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RESEARCH ARTICLE

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Examining changes in household carbon footprints across generations in the UK using decomposition analysis

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Abstract

To meet climate targets, consumption-based household emissions need to fall rapidly. An important but still poorly understood question is whether generational change could contribute to decreases in emissions. It is sometimes assumed that younger generations such as Millennials and Generation Z are more concerned about climate change and have greener lifestyles than previous generations of the Silent Generation, Baby boomers, and Generation X, but carbon footprinting analysis typically focuses on age groups rather than comparing generations over time. This paper provides a first assessment of the change in consumption-based carbon footprints of the Silent, Baby boomer, Generation X, and Millennial generations within the United Kingdom between 2001 and 2020 and a comparison of the footprints of different generational groups. The analysis is based on environmentally extended input–output analysis, using the Living Costs and Food Survey and emission data from the UK multi-regional input–output database. We find some evidence for the hypothesis that younger generations have smaller footprints than older generations as Generation X and Millennial households have smaller carbon footprints compared to the generation before them at a similar life stage. We find that factors such as decarbonization, household occupancy, total expenditure, and changing consumption patterns contribute to the UK's changing carbon consumption emissions between 2001 and 2020, and the importance of these factors varies for different generational groups. However, future research that uses a longer time series is required to assess generational differences in carbon footprints over the whole lifespan of several generations.

KEYWORDS
carbon footprints, consumption-based accounting, effects of aging, generations, industrial ecology, structural decomposition

1 | INTRODUCTION

Rapid emission reductions are needed to prevent dangerous levels of climate change. The United Kingdom has committed to Net Zero by 2050 (UK Government, 2019) and the UK's Sixth Carbon Budget requires a 78% reduction in territorial emissions between 1990 and 2035 (CCC, 2020). The literature increasingly highlights the role that demand reduction can play in achieving climate targets, in addition to technological improvements that reduce the emission intensity of production and consumption (Barrett et al., 2022; Creutzig et al., 2022; Scott et al., 2022). In the United Kingdom, the Climate Change Committee has repeatedly recommended that the Government should outline ambitions for consumption emissions reductions (CCC, 2022). Since it is often assumed that younger generations are more concerned about climate change and more likely to act in environmentally friendly ways, a policy-relevant question in this debate is whether generational shifts, for example, the decline of the Silent and Baby boomer generations and the emergence of Millennials, are likely to contribute to demand reduction over time.

A focus on generations in emissions studies offers a different perspective compared to a focus on age or life course. Several studies have shown that age has an impact on emissions as consumption patterns differ across the life course (Büchs & Schnepf, 2013; Lévay et al., 2021). However, the sociological concept of generation differs from a focus on age or life course as it assumes that identities, worldviews, and lifestyles of social groups born during a certain period of time are shaped by formative experiences of specific political and economic events such as wars, economic crises, or other major historical events (Mannheim, 1952). While it is common in the literature to attach labels and birth cohorts to generations, for instance, the Silent Generation (born ~ 1924–1945), Baby boomers (born ~ 1946–1964), Generation X (Gen X, born ~1965-1980), Millennials/Generation Y (born ~ 1981–1996), and Generation Z (born ~1997-2012) (Pew Research Centre, 2015), it needs to be emphasized that these definitions are not universally accepted and should be understood as emergent and socially constructed. Much research on generations is interested in social change because generations could play a crucial role in social transformation by challenging established ways of thinking and acting, based on their specific historical experiences (Edmunds & Turner, 2005; Mannheim, 1952). Much of the early research on generation has focused on national events (e.g., the American Depression, the Spanish Civil War, etc.). However, generations are increasingly understood as global phenomena because key historical events often have global impacts due to the globalized nature of economies and the role of social media (Au, 2020; Beck & Beck-Gernsheim, 2008; Edmunds & Turner, 2005).

Previous research on household emissions has considered the role of age, but the role of generational characteristics and generational change for emission reduction remains poorly understood. To our knowledge, an analysis of the carbon footprints of generations and how footprints of generations have changed over time is lacking. Using 20 years of data from the UK Living Costs and Food Survey (LCFS), we construct generational groups and examine their emissions over time. We then assess through structural decomposition analysis (SDA) how factors such as decarbonization of production, household occupancy, changes in per capita expenditure, and the composition of consumption baskets, as well as changes in overall population size have contributed to the reduction of the UK's carbon footprint for each generational group. We consider if there are generational differences in the importance of these factors. Section 2 provides a brief overview of previous research on the roles of age and generations for carbon footprints and environmental attitudes and behaviors. Section 3 explains the data and methods, Section 4 reports the results, Section 5 discusses the results, and Section 6 concludes.

2 | LITERATURE REVIEW

2.1 | The role of age in carbon emissions

Previous research has examined the role of age and other socio-economic characteristics such as income, household size, education, employment status, gender, rural/urban location, ethnicity, and health status in household emissions and energy use. Bivariate and multivariate studies on the role of age in various countries consistently show that total (direct and indirect) emissions and energy use tend to increase with age but fall again with old age (e.g., 75/80+ years depending on the study) (Büchs & Schnepf, 2013; Christis et al., 2019; Haq et al., 2007; Lévay et al., 2021; Liu et al., 2022). However, the association between age and emissions differs across consumption domains. For instance, older people are more likely to have high home energy emissions than younger or middle-aged people, presumably due to reduced mobility and a greater likelihood of being at home during the day (Büchs & Schnepf, 2013; Büchs et al., 2018; Christis et al., 2019; Lévay et al., 2021). Emissions from car travel tend to be higher for middle-aged and older people compared to those of younger people, but car travel emissions decline again beyond a certain age when older people become less mobile (Büchs et al., 2018; Mattioli et al., 2023). Conversely, younger people are more likely to have high carbon emissions from air travel while the likelihood to fly and the number of flights declines with age (Büchs & Mattioli, 2021; Mattioli et al., 2023). Emissions increase with household size, but per capita emissions are lower for larger households. This is especially so for domestic energy as larger households share more space, appliances, etc., and thus benefit from economies of scale (Christis et al., 2019; Feng et al., 2021; Ivanova & Büchs, 2022; Lévay et al., 2021). Household size is also closely associated with age: household sizes tend to be largest for middle-aged household representatives who often live with partners and children and lower for both younger and older households who live without children, and sometimes even alone.

2.2 The role of generation

Despite recent discourses around greater environmental awareness and action by young generations, the role of generation as a potential driver for change remains poorly understood. Current public discourses suggest that younger generations are more concerned about climate change and more likely to act in environmentally friendly ways than older generations because younger generations will be more exposed to climate change impacts. The "climate for future" or "Fridays for Future" youth strikes triggered by action taken by then-15-year-old Greta Thunberg in 2018 supported this perception. The idea that generational change could support emission reduction also aligns with theories about an increasing shift toward post-materialist (and pro-ecology) values in post-industrial societies (Inglehart, 1971, 1981). However, opposing discourses also exist that portray younger generations as more strongly driven by extrinsic than intrinsic motivations than older generations like the Baby boomers, and more aligned with a throwaway, consumerist culture (Diprose et al., 2019; Twenge et al., 2012).

