivanova, D., Wood, R., 2020. The unequal distribution of household carbon footprints in Europe and its link to sustainability. Global Sustainability 3. <https://doi.org/10.1017/sus.2020.12>

Kartha, S., Kemp-Benedict, E., Ghosh, E., Nazareth, A., 2020. The Carbon Inequality Era.

Kerkhof, A.C., Benders, R.M.J., Moll, H.C., 2009. Determinants of variation in household CO2 emissions between and within countries. Energy Policy 37, 1509–1517.

Millward-Hopkins, J., Steinberger, J.K., Rao, N.D., Oswald, Y., 2020. Providing decent living with minimum energy: A global scenario. Global Environmental Change 65, 102168. <https://doi.org/10.1016/j.gloenvcha.2020.102168>

Oswald, Y., Owen, A., Steinberger, J.K., 2020. Large inequality in international and intranational energy footprints between income groups and across consumption categories. Nature Energy 5, 231–239. <https://doi.org/10.1038/s41560-020-0579-8>

Piketty, T., Chancel, L., 2015. Carbon and inequality: From Kyoto to Paris. Paris Sch Econ (www. parisschoolofeconomics. eu/en/news/carbon-and-inequality-from-kyoto-to-parischancel-piketty/).

Riahi, K., Vuuren, D.P. van, Kriegler, E., Edmonds, J., O’Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42, 153–168. <https://doi.org/10.1016/j.gloenvcha.2016.05.009>

Scruggs, L., 1998. Political and economic inequality and the environment. Ecological Economics 26, 259–275.

Sommer, M., Kratena, K., 2017. The Carbon Footprint of European Households and Income Distribution. Ecological Economics 136, 62–72.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta‐Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J.H., Theurl, M.C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.-H., Koning, A. de, Tukker, A., 2018. EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. Journal of Industrial Ecology 22, 502–515. <https://doi.org/10.1111/jiec.12715>

Steen‐Olsen, K., Wood, R., Hertwich, E.G., 2016. The Carbon Footprint of Norwegian Household Consumption 1999–2012. Journal of Industrial Ecology 20, 582–592. <https://doi.org/10.1111/jiec.12405>

Weber, C.L., Matthews, H.S., 2008. Quantifying the global and distributional aspects of American household carbon footprint. Ecological Economics 66, 379–391. <https://doi.org/10.1016/j.ecolecon.2007.09.021>

Werner, S., 2017. International review of district heating and cooling. Energy 137, 617–631. <https://doi.org/10.1016/j.energy.2017.04.045>

Wiedenhofer, D., Guan, D., Liu, Z., Meng, J., Zhang, N., Wei, Y.-M., 2017. Unequal household carbon footprints in China. Nature Climate Change 7, 75–80.

Woodward, D., 2015. Incrementum ad Absurdum: Global Growth, Inequality and Poverty Eradication in a Carbon-Constrained World. World Social and Economic Review 2015, 43.

### Colophon

This report was generated on 2021-01-22 14:14:46 using the following computational environment and dependencies:

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#> setting value   
#> version R version 3.6.3 (2020-02-29)  
#> os Ubuntu 16.04.3 LTS   
#> system x86\_64, linux-gnu   
#> ui X11   
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#> ctype en\_US.UTF-8   
#> tz Europe/Berlin   
#> date 2021-01-22   
#>   
#> ─ Packages ───────────────────────────────────────────────────────────────────  
#> package \* version date lib source   
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#> backports 1.1.8 2020-06-17 [1] CRAN (R 3.6.3)  
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#> bit 1.1-15.2 2020-02-10 [1] CRAN (R 3.6.3)  
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#> crayon 1.3.4 2017-09-16 [1] CRAN (R 3.6.3)  
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#> [4] /usr/lib/R/library

The current Git commit details are:

#> Local: master /home/jaccard/ownCloud/Shared/europe.inequality  
#> Remote: master @ origin (git@gitlab.pik-potsdam.de:pichler/europe.inequality.git)  
#> Head: [5257142] 2021-01-22: edit references