Reducing total and saturated fat for lowering food energy density: potential health impacts of a gradual reformulation strategy in the UK

Submitted in partial fulfilment of the requirements of the Degree of Doctor of Philosophy

Wolfson Institute of Population Health,
Queen Mary University of London

Roberta Alessandrini

2023

Statement of Originality

I, Roberta Alessandrini, confirm that the research included within this thesis is my own work or that where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged below.

I attest that I have exercised reasonable care to ensure that the work is original and does not to the best of my knowledge break any UK law, infringe any third party's copyright or other Intellectual Property Right, or contain any confidential material.

I accept that the College has the right to use plagiarism detection software to check the electronic version of the thesis.

I confirm that this thesis has not been previously submitted for the award of a degree by this or any other university.

Signature: Roberta Alessandrini

Date: 10/01/2023

Details of collaboration and publications

This thesis was undertaken at the Wolfson Institute of Population Health, Queen Mary University of London, under the supervision of Professors Feng J He and Graham A MacGregor.

Chapters 4 and 5 have been partially published. Full details can be found in Appendix I: "Publications related to this thesis".

Abstract

Background: Manufactured and out-of-home (MOOH) foods contribute to excessive calories and have a critical role in fuelling the obesity epidemic.

Aims: 1) To show policymakers and food producers that reducing food energy density through a 20% fat reduction in MOOH food categories is a realistic and feasible public health nutrition strategy; 2) To predict the health impacts of a fat reformulation strategy to persuade UK policymakers to implement it in the MOOH food sector to reduce obesity prevalence in the UK.

Methods: Firstly, I carried out a survey of cakes and biscuits sold in UK supermarkets to evaluate the variation of total fat, SFA, and energy/100g. Secondly, I evaluated the energy reduction in the NDNS population resulting from the proposed strategy. I predicted the bodyweight reduction by using a weight loss model. I scaled up the resulting bodyweight reduction to the UK adult population. I estimated the reductions in overweight/obesity and type 2 diabetes cases, ischemic heart disease (IHD), and strokes deaths that could be prevented from the strategy.

Results: There was a 40% average fat variation in cakes and biscuits. The proposed fat reformulation strategy in MOOH foods would reduce mean energy intake by 67.6 kcal/d/person and mean bodyweight by 2.7 kg/person. Obesity and overweight prevalence would be reduced by 6.8%, corresponding to 4.5 million cases of obesity/overweight being reduced in the UK. The bodyweight reduction could prevent 180,000 cases of type 2 diabetes over two decades. The SFA reduction would prevent 97,000 IHD and stroke deaths over 20 years.

Conclusions: Fat reformulation is a feasible strategy to reduce fat and energy density in cakes and biscuits. A 20% fat reduction (particularly SFA) in MOOH foods would prevent obesity, type 2 diabetes, and cardiovascular disease and bring SFA intake within the recommended intakes.

Author's Contribution

I have carried out the work outlined in this thesis under the primary supervision of Professors Feng He and Graham MacGregor. Professors Feng He and Graham MacGregor conceived the original idea of a fat reformulation strategy in the UK. Each research chapter has benefited from collaboration with other researchers, the specific contribution of whom is detailed below.

In chapter 4*"Cross-sectional surveys of manufactured cakes and biscuits sold in UK supermarkets*", Dr Kawther Hashem collected and categorised the data. I developed the analysis plan and performed the statistical analyses on all data and wrote the first draft of the manuscript. All co-authors (myself, Professor Feng He, Dr Kawther Hashem, Dr Monique Tan, and Professor Graham MacGregor) contributed to the interpretation of the results, revision of the manuscript and approved the final draft of the manuscript.

In chapter 5 *"Modelling the potential impact of gradual reduction of fat content in manufactured and out-of-home food on obesity in the UK"*, Dr Yuan Ma and Professor Feng He designed the original analysis plan. Dr Vincenzo Scrutinio and I refined the analysis plan and run the analyses. Professor David Wald provided further input for the data analysis. I wrote the first draft of the manuscript. All authors (myself, Professor Feng He, Dr Yuan Ma, Dr Vincenzo Scrutinio, Professor David Wald, and Professor Graham MacGregor), interpreted results, commented on the manuscript, made critical revisions, and approved the final version of the manuscript.

Acknowledgements

I would like to thank my supervisors, Professors Feng He and Graham MacGregor for teaching me everything about academic research. A special thank goes to Professor Feng He for her continuous support and feedback, for giving me an opportunity at the time when I needed it most, and for being a constant source of reassurance, calm and optimism. I want to thank Professor Graham MacGregor for teaching me to always look at the bigger picture and for being an example of activism at its finest form.

I am very grateful to all my colleagues at Consensus Action on Salt, Sugar, and Health for welcoming me into their teams. Without their support, encouragement, and knowledge, my PhD journey would have been far more lonely and less exciting.

This research would not have been possible without Queen Mary University of London's support, who funded my doctoral studentship and provided high-quality research training.

I want to thank all the new and old friends who encouraged me so generously and unconditionally over these last three years and a half. A special thank goes to my friends from the Goodenough College in London; our dinners at the College canteen have been a natural antidepressant and made my student life great fun.

Finally, I would like to thank my partner Stefano, who has always been my greatest supporter and pushed me to pursue a research degree. I am grateful to my mother and father for having given me the opportunities and experiences that made me who I am, and to my brother for reminding me that life is short, and for this reason, one must make dreams happen.

Abbreviations

BMI	Body Mass Index
CASSH	Consensus Action on Salt, Sugar, and Health
%E	Percentage of dietary energy
FOP	Front-of-pack nutrition labelling
IHD	Ischaemic heart disease
MUFA	Mono-unsaturated fatty acids
MOOH	Manufactured and out-of-home
NCD	Non-Communicable Disease
NDNS	National Diet and Nutrition Survey Rolling Programme
NGO	Non-governmental organisation
PHE	Public Health England
PUFA	Poly-unsaturated fatty acids
RCT	Randomised Controlled Trials
SACN	UK Scientific Advisory Committee on Nutrition
SDIL	UK Soft-drinks industry levy
SFA	Saturated fatty acids
SSB	Sugar-sweetened beverages
WHO	World Health Organization

Table of Contents

List of Figures

List of Tables

Chapter 1 | Obesity, health, and society

1.1 Definition

The World Health Organisation (WHO) defines obesity and overweight as excessive body fat accumulation that presents a risk to health. The body mass index (BMI) is the most widely used method to measure the excess of body fat accumulation. It is defined as a person's weight in kilograms divided by the square of height in meters (kg/m^2) (1). A body mass index (BMI) between 25kg/m^2 and 30kg/m^2 is considered overweight; a BMI of over 30kg/m^2 as having obesity and over 40kg/m^2 as having severe obesity (1). Although the BMI is the best assessment method of overweight and obesity at the population-level in adults (as it is the same for both sexes in adults from all age groups), it is a poor indicator of central or visceral adiposity. The latter is the type of obesity associated with the worst health outcomes (2). The National Institute for Health and Care Excellence (NICE) recommends using the waist-to-height ratio as a complementary method to assess overweight and obesity in individuals with a BMI >35 kg/m^2 (2). The NICE defines obesity with central adiposity as a waist-to-height ratio greater than 0.5 (2).

1.2 The impacts of obesity on health

Living with obesity and overweight is associated with long term physical, psychological and social problems, and a reduced life expectancy (1, 3). People with obesity have an increased risk of developing non-communicable diseases (NCDs) such as type 2 diabetes (T2D), cardiovascular disease (CVD) such as coronary heart disease and stroke, at least 12 types of cancers, osteoarthritis, breathing problems, and mental illness such as clinical depression and anxiety (1, 4, 5). The recent COVID-19 pandemic has brought to light additional risks for people living with obesity, such as an increased risk of testing positive for COVID-19, hospitalization, need for advanced levels of treatments, and death (6). In addition to this, obesity can lead to social stigma, isolation, reduced educational attainment and chances of finding and retaining employment (7-9). Obesity is a costly issue for society as it leads to increased NHS costs, loss of productivity and reduced quality of life (10). A recent report estimated that the annual cost of obesity in the UK is £58 billion. For context, this is of an equivalent magnitude to around 3% of the 2020 UK's gross domestic product (10).

Obesity causes disease through complex hormonal and metabolic changes in the human body. The excess of body weight is stored in the adipose tissue which secretes hormones and other substances that promote low-grade chronic inflammation. Evidence shows inflammation of the adipose tissue is the underlying cause the many NCDs associated with obesity (4). An excessive body weight causes disease also via more straightforward ways. For example, individuals with obesity carry extra weight and put their joints under mechanical stress. It has been estimated that globally 4.7 million NCD deaths were attributable to obesity and overweight in 2017, accounting for 17.7% of all causes of death for that year (11)

1.3 Obesity and overweight trends

Worldwide obesity has nearly tripled since 1975 (12). In 2016, 39% of the world's adult population was overweight, and 13% had obesity (12). The most recent statistics indicate that in England, the prevalence of overweight is 35%, and the prevalence of obesity is 29%; so three quarters of the adult population have either overweight or obesity (13). According to the Organisation for Economic Co-operation and Development, the UK is the 10th heaviest country among the 36 wealthiest nations, and has the highest obesity levels in Western Europe (14).

Globally and in just 40 years, the number of school-aged children and adolescents with obesity has risen more than tenfold, from 11 million to 124 million (12). While in the past century, obesity and overweight were prevalent mostly in affluent societies, over the last decades the prevalence of obesity has increased also in developing regions, thus becoming a global health problem affecting an increasing number of countries worldwide (12). Recent projections showed that by 2050, 45% of the world population will be overweight and 16% will have obesity (15).

1.4 What causes obesity?

The causes of overweight and obesity are complex. But in essence the accumulation of excess body fat is caused by an energy imbalance between the energy consumed and the energy expended over a period of time (16). In other words, individuals with obesity take more energy ('calories') in through eating and drinking than what is used up through metabolism and physical activity. Thus, the individuals' energy balance is influenced primarily by these three factors:

Physiology and genetics — some individuals have an underlying propensity to accumulate body fat and conserve it because of genetic factors, the influence of early life experiences, and the sensitivity of the appetite control system. A very small percentage of the population has an increased risk of accumulating body fat because of endocrine alterations such as hypothyroidism or Cushing's disease.

Eating and drinking habits — an individual's energy intake is determined by their motivation and opportunity to eat and drink.

Physical activity habits — the energy expenditure is mostly determined by the frequency, intensity, and duration of activity.

1.5 Wider obesity determinants

While the study of the genetics of obesity is an important area of investigation that has helped a better comprehension of the condition, a large body of evidence has shown that genetics alone cannot explain the current rates of obesity seen in many populations of the world today (17, 18). It has been shown that societal changes that have occurred in the external environment over the last century are the most important factors which contributed to the creation of an "obesogenic environment" (16). The term which was first adopted in the 1990s to explain the current obesity epidemic and has been defined as the "sum of the influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals and populations" (19). Figure 1 shows the main obesity determinants and how these influence individual's food and physical activity choices and thus the risk of obesity.

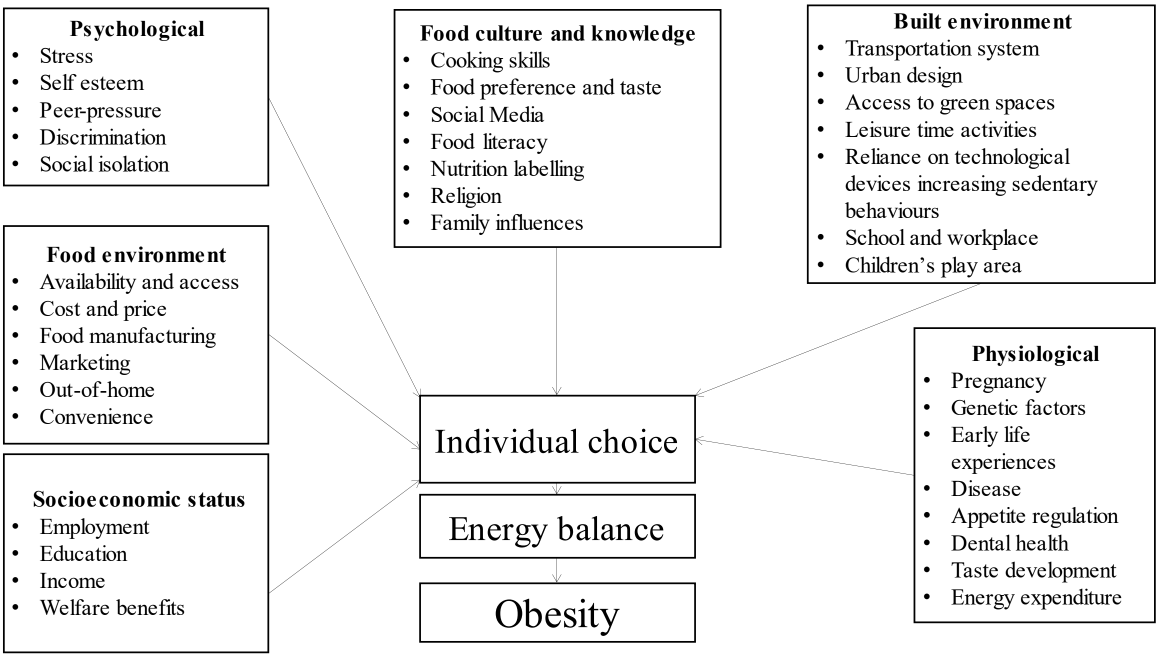


Figure 1.1 Most important obesity determinants influencing food choices in individuals and populations. The figure has been adapted from Human Nutrition: Elements for European Action (20).

1.4.1 The food environment

Over the past 50 years, the world's food environment has undergone radical changes. Not long-ago meals were prepared mostly at home. Research showed that in the UK, home-cooked food represented more than half of the food budget in 1980, but less than a third in 2000 (21). Longer working hours and the increased price of cooking ingredients compared to ready-to eat meals contributed to a marked decline of home cooking and preference for convenience food, particularly in lower socio-economic groups (22). Today individuals buy around half of their meals from the out-of-home sector which includes restaurants, fast-food outlets, and ready-to-eat foods available from supermarkets (23, 24). Food delivery apps have made the acquisition of out-of-home meals a quick, easy, and convenient operation (25).

Evidence has consistently shown that manufactured foods and meals from the out-of-home sector (including those purchased through food delivery apps) are high in calories and fat, and come in larger portion sizes, putting people at risk of obesity (25-28). Fast foods and pre-packaged manufactured products are widely available as they are efficiently distributed due to their longer shelf life and higher profitability (29, 30).

Fast foods and manufactured food and drink products are also heavily marketed and promoted. Evidence has shown that the marketing of these products to children may influence their food choices by taking advantage of their developmental vulnerabilities, thus increasing their obesity risk (31, 32). Evidence has uncovered the effect of various types of food marketing on children including advertising on TV, the digital environment, sports sponsorship, cartoon characters on food packaging, and collectible toys (32, 33)

1.4.2 Food culture and knowledge

The past decades have been characterised also by radical changes in food culture in almost all societies of the world. The consumption of traditional diets' staples such as legumes and whole grains has sharply been reduced due to lack of time, declined cooking and food purchasing skills, and increased preference for more processed and palatable foods (34, 35).