While many studies on environmental attitudes and behaviors are framed around generations, most of them examine age groups from cross-sectional surveys at one point in time. Very few studies utilize longitudinal data (Konietzka & Neugebauer, 2023; Lorenzini et al., 2021) or cross-sectional data over a period of time (Swim et al., 2022). However, several studies cover change over longer time frames; for example, Bardazzi and Pazienza (2017, 2020) examine generational cohorts' residential energy use, and Bardazzi and Pazienza (2018) consider the consumption of private transport fuel over a 20-year period. Chancel (2014) assesses the direct[1] carbon emissions of households belonging to different generational groups between 1980 and 2000, finding that French Baby boomers have higher emissions than other generations. However, to our knowledge, there is currently no study that estimates both direct and indirect emissions of generational groups over time. Estimating the complete carbon footprint allows us to consider not only the carbon footprint of residential energy use and travel but also of food, goods, and services, which constitute a large share of people's carbon footprints.

Studies that focus on environmental behaviors through a generational lens remain inconclusive as to whether younger generations are choosing to behave in an environmentally conscious manner or whether there are other external factors influencing their behavior. For example, one longitudinal study finds that car ownership in post-industrial cities in Germany is declining across generations and that Millennials are the least likely of all generations to use a car (Konietzka & Neugebauer, 2023). Counterintuitively, however, bike use increased more among Baby boomer and Generation X members than among Millennials (ibid.). The authors interpret this result as pointing to socio-structural reasons for the decline in car use, for instance greater financial pressures on younger generations, rather than evidence for a generational shift in behaviors (ibid.). A study in China also finds lower environmental concern and environmental behaviors among younger compared to older generations (Dermody et al., 2021).

With regard to environmental attitudes, a longitudinal study in Switzerland concludes that the young climate strike generation had the most environmentally friendly attitudes but that attitudes of all generations have become more environmentally friendly over time (Lorenzini et al., 2021). A study in the United States using cross-sectional survey data over time similarly finds that climate change worry had increased most among Generation Z and Millennial members (Swim et al., 2022). Other cross-sectional studies also conclude that younger generations have more environmentally friendly attitudes than older generations, for example, in Spain (Caballero, 2017); in the United States in relation to sustainable travel options (Rahimi et al., 2020) and to climate change specifically (Ross et al., 2021); in Europe (Skeirytė et al., 2022); in Japan in relation to support for Sustainable Development Goals (Yamane & Kaneko, 2021); and in Beijing in relation to private car use (Zhou & Wang, 2019). However, some research presents opposing evidence, for example, that Millennials did not feel more responsible for their environmental footprint than Generation X members (Gómez-Román et al., 2020); that younger generations in the United States were not more environmentally concerned than older generations (Gray et al., 2019); or that there was no significant difference in climate concern between Generation X and Generation Z members in South Africa (Kgomo & Modley, 2023).

2.3 Understanding drivers of change for consumption-based emissions

In the fields of demography and epidemiology, the age, period, and cohort (APC) lens has long been important for understanding time-varying elements (Yang et al., 2008) in a population. Yang et al. describe *age effects* as "variation associated with different age groups," *period effects* as "variation over time periods that affect all age groups simultaneously," and *cohort effects* as "changes across groups of individuals who experience an initial event such as birth in the same year or years" (Yang et al., 2008). APC approaches are most commonly used in health sciences (Fosse & Winship, 2019) and have been applied to try to understand the change in obesity (Reither et al., 2009), psychological distress (Keyes et al., 2014), and drug use (Chen et al., 2003). More closely related to our research question, the work by Bardazzi and Pazienza (2017, 2018, 2020) and Chancel (2014) employs the use of APC methods to decompose changes in Italian and French households' energy use and direct emissions (respectively) into age and cohort effects. Using an APC lens to understand time-varying effects associated with changing carbon footprints appears to be a novel and potentially useful endeavor.

In the field of input–output (IO) analysis, SDAs are the state-of-the-art methodology for examining the driving forces of changes in energy and emission footprints (Lan et al., 2016; Rose & Chen, 1991a; Sun, 1998). Classic decomposition studies often follow the IPAT (Impact = Population x

Affluence x Technology) model and involve decomposing total consumption emissions into the following drivers: population change, changes in per capita expenditure (affluence), and emissions intensity of products (technology). Yu et al. (2022) demonstrate per capita expenditure is the most important factor in the increase in Chinese indirect household emissions, contrasting with technology playing the most important role in Japan's more stable household carbon footprint. Similarly, Lee et al. (2023), focusing on regions within the European Union, find that overall population changes and consumption baskets have minor effects in comparison to changes in overall consumption and emissions intensity. Very few studies find population change is an important driver of energy or emissions footprints and those that do tend to be older and/or focus on the Global South (Wachsmann et al., 2009).

Very few decomposition studies consider the effects of changing demographic structures. Chen et al. (2022) derive a rural/urban population structure for their investigation into changes in direct carbon emissions from household consumption in China and find it has minimal effect. Huang et al. (2019) analyze the possible effects of Japan's ageing society on emissions. They decompose emissions change into several drivers including the distribution of households, defined as "the proportion of younger households to total households." They conclude that "if Japan maintains an ageing society with a low birth date, the indirect CO_2 emissions generated by households will continue to grow." In contrast, Bardazzi and Pazienza (2018, p. 404) focus on direct emissions using the APC methodology and predict that in the longer term, "an ageing population [may eventually] lead to an overall fall in car-related GHG emissions" while they predict residential energy use will increase. Chancel (2014, p. 202) comments on the issue of cohorts born in the 1960s facing a "technological lock-in," living in "inefficient and high CO_2 emitting dwellings," and notes that the efficient housing options for younger generations may lead to decreases in emissions, albeit slowly.

There is a research gap related to the question of how consumption-based (i.e., direct and indirect) emissions of different generations compare and have changed over time. Structural drivers that could be explored include decarbonization, ageing societies, generational change, and other types of changes in expenditure made by different groups in the population of a country. We therefore propose the use of an APC lens using the IO SDA technique to explore drivers of differences in generations' carbon footprints in the United Kingdom.

3 | DATA AND METHODOLOGY

To understand differences in carbon footprints across generations, we first calculate the UK's carbon footprint from 2001–2020; determine the portion that is associated with household final demand; and then annually disaggregate the UK's carbon footprint by generational group. We then use SDA to first assess the drivers of change in each generation's total footprint over time and second to explain differences in household-level footprints between two different generations at the same life stage. In this section, we provide further information on the methods and datasets used.