With the transformation of the food supply, social norms related to eating have changed. Children are given more control over food choices. Grazing, snacking and eating on the go are common and contribute a substantial proportion of total calorie intake (16). In parallel, an increasing number of people tend to eat alone due to social changes and an altered attitudes towards cooking and eating practices. Commensality used to be a very important aspect of food consumption. There is an indication that eating meals as a shared social activity focusing on pleasant conversation and without digital distractions might have an impact on obesity prevention and stress reduction (36-39). At the same time, communication and technology devices might provide entertainment and mitigate negative emotions like loneliness and boredom which were prevalent during the COVID-19 pandemic (40).

Nowadays the average citizen can access an abundance of information about healthy diet and obesity prevention from a variety of sources (41). The internet, smartphones and social media have also made information about healthy diet and obesity prevention accessible to an increasing number of people. However, the internet also offers a plethora of inaccurate nutrition advice and, as a result, people can easily become misinformed (42). Evidence shows that mostly educated people have the resources to navigate and understand this wealth of information (43-45).

1.4.3 Socioeconomic status

Obesity is more prevalent in groups with lower socio-economic status, which are groups with less well-paid employment status, fewer years of academic schooling or similar social disadvantages (22, 46). Obesity is more prevalent in poor and insecure populations; the relationship might seem paradoxical as food insecurity is traditionally associated with underconsumption while obesity is commonly linked to overconsumption (47, 48). Poorer people face many barriers when it comes to healthier lifestyles. For example, healthier diets rich in fruit and vegetables are more expensive and require time and food preparation skills (30, 49, 50). Recently, the rising cost of energy bills in the UK has emerged as another contributor of food insecurity as families reported consuming more cold and lower quality food to save on energy bills (51). Some authors suggested that it is relatively inexpensive to develop obesity as calorie dense foods such as fast and snack foods, sugary drinks are easy to access, relatively cheap and do not require any preparation (30, 52). People from less advantaged backgrounds are also more likely to live in neighbourhoods with reduced access to healthy and nutritious food items and an abundance of junk food outlets, convenience and liquor stores. These areas are respectively called “food deserts” and “food swamps” (53, 54).

Compared to the rest of the population, women and children with lower SES have an increased risk of developing obesity (46, 48). Women have higher chances to develop obesity due to their reproductive role, but also face different societal pressures such as discrimination in employment and income, lower self-esteem with a failure to meet social norm and reduced opportunities for physical activity (22, 55). At the same time, women take on the burden of food shopping and meal preparation in the home and are the first to reduce food intake or skip meals to accommodate family needs (55). Women from low socio-economic groups have higher chances to give birth to either under- or over-weight babies (both risk factors for later obesity) and are less likely to breastfeed their babies and to follow recommendations for healthy infant feeding (also linked to obesity risk) (22).

1.4.4 The built environment

The built environment encompasses a range of physical and social elements such as residential or commercial buildings, transportation infrastructure, and parks or other open spaces that make up the structure of a community (56). There is consensus that changes in the built environment, driven by the increased rates of urbanisation have contributed to the high rates of obesity seen today. Most of the world population lives in urban contexts with limited access to green spaces, a dominance for sedentary employment, motorised transport, and disincentives for physical activities such as walking and cycling (57, 58). The situation is even more problematic in disadvantaged areas as evidence showed a lack of green spaces and places where to exercise, limited access to shops selling healthy foods (i.e. food deserts), higher rates of traffic and air pollution, and safety concerns (59, 60). Research has also showed that people living in highly deprived neighbourhoods have an increased BMI due to the higher density of fast-food outlets available in that area (61, 62).

1.4.5 Psychological factors

Numerous studies have shown the association between obesity and various mental health conditions such as depression, eating disorders, anxiety, and substance abuse (63). Many individuals who have obesity struggle with issues related to their mood, self-esteem, quality of life, and body image (64). Chronic stress appears to be associated with a greater preference and consumption for comfort foods, which are high in sugar, calories, and fat (64). Evidence also shows that mounting stress and sleep deprivation, which are common issues in modern life, can increase levels of cortisol which plays a role in the development of obesity (65). People with obesity are also more likely to suffer from mental health issues as they are often discriminated at school or work and are more likely to be socially isolated (63).

In summary, obesity is caused by a myriad of environmental, psychological, and social factors that affect diet and physical activity behaviours in individuals. Fixing obesity is complex as this requires the modification of all obesity determinants through the creation and implementation of effective public policies. The following sections of this PhD thesis will explore the evolution of the public policies aimed at reducing obesity prevalence at the global level and in the UK (as this thesis will focus on UK strategies to reduce obesity).

1.6 Is obesity a disease?

Some countries and public health organisations, such as the World Obesity Federation and the World Health Organization, define obesity as a disease (66-69). On the other hand, many other organisations, and countries such as the UK, are reluctant to define obesity as a disease mainly for the following reasons. The most important one is that, as explained in section 1.2, obesity increases the risk of developing certain diseases. However, it is possible to live with obesity without developing any diseases mostly associated with it (66). Another important reason is that while the BMI is a good way of measuring obesity at the population level, the assessment of obesity at the individual level can be complex as it requires the considerations of other factors such as the body muscle mass, the waist circumference and the individual's ethnicity (67, 68).

As explained in section 1.4, obesity is caused by a myriad of factors which cannot be entirely controlled by individuals. According to some authors, classifying obesity as a disease might create a culture of "personal irresponsibility", while according to some others, a diagnosis of obesity might "reduce the stigma experienced by people with weight concerns" and might "change the discourse about blame for the condition" (69, 70). According to the World Obesity Federation, the definition of obesity as a disease does not lessen but rather increases the importance of obesity in public policy and thus increasing the societal responsibility towards the implementation of obesity prevention policies (69, 71).

1.7 Gradual recognition of obesity as a policy priority

1.7.1 The WHO's deliberations on obesity

In the 80s, the UK and the USA were the first countries to recognise obesity as a public health issue which needed to be addressed through governmental policies (72-74). At the time, the WHO, did not consider obesity as a public health concern as the international organization was mostly focussing on problems such as undernutrition and epidemics affecting developing nations (75). Only in the 90s, the WHO started considering obesity as a CVD risk factor leading to increasing medical costs, and after noticing that the prevalence of obesity was quickly rising also in developing nations (73). The WHO produced its first reports on the issues of obesity, diet, and cardiovascular disease in 1988, 1990 and 2003, respectively (76).

Later efforts by the WHO to set a global strategy to halt the obesity epidemic included the preventive strategy of the 2002 World Health Assembly which exhorted countries to set their own national obesity strategies and the 2005 Kobe meeting on childhood obesity (77, 78). In the subsequent years, the global response to obesity included extensive research showing that obesity was mostly caused by a myriad of factors and that the environment in which people live heavily influences the risk of obesity (17). In the years 2000s, the WHO Europe produced region-specific reports which acknowledged the wider obesity determinants and prompted countries to develop integrated and multisectoral policies to prevent obesity and improve diets in Europe (22, 79, 80). In 2013, the WHO released "the global action plan for the prevention and control of NCDs between 2013 and 2020" (81). The strategy had the ambitious goal of reducing NCD mortality by 25% and included very specific targets for risk factors such as high blood pressure and tobacco use but did not include any specific target for obesity (81).

International surveys such as the WHO European Childhood Obesity Surveillance system (which started in 2006), showed that obesity was becoming highly prevalent also in children (82). Policymakers from different political orientations started to embrace the idea that children — who, unlike adults, cannot self-manage and make responsible decisions to safeguard their health — needed more policy action to reduce obesity risk. Therefore, in 2016, the WHO commissioned the *Ending Childhood Obesity* report which comprised a set of recommendations including creating a healthy food environment in schools and stressed the importance of the adoption of a life course approach to obesity prevention in children (83). At this point, an increasing body of evidence had shown that specific policy actions such as taxation of sugar-sweetened beverages (SSBs) and advertising restrictions of unhealthy products had some effectiveness (32). Such policy actions started to be included in strategies such as the 2016 *EU Action Plan on Childhood Obesity* and in the subsequent reports (84, 85). In these years the WHO started producing specific policy briefs, rather than more generic strategies, to help countries to develop policies focussing on interventions such as front-of back nutrition labelling, fiscal policies, reformulation, healthy food procurement, marketing of unhealthy food, and sustainable food systems (86-88).

It is worth mentioning that all the documents produced by the WHO are not legally binding and that they can only influence the countries' policy agenda. Nonetheless, the

WHO has often been criticised as its recommendations have been often influenced by the interests of other United Nations's agencies such as the Food and Agriculture Organisation (FAO), some transnational food companies, or even the government of some countries interested in defending a particular food industry (e.g. sugar, processed meats, tropical fats) (73).

1.7.2 The various UK Governments deliberations on obesity

The first UK report that considered obesity as a problem of governmental concern was published in 1976 by the Department of Health and Social Security and Medical Research Council (89). The report shed light on the magnitude of the problem and highlighted that extensive research was needed on the topic (72). In 1991, the Conservative Government in England formally recognised obesity as public health threat and published *Health of the Nation: a strategy for Health in England (90)*. The strategy set targets to reduce adult obesity prevalence to the levels recorded in 1980 by the year 2005. However, the recommendations included in the strategy were never adopted as a public policy (91). Obesity came back to the political agenda in 1999, when the labour Government published *Saving Lives: Our Healthier Nation* (92). The strategy contained only a few and very specific policies, such as the reduction of food deserts and improved access to healthy food in deprived areas. In 2001, the National Audit Office, a body evaluating the cost-effectiveness of governmental actions, reported that obesity prevalence increased by three times in the past 20 years in England, and stated that governmental action had been largely insufficient (93). At this time, an inquiry conducted by a parliamentary health committee brought to light the role of the food industry in limiting the government actions on obesity and the need for urgent new policies. Therefore, the Government responded proactively, and the Department of Health published *Choosing a Better Diet and Choosing Physical Activity* which included specific policy actions (many of which focused on children) to halt the obesity epidemic. Nevertheless, survey data showed that obesity prevalence continued to increase year by year particularly in children, and the National Audit Office heavily criticised the Department of Health's programmes (93).

In 2005 the UK prime minister commissioned *Foresight 'Tackling Obesities: Future Choices' project*, a comprehensive evidence-based series of reports aimed at better understanding the causes of obesity and its future trends in the UK (16, 94). In its conclusions, the project stressed the importance of implementing long-term system-wide policies which needed a continuous evaluation and amelioration. The report also highlighted that obesity was not only a health issue but also a societal and economic issue which needed to be handled with clearer leadership and accountability (16).

In 2008, the Government released *Healthy Weight, Healthy Lives,* a strategy in which obesity was under the shared responsibility of the Departments of Health and Education and for which there was a large, allocated budget for a period of three years (95). The Healthy Weight, Healthy Lives emphasised the importance of making changes in the environment in which families with young children live (95). However, in 2010 a new coalition Government was elected in the UK and following the global financial crisis the budget and responsibility for obesity policy was changed. In 2011, the Government then issued the *Call to Action on Obesity* which reiterated the importance of changing behaviours in individuals over changes of the environment in which people live (96). In these years, the responsibility for the design and implementation of obesity prevention shifted from central Government to local authorities. These were the years of the controversial *Responsibility Deal*, in which most of the obesity budget was spent on many education and social marketing campaigns, and voluntary pledges from the food industry and other partners replaced governmental top-down policies (97, 98).

From 2015 onwards the conservative Government published four strategies focussing on reducing obesity among children. Compared to the past, the strategies proposed legislation to limit the consumption of certain foods, and increasingly focussed on reformulation as a way of reducing calorie intake to tackle obesity. The first strategy, *Childhood Obesity: a plan for action* proposed two new and innovative policy actions: introduction of a Soft Drink Industry Levy (SDIL) and the sugar reduction programme which had the objective of reducing sugar by 20% in the products that children consume most (99). The management and evaluation of the sugar reduction programme was given to Public Health England, a governmental body established in 2013 (100). The second strategy, *Childhood Obesity: a plan for action chapter 2* included a plan to reduce calories by 20% in the foods that children consume most and proposed a ban on unhealthy food advertising and price promotions (101). In *chapter 3* (included in the wider public health strategy *Advancing our Health: prevention in the 2020s)* the Government announced the end of sale of energy drinks to children under the age of 16, and the consideration of other harder policies such as the extension of the SDIL to milk-based drinks, as well as the creation of better Front-of-Pack (FoP) nutrition labelling (102). In 2020, the Government published *Tackling Obesity: empowering adults and children to live healthier lives*, a strategy including a) legislation to require the out-of-home food businesses, such as restaurants, cafes and takeaways with more than 250 employees, to add calorie labels to the food they sell; b) advertising ban of foods high in fat, sugar or salt (HFSS) before 9pm and a total restriction of paid-for HFSS advertising online and; c) and in-store and online promotion restrictions for HFSS products. Among all these policies, only the calorie labelling has been implemented in April 2022 (103). The other measures (which should have been implemented by the end of 2022) are currently being delayed until 2025 by the current Government with the motivation that this might exacerbate the present cost-of-living crisis (104). Another recent and important document focusing, among others, on solutions to solve the obesity problem in the UK is the National Food Strategy, an independent review commissioned by the Government (105).

In summary, obesity was slowly recognised a public health problem internationally and in the UK. The first obesity prevention policies were very broad, focussed mostly on "downstream" approaches such as behaviour change and did not include any "upstream" intervention (i.e. those aimed at changing the food and physical activity environment in which people live). Over the years, the UK Government published a large number of obesity prevention strategies, but only a few have been implemented (106). The section below will provide an overview of the implemented policies. Meanwhile, it is worth noting that the prevalence of obesity has continued to increase. Extensive research highlighted the importance for governments to take bolder actions and to implement stronger measures such as legislation to reduce obesity prevalence.

1.8 Types of obesity prevention policies

Obesity is a complex and multifaceted problem. Most experts agree that no single policy alone can reduce the prevalence of obesity and that a multitude of different and effective policies are needed (17, 18). Countries around the world have implemented a wide range of obesity prevention actions in many policy areas. According to the Nourishing framework all the existing nutrition policies can be categorized in three domain areas (107):

- **Policies aimed at changing the food environment**. These types of policies address the environmental determinants of obesity and promote, in most cases, healthy food choices without the individuals' direct involvement. In other words, these actions are aimed at making the "healthy option the easy option". Examples of policies falling under this domain area are the advertising ban for unhealthy food products to children; the improvement of the nutritional quality of foods served in retail and out-of-home settings; taxes on SSBs; the provision of vouchers for the purchase of healthy foods; or the limitation of the number of fast-food outlets in certain geographical areas.

- **Policies changing the food system.** Policies within this domain tackle the entire food system to ensure a healthy food production and provision in all the sectors of the society. Examples of policies falling under this domain area are standards for public procurement, the support of urban agriculture; the development of heathier ingredients such as oils with less saturated fat.

- **Behaviour changes and communication policies.** These policies involve the provision of information and tools aimed at changing the food behaviour of individuals or of an entire population. The policies require a higher degree of individual agency. Examples of policies falling under this domain area are the provision of courses to learn healthy cooking skills, the development and dissemination of food-based dietary guidelines; social marketing campaigns to promote the consumption of fruit and vegetables; or the provision of nutrition counselling in healthcare settings.

Most of the proposed and implemented policies are behaviour change and communication policies. These "high agency interventions" tend to be preferred by governments around the world as they are compatible with a neo-liberal approach centring individual responsibility, do not require high-level political commitment, and are easier to evaluate (106-108). Low-agency interventions have been reported to widen inequalities and to have a reduced effectiveness on obesity prevention (109). On the other hand, a large body of evidence shows that policies changing the food environment are more equitable and have the potential of reaching the individuals at higher risk of obesity (108, 109). Changes in the food environment also have the potential of creating longer-lasting changes in a population. For example, the adoption of the indoor smoking ban has been associated to a reduced prevalence of smoking and respiratory disease, and lung cancer mortality (110, 111).

1.9 Effectiveness of obesity prevention policies

In the last 40 years, hundreds of obesity prevention policies have been implemented around the world. Only a very small fraction of these have been evaluated (112). Most evaluations report predominantly intermediate outcomes such as changes in dietary intake (112). To date, there is no single policy action that has been shown to reduce obesity prevalence. However, some policies have gained prominence and might show promising results in reducing obesity in the entire population (113). These actions are:

- **Fiscal interventions**. More than 50 countries have implemented taxes on SSBs (114). In some of these countries such as the UK and Mexico, the introduction of the tax has been effective in promoting reformulation and/or reducing purchases (115-117). In 1974, the USA Government implemented the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) which offered vouchers for redeeming fruit, vegetables, and milk for low-income families. The programme has shown to be effective in improving a large number of outcomes including dietary intake and access to healthy foods (118).

- **Advertising and promotion restrictions of unhealthy foods to children.** The advertising of unhealthy food products on TV and social media have been reported to have a direct effect on children's nutrition knowledge, preferences, purchase behaviour, and consumption patterns (31, 32) In 1976, the Canadian Province of Quebec has banned any commercial advertising including food items aimed at children on TV, radio, print, and on mobile phones. The ban has resulted in reduced sales of fast food and an improvement of the nutritional quality of products marketed in other Canadian Provinces (119, 120).

- **Warning and front-of pack nutrition labels.** Many countries have implemented voluntary FoP nutrition labelling that provides information on calories and key nutrients such as saturated fat, salt, and sugar in a visible format. Chile, Perú, Uruguay, Argentina and Mexico are some of the countries that have implemented mandatory warning logos for products with excessive amounts of calories and unhealthy nutrients. Evidence shows that FoP colour-coded labels and warning logos can nudge consumers' purchasing behaviour towards healthier choices (121).

- **Interventions to improve diet and physical activity across the life course**. Interventions during preconception, pregnancy and infancy can reduce children's risk of developing obesity obese later in life (122, 123). The Amsterdam Healthy Weight Approach (AHWA) is the only intervention which has reduced obesity in a population. The AHWA is a long-term, municipality-led program which has the objective of improving children's physical activity, diet, and sleep through actions in the homes, neighbourhood, school, and municipality. Since 2013, the AHWA has reached more than15,000 children. During this time, the estimated prevalence of overweight or obesity in children and adolescents aged 2-18 years in Amsterdam has declined from 21% in 2012 to 18.7% in 2017 (124, 125).

1.10 Policies implemented in the UK

The UK was one of the first countries recognising obesity as a population health problem. Recent evidence showed that over the last 30 years, the various Governments in power proposed almost 700 wide-ranging policies contained in fourteen strategies aimed at preventing obesity in England (91). It is worth mentioning that the UK Government has delineated government policy as "a course or general plan of action to be adopted by government, party, person etc." and "statements of the government's position, intent or action". According to this definition, a voluntary programme led and monitored by the government can be considered as public policy as well as the introduction of new regulation. Of the hundreds of policy actions proposed, only a very small number of policies have been implemented. Some examples of implemented policies are reported in the Table 1.1 below. The policies have been organised according to an adapted version of the "Nuffield Foundation's intervention ladder". The ladder is a public health framework widely used to characterise policies according to their level of intrusiveness (91, 126).

Table 1.1 Examples of implemented obesity prevention policies organised according to the Nuffield Foundation's intervention ladder.
The highest rung of the ladder includes "harder" policies while the lowest rung describes "softer" policies

Rung	Policy type	Action	Examples of policies implemented in the UK	Year of implementation
7	Eliminate choice	Regulate to eliminate choice entirely	• The legal limit of industrially produced trans fats in food products (127). • Products that do not comply with the Government Nutrients profiling Model cannot be advertised during children's programme on TV (128).	2019 2006
6	Restrict choice	Remove inappropriate choice option	• Unhealthy foods such as crisps, chocolates, and SSBs, have been removed from vending machines in NHS hospitals (Wales) (129).	2008
5	Guide choice through disincentives	Use (financial) incentives to guide people not to pursue certain activities	• The Soft Drinks Industry Levy (SDIL) has been designed in a way that promotes lower prices in SSBs with lower sugar content (116).	2018
4	Guide choice though changing the default	Make "healthier" the default option for people	• The salt reduction programme set voluntary salt targets for the industry to achieve. The targets are specific for each food category (130, 131).	2003
3	Enable choice	Enable people to change their behaviour	• The Fruit and Vegetables Scheme provides a daily portion of free fruit or veg outside school lunch to all schoolchildren (England) (132).	2004
2	Provide information	Inform and educate people	• The Government's 5-A-DAY campaign promotes a daily consumption of 5 portions of fruit and vegetables. • The voluntary FoP nutrition labelling informs consumers about the overall nutritional quality of pre-packaged products (121, 133, 134). • The provision of calorie labelling in the out-of-home sector (England) (135).	2003 2013 2022
1	Do nothing	No action or simply monitor the situation	• The National Child Measurement Programme measures every year the height and weight of school children (13)	2006

1.10.1 Have obesity prevention policies worked?

Although obesity has been on the political agenda of the various UK Government for the last decades, most of the hundreds of proposed policies have never been implemented and, as a consequence, the prevalence of obesity in the UK has not been successfully reduced (106). According to Theis and White, the failure of the obesity policy in the UK is attributable to several factors. First, policies have largely been proposed in a way that does not readily lead to implementation. For example, most policies did not include specific targets to be achieved in a given timeframe or did not include details of an allocated budget. On the contrary, when interventions are well managed and include clear targets, they are more likely to produce the desired results. For example, the salt reduction programme was successful in reducing salt in many food categories and salt intake in the UK population (136). Second, governments in charge rarely commission research evaluating the impact of previous policies and therefore they do not learn from policy failures. Third, governments have tended to adopt less interventionist policy approaches. Softer policies have a lower political resistance as they are well accepted by businesses and the population. More downstream approaches do not address the wider obesity determinants and make a high demand on individual agency and require personal resources such as knowledge, engagement, and ability or power to make healthy food and physical activity choices. Such approaches leave to the individual the responsibility to make healthy choices rather than addressing the wider determinants of obesity and thus are less likely to be effective or equitable (108).

1.11 Reformulation as a strategy for tackling obesity

1.11.1 Definition of reformulation

Whilst the causes of obesity and overweight are multifaceted, ranging from genetic and psychological to social and environmental factors, the nutritional quality of the food supply plays a major role in its onset (137, 138). Manufactured and out-of-home (MOOH) food products have been reported to be high in energy density — meaning that they provide many calories in a small unit of volume — and high in unhealthy nutrients such as saturated fat, salt, and sugar (139-141). The nutritional quality of MOOH foods can be improved through product reformulation. Reformulation can be described as an effort to reduce the unhealthy component of food products at the time of production, without worsening the overall nutritional quality of the product (142). Product reformulation has repeatedly been recommended by many leading national and international public health organisations such as the WHO, the United States' Institute of Medicine to reduce population intakes of unhealthy nutrients (143, 144).

1.11.2 Advantages of product reformulation

In recent years, product reformulation has received prominence as an intervention with a lower political resistance (depending on how it is implemented) and higher cost-effectiveness (136, 145). Product reformulation as a public health strategy can yield substantial health benefits because it can reach all socio-economic groups and has a potentially large population impact (136). If reformulation happened across the board in a country, the entire population would consume less of the nutrients of concern such as salt or sugar without modifications of consumers' eating habits. In contrast, other public health nutrition interventions (e.g. nutrition education,) are very costly, require a high level of individual agency, and might only be effective in changing the behaviour of small population subgroups (e.g. health-conscious individuals) (146, 147). Another advantage of product reformulation is that unlike other government interventions aimed at discouraging the purchase of some food products (e.g. food taxes increasing food prices at the point of sale), consumers would continue buying their usual products, resulting in no loss of sales for the manufacturers. From the perspective of food and drink manufacturers, reformulation appears to be a feasible way of meeting the demand of producing healthier products without losing sales (148, 149).

1.12 The UK reformulation strategies

The UK has been the first country to propose and use reformulation as a strategy to improve population health. Reformulation has repeatedly been reported as a key policy action to improve population health since 1999, when the Government published the strategy *Saving lives: our healthier nation* (92). In the document, the Government stated its intention to seek partnerships with the food industry with the aim of reducing salt content in processed foods. This intention eventually turned into action. In 2003, the Government — with input from the non-governmental organisation Consensus Action on Salt, Sugar and Health (CASSH) and other stakeholders — set voluntary salt reduction targets for over 80 food categories (130). Since the beginning of the programme, progress has been monitored, and the reformulation targets have been re-set five times. As a result, the salt content of many food products, for example, bread and breakfast cereals, has decreased by 20-50% since 2003 (33, 136, 150).

In 2008, the Food Standard Agency (FSA) launched a consultation for a saturated fat and energy intake reduction programme (151). The programme proposed to reduce saturated fat and energy intake at the population level through several actions including reformulation of mainstream products such as cheese and biscuits (151, 152). The plan also intended to review the legislation setting the limits for the fat content of popular products such as ice cream and biscuits to encourage the production of healthier products from the industry (151). The programme was proposed in the years of the controversial Responsibility Deal and it was never fully developed and implemented.

In 2016, the UK became the first country to pioneer a sugar reformulation programme as part of a wider sugar reduction programme (99, 153). The sugar reduction programme shared some similarities with the salt reduction programme and challenged the food industry to reduce the overall sugar content in the nine food categories that contribute most to sugar intake in children. The programme had the goal of reducing sugar content by 20% in the selected categories by the year 2020 (154). Manufacturers could choose to achieve a 20% reduction through more than one approach: via product reformulation, by reducing portion size, or promotion of their lower-sugar products. It is worth noting that the programme mostly promoted sugar reduction in products that are both high in sugar, saturated fat and calories (e.g. biscuits and cakes). Between 2015 and 2019, the programme resulted in only 3% sugar reduction when considering all categories, primarily due to substantial reductions achieved in the yoghurt and breakfast cereal categories (155). A recent analysis showed that if the sugar programme was achieved in its entirety and resulted in the planned sugar reduction, it would reduce mean calorie intake by 25kcal/person/day (156). If implemented, the programme could reduce obesity prevalence by 5.5% in children and adults and by 2.2% in adolescents. The study also estimated that over ten years, 51,729 quality-adjusted life years and £285.8m in health care costs could be saved (156). In 2017, the Government launched the calorie reduction programme. The programme challenged the food industry to voluntarily achieve a 20% calorie reduction in the product categories that contribute most to the whole population calorie intake by 2024 (157). The calorie reduction programme shared the same design of the sugar programme; manufacturers could choose to achieve a 20% reduction through product reformulation, by reducing portion size, or promotion of their lower-calorie products (158). The initial proposals to the programme included more than twenty food categories such as pizzas and ready meals but excluded important contributors of calories and saturated fat such as cheese and processed meats. Following a public consultation, PHE removed most of the food categories from the plan. The calories reduction targets, published in 2020, mainly focussed on ready meals and takeaways categories sold in both retail and out-of-home (157).The calorie programme had some important shortcomings; first, it focussed only on savoury foods and excluded sweet foods such as cakes and biscuits as these had already been included in the sugar programme. Second, it focused only on calories and not on saturated fat. Reducing food energy by reducing its saturated fat content might reduce obesity while also reducing LDL cholesterol and thus CVD.

Despite its importance, the calorie programme has had minimal support and attention. The COVID-19 crisis and the increase in food prices have led the Government to focus less on obesity. Public Health England, the governmental body responsible for implementing and monitoring the programme, was abolished in 2020, ostensibly after its poor management of the COVID-19 crisis. Many academics and health advocates felt that the Government used Public Health England as a scapegoat for the poor design and failure of its own COVID-19 prevention actions (159-161). In 2021, the UK Government announced that PHE would be replaced with the Office for Health Improvement and Disparities (OHID) which would focus on public health issues, including nutrition and obesity (162). At the moment, there is uncertainty over the future of the salt, calorie, and sugar programmes which were previously under the PHE's remit. The OHID has not published any updates about the progress of the programmes.

Nevertheless, both the UK sugar and the calorie programmes set an example for other countries to follow. In 2022, the WHO developed a regional sugar and calorie reduction programme which will involve the 53 countries of the European region and will be led by the United Kingdom. Even if only in theory, reformulation as an approach to reduce obesity prevalence is becoming increasing popular. In fact, one of the National food Strategy key policy recommendations is the proposal of a salt and sugar tax to promote reformulation in the manufactured and out-of-home foods.

1.13 TFA reformulation actions all over the world

Denmark was the first country to promote trans fatty acids (TFA) reformulation and impose a legal limit on the amount of TFA in food products in 2003 (88, 163). At the time, Willett and colleagues carried out an investigation which assessed the impact of TFA on coronary heart disease (164). The study pushed the Danish Nutrition Council to investigate the health effects of TFA consumption. Their investigation suggested that 50,000 Danish citizens were at high risk of cardiovascular disease due to high intakes of TFA in products such as margarine (165). Consequently, the Danish Government introduced legislation prohibiting more than two grams of industrially produced TFA per 100g of fat in oils, fats, and food products. The regulation did not cause any adverse reaction by the Danish population, the Ministry of Health and the Danish margarine industry, as the latter had already developed products with lower TFA levels (88, 163). Since the regulation was implemented, several studies have demonstrated its health gains at the population level (166). Many countries followed the Danish example by imposing a legal limit to TFA or by setting up voluntary TFA reformulation programmes (127, 166). In April 2019, the European Commission issued a regulation that had made illegal, from April 2021, to sell products containing more than two grams of TFA per 100g of fat (167).

1.14 Fat reformulation to address both obesity and NCD

Although the calorie reduction programme has never been fully implemented and monitored, one of its weaknesses is that it does not focus on dietary fat. Dietary fat is the most energy-dense nutrient (168). Foods high in fat such as chocolate, biscuits, sausages, or cheese have high amount of dietary fat and therefore have a high energy density. A large body of evidence from observational and experimental studies shows that individuals consuming high energy-density foods are more likely to have an excessive calorie intake and have obesity (169-175). Therefore, reducing fat in foods could reduce their energy density and reduce energy intake and obesity prevalence at the population level. Moreover, some types of fat such saturated fat have negative health effects and their removal could further benefit the population health. Chapter 2 of this thesis will focus on the different aspects of dietary fats including the health implication linked to their consumption.

Chapter 2 | General background on fat and health

This chapter provides some background information on dietary fat (with a particular focus on saturated fat). It will also provide an overview of dietary fat intakes the UK and fat consumption recommendations from main public health organizations. The chapter also includes a review of studies estimating the health impacts of reducing fat in foods.