3.1 | Calculating carbon footprints using the UK multiregional input–output model

Environmentally extended input–output analysis is the dominant method for reassigning global greenhouse gas emissions from the point of production to the point of final consumption. The Leontief input–output model, constructed from observed economic data, shows the interrelationships between industries that consume goods (inputs) from other industries in the process of making their own products (outputs) (Miller & Blair, 2009). The fundamental Leontief equation[2] $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$ indicates the inter-industry requirements of each sector to deliver a unit of output to final demand. Since the 1960s, the IO framework has been extended[3] to account for changes in industrial pollution (emissions) due to a change in final demand.

The University of Leeds constructs a UKMRIO (Multiregional Input–Output) database to calculate the UK's consumption-based emissions account (CBA) (Barrett et al., 2013). The United Kingdom is one of the few nations to report consumption-based emissions alongside territorial and production-based emissions accounts, and these data have now been recognized as an "Official Statistic" (Defra, 2023). To meet Official Statistic requirements, the database needs to be partially constructed using data published by the UK's national statistical agency, the Office for National Statistics (ONS), and it is important that data from these original tables are preserved as much as possible. For this reason, a bespoke database is constructed rather than taking UK outputs from an international MRIO database, such as Eora (Lenzen et al., 2013), EXIOBASE (Wood et al., 2014), GTAP (Andrew & Peters, 2013), OECD-ICIO (Rouzet & Miroudot, 2013), or WIOD (Dietzenbacher et al., 2013). In producing the UKMRIO, we follow the recommendations and methods from Tukker et al. (2018) and Edens et al. (2015). Supply and use tables are taken directly from the ONS; these are converted to a format where the use and final demand tables show domestic transactions in basic prices. Imports are then disaggregated by trade region using proportional shares from the EXIOBASE MRIO database (Wood et al., 2014). It is important to construct an MRIO rather than use a single region table for carbon footprint calculations because emission intensities vary across the world.

3.2 | Disaggregating the national footprint using the Living Costs and Food Survey

The environmentally extended Leontief equation ($\mathbf{F} = \mathbf{eLy}$), with $\mathbf{y}$ representing final demand by UK households, calculates the emissions associated with demand for goods and services by all UK households. To understand the carbon footprint by generational groups, we need to determine how much of the annual final demand was associated with households from each of the Silent, Baby boomer, Generation X, or Millennial generation cohort.

Since the 1950s, the ONS has annually surveyed UK households on their expenditure (UK Data Service, 2023). In 2008, this survey became known as the LCFS. The LCFS achieves an annual sample of around 6000 UK households and is used to provide information on retail price indices, National Account estimates of household expenditure, the effect of taxes and benefits, and trends in nutrition. It also provides information on household expenditure on over 300 different product types (coded by the European Standard Classification of Individual Consumption by Purpose [COICOP]). Additional information is collected such as the age, sex, and occupation of members of the household; the total household income and taxes paid; and the location, tenure, and dwelling type. The survey strives to produce a representative sample of UK households and supplies a weight for each observation to indicate the proportion of UK households that are represented by this profile. For example, the first household in the 2020 survey has a weight of 2990, and the sum of all weights is 28,198,240. We use the weights to convert the sample into a set of data that is representative of all 28.2 million households in the United Kingdom in 2020. Using the recorded age of the household reference person, we can calculate their birth year and hence the generation that they belong to. From this, we derive a set of total expenditure by each generation group for the years 2001–2020.

The LCFS collects expenditure data on goods and services coded by COICOP, but the United Kingdom uses a 112-sector classification in its supply and use tables, which is aligned with the Standard Industrial Classification (SIC). Fortunately, bridging tables exist that map expenditure by SIC to COICOP. This allows the calculation of total UK household emissions by 105 COICOP rather than 112 SIC categories. Dividing the annual emissions by the total weighted annual expenditure by product from the LCFS provides a COICOP-based carbon multiplier.[4] These multipliers can be used to turn the expenditure by generation group into carbon footprints by generation group. The UK total household consumption-based emissions account is preserved as the sum of the generational footprints.

3.3 | Assessing drivers of change using structural decomposition analysis

This paper aims to examine generational changes in UK household emissions between 2001 and 2020. As the UK's electricity sector has decarbonized and cars, appliances, public transport, and general production processes have become more energy efficient (Hardt et al., 2018), the emissions per Great British Pound spent on products (carbon multiplier) reduced. At the same time, there have been reductions in total expenditure due to the economic crisis in 2007, the COVID-19 pandemic in 2020, and most recently the cost-of-living crisis. As well as spending less, households are choosing to spend their money on different types of goods, and finally, we are experiencing a change in the size of the generational groups as Generation X households start to outnumber the Baby boomers who preceded them. This paper examines the following questions: Which of these factors are driving the reduction in UK emissions, which are working to cause increases, and are there generational differences in the relative importance of the factors?

A simple comparison of year-on-year changes in expenditure on goods and services compared to the change in the multiplier is insufficient to understand the drivers of change since both measures are affected by changes in prices. To make meaningful year-on-year comparisons, both the household expenditure data and the product multipliers need to be converted from current prices to constant prices. For this study, we use the UK sectoral consumer price index data with the index year 2010, inflating the expenditure and multipliers on goods pre-2010 to 2010 prices, and deflating post-2010 expenditure and multipliers to their 2010 levels.

Now that we have comparable year-on-year data, we employ SDA to determine the drivers of change in UK emissions. SDA is an "analysis of economic change by means of a set of comparative static changes in key parameters in an input–output table" (Rose & Chen, 1991b). Using the Dietzenbacher and Los (1998) decomposition technique, if emissions are calculated via the multiplication of three factors ($e = abc$, say), then the change in e ($\Delta e = a_1 b_1 c_1 - a_0 b_0 c_0$) can be described as six equivalent decomposition equations:

$$\Delta e = \Delta a b_1 c_1 + a_0 \Delta b c_1 + a_0 b_0 \Delta c$$

$$\Delta e = \Delta a b_1 c_1 + a_0 \Delta b c_0 + a_0 b_1 \Delta c$$

$$\Delta e = \Delta a b_0 c_1 + a_1 \Delta b c_1 + a_0 b_0 \Delta c$$

$$\Delta e = \Delta a b_0 c_0 + a_1 \Delta b c_1 + a_1 b_0 \Delta c$$

$$\Delta e = \Delta a b_1 c_0 + a_0 \Delta b c_0 + a_1 b_1 \Delta c$$

$$\Delta e = \Delta a b_0 c_0 + a_1 \Delta b c_0 + a_1 b_1 \Delta c$$

The effect that *a* has on the change in *e* is calculated as the mean of the first term from each of the six equivalent equations, with the effect of *b* and *c* following this pattern. With five terms, the number of equivalent equations increases to 5! (120). In this paper, we calculate several decomposition analyses, decomposing changes in emissions as a result of factors including total expenditure, proportion of expenditure on different products, emissions intensity of products, number of households, and household occupancy.