2.1 The structure of different types of dietary fat

Together with protein and carbohydrates, fat is one of the main macronutrients in foods, and is an important source of energy as one gram of fat provides roughly nine kilocalories of energy. In contrast, both protein and carbohydrates provide around four kilocalories per gram (168). Dietary fats are mostly triglycerides, with each triglyceride molecule composed of three fatty acids and glycerol. Fatty acids can be classified into saturated (SFA) and unsaturated fatty acids. SFA has no double bonds in their carbon chain. The unsaturated fatty acid can be monounsaturated (MUFA), with one double bond, or polyunsaturated fatty acids (PUFA), with more than one double bond (Table 1.1). In general, triglycerides contain a blend of different types of fatty acids (168). SFA is solid at room temperature, while PUFA and MUFA are liquid at room temperature. Unsaturated fatty acids can also be classified according to their double bonds' geometric configuration; most have the *cis* configuration. However, some fatty acids have at least one double bond in the *trans* configuration. These are referred to as *trans*-fatty acids (TFA). Fatty acids can also be classified according to their chain length — i.e. the number of carbon atoms — in short, medium, and long-chain fatty acids (Table 1.1). Two PUFAs, the linoleic and the α-linolenic acids are essential, and therefore humans must obtain them from dietary sources (168). SFA are not essential fatty acids as the human body can produce them (176).

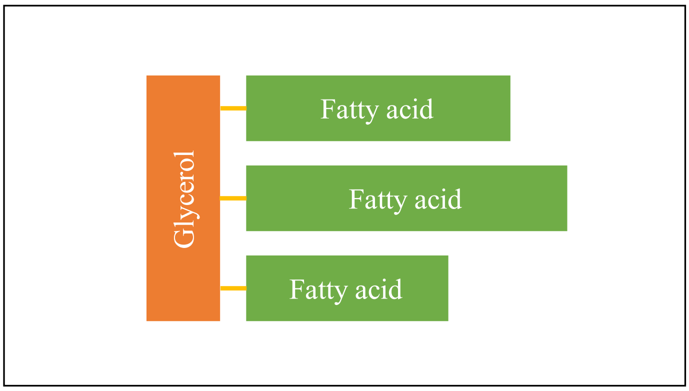


Figure 2.1 Basic structure of a triglyceride adapted from (168).

Table 2.1 Main dietary fatty acids
adapted from (168).

Type	Carbon atoms	Common name	Systematic name (- acid)
SFA	4	Butyric	Butanoic
	6	Caproic	Hexanoic
	8	Caprylic	Octanoic
	10	Capric	Decanoic
	12	Lauric	Dodecanoic
	14	Myristic	Tetradecanoic
	16	Palmitic	Hexadecanoic
	18	Stearic	Octadecanoic
MUFA	16	Palmitoleic	Hexadecenoic
	18	Oleic	Octadecenoic
PUFA	18	Linoleic	Octadecadienoic
	18	α-linolenic	Octadecatrienoic
	18	Rumenic	(Cis-9, trans-11-) Octadecadienoic
	20	Arachidonic	Eicosatetraenoic
	22	Eicosapentaenoic (EPA)	
		Docosapentaenoic (DPA)	
		Docosahexaenoic (DHA)	
TFA	18	Elaidic	(trans -9-) Octadecenoic
		Vaccenic	(trans-11-) Octadecenoic

2.1.1 The composition of edible fats

Foods often contain a combination of different fatty acids (most fatty acids are described in Figure 2.1). For example, olive oil is a good source of MUFA but also contains SFA and PUFA in smaller proportions. Animal products are rich in SFA but also contain large proportions of MUFA and PUFA (168). Some types of tropical fats such as coconut and palm oil have a higher proportion of SFA than other vegetable oils such as sunflower and rapeseed oil. Animal-sourced fats such as butter and lard are also high in SFA.

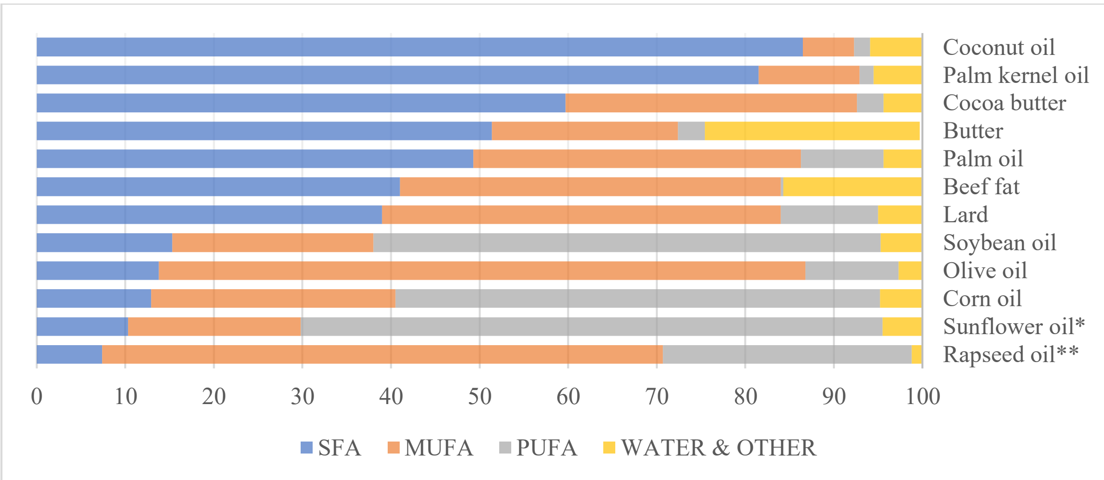


*Figure 2.2 Percentage of SFA, MUFA, and PUFA in edible fats presented in descending order according to SFA content. *High-linoleic acid sunflower oil. **Low-erucic rapeseed oil.*

2.2 Total fat intake recommendations

Dietary fat has important body functions, as it contributes to energy intake, provides essential fatty acids and is critical for the absorption of fat-soluble vitamins. Despite this, the human body can adapt to different percentages of energy (%E) from dietary fat, and experts have identified a low minimum fat intake at 15%E (176, 177). For infants whose diet are based on maternal milk, the recommended intake of fat is around 40%E (176). In the UK, the total fat intake recommendation is that it be less than 35% of the total food energy (178, 179). This is based on the sum of the different proportions of fatty acids that would prevent cardiovascular disease (particularly SFA) and, at the same time, prevent essential fatty acids deficiencies (178, 180).

2.3 Fat intake and obesity

In 2003, the World Health Organization (WHO) reported that energy balance is the most important determinant in the prevention of overweight and obesity, regardless of the total contribution of macronutrients to total energy intake (76, 177). In other words, excess dietary energy in relation to the individuals' energy needs is the biggest cause of weight gain. More recently, a Cochrane meta-analysis commissioned by the WHO Expert Advisory Subgroup on Diet and Health, which included data from 32 randomised controlled trials (RCTs) and 25 cohort studies, looked at the effect of reducing %E from total fat on body weight and total body fat in both adults and children who were not aiming to lose weight. The review found that a reduced %E from total fat leads to a small but stable decrease in body weight, body mass index, and waist circumference (181). This effect was found both in adults and children and was sustained over time (181). In 2020, the findings were incorporated into the WHO recommendation on healthy diets because diets with less than 30%E from fat help maintain healthy body weight (182). In line with the WHO recommendations, the European Food Safety Authority (EFSA) also reports that in *ad libitum diets* (i.e. those diets in which food and energy intake are not controlled), a lower total fat intake is associated with a reduced risk of weight gain (176). In its recommendations, EFSA reported that there is no evidence supporting the assertion that increased proportion of a particular type of fat, such as SFA, has any effect on body weight (176).

2.4 Saturated fat and cardiovascular health

2.4.1 "Bad versus good fat" and the diet-heart hypothesis

Different fatty acids have distinctive biochemical properties and can produce different metabolic and physiological effects with different clinical manifestations. Some types of fats such as the essential PUFA n-3 and n-6 have important physiological and structural body functions and overall positive health effects. On the other hand, industrially-produced TFA have negative health effects, and experts have advocated for their elimination from the food supply chain since the early 2000s (166). The health effects of animal fats (high in SFA) have been investigated since the 1960s as animal fat was found to have a central role in the "diet-heart hypothesis". The diet-heart hypothesis, first proposed by Ancel Keys in 1950, consisted of a sequence of relationships in which diets with a higher %E from fat raise serum cholesterol, leading to increased cardiovascular mortality (183). Soon after, researchers began to focus on the health effects of replacing animal fat, high in SFA, with vegetable oils high in MUFA. The understanding of different fractions of serum cholesterol (e.g. low and high-density lipoprotein) as biomarkers of atherogenicity allowed a better comprehension of the diet-heart hypothesis (184). In recent decades, researchers have been focussing on the effects of a higher %E from SFA on serum low-density lipoprotein cholesterol (LDL), the "bad cholesterol", and other cholesterol fractions in both RCTs and epidemiological studies (185). Globally, cardiovascular disease (CVD) is the leading cause of death and morbidity, and increased LDL is an important risk factor (186). According to the Global Burden of Disease study, the disease burden due to increased LDL has been increasing since 1990. The same study affirmed that high LDL cholesterol remains a major threat to public health (186).

2.4.2 WHO saturated fat recommendations

In May 2018, the WHO reviewed all the relevant evidence and provided new draft recommendations for SFA intake which states that:

> *"in adults and children whose SFA intake is greater than 10% of the total energy intake, the recommendation is to reduce saturated fatty acid intake (strong recommendation)".*

This recommendation is primarily based on high-quality evidence for reduced LDL cholesterol in adults and children and moderate quality evidence for reduced risk of cardiovascular disease events in adults (187). The WHO guideline development group highlighted that strong recommendations could be adopted as policy in most situations as the group feels confident that the desirable consequences of implementing the recommendation outweigh the undesirable consequences. The WHO also suggested to:

> *"replace SFA, if needed, with PUFA as a source of replacement energy (conditional recommendation)".*

The replacement fat can be either MUFA or PUFA, however PUFA was chosen as the primary replacement source as it was shown to have the biggest effect on reducing LDL and CVD events (187). Conditional recommendations are those in which the WHO guideline development group is uncertain that the desirable consequences of implementing the recommendation outweigh the undesirable consequences.

2.4.3 UK saturated fat recommendations

In 2019, the UK Scientific Advisory Committee on Nutrition (SACN) reviewed the evidence on the health impacts of SFA (179). The new recommendation does not differ from the previous one issued by the Committee on Medical Aspects of Food Policy (COMA) in 1994 (188), and states that:

> *"the population average contribution of saturated fatty acids to total dietary energy to be reduced to no more than 10% for adults and children aged 5 years and older".*

The COMA and the SACN recommendation are primarily based on the effects of SFA intake on LDL cholesterol concentrations and their role in coronary heart disease. The guidelines also recommend that the UK Government should consider population strategies to reduce SFA intake (179).

2.4.4 Saturated fat recommendations from other organisations

Other public health organisations worldwide have published similar recommendations to the WHO's to keep %E from SFA intake around 10%E (Table 2.2). Like the WHO and UK recommendations, these usually refer to the entire population and do not apply to infants.

Table 2.2 SFA intake recommendations from different public health organisations.

Source	Year	Recommendations
UK's National Institute of Health and Care Excellence (189)	2022	▪ People at high CVD risk should consume 7%E or less from saturated fat.
European Food Safety Authority (176)	2010	▪ *"SFA are synthesised by the body and are not required in the diet."* ▪ *"SFA intake should be as low as is possible within the context of a nutritionally adequate diet.*
German Nutrition Society (190)	2015	▪ 7-10%E from SFA
Australian Government Department of Health and the New Zealand Ministry of Health (191)	2013	▪ 8-10%E (SFA and TFA combined)
Scientific Report of the US Dietary Guidelines Advisory Committee (192)	2015	▪ SFA<10%E
Nordic Nutrition Recommendation (193)	2012	▪ SFA<10%E
European Societies of Cardiology and Atherosclerosis (194, 195)	2011	▪ SFA intake should be lower than 10%E and should be further reduced at <7%E of total intake in the presence of hypercholesterolemia.
French Agency for Food, Environmental and Occupational Health & Safety (196)	2010	▪ SFA ≤12%E
Academy of Nutrition and Dietetics (197)	2014	▪ 7-10%E
American Heart Association / American College of Cardiologists (198)	2013	▪ For those who would benefit from LDL cholesterol reduction, SFA should be 5-6%E
Institute of Medicine (199)	2005	▪ Recommendation to keep SFA consumption *"as low as possible while consuming a nutritionally adequate diet"*

2.5 Total and saturated fat intake and dietary sources in the UK population

The intake of total and saturated fat in the UK population is estimated through the National Diet and Nutrition Surveys (NDNS). The survey estimates, among other nutrients, intakes of total and saturated fat in different age groups and makes statistical comparisons with the previous years. Figure 1.3 shows the average total and saturated fat intake expressed as %E, in different age groups of the UK population in 2014/2016 (200). The red line in the graph denotes the recommended level of 10%E from SFA. Almost all the age groups met the UK recommendation for total fat (35%E) but exceeded the WHO recommendation (30%E). All age groups exceeded the SFA recommendation of 10%E. These figures would have under-estimated the true intakes as evidence suggests that underreporting occurs more frequently for high-fat foods (201-203). The global average for SFA has been reported to be 9.4%, with wide variation among regions and countries. (204). Whilst the measurement methodologies differ markedly, it is clear that the UK average SFA intake of 12.5%E (for an average of all the age groups) is above the global average.

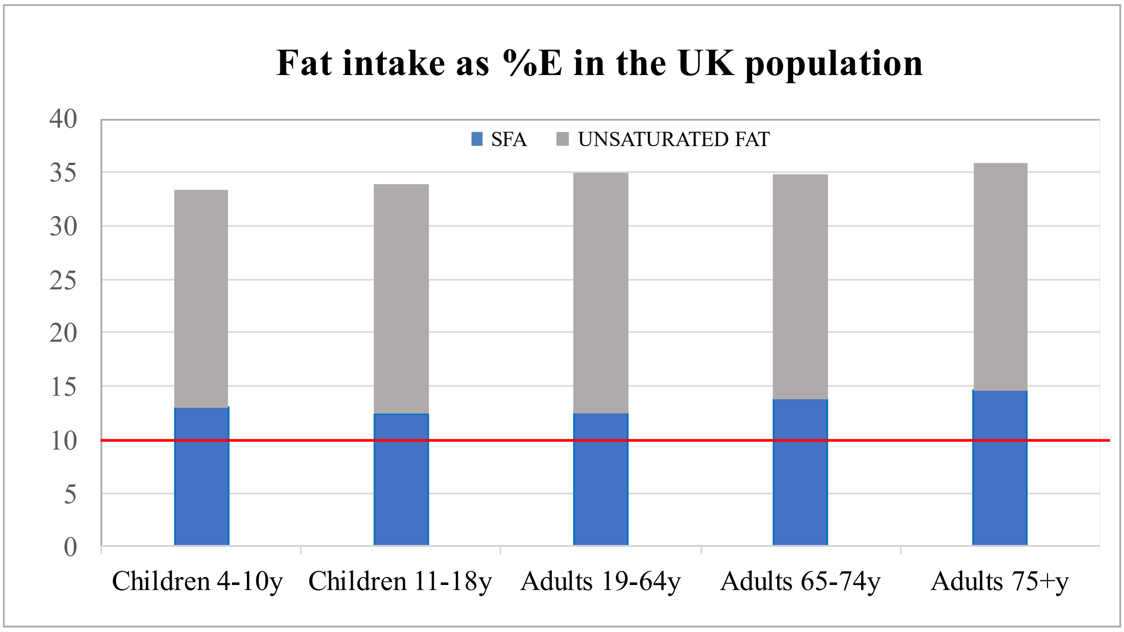


Figure 2.3 %E from unsaturated fat (grey bars) and SFA (blue bars) by age group. The red horizontal line denotes the 10%E recommendation for SFA. Data source: NDNS (2014/2016).

Figure 2.4 shows the top contributors of total fat (A) and SFA intake (B) in the diet of UK adults. The meat and cereal products categories provided nearly half of the total fat intake. The categories of potato-based products such as chips, roast potatoes, savoury snacks, nuts, and seeds cumulatively provided 12% of the total fat intake.

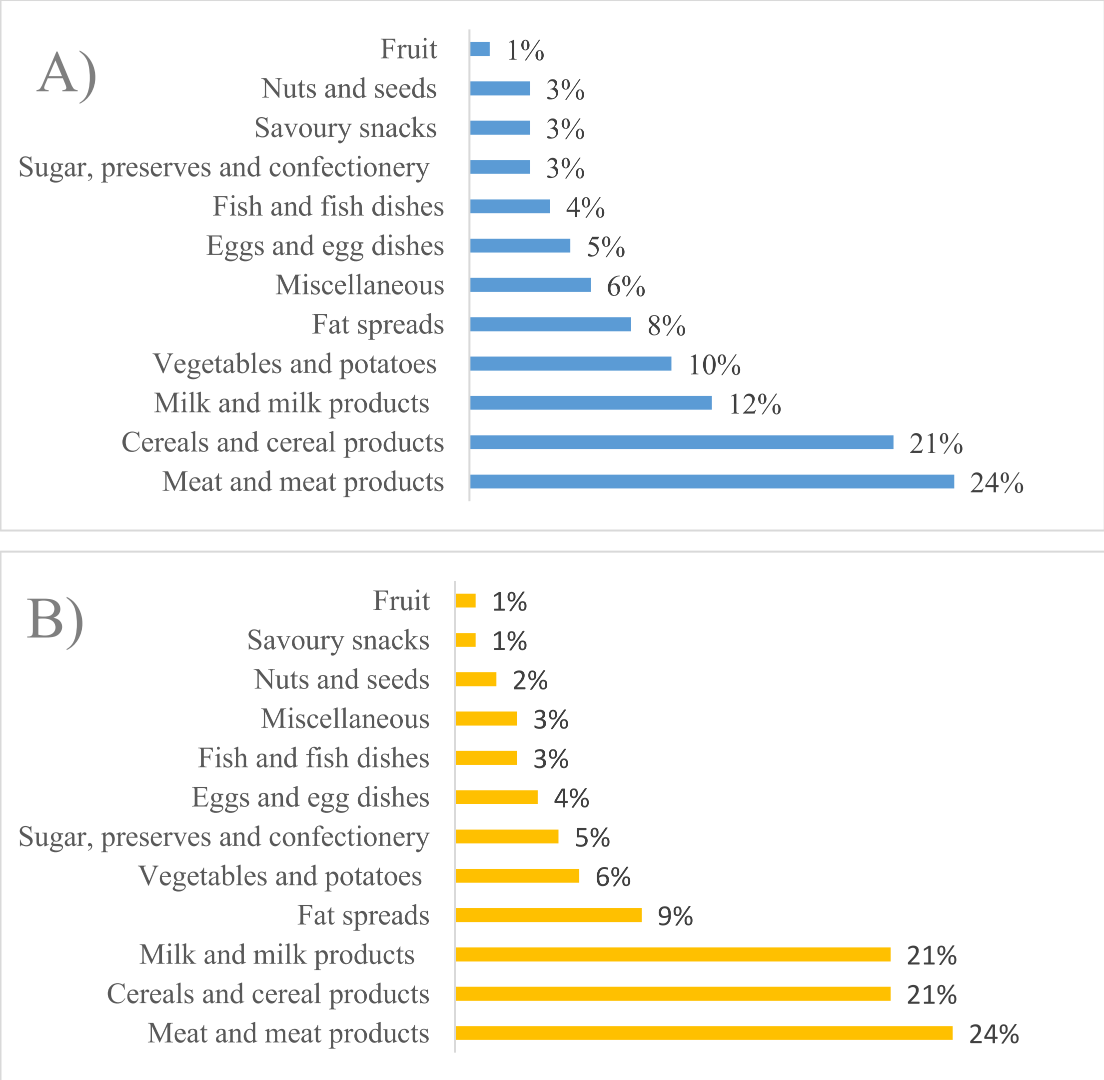


Figure 2.4 Food groups 'percentage contribution to average total fat (A) and SFA (B) intake in the UK adult population (19-64 years old). Data source NDNS 2014/2016.

The food groups that contributed most to SFA intake were meat and products, milk and products (about half from cheese), and cereals and products (half from biscuits, buns, cakes, pastries, fruit pies and puddings). Unfortunately, the grouping system used in the NDNS is too broad and it is not possible to single out which manufactured and out-of-home food categories were the most important contributors of total and SFA in UK diets. For example, manufactured food categories such as cakes and biscuits were grouped with homemade pasta and rice dishes. In the US, sandwiches, desserts and sweet snacks were identified as the leading SFA contributors in the entire population (Figure 2.5) (205). Diets in the UK and the US are very similar, and it is likely that the top contributors of SFA are the same in both countries.

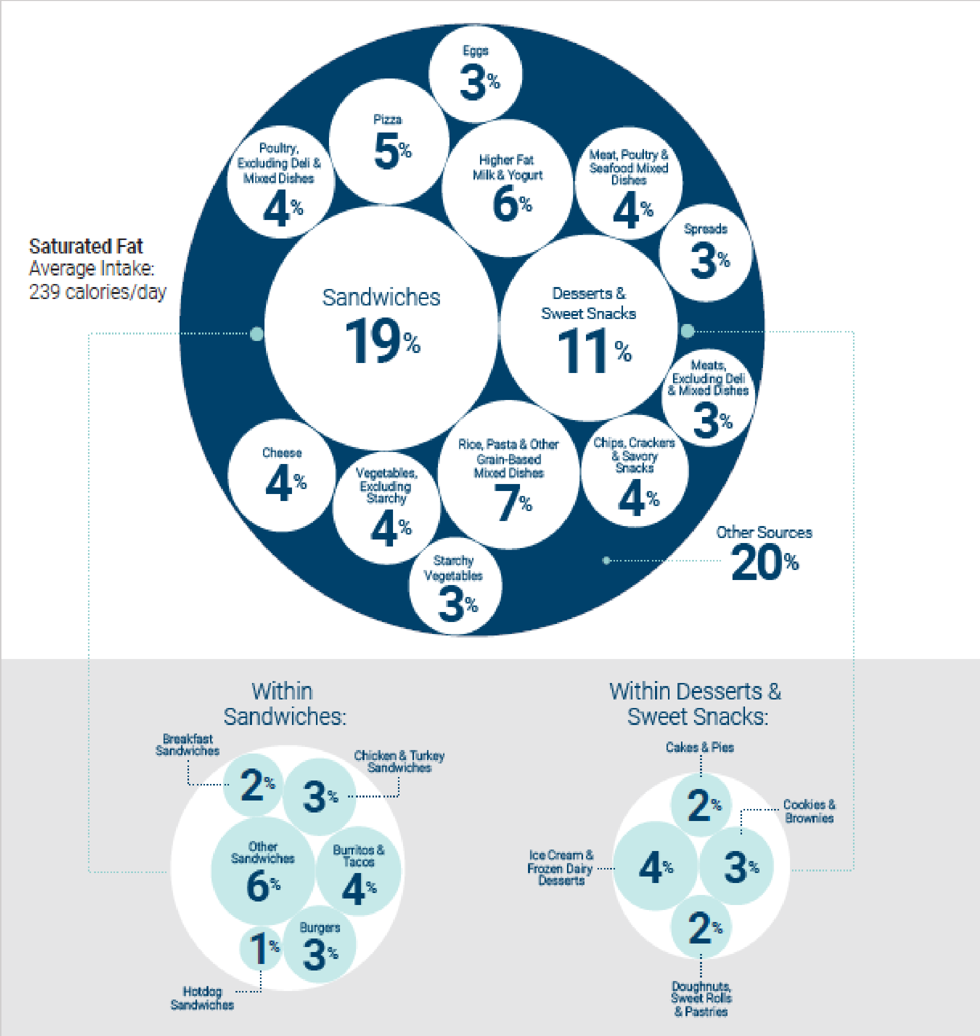


Figure 2.5 Top sources and average intakes of SFA in the US population aged one and older. Data source: Analysis of What We Eat in America, NHANES, 2013-2016, ages 1 and older, 2 days dietary intake data, weighted (from DietaryGuidelines.gov).

A recent time trend analysis of UK data showed that between 2008 and 2018, there has been no change in the total fat as %E and a minimal and non-significant increase in the %E from SFA (Figure 2.6) (206).

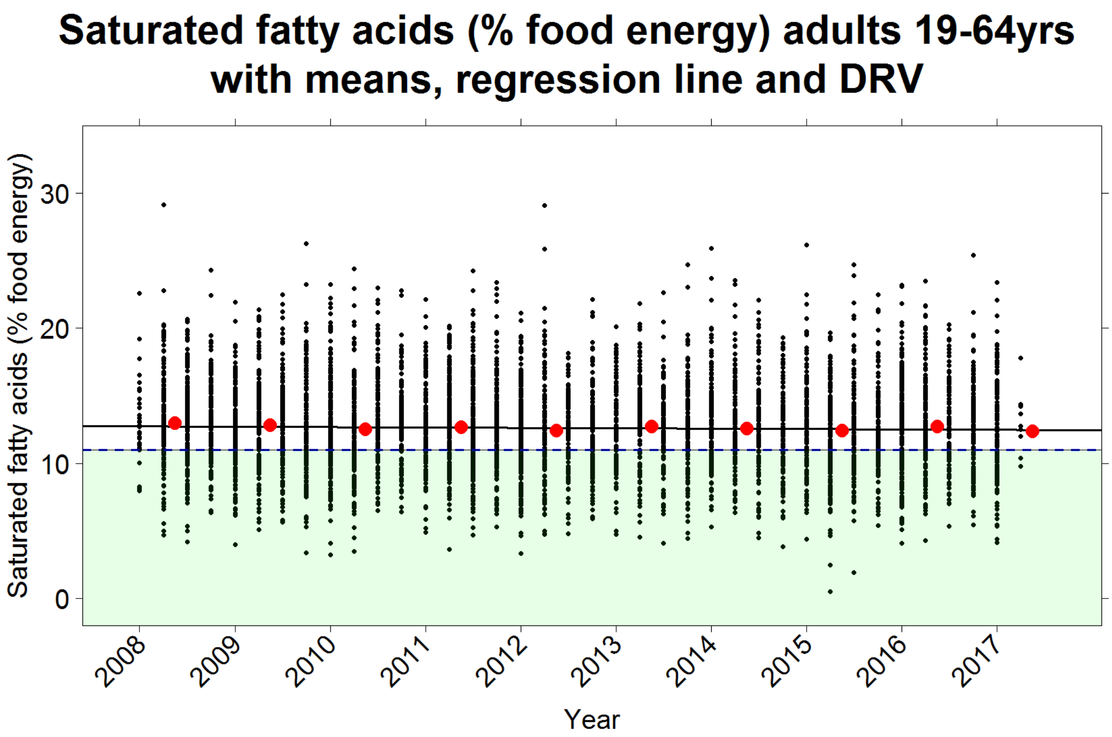


Figure 2.6 SFA as %E in the UK adult population from 2008 to 2017
The red dots indicate the mean value per calendar year. The black dots indicate the individual participant values. The blue dashed line indicates the UK SFA dietary reference value (DRV). The dots in the light green area indicate those participants meeting the recommended SFA intakes. Source: NDNS 2008/2017 (public sector information licensed under the Open Government Licence v3.0).

Another analysis included in the latest SACN draft report considered the SFA intake changes between 1985/86 and 2008/14 (179). The analysis showed that in adults, while meat, milk and cereal products have been the main SFA contributors across all survey years, there has been a marked decline in the contribution of whole milk and butter due to the reduced consumption of these dairy products (179).

Again, due to broad food grouping system used in the NDNS surveys, it is impossible to determine whether intake from total and SFA from manufactured and out-of-home foods has changed over time. Nevertheless, since home cooking has been declining (24, 207), it is plausible that compared to the past decades, a higher proportion of the total and SFA intake of the UK population comes from manufactured and out-of-home foods and meals.

2.6 Fat reformulation for energy density reduction in food products

Most manufactured and out-of-home (MOOH) food products have a high energy density. The surveys carried out within this PhD research (chapter 4) showed that in cakes and biscuits, fat content is proportional to products energy density (i.e. the higher the fat content, the higher the energy density). Since fat is the most energy-dense nutrient (168), fat reformulation could result in a considerable reduction in food energy density and thereby reduce calories and fat intake at the population level. If the reformulation strategy were focussed on SFA, this could not only reduce food energy density and thereby calorie intake, but also have an additional and independent effect in lowering population LDL cholesterol. In most MOOH products, fat contributes to a product’s weight, and to achieve a reduction in food energy density, the removal of fat from a product should be accompanied by; a) the addition of minimally calorific ingredients such as fruit, vegetables, and whole grains which are high in dietary fibre and water; b) fat replacers, and c) the use of category-specific technologies to reduce fat (chapter 6). The current guidelines and recommendation encourage SFA substitution with PUFA- and/or MUFA- rich oils in both home cooking and food manufacturing (208). However, as all the different types of fat have approximately the same energy density, swapping SFA-rich fats with MUFA- and PUFA-rich oils would not reduce food energy density. To date, there is no reformulation programme focusing on fat reduction, with a strong focus on SFA, to promote a reduction in food energy density. Despite the UK calorie reduction programme encouraging the reduction of products' energy density through reformulation, fat reformulation has not been explicitly mentioned in the programme.

2.6.1 Fat reformulation: evidence from modelling studies

Three recent and comprehensive systematic reviews summarised all the available evidence on the effects of reformulation on nutrient intake and health (146, 209, 210). The reviews reported a good body of evidence documenting the effects of salt and sugar reformulation. However, evidence for fat reformulation was limited as most of the studies focused on the substitution of TFA with other types of fat. Only a few modelling studies focussed on SFA reformulation (Table 1.3). These studies have been mainly conducted on Dutch food and nutrition data and modelled the substitution of existing products available in the market with products of the same category that also complied with the International Choice Programme (ICP) (211). The ICP is a scheme relying on category-specific limits for SFA, TFA, added sugar and salt. The ICP complying products are healthier alternatives than ordinary products of the same category. They contain lower levels of unhealthy nutrients and can display an easily recognisable logo on their packaging (211). Most of the studies modelled food intake data by substituting regular products with those complying with the ICP (referred here as to ICP products) (212-216). The studies, summarised in Table 2.3, reported a substantial reduction of SFA intake and, in some cases, also of calorie intake in the study populations (213, 214). Two studies have evaluated the impacts of substituting regular products with ICP products as deaths averted and as changes of LDL concentrations in the study population (212, 213). It is worth noting that the ICP products are lower in SFA and have more fibre, less salt, added sugars and TFA, and have a different fat composition (i.e. they are higher in PUFA and MUFA) compared to the regular products in the same category. Their lower energy density results from the reduction of multiple nutrients, which is therefore not solely delivered through a decrease of SFA. Almost all the studies modelling the substitution of regular products with ICP products did not consider the impact of the ICP logo on consumer choices. Another study included in Table 2.3 modelled nutrient composition of products to meet the Nestlé Nutrient Profiling System (NNPS) in French and US diets (217). The remaining studies did not refer to any known reformulation scheme (218, 219).

Table 2.3 Summary of modelling studies evaluating the health impacts of total and SFA reformulation

Author	**Study characteristics**			**Reduction of individual's intake**		**Health Outcomes**	**Other nutrients**
	Data sources, focus population	**Target food**	**Intervention**	**SFA and/or total fat**	**Energy density**		
Vyth et al, 2012 (213)	Dutch National Food Consumption 1997-1998	Food categories comprised in the ICP including: • Bread • Processed meat • Dairy products • Oil and fats	• Minimum scenario: 24% ICP compliant +76% original food data • Medium scenario: 48% ICP compliant + 52% original food data • Maximum scenario: 100% ICP compliant foods	Median intake of SFA reduced from 15.9%E at baseline to 9.8%E in the maximum scenario	Energy intake reduced from 2241 to 1956kcal/day in the maximum scenario	Average predicted changes in LDL and total cholesterol levels were 0.25 and 0.31 mmol/l, respectively	TFA MUFA PUFA Protein Sodium Added sugar Fibre
Roodenburg et al, 2013 (214)	Dutch Food Consumption Survey in young adults (19-30y) 2003	Food categories included in the ICP (as above) plus snacks. 430 ICP products out of 1600 consumed by the population	• Scenario 1: usual intake • Scenario 2: all the foods that did not comply with the ICP replaced with complying foods • Scenario 3: same as scenario 2 but corrected by the energy density between the original and the replacement food	• -40% SFA daily intake in scenario 2 • -32% SFA daily intake in scenario 3 Median SFA in grams reduced from 32.8 to 19.6 and 22.4 in scenario 2 and 3, respectively	Energy intake was reduced by 15% by replacing regular products with ICP products	-	Carbohydrates, Protein TFA MUFA PUFA Sodium Total Sugar Several minerals and micronutrients
Temme et al, 2011 (216)	Dutch Food Consumption Survey in young adults (19-30y) 2003 Market share information for Choice and ordinary products.	Food categories included in the ICP (as above) and similar products	• Scenario 1: Foods not complying with the ICP replaced with similar existing foods not carrying the ICP label with real market shares • Scenario 2: Foods not complying with the ICP replaced with similar existing foods not carrying the ICP label with 100% market share • Scenario 3: Replacement of all products with ICP complying products	% reduction in SFA intake was -2.5%, 10% and 40% in scenario 1, 2 and 3 Median SFA intake decreased from 31.9 (reference) to 19 g /day in scenario 3	-	-	TFA Sodium Added sugars

Roodenburg at al, 2011 (215)	Foods and nutrition data in the Netherlands, Greece, Spain, the USA, Israel, China, and South Africa	Food categories included in the ICP (as above) and similar products.	Nutrient intakes based on Typical Daily Menus are compared with intakes from Choices Daily Menus in which ICP foods have replaced regular foods	SFA reduction of %E was reduced: • −45% (Netherlands) • −42% (US) • −41% (Spain) • −36% (China) • −37% (Israel)	Change in energy intakes ranged between −2% for China and −17% for Spain and Greece	-	TFA Sodium Added Sugar Fibre
Leroy et al, 2016 (212)	INCA2 (French food and nutrition survey 2006-2007); French Observatory of Food Quality (Oqaly)	Food categories comprised in the ICP including: • Processed meat and fish • Sauces • Main courses • Bread and sandwiches • Processed FV	• High reformulation scenario: nutrient reduction targets more challenging in case of high content of nutrients of concern • Low reformulation scenario: nutrient reduction targets less challenging and close to real nutrient composition of the target products	• -14.8% SFA (high scenario) • -11.7% SFA (low scenario)	-	1897 deaths averted per year due to SFA reformulation in the high reformulation scenario	Sodium Added sugar Fibre
Schickenberg et al, 2009 (220)	Dutch Food Consumption Survey in young adults (19-30y) 2003	All food categories Dutch cheese, meat (as meal centre) and milk were the main contributors to SFA intake for most participants.	For each participant, the three products (from different product groups) that contributed most to their SFA intake were ranked in order of diminishing contribution. These products were sequentially replaced by lower SFA alternatives available in Dutch supermarkets	Mean cumulative reduction of 4.9%E as SFA (baseline value=12.4%E) after three replacements After the three replacements, 63% of the participants would have SFA <10%E	Average energy intake changes from 2413 kcal at baseline to 2341 kcal after the three substitutions (-74kcal)	-	-
Combris et al 2011, (219)	INCA2; Observatory of Food Quality (Oqaly)	Breakfast cereal Biscuits Pastries Bread-based products	Moderate to high reformulation based on food nutrient distribution	Average reduction in total fat content • -7.5% in breakfast cereals • -5.3% in biscuits • -9.9% in bread-based products	-	-	Sodium Fibre
Patterson et al 2010, (218)	EYHS (European Youth Heart Study)	Ten different scenarios. Some of them modelling	Three scenarios consisted of substituting:	Average change of SFA as %E • -1.1	-	-	Sugar (sucrose)

	comprising >2000 grade 3 and 9 Swedish Children	composition and intake of • Cheese • Milk and products • Chocolate, cakes, biscuits, chips crisps and other sweet food • Burgers, sausages and meat products	• Full-fat cheese with low-fat cheese • Full-fat milk with reduced-fat milk • Switching full-fat milk and reduced-fat milk with skimmed milk	• -0.6 • -2.0			
Gressier et al 2017, (217)	INCA 2 and US NHANES 2011–2012	All foods that did not meet the NNPS	• First scenarios in which all the products not meeting the NNPS were reformulated to meet the NNPS standards • Second substitution scenarios in which products failing to meet the NNPS standards were replaced with the closest item passing the standards within the same category	Average change of SFA as %E in scenario 1: • -4% in the French population • -1% in the US population Average change of total fat as %E in the scenario 2: • -6% in the French population • -3% in the US population	Average reduction in mean daily energy in the scenario 1 and 2 were -88 and -225 kcal respectively for both the US and the French population	-	Protein Added Sugar Fibre Sodium Calcium

2.6.2 Challenges related to SFA reformulation in manufactured and out-of-home foods

Fat is commonly used for the production of manufactured foods such as cakes, biscuits, chocolate confectionery and other baked and fried foods. Palm oil, which is high in SFA, is widely used in food manufacturing as it is considerably cheaper than other types of vegetable oils (149). Compared to PUFA, SFA confers to products a range of desirable characteristics for both consumers and producers (221). For example, in baked goods, SFA are bulk ingredients and are known inhibitors of oxidation and therefore extend the products' shelf life. They contribute to dough plasticity, moisture, and tenderness. In meat products, animal fat, which is rich in SFA and solid at room temperature, has a role in determining products' characteristics such as mouthfeel, texture, juiciness, and heat transfer (222). As in many manufactured foods, fats are bulk ingredients (i.e. they contribute substantially to products' weight), and the main issue is how to keep products weight unaffected when reducing fat content. The addition of minimally calorific ingredients such as fruit, vegetables, pulses and whole grains (high in dietary fibre and water) or fat replacers could be a feasible strategy for some categories (e.g. cakes or ready meals) but less for others (e.g. chips or chocolate confectionery). In the literature, there are many category-specific technologies that can be used to reduce fat content (chapter 6). Due to time constraints, I did not examine in detail these food technologies. Instead, I carried out some cross-sectional surveys considering the fat variation within some popular food categories to show that fat reformulation is possible.

2.7 Environmental sustainability aspects of fats high in SFA

2.7.1 Palm and coconut oil

Palm oil is one of the world's most commonly used oils in food manufacturing (223). It is said to be found in more than 50% of the food products available in supermarkets though this information can be hard to retrieve since it is labelled under more than 200 different names (224). The widespread use of palm oil is attributable to its low cost — due to high productivity per yield — and its favourable characteristics. Unlike other vegetable oils, palm oil is semi-solid at room temperature and has a low smoking point. Palm oil and palm kernel oil have a higher SFA ratio than other vegetable oils, except coconut oil (Figure 2.2). A recent meta-analysis of clinical trials reported that compared to other vegetable oils low in saturated fat, palm oil significantly raises LDL cholesterol (225).

Palm oil has been a matter of concern for its health impacts (due to their high SFA content) and its adverse environmental effects in terms of deforestation and biodiversity loss (223, 226). Palm oil production in South-East Asia requires clearing land for plantations performed by slash-and-burn practices causing air pollution, increased greenhouse gas emissions, loss of tropical rain forests, and the endangered species that inhabit these (223). Many national and international environmental NGOs have brought public attention to the issue and have called on food manufacturers to eliminate palm oil from their food products or to use only certified sustainable palm oil. A few leading supermarket chains in the UK opted for products containing only sustainable palm oil while others, such as Iceland, have pledged to altogether eliminate palm oil from its supply chain (227).

Coconut oil is a type of edible fat with the highest concentration of SFA (Figure 2.2). Coconut oil consumption has traditionally been high in tropical regions where this is produced (i.e. Southern India). However, recently, its popularity has increased in global north’s countries such as the UK (228). While coconut plantations have not been implicated in significant demand-driven deforestation so far, the increasing popularity of coconut oil, also as a plant-based ingredient, can pose biodiversity and sustainability concerns (229).

The elimination of palm and coconut oil from products could have positive implications for the food supply chain's environmental sustainability and result in products with low SFA content, thus reducing SFA intake at the population level. However, the elimination of tropical fats from product recipes and their replacement with other fat types would not reduce products' energy density. Similarly, the replacement of tropical fats with other fats with a higher environmental footprint would not result in products with a lower environmental footprint.

2.7.2 Butter

Butter is a common ingredient in many traditional and widely consumed products such as pies, sauces, biscuits, and cakes. Compared to plant-based commodities, dairy production (including butter) causes more greenhouse gas emissions, eutrophication, acidification, and water scarcity and requires greater amounts of land (230, 231). One study compared the environmental impacts of producing margarine and butter in the UK, Germany and France and found that margarine production requires approximately half of the land used for producing butter (232). Fifty percent of butterfat is SFA, therefore reducing butter content in food products could not only prove beneficial from an environmental perspective as it would free up more land but could also have the additional benefit of reducing SFA intake at the population level. Also in this case, if butter were to be replaced with another type of fat — e.g. one high in PUFA — the food products energy density would not be reduced.

Chapter 3 | Methodology and methods

This chapter presents the methodology used for this research, including the research questions, the theoretical concepts, the ontological and the epistemological positions, and a detailed description of quantitative methods adopted to investigate the research questions.

3.1 Introduction

As described in chapter 1, the idea for this research emerged from an interaction with Consensus Action on Salt, Sugar, and Health (CASSH), which is the organization behind the success of the ongoing UK salt reduction programme. The CASSH team and I noted that the PHE calorie reduction programme should have focused on (saturated) fat reformulation instead of focusing exclusively on calories. Reducing saturated fat intake would not only reduce calorie intake, thus preventing obesity, but would also have additional beneficial effects on reducing CVD risk by lowering cholesterol levels. Therefore, the main objective of this research was to produce evidence showing the health benefits of a (saturated) fat reduction strategy in the UK.

Aside from producing evidence to persuade policymakers about the health benefits of salt, sugar, and fat reformulation policies, CASSH regularly carries out product surveys showing the high levels of salt, sugar, calories, and saturated fat in manufactured and out-of-home (MOOH) food categories. The surveys have many purposes. One of them is to increase public awareness and draw policymakers' attention on the issue of food products' unhealthiness. The other purpose is to show the food industry that producing a food product with fewer unhealthy nutrients is indeed possible, as surveys consistently show a considerable variation in the content of unhealthy nutrients within the same food category. In the context of this PhD research, the surveys have had the critical function of showing the feasibility of a fat reformulation strategy to reduce energy density in MOOH food products.

3.2 Research questions

The research questions for the present PhD thesis are outlined below:

- To what extent do total and saturated fat content vary in MOOH foods?

- What are the potential impacts of a 20% fat reformulation strategy (preferably focussing on SFA) on energy intake, obesity, type 2 diabetes, and CVD in the UK?

3.3 Aims

The aims of the present thesis are:

- To show policymakers and food producers that reducing food energy density through a 20% fat reduction in MOOH foods is a realistic and feasible public health nutrition strategy.
- To predict the health impacts of a fat reformulation strategy to persuade UK policymakers to implement it in the MOOH sector to reduce obesity prevalence in the UK.

3.4 Main objectives

The main objectives of the present thesis are:

- To examine the extent of the variation of fat and saturated content within MOOH food categories.
- To develop health impact data resulting from the fat reformulation strategy (i.e., reduction in obesity prevalence, and cases of obesity, type 2 diabetes, and CVD).

3.5 Secondary objectives

The secondary objectives relative to the first research question are:

- To determine whether products with less fat are those with a reduced energy density.
- To establish if fat rather than sugar is the biggest contributor to energy density in MOOH food products.
- To assess the overall healthiness of selected MOOH food categories.

The secondary objectives relative to the second research question are:

- To determine which MOOH food categories contribute most to calorie and fat intake in the UK population.
- To determine the share of calories from MOOH foods in different age groups.

- To discover which population subgroups (income and age) would benefit most from the proposed fat reformulation strategy.
- To establish the average fat reduction in selected MOOH food categories resulting from the strategy.

To develop the research questions, aims and objectives of the present thesis, I used, whenever possible, frameworks widely used in quantitative research (233). For the development of the research questions, I used the PICO (population, intervention, comparison, outcome) framework (234). Both research questions are descriptive as they seek to quantify responses to one or more variables (233). For setting the research objectives, I used the SMART framework (specific, measurable, achievable, realistic, time-bound) whenever possible (235).

3.6 Research approach

3.6.1 Theoretical concepts

As explained in chapter 1, this research is based on the perspective that obesity results primarily from broader social and environmental drivers rather than individual behaviours. Therefore, halting and reducing the prevalence of obesity requires the implementation of upstream governmental policies rather than downstream interventions, which mainly focus on behaviour change and require high levels of individual agency (17, 108). This research is also based on the idea that governments should find solutions to act on wider drivers of obesity to protect the health of the entire population. Consequently, governments should implement policies that drive the food industry to offer healthier options (236).