3.4 | Data and methodological limitations

The LCFS records the year of birth of the household reference person, and this is the data point used to determine the household's generational group. We are making the assumption that the expenditure assigned to the whole household is the representative expenditure of that generation, when in fact there may be members of several generations within the household. This assumption could be mitigated by resampling from the survey to only include single-person households, but we argue that much of the variation in spending behavior between Generation X and the Silent Generation could be explained by the fact that Generation X is spending on behalf of their children, whereas members of the Silent Generation are more likely to live alone. Excluding multi-person households would also introduce bias and no longer be representative of trends in the United Kingdom (Toro et al., 2024).

4 | RESULTS

4.1 | How has the UK's carbon footprint changed over time?

Between 2001 and 2020, the emissions associated with UK households' consumption reduced from 620 MtCO_2e to 396 MtCO_2e, a reduction of 36% (Figure 1a). We see emissions increase to 2007, followed by a rapid decline of 15.5% to 2009 during the financial crisis, a slower decline of 17% (over 10 years) to 2019, and finally a reduction of 19.0% (93.0 MtCO_2e) between 2019 and 2020 due to the COVID-19 pandemic.

Emission reductions differ by product group: In the 18 years between 2001 and 2019, we see reductions of 22.6% for food, 34.3% for housing, 33.2% for goods, and 34.0.3% for services and an increase of 10.2% for transport (Figure 1a). Focusing on the effects of the COVID-19 pandemic between 2019 and 2020, we see reductions of 2.8%, 1.0%, 37.3%, 7.6%, and 27.8% for food, housing, transport, goods, and services, respectively. Considering the more detailed COICOP 3 level categories, the total 93.0 MtCO_2e reduction during the COVID-19 pandemic was driven by emission reductions from air travel (29.4 MtCO_2e), personal transport (22.3 MtCO_2e), and restaurants (8.8 MtCO_2e).

4.2 | How have the emissions attributed to each generation changed over time?

Figure 1b also shows the same UK emissions by generation group. Changes in emissions of generation groups will result from a combination of changes in the number of households headed by this generation as well as changes in expenditure and decarbonization of production. The Silent Generation has seen their total emissions change from 199.6 to 44.0 MtCO_2e between 2001 and 2020—a reduction of 77.9%. Baby boomers' emissions reduce by 54.7%, Generation X' by 2.4%, and emissions associated with Millennial-headed households increase by 5058.1%. This large increase results from Millennials being age 20 and under and representing a very small number of households in 2001. Between 2019 and 2020, Baby boomers contributed most to emission reduction (45.3 MtCO_2e), followed by Generation X, Silent, then Millennials. When we consider generations and the products that they are consuming, Baby boomers' air travel (11.5 MtCO_2e reduction), Baby boomers' car travel (10.1 MtCO_2e), and Generation X's car travel (9.3 MtCO_2e) are the items with the largest reductions between 2019 and 2020 (see Supporting Information for detailed breakdowns).

To determine whether certain generations are responsible for more than their fair share of emissions, we can compare the average footprint of each generation with the average UK footprint, calculating how many times higher it is than expected (Figure 2). This allows us to investigate the emissions effect of aging, removing the overall emissions reduction pattern observed in the United Kingdom. If we take the per capita perspective

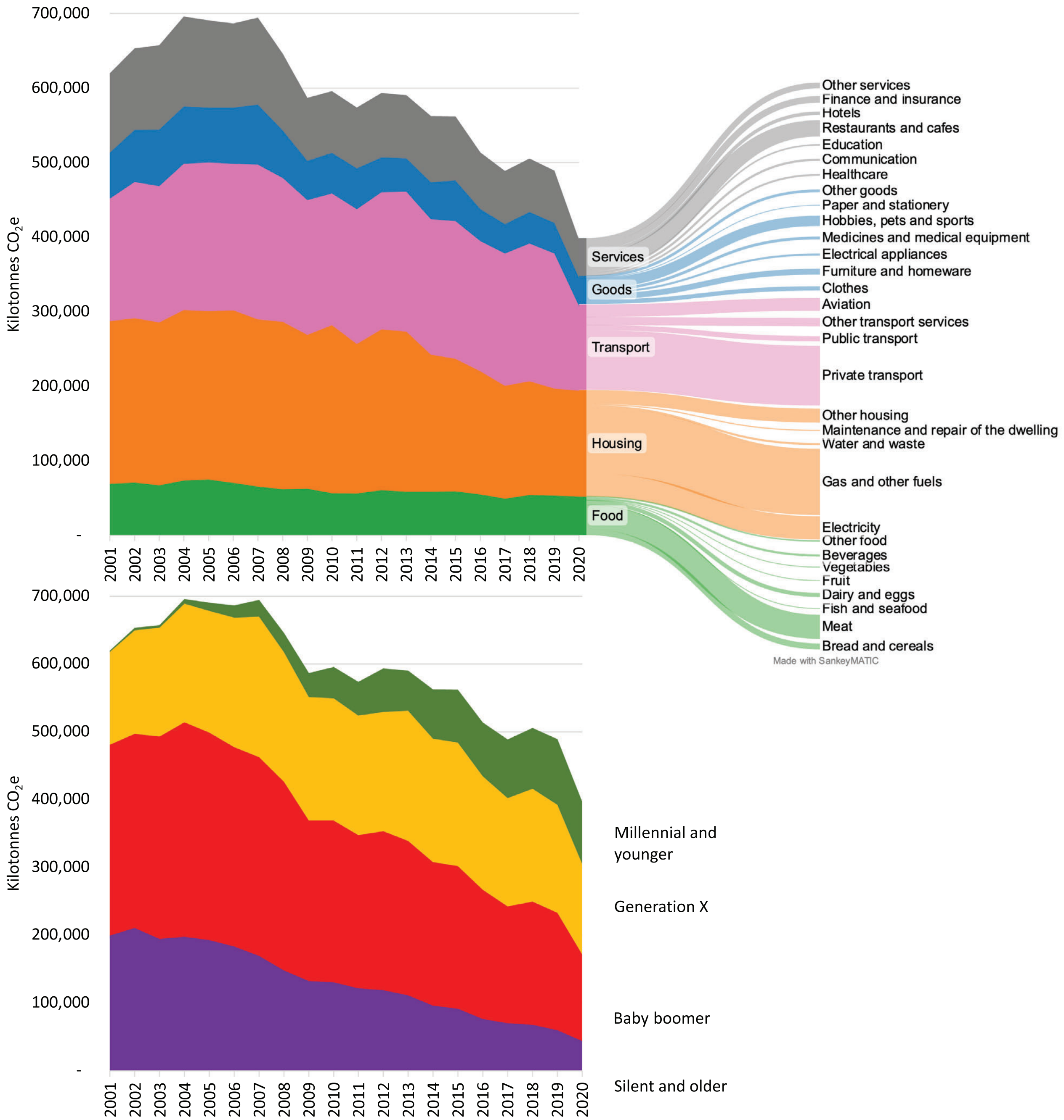

FIGURE 1 (a) UK household carbon footprint 2001–2020 by product group (top). (b) UK household carbon footprint 2001–2020 by generational group of the household reference person (bottom). Underlying data for this figure are available in sheets "Fig 1a" and "Fig 1b" of the Supporting Information.

first (solid line), our results from a 20-year time series reveal that Millennials (green) and Baby boomers (red) appear to generate more emissions with age, but the Silent Generation (purple) and Generation X (yellow) maintain a similar position respective to the UK average.

However, when we consider emissions per household (dashed), Millennials and Generation X appear to generate more emissions with age, but Millennial households always maintain a position below the UK average. The Silent Generation and Baby boomers show reductions respective to the UK average, but the Baby boomers always maintain a position above the UK average. Figure 2 reveals the importance of choosing per capita versus household emissions as a unit of measure, and that household occupancy should be considered when assessing differences in generational footprints. Figure 2 suggests that part of the reason that *per capita* Baby boomer footprints increase relative to the UK average is due to reduced household occupancy when Baby boomers become "empty-nesters" but continue to heat and power the same size of dwelling. Conversely, the Baby boomer *per household* footprint decreases relative to the UK average due to their household size decreasing in this time period.

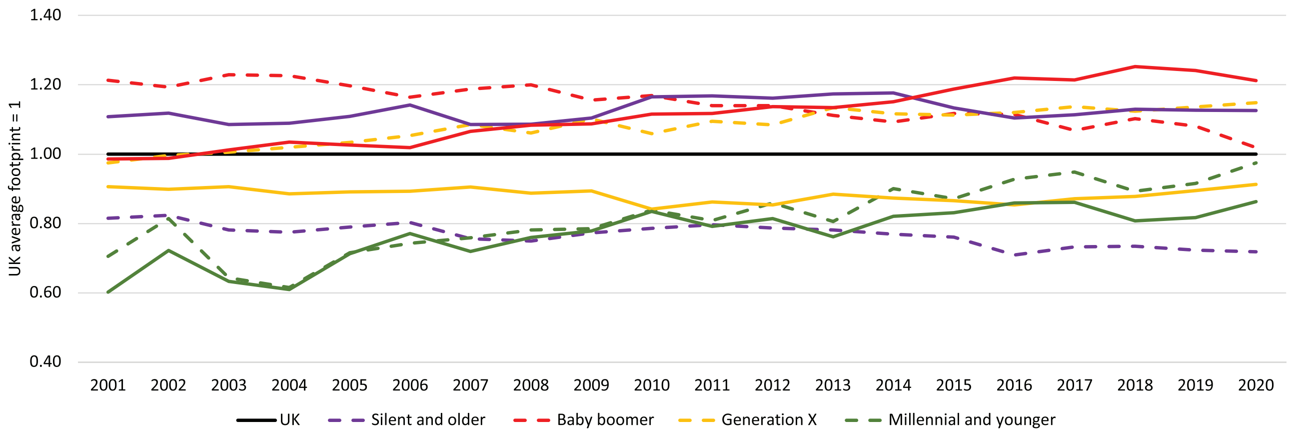

FIGURE 2 Per capita (solid line) and household (dashed line) footprints of generational groups of the household reference person relative to the UK average, 2001–2020 (UK average = 1). Underlying data for this figure are available in sheet "Fig 2" of the Supporting Information.

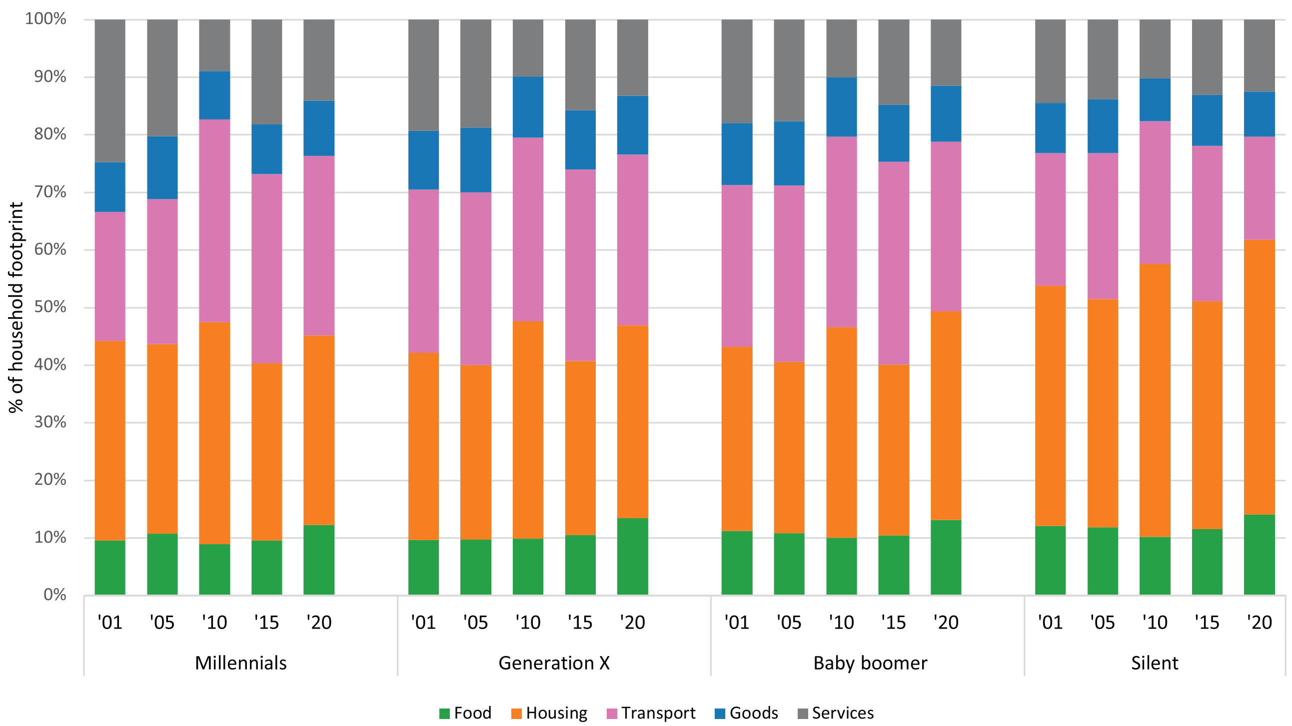

FIGURE 3 Breakdown of household footprint by year, generational group of the household reference person, and broad consumption category. Underlying data for this figure are available in sheet "Fig 3" of the Supporting Information.

In 2020, Generation X is around the age that the Baby boomers were in 2001, but they do not exceed their expected emissions share as much as the previous generation did at the same life stage. Millennials are now the age Generation X was in 2001 and have an emissions share of 23% of the total, which is similar to the 22% share that the previous generation had at the same life stage.

4.3 | Structural changes in generational household footprints

Figure 2 suggests that household footprints change with ageing, depending on what life stage the household is at, but are we able to determine the cause of change and will all households behave similarly when they reach certain ages? First, we assess the contribution that different consumption items make to each generation's footprint.

Figure 3 shows that the consumption items that make up a household's footprint are similar across both time and generation albeit with some differences. For example, compared to all other generations, a greater share of the Silent Generation's impact is associated with housing emissions.

TABLE 1 Structural decomposition analysis (SDA) variables used.

What are the most important drivers of change in the household emissions associated with each generation between 2001 and 2020?			
	Variable short name	Description	Unit
T	Total	Total UK consumption-based emissions of a generation	Ktonnes CO_2e
h	Number of households	Total number of households in that generation [1 × 1]	NA
o	Occupancy	Population per household headed by that generation [1 × 1]	NA
e	Expenditure per capita	Total per capita expenditure by a household headed by that generation	£ GBP
b	Basket of goods	Proportion of expenditure by product group for that generation	NA
m	Multiplier	Emissions intensity of products	Ktonnes CO_2e/£

Is it possible to isolate the *effect* that changes in level and type of expenditure have had on each generational group's household footprint and isolate these changes from the overall reduction due to decarbonization?

The drivers behind the UK's reduction in emissions between 2001 and 2020 are complex. The emission intensity of products has fallen mainly due to the decarbonization of the electricity sector. There have also been overall emission reductions due to a change in overall expenditure after the global financial crisis in 2008 and the COVID-19 pandemic in 2020. Can we explore these changes in emissions and the associated drivers through a generational lens? Do all generational groups exhibit the same types of changes in expenditure? How much of the change in footprint attributed to each generation is down to changes in the household composition as Baby boomers become empty nesters and Generation X builds their families?

For this paper, we first assess "what are the most important drivers of change in the total emissions associated with each generation from 2001 to 2020?" To calculate this, we take the simple equation for a generation's consumption emissions $\mathbf{T_g} = \mathbf{m}.\mathbf{y_g}$, where $\mathbf{T_g}$ is the total emissions associated with that generation's expenditure, $\mathbf{m}$ is the product-based carbon multiplier, and $\mathbf{y_g}$ is the expenditure by product for that generation. We can disaggregate $\mathbf{y_g}$ into four further factors: $\mathbf{h}$ the number of households in that generation, $\mathbf{o}$ the average household occupancy of households in each generational group (persons per house), $\mathbf{s}$ the total annual per capita expenditure attributed to that generational group, and $\mathbf{b}$ the basket of goods (proportion of expenditure by product for that generational group). Thus, we use a five-factor decomposition on the equation $\mathbf{T} = \mathbf{h}.\mathbf{o}.\mathbf{e}.\mathbf{b}.\mathbf{m}$. Table 1 provides additional information about each variable.

Second, we pose the question "What are the drivers of difference between household footprints of generations at the same life stage?" Here we use $\mathbf{T} = \mathbf{o}.\mathbf{e}.\mathbf{b}.\mathbf{m}$, where $\mathbf{T}$ is the average household carbon footprint of a generation.

For the first analysis, we compare time t_n with t_0. We set t_0 to be 2001 to allow a yearly comparison of the years up to 2020 with 2001. We then split the time series into ~5-year intervals to assess the drivers of change in four distinct time periods (2001–2005, 2005–2010, 2010–2015, and 2015–2020). For the final analysis, we compare Millennials in the year 2019 with Generation X in 2004; Generation X in 2019 with Baby boomers in 2004; and Baby boomers in 2019 with Silent Generation in 2001. These particular years and pairings are chosen to compare the groups at the same age.

Figure 4 shows the results from the initial decomposition analysis. Change in the number of households (blue) contributes to reducing the footprint for the Silent Generation between 2001 and 2020, but this factor has little effect on the size of the total Baby boomer footprint. Conversely, more and more Generation X and Millennials became the household reference person in LCFS as they move into their own homes, and this rise in population increases the size of the total footprint associated with these groups. Occupancy changes (gray) have driven down the total emissions associated with Baby boomer households. The observed time period corresponds with the time when these households tend to become 'empty-nesters' as children leave home to become households of their own. Occupancy changes increase the total footprint of Generation X, indicating these households are starting families.

Between 2001 and 2005, the emissions intensity of products (green) was a positive driver that increased emissions for most generational groups. During this time period, the United Kingdom increased the portion of imported goods, and the average emissions intensity of many goods rose. For most household groups, emissions intensity has been a negative driver of change post-2005. In this period, the carbon intensity of UK electricity rapidly reduced and products could be made using fewer emissions. Total per capita expenditure (pink) served to increase emissions at the start of the time period. The economic recession of 2008–2009 seems to have had the greatest effect on the Silent Generation and Generation X, whereas expenditure reductions due to COVID-19 had the greatest effect on the emissions associated with Baby boomers. Generally, all generations are consuming greener baskets of goods[5] (orange), with the exception of the Silent Generation between 2010 and 2015 and Generation X and Millennials during the early years of the analysis. 2010–2015 corresponds with the time when the members of the Silent Generation reached retirement age, perhaps leading to a change in spending habits associated with being at home more and thus consuming more electricity and heating fuels, while also taking a greater number of holidays. For Millennials and Generation X, the time periods when the basket effect is positive also correspond to times when total expenditure has a positive impact on emissions and the groups are in their early 20s. Perhaps, we are seeing a change in spending habits due to increased earning potential.

Figure 5 and Table 2 reveal the drivers of difference between households of different generations at a comparable stage in their life course. In 2019, Millennials, who were aged <39, had a household footprint that was 12.9 tonnes CO_2e smaller than that of Generation X at the same age.

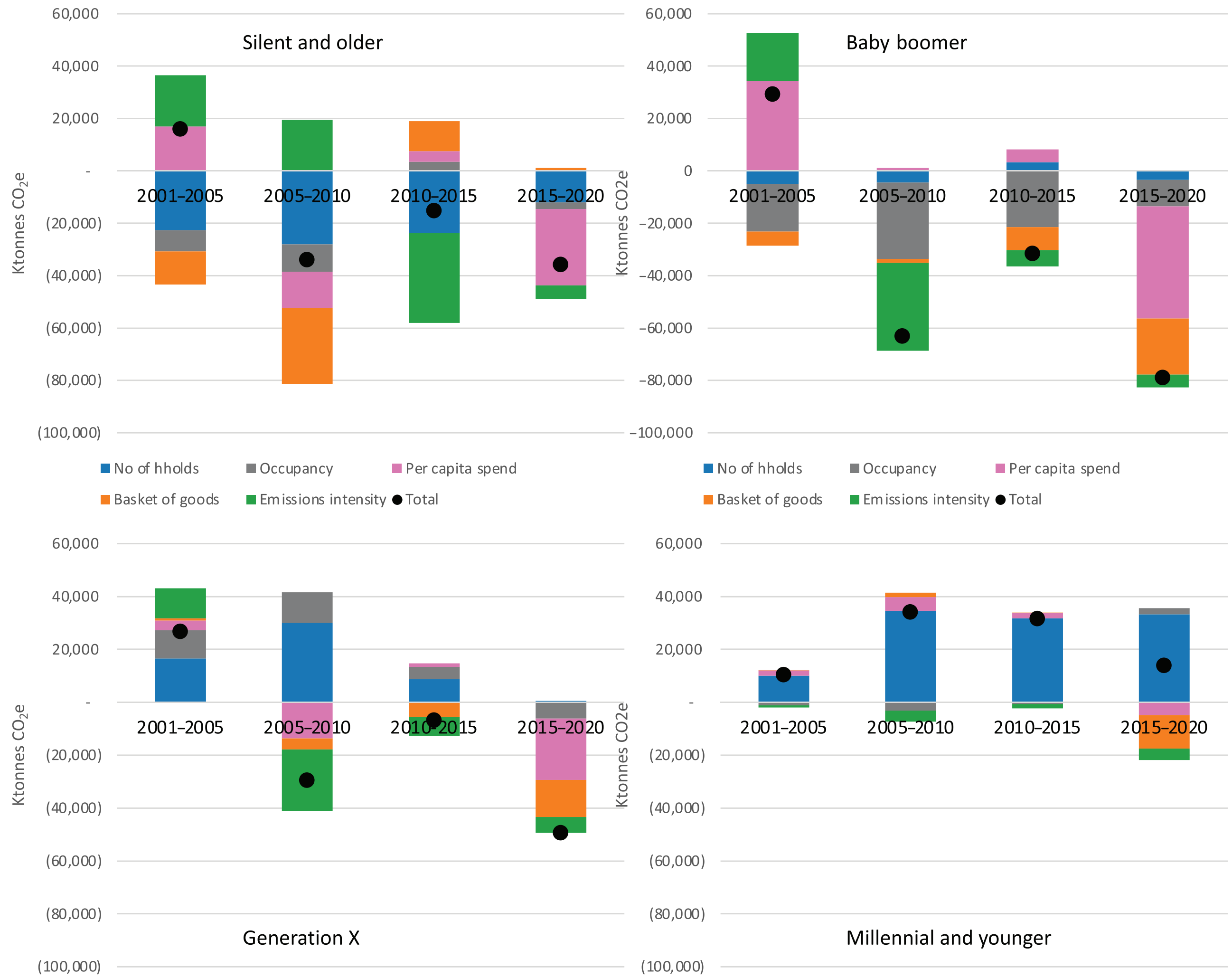

FIGURE 4 Structural decomposition analysis showing the important factors driving changes in total emissions by each generational group of the household reference person between 2001 and 2020. Underlying data for this figure are available in sheet "Fig 4" of the Supporting Information.

TABLE 2 Explanation of data used in Figure 5.

Group 1	Group 2	Calculation	Variable	Description
Millennials aged < 39 in 2019	Gen X aged < 39 in 2004	$T_{m19} - T_{x04} = o.e.b.m$	$\mathbf{T_{m19}}$	Household emissions of Millennials in 2019
			$\mathbf{T_{x04}}$	Household emissions of Gen X in 2004
Gen X aged 39–54 in 2019	Baby boomers aged 39–54 in 2003	$T_{x19} - T_{b03} = o.e.b.m$	$\mathbf{T_{x19}}$	Household emissions of Gen X in 2019
			$\mathbf{T_{b03}}$	Household emissions of Baby boomers in 2003
			$\mathbf{T_{b19}}$	Household emissions of Baby boomers in 2019
			$\mathbf{T_{s01}}$	Household emissions of Silent in 2001
Baby boomers aged 55–73 in 2019	Silent generation aged 56–73 in 2001	$T_{b19} - T_{s01} = o.e.b.m$	$\mathbf{o}$	Effect of household occupancy on the emissions difference
			$\mathbf{e}$	Effect of expenditure on the emissions difference
			$\mathbf{b}$	Effect of basket of goods on the emissions difference
			$\mathbf{m}$	Effect of emissions multiplier on the emissions difference

Clearly, improvements in emissions intensity explain the majority (63%) of this difference, but other factors also contribute. The type of products bought by Millennials in 2019 are less emissions intensive and they spent less per person and have fewer people per household, each factor contributing 18%, 13%, and 7%, respectively, to the lower household emissions. Similarly, 2019 Generation X households, aged 39–54, had a footprint 12.7 tonnes smaller than similarly aged 2003 Baby boomers. In this comparison, expenditure per capita is the second largest driver of difference and occupancy acts as a positive driver, implying that at a similar age Baby boomers have started to decrease their household size. When we compare the Baby boomers at ages 55–73 with their Silent Generation counterparts, it is only the emissions intensity and basket of goods factors that con-

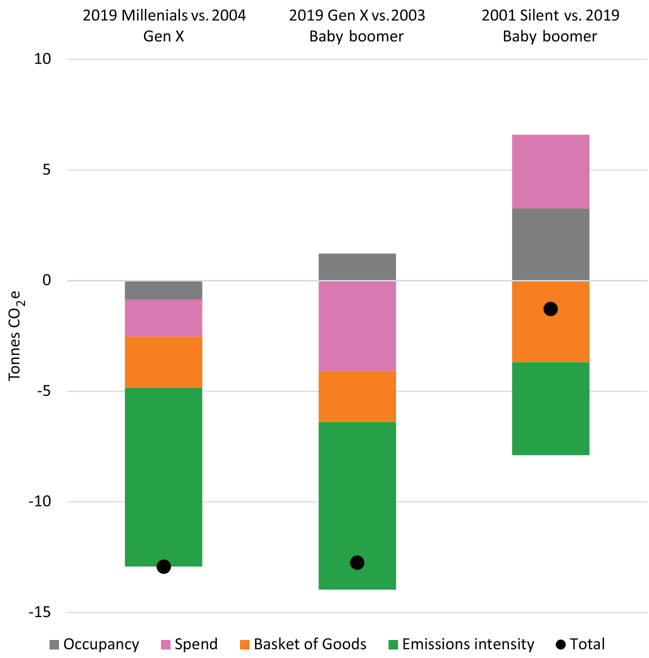

FIGURE 5 Structural decomposition analysis comparing average household emissions of different generational groups (by household reference person) at the same life stage. Underlying data for this figure are available in sheet "Fig 5" of the Supporting Information.

tribute to the 1.3 tonne reduction. Baby boomers have a larger equivalent expenditure and a larger household occupancy than the Silent Generation at the same life stage.

5 | DISCUSSION

5.1 | Can we determine age, period, and cohort effects in the change in UK consumption emissions?

Many authors warn that an ageing population leads to rising emissions (Huang et al., 2019; Liu et al., 2022) and that carbon footprints increase with age until the consumer reaches very old age (Büchs & Schnepf, 2013; Christis et al., 2019; Huang et al., 2019; Lévay et al., 2021; Liu et al., 2022). Authors such as Chancel (2014) have found that the Baby boomer Generation has consistently larger than average emissions impacts, and Ivanova and Büchs (2022) warn that shrinking household sizes slow down per capita emission reductions.

Our analysis confirms that when considering *age effects*, it is critical to report whether footprints are measured at a household or individual level. Per capita results show that in the United Kingdom, between 2001 and 2020, Baby boomers and Millennials have increased their per capita footprints relative to the UK average, with Baby boomers continuously above the UK average and Millennials below (Figure 2). Per capita emissions from the Silent Generation and Generation X have maintained their position relative to the average, implying that these groups have not increased emissions with age. However, if the unit of analysis is the household, younger households increase emissions as they get older, partly due to starting a family, and older households decrease their emissions as their children move out and start households of their own. Our analysis is in agreement with Chancel (2014)—we find Baby boomers have a larger carbon footprint than the UK average both from a per capita and household perspective. We also observe Ivanova and Büchs' (2022) effect of shrinking household sizes increasing the per capita footprint of this group. It appears that in the United Kingdom, there is some evidence of age-increasing carbon footprints (the *age effect*), but these rapid increases may be concentrated at certain points in a life course and it depends on the unit of analysis.

We certainly observe *period effects* on the UK's carbon footprint by generational groups, as consumption-based emissions of all generational groups fall in the period 2001–2020 due to rapid decarbonization, the global economic crisis in 2007–2009, and the COVID-19 pandemic in 2020. *Cohort effects*, however, are harder to pinpoint. We would need to observe Millennials becoming settled family units and Generation X becoming retirees to be confident at asserting any generational traits to emissions profiles. We are unable to fully determine whether UK generational groups follow the same consumption patterns with ageing as the generation preceding them or whether there are behaviors that are unique to individuals born at a particular time. We have, however, been able to pair household footprints from generational groups at similar ages and used decomposition to unravel the cause of the difference between the emissions profiles (Figure 5). Some drivers of differences, such as emissions intensity, are clearly *period effects* associated with the production processes of the time. Total expenditure and basket of goods may be a combination of *period* and *cohort effects* reflecting both the economic landscape of the time and lifestyle factors unique to cohorts. Occupancy may also be described as a *cohort effect*. Millennials are having children later and in smaller numbers than the generation that precedes them; occupancy explains Millennials' lower household footprint compared to Generation X. We observe that toward the end of our observation period many young adults remain in the parental home for longer than in previous generations due to soaring house prices; some older-headed households have larger footprints due to them containing more people than in previous years.

5.2 | Is generational change a driver of the UK's carbon footprint?

In contrast to studies that posit that the effect of population change on consumption emissions is minimal in Global North nations (Lan et al., 2016; Lee et al., 2023), we demonstrate that when you consider *structural change* (i.e., decomposing the change in each generational groups' consumption-based emissions into drivers of change; Figure 4), the effect is evident but complex. There is evidence to show that emissions change with ageing but the changes are not the same across all generational groups. For generational change to reduce the consumption emissions of a nation, the spending behaviors, both in terms of total spend and the basket of goods, of subsequent generational groups must become greener compared to the generation before them. In addition, if society is ageing, the link between increased age and increased emissions must be decoupled through, for example, a policy designed to help older households downsize to smaller homes and to support more household sharing/multi-generational living.

5.3 | Policy implications

This study cannot predict how emissions may change due to generational change, but it makes a valuable contribution to climate policy by demonstrating that households of different generations consume differently and that we cannot assume all households follow the behavioral patterns of their predecessors. Returning to the idea of APC effects, climate policy designed to bring about more sustainable consumption behavior needs to recognize that the needs of households change with *ageing* and life stage. Households generate more emissions in certain periods of life and policy should be designed to target age groups respectively. Climate policy also needs to recognize *period* effects—for example, the COVID-19 pandemic affected the spending behaviors of all ages. With regard to *cohort* effects, our results indicate that consumption patterns can differ between generations. These differences may be related to different levels of concern about climate change and different outlooks on life that shape cultures of consumption, and they may equally reflect that younger generations have smaller families later in life. The framing of policies, campaigns by green organizations as well as environmental media reporting should bear this in mind when they target specific groups with messages that aim to encourage sustained reductions of carbon footprints. For instance, policymakers may find that policies or incentives designed to reduce the impact of Generation X at 50 may not work for Millennials when they reach this age, implying that policy design and framing need to be adjusted accordingly. While we focus on generations and age groups in this research, we acknowledge that these are not homogeneous groups. Rather, attitudes, behaviors, life choices, and resulting carbon footprints are additionally shaped by factors such as income, education, employment, health, gender, and location. These factors remain important for policy design and framing.

6 | CONCLUSION

As far as we are aware, this study is the first to use SDA to determine the drivers of change in generational footprints over time and to explain differences between generational groups at the same life stage. We find that emissions of UK households do change with ageing, but this change is different in nature for different generational groups. There is evidence that different age cohorts have differing characteristics at the same life stage and this can influence their footprint. Household occupancy is a critical example of such a characteristic. We recognize that from the 20-year time period, limited conclusions can be drawn about cohort effects and that future work is required to examine generational effects. We also recognize that this work speaks about generations as if they are homogeneous groups where in reality, there will be large differences in spending behavior within a group depending on wealth, household composition, and other factors. We recommend future work investigates within-cohort variations and this will bolster the findings.

This type of work is important not only for the UK Net Zero Policy but for other nations facing similar demographic shifts to the United Kingdom. The effect of population change on global emissions was considered to be an outdated area of study (Satterthwaite, 2009), but we have shown there is fruitful work to be done considering different structural drivers of change. There is scope to determine which countries follow patterns seen in the United Kingdom and where and when differences occur. However, this type of analysis is only replicable in countries with a long history of household consumption surveys. We recommend National Statistical Offices prioritize the collection of these data now and into the future.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supporting information of this article.

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ENDNOTES

[1] Defined as emissions from electricity, gas, liquid home fuel, gasoline, coal, personal transportation, and air transport.

[2] $\mathbf{x}$ and $\mathbf{y}$ are vectors of total output and final demand, irrespectively. $\mathbf{I}$ is the identity matrix and $\mathbf{A}$ is the technical co-efficient matrix which shows the inter-industry requirements. $(\mathbf{I}-\mathbf{A})^{-1}$ is known as the Leontief inverse.

[3] Let $\mathbf{f}$ be a row vector of annual emissions from each industrial sector. Let $\mathbf{e}=\mathbf{f}\hat{\mathbf{x}}^{-1}$. Then, $\mathbf{e}\hat{\mathbf{x}}=\mathbf{e}(\mathbf{I}-\mathbf{A})^{-1}$, which simplifies to $\mathbf{F}=\mathbf{eLy}$ where $\mathbf{F}$ is the annual emissions required to meet final demand $\mathbf{y}$.

[4] LCFS expenditures are in consumer prices and the spends include value added tax (VAT). This means we are producing a set of multipliers that work with consumer prices rather than basic prices.

[5] The proportion of spend on carbon intensive goods has reduced over time.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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