There are many public health theories that support population-level approaches to intervention. One of the most suitable theories to the research problem presented in this thesis is the population strategy of prevention by Geoffrey Rose (237). Rose’s theory states that reducing the disease risk factor in the entire population yields more public health benefits (in terms of numbers of cases reduced) than reducing the risk factor in a small number of high-risk individuals (237). Thus, if applying Rose’s theory to the context of this thesis, the implementation of a fat reformulation strategy would result in a small reduction of body weight in the entire population and produce large public health benefits. Compared to targeted approaches, population-level strategies present the advantage of being inclusive as they attempt to remove the root cause of disease in the entire population, and to be "behaviourally appropriate" — i.e. if healthier MOOH foods become the default option it will be less necessary to persuade people to choose healthier MOOH foods (238). Nevertheless, Rose's theory tends to view prevention under a dichotomous lens (population-approaches against targeted approaches in high-risk individuals). Preventing obesity through a high-risk individual approach is poorly applicable to the obesity problem in the UK where the high-risk group (i.e. individuals with obesity) compose 29% of the population. It would not be possible to treat these many individuals with bariatric surgery or weight management programmes as the cost of this approach would be excessive. Moreover, the prevention of obesity through a high-risk individual approach aligns with neoliberal and individualistic views which are the same ideologies that have contributed to the rise of obesity in the past few decades (239, 240).

Harm reduction was also used as conceptual framework guiding the present PhD research. Harm reduction can be defined as the set of practical strategies, policies and ideas aimed at reducing the health consequences associated with the use and consumption of harmful substances (241). Nearly a hundred countries have harm reduction policies in place as an approach to minimise the adverse health effects of drugs, tobacco, and alcohol. Harm reduction approaches have the advantage of not blaming individuals for choosing health behaviours which result in harm. These approaches consider all the factors determining unhealthy behaviours and aim to address them systematically. Such approaches can reduce the negative effects of problematic behaviours without necessarily eliminating them entirely. Evidence shows that harm reduction approaches have been associated with reduced drug and alcohol-related mortality and positive outcomes such as reduced stigma (242, 243).

Food reformulation can be considered an example of a harm reduction strategy (244). As explained in chapter 1, food reformulation involves reducing the level of potentially harmful components of a product (e.g. salt, sugar, saturated fat) and replacing them with healthier alternatives without compromising the product's sensory properties. Reformulation has many advantages. First, it effectively reduces unhealthy nutrient intake in the population (136, 245, 246). Second, it does not rely on individuals' behaviour and requires the food industry to make minimal changes in the way food is produced. Most nutrition experts agree that changing how people choose, prepare, and consume food is complex and ineffective from the public health point of view (247-249). Third, reformulation as a public health approach to tackle obesity reduces the emphasis on individual responsibility in dietary change, thus reducing the stigma experienced by people living with obesity and overweight (244). Therefore, reducing but not eliminating the negative factor, such as excessive calorie and saturated fat content in MOOH foods, might be a winning strategy that could work much better for governments, the food industry, the healthcare care sector, and consumers. In the present PhD research, reformulation is used as a harm reduction approach to reduce obesity prevalence and saturated fat intake in the population.

3.6.2 Epistemological and ontological viewpoints

Before outlining the methodology for this research, I will explore my epistemological and ontological viewpoints as these are important to understand, drive, and interpret the present research. Ontology is a branch of philosophy that deals with the nature of the world and what can be known about it (250). Epistemology is another branch of philosophy that deals with the nature of knowledge and how this can be acquired (250). The key ontological positions in research are objectivism and constructivism. Objectivism assumes “that reality exists independently of our beliefs and understandings” and that “the causal links between events and their causes can eventually be uncovered by science” (250). Constructivism assumes that “reality is subjective” and that “there exist only estimates, or approximate observations or views of reality”. The key epistemological positions in research are positivism and interpretivism. Positivism suggests that the world exists independent of knowledge and that causal relationships can be identified and that "the world is independent of and unaffected by the researcher” (250). Interpretivism assumes that "the researcher and the social world impact on each other” and that "objective and value-free inquiry is not possible since findings are inevitably influenced by the researchers’ perspectives and values” (250).

My own ontological and epistemological stances are congruent with objectivism and positivism as I have been trained in the fields of medicine, epidemiology, and human nutrition. The line of enquiry for this research comes from a perspective that there is one reality which can be explored through the use of statistical methods and that findings can be presented through numerical estimates that can potentially be generalisable.

However, it must be highlighted that these stances are not entire applicable to this research. The modelling part of this research required the formulation of some model assumptions, which are conditions set by the researchers and should reflect phenomenon happening in real life conditions. I aimed to remain objective when choosing the model assumptions; I talked to experts in the field, read the relevant literature, and carefully pondered all the elements impacting on the experiment results if conducted in the real word. However, I am aware that the assumptions I chose for the modelling study are potentially subjective and reflect my view of the world thus aligning with a constructivist position.

3.6.3 Quantitative Research

Quantitative research attempts to estimate cause and effect among the variables of interest. Quantitative research refers to gathering and evaluating numerical data to test a hypothesis or identify patterns and correlations between variables. There are several types of quantitative research designs (251). These are: descriptive research design; survey research; correlational research design; quasi-experimental research design; and experimental research design. Descriptive research designs attempt only to observe and measure the variables to investigate them. Survey research is used to gather data at a given point in time. Correlational research is a non-experimental method used to uncover a relationship between two variables with no influence from any other external variable. As an experimental research design, quasi-experimental research also aims to identify a cause-and-effect relationship between two variables. This type of design is often used when a true experiment cannot be carried out due to ethical reasons. It is widely used in public health, education, and policy analysis (252). Experimental research designs are carried out to establish the impact of a factor (or independent variable) on the dependent variable.

3.7 Methods selection

Public health nutrition is concerned with the improvement of the nutritional health of an entire population (not individuals) (253). Populations live in complex social and environmental systems; thus, carrying out research in public health nutrition is particularly challenging (252, 254). Most of the time, it is impossible to carry out an experiment on an entire population; therefore, researchers focus on a smaller group of individuals to then generalise the findings to the entire population.

Within the quantitative research methodologies used in public health nutrition, there are observational studies and experimental studies. In observational studies, the dietary intake, and the occurrence of an outcome of interest are tracked over many years in the study population which usually comprises a large number of participants. These studies cannot be used to test an intervention's effectiveness and establish causal relationships and are generally considered less reliable. However, these studies are extremely important for determining possible connections between diet and health that would be unethical to test in other ways. For example, the elevated risk of coronary heart disease in people consuming high levels of trans fats has been detected through observational studies (164).

Experimental studies such as feeding studies and randomised controlled trials (RCTs) are regarded as the gold standard for evaluating the effectiveness of interventions in the field of nutrition. A feeding trial involves the provision of meals, snacks, and drinks to all the study participants so that the researcher can fully control their dietary intake. In this type of study, the ingredients for meal preparation are carefully weighted and participants bring back all the foods that have not been consumed. Body weight and other outcomes are measured throughout the study. In RCTs, participants are assigned to intervention and control diets, and encouraged to consume their assigned meals and/or supplements for the duration of the intervention period. The participants' body weight (and other outcomes) are then measured at the end of the study (254). This type of study design requires participants to have regular contact with the researchers, to self-monitor their food intake and to have high levels of motivation to change. The main advantage of feeding studies is that its results are highly accurate as the researcher can strictly control the food intake of the participants, exactly like when testing the effects of the administration of a drug. RCTs share some similarities with feeding studies but are usually carried out to assess the effects of long-term dietary modifications. The results of a RCTs in nutrition are less accurate than those of a feeding study as the researchers cannot fully control participants' food intake and other external factors (254). The disadvantages of both types of studies include their high cost, and the high participants' adherence.

Both observational and experimental study designs are not suitable to explore the main research question of this thesis for many reasons:

1. Observational studies do not consider the concept of testing the effectiveness of an intervention. One of the research aims is to predict the impact of a fat reformulation strategy in MOOH food categories.
2. Experimental studies are costly, require highly compliant individuals, and can be carried out only for a short time. This is particularly problematic as many nutrition-related diseases and conditions, such as type 2 diabetes and overweight, occur after long-term dietary exposure (254).
3. In experimental study designs, participants are asked (to some extent) to change their food behaviour. The present research does not involve any kind of behaviour change. Like the UK salt reduction programme, the fat reformulation strategy proposed in this thesis would be implemented "silently" and gradually by the food industry. Consumers' taste will slowly adjust, and individuals will keep buying and consuming the same products (255).
4. Experimental research designs do not account for the hundreds of factors that affect food consumption of individuals in their food environment.

Modelling studies

In an ideal situation, the way to investigate the main research question of the present thesis would be to implement a nationwide fat reformulation strategy targeting MOOH foods available in the UK and to measure the body weight changes in the entire UK population over time. However, one of the main objectives of the present thesis is to produce evidence before implementation to convince policymakers to enforce a fat reformulation strategy to reduce obesity prevalence and CVD risk. This problem can be overcome using a modelling study. Modelling studies are becoming increasingly popular in public health (245, 256, 257). Their results are useful when data from experimental and observational studies do not adequately answer the research question or research cannot be carried out for ethical reasons. A modelling study can be described as the simulation of a partial representation of a system (258). Modelling studies enable the estimation of population-wide health benefits, harms, and trade-offs from interventions in the long term. They allow the integration of evidence from different fields, and assess the cost-effectiveness of an intervention and provide answers to "what if" scenarios (258). Insights from experts and other stakeholders in the field can be considered by researchers and included in simulations. The data used in modelling studies can be obtained from primary (i.e. collected by the researchers carrying out the modelling) or secondary data sources (i.e. collected by somebody else).

Modelling studies present the advantages of being cheap, quick, and safe and do not require the intervention to be implemented. They can provide a realistic scenario of a potential outcome to policymakers before a population-wide intervention is implemented and can be used to find unexpected problems. The main disadvantages are that researchers can make programming mistakes when developing the models or that the results might be incorrectly interpreted. The other drawback is the credibility of the results as policymakers and scientists might not find the assumptions or results realistic and reliable (258).

Food surveys

The other research question of this thesis is to assess to what extent fat (and calorie) content varies in MOOH foods. As previously described, one of the criticisms of modelling studies is that results are not credible because the experiment has not been conducted in a real-world setting. This second research question complements the results of the modelling study by supporting the idea that a 20% fat reduction in MOOH food categories is a realistic and feasible strategy.

One way of investigating the second research question would be examining the fat and calorie reformulation practices in single products. However, when a food product is reformulated, its nutritional label is replaced with an updated version and the old label becomes unavailable. To find out this information, I could directly ask this information to single food manufacturers, but this would require a large amount of time and the willingness of manufacturers to share such information.

A way to overcome this problem would be to carry out cross-sectional product surveys focusing on single product categories (e.g. biscuits, plant-based burgers). Cross-sectional food surveys are a quick and cheap method for assessing differences within more than one variable at a given time.

When applying this method to the second research question of this thesis, its most significant limitation is that it cannot assess whether reformulation is possible within a single product (e.g. a Mars bar). However, this method can be used a good proxy for understanding if reformulation is possible within similar products already available on the market.

The other disadvantage of product surveys is that like any other type of observational study design, they cannot be used to show any causal relationship but only associations (see chapter 5).

3.8 Methods used

This section will provide details of the methods used to investigate the research questions of this thesis. Table 3.1 reports the research questions, aims, primary and secondary objectives, and methods selected for this research.

Table 3.1 The research questions, aims, objectives and methods used in this thesis

Research questions	Aims	Main Objectives	Secondary Objectives	Analysis method
To what extent do fat content vary in MOOH?	To show policymakers and food producers that reducing food energy density through a 20% fat reduction in MOOH foods is a realistic and feasible public health nutrition strategy	To examine the extent variation in fat content within MOOH food categories.	• To determine whether the products with less fat are those with a lower energy density • To establish if fat rather than sugar is the biggest contributor to energy density in MOOH food products • To assess the overall healthiness of MOOH food categories	Descriptive statistics and correlation analysis of cross-sectional survey data in MOOH food categories
What are the potential impacts of a 20% fat reformulation strategy (preferably focussing on SFA) on energy intake, obesity, type 2 diabetes, and CVD in the UK?	To predict the health impacts of a fat reformulation strategy to persuade the UK policymakers to implement it in the MOOH sector to reduce obesity prevalence in the UK.	To develop health impact data resulting from the fat reformulation strategy (i.e., reduction in obesity prevalence, and cases of obesity, type 2 diabetes, and CVD).	• To determine which MOOH food categories contribute most to calorie and fat intake in the UK population. • To discover which population subgroups (income and age) would benefit most from the proposed strategy. • To establish the average fat reduction in MOOH food categories resulting from the strategy.	Secondary data analysis and data modelling of the NDNS food consumption data

3.8.1 Methods used in the surveys of fat content in MOOH foods

This section will provide all the details about the methods used to answer the first research question which investigates the feasibility of a fat reformulation strategy to reduce food energy density of MOOH categories. I addressed this research question by carrying out cross-sectional surveys of popular manufactured products. I investigated the fat and energy content variation within each category and determined if food energy density correlated with fat content. Due to the limited amount of time available, I could only carry-out out two surveys: one focussing on manufactured cakes, and the other focussing on manufactured biscuits. Nevertheless, cakes and biscuits are widely consumed in the UK and are among the top contributors of fat and calories in the UK diets (see chapter 5).

Data sources

The data used for the cakes and biscuits surveys were collected in 2016 by colleagues at CASSH and published elsewhere (259). At that time, the purpose of data collection was to evaluate the sugar content and energy density of biscuits and cakes. The data on total and SFA for the same products were also collected.

The nutrient data (including fat and calories) were taken from the nutrient panel of products available in supermarkets. Data were collected from products sold in nine stores. Each store belonged to one of the following supermarket chains: Aldi, Asda, Lidl, Morrisons, Sainsbury's, Tesco, The Co-operative, Waitrose, and Marks & Spencer. These nine chains jointly held more than 90% of the UK grocery market share (260). The data were collected on one occasion for each supermarket in the London metropolitan area. To obtain the largest possible sample, large stores were chosen instead of smaller stores. Due to the sampling strategy used, the sample could be considered representative of the manufactured cakes and biscuits available on the UK market. The nutrient data were collected through two free smartphone applications called the "Food Data Collector" and "FoodSwitch". The first application is specific for research staff, while consumers mostly use the second application. Once collected, the researchers reviewed and approved the data for inclusion in the George Institute for Global Health's FoodSwitch database. The database is available in many countries. The UK has its own database managed by CASSH at the Wolfson Institute of Population

Health in London. As a member of CASSH, I have been able to access the database, and check and enter the products' data.

Inclusion and exclusion criteria and product categorisation

The cake and biscuits products were collected according to the following inclusion and exclusion criteria:

- Own-label (i.e. those products produced for a supermarket chain) and branded (i.e. those made by a well-known manufacturer and has the manufacturer's label on it) cakes and biscuits were included.
- Reduced-fat biscuits and cakes (i.e. products with a reduced-fat claim) were included.
- Savoury biscuits, crackers, and crispbreads, which are often grouped with cakes and biscuits, were excluded.
- In-store self-service bakery items and any product without nutrition information were excluded.

Data curation

Once collected, the data for each product type (e.g. biscuits) were organised according to their categories (e.g. shortbreads, digestives) following a specific set of defined criteria such as name, products' definition, and recipe. This operation aimed to compare the fat and energy content of products belonging to the same category. Not all the products fit in specific categories; some were left uncategorised and excluded from the within-category analysis. Data for all the products (categorised and uncategorised) were in included in the general analysis and contributed to the overall results.

Statistical analyses

- To detect the variation of fat and energy content within each category, I reported descriptive statistics (mean, SD, range) for total fat, SFA, and energy density (kcal/100g) for all the cakes and all the biscuits included and for each cake and biscuits category.
- To test whether there was a correlation between fat content and energy density, I calculated the mean percentage of energy contribution from total and saturated fats and sugar for cakes and biscuits. I performed Pearson correlation analysis between total fat, SFA, sugars (g/100g) and energy density (kcal/100g) by using

the software IBM SPSS Statistics 25. Finally, I calculated the percentage variation of fat within each category.

- I compared the total fat and the saturated fat content of each product with the criteria used for colour coding adopted in Front of Pack Labelling (FoP) in the UK (134). Products containing ≤3 g/100g of total fat are classified as green/low, products with >3 g and ≤17.5g/100g of total fat are classified as amber/medium, and products >17.5g/100 g of total fat as red/high (261). For SFA, products containing ≤1.5 g/100g are classified as green/low, products with >1.5 g and ≤5g /100 g are classified as amber/medium, and products >5 g/100 g as red/high.
- I calculated the ratio of all cakes and biscuits that would get a green/amber/red code for total and SFA (261)

3.8.2 Methods used for the modelling study

This section will provide details on the methods used in the modelling study, which was carried out to answer the second research question.

Overall structure of the proposed fat reformulation strategy

In this research, I propose a reduction of food energy density, through a gradual reduction of fat content in MOOH food categories. The goal is to achieve a 20% fat reduction (preferentially SFA) in MOOH food categories within five years. Based on the UK national food consumption data, I estimated the potential impact of the proposed fat reformulation strategy on energy and fat intake at the population level.

Data sources

To develop the model, I used data from the NDNS for the years 7&8 (2014/16), which includes self-reported information on foods, nutrient intake, and socio-demographic information such as age and total household income in the last 12 months in a representative sample of the UK population (n=2723). The NDNS also includes bodyweight and height data measured by the NDNS field workers (262). The NDNS data are freely available for PhD students enrolled in UK universities.

Selection of the food categories included in the strategy

To determine the share of MOOH food categories in UK diets, I used the 2014/2016 NDNS data. I extracted data for all the relevant NDNS food categories coded as "manufactured and out-of-home" (previously abbreviated as MOOH). Figure 3.1 shows some of the 46 food categories included in the reformulation strategy outlined in this research. The complete list of the categories included in the modelling study is reported in chapter 5.

Cereals, vegetables and potato-based products

- Pizza
- Pasta (manufactured products and ready meals)
- Rice (manufactured products and ready meals)
- Chips purchased including takeaway
- Crisps and savoury snacks

Sweet and savoury miscellaneous products

- Biscuits (manufactured/retail)
- Buns cakes and pastries (manufactured)
- Sponge puddings (manufactured)
- Fromage frais and other dairy desserts
- Ice cream
- Chocolate confectionery

Protein-rich products

- Burgers and kebabs
- Sausages
- Meat pies and pastries
- Manufactured pork products
- Manufactured beef products
- Manufactured coated chicken/turkey products
- Manufactured chicken products
- White fish coated or fried
- Meat alternatives
- Cheddar and other cheese categories

Figure 3.1 NDNS's manufactured and out-of-home food categories included in the reformulation strategy outlined in this PhD thesis.

I included manufactured and out-of-home products because the fat reformulation strategy proposed in the present thesis aims to change the production practices of food manufacturers and chefs working in the out-of-home sector (i.e. restaurants, canteens, takeaways). I excluded the following categories:

- All homemade food categories and all the minimally processed food categories typically used to prepare homemade meals — such as bread, milk, fresh meats, grain products, oils and fats, pulses, nuts, fruit, and vegetables — as the proposed reformulation strategy does not focus on changing consumer behaviour.
- All drinks, such as sugar-sweetened drinks, milk-based drinks, alcoholic drinks, fruit juices as in most cases they have a negligible fat content and fat reformulation would not be an effective strategy for reducing their energy density.
- Nutrition supplements.

<u>MOOH's ranking according to their calorie and fat content</u>

After selecting the categories to include in the reformulation strategy, I calculated the share of the calories from the selected MOOH food categories (e.g. biscuits, pizza, chips) in each NDNS participant's diet. I then ranked the selected food categories according to the calories provided to the whole NDNS population. I did the same for total fat and SFA. I also calculated the share of the NDNS participants consuming the selected food categories. I performed the above analyses to show that a large share of energy comes from MOOH foods and that tackling obesity through policies focussing on these sectors and categories could lead to substantial benefits. Ranking the selected food categories according to their contribution of calories, total fat, and SFA helped determine if the main dietary sources of calories were also the main dietary sources of total and SFA.

Modelling and scenarios

I calculated the calories from the selected MOOH food categories in the diets of the whole NDNS population. I then calculated the baseline data (calories, fat and SFA) for each MOOH food category for each NDNS individual. Figure 3.2 summarises the main steps of the modelling strategy.

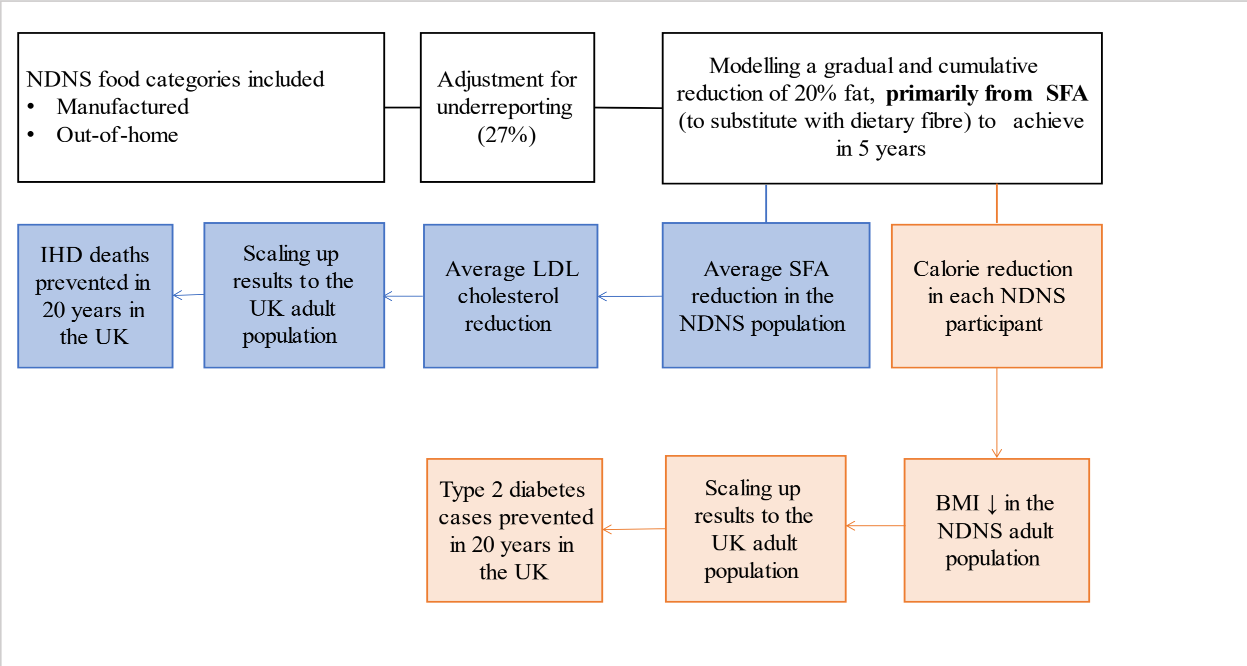


Figure 3.2 The different steps taken in the modelling study.
The study started with the step depicted in the top left white box. The step involved the selection of the MOOH food categories from the NDNS data. Then (moving clockwise) the resulting food intake data were adjusted for underreporting. At this point it was possible to model a 20% fat reduction which focussed preferably on saturated fat. The reduction was set to be achieved in 5 years with a yearly average reduction of ≈4% fat. The reformulation strategy assumed that all the fat reduced would be substituted with dietary fibre. Then moving down, the orange boxes describe the various steps taken to calculate the reduction in obesity prevalence, and the cases of obesity and diabetes being reduced in the UK if the fat reformulation strategy would be implemented. Going back up, the blue boxes show the various steps taken to calculate the reduction in IHD deaths resulting from the saturated fat reduction in the UK.

Accounting for underreporting

Since a large body of evidence shows that underreporting is frequent in self-reported food intake studies (202, 203), I used the estimates provided by the NDNS doubly labelled water (DLW) sub-study to adjust the baseline estimates. According to the DLW study, which is an established method generally agreed to be the most accurate for detecting misreporting of energy intake, survey participants underreport, on average, 27% of their energy and nutrient intake (263). I, therefore, multiplied energy and nutrient intake by 1.27 so that the baseline estimates could be closer to the real energy and nutrient intakes.

Modelling a gradual fat reduction in MOOH foods

Using the adjusted baseline data for each food consumed within the selected MOOH category by each participant, I generated a 20% fat reduction with a constant yearly proportional decrease (corresponding to a 4.4 % annual reduction) to achieve in five years. I generated the fat reduction in each single food (e.g. chocolate biscuit) included in the selected MOOH food category (i.e. biscuits category). The fat reduction was carried out predominantly by a reduction of SFA content. However, for a few products (e.g. potato snacks) that are relatively high in fat but low in SFA, I firstly reduced the SFA and then when there was no SFA left in the food, I reduced the rest of the remaining fat. I then calculated the energy intake reduction arising from the reduction in fat intake for each participant in the NDNS dataset.

Calculation of body weight changes

To determine the impact of reduced energy intake on bodyweight, I calculated the expected change in steady-state bodyweight for each adult (defined as older than 18 years) at an individual level using the mathematical model proposed by Hall & Jordan (264). The model takes into account the dynamic physiological adaptation to changes in bodyweight and has been externally validated; the predicted change in bodyweight from the Hall and Jordan model closely matches the weight loss observed in several long-term intervention studies (r=0.983) (264). I applied the model to each adult in the NDNS, taking into account age, sex, weight, height and level of physical activity of each individual. This modelling method has previously been used to evaluate the impact of a 40% reduction of sugar in soft drinks (265).

Calculation of the health impacts of the proposed strategy

After calculating the weight loss for each individual, I calculated the new BMI and the changes in the prevalence of obesity and overweight corresponding to the 20% fat reduction in the fifth year of the strategy. As the last step, I scaled up the calculated prevalence of obesity and overweight to the whole UK adult population. I then calculated the number of overweight and obese cases that could be prevented nationwide if the strategy would be implemented. I obtained the estimates of the mid-year UK population size in 2018, which was 66.5 million, from the Office for National Statistics website (266). To predict the number of obesity-related type 2 diabetes that would be prevented, I used the calculation from Wang and colleagues, whereby a 1% reduction in BMI of the entire UK population would prevent 191,000 (95%CI 178,000; 202,000) incident type 2 diabetes cases in two decades (267). This estimation was simulated by creating virtual UK individuals based on the projected BMI distribution, and the risk of developing type 2 diabetes was simulated as a function of age, sex, and BMI (267). I calculated the percentage of energy (%E) from fat and from SFA before and after the implementation of the proposed strategy. I determined the resulting change in LDL cholesterol from SFA reduction using the published equations by Yu-Poth and colleagues where a reduction of 1% in energy from SFA decreases serum LDL cholesterol by 0.05 mmol/L (268). I estimated the relative risk reductions for ischemic heart disease (IHD) and stroke corresponding to this LDL-cholesterol change using the proportional relationship between LDL-cholesterol and risk of these disorders reported by Law and colleagues; for IHD, $(1-0.39)^{(\text{Change in LDL cholesterol}/1.8)}$ and for stroke, $(1-0.83)^{(\text{Change in LDL cholesterol}/1.8)}$ (269, 270). I calculated the number of IHD and stroke deaths that would be avoided in the UK through the proposed strategy, by multiplying the number of yearly IHD and stroke deaths by the corresponding risk reductions (271).

Statistical analyses

I reported means and 95% CI where appropriate. I calculated 95% CIs using the bootstrapping method (resampling 1000 times) because it provides robust estimates even when data are skewed (272). I calculated the predicted reduction in energy intake by using STATA version 15 and built the bodyweight reduction model in R version 3.6.1. To assess whether there was a statistically significant difference in bodyweight reduction and energy intake between different income groups, I used the non-parametric test Kruskal-Wallis Rank Sum Test.

Sensitivity analyses

To test the robustness of the predicted changes in bodyweight, I used two alternative methods to calculate the change in bodyweight arising from the reduction in energy intake. First, I used the "3500 kcal=1 lb rule" (264). According to this method which does not take into account important individual variables such as sex and initial bodyweight, a cumulative energy intake deficit of 3500 kcal would result in a reduction in bodyweight of 1 lb (i.e. 0.45 kg). Second, I used the model proposed by Christiansen and Garby which has been used elsewhere to assess weight change from energy reduction in studies conducted in the UK (273).

Model assumptions

The primary assumption for the proposed strategy is that consumers would not change their food purchasing habits, the amount of the food they consume, and their physical activity levels. I assumed that the fat reduction would occur gradually and that consumers would not detect any taste difference in the reformulated products for two reasons. First, the experience from the UK salt reformulation strategy (chapter 1), which led to a gradual salt reduction in many food categories, showed that the population's taste adjusted to lower salt concentrations without switching to higher salt alternatives or adding salt at the table (136, 255). Second, some results from cross-sectional surveys showed that a 20% fat reduction corresponds to a reduction of a few grams of fat (chapter 4) which might have a minimal effect on satiation and satiety. Evidence shows that rather than the fat content, the food volume or its weight plays a more critical role in regulating food intake (174).

Another important assumption is that to avoid portion size changes (i.e. to keep products weight unchanged), I assumed that manufacturers would gradually replace fat with fibre-rich ingredients such vegetables and fruit, legumes, fat replacers, or that they would use category-specific technologies to reduce fat (see chapter 6). Although some of the ingredients used to replace fat (e.g. vegetables) provide some energy, their energy per gram is so small that in the model I assumed that every gram of fat reduced would result in a net energy reduction of 9 kcal (i.e. the calories of one gram of fat).

On the supply chain side, a primary assumption for the model is that the food manufacturers implementing the strategy would not advertise the reformulated product as a “reduced-fat", "light", or "reduced-calories" product. There is evidence showing that individuals tend to overconsume a food product when being aware of consuming a reduced-fat food product (274).

Chapter 4 | Results of the cross-sectional surveys of cakes and biscuits

The present chapter shows the results of the cross-sectional surveys considering the total fat, SFA, and sugar content of the cakes and biscuits categories; the work undertaken has contributed to the publication listed below:

- Roberta Alessandrini, Feng J He, Kawther M Hashem, Monique Tan, Graham A MacGregor. Reformulation and Priorities for Reducing Energy Density; Results from a Cross-Sectional Survey on Fat Content in Pre-Packed Cakes and Biscuits Sold in British Supermarkets. Nutrients 2019, 11, 1216.

The fat reformulation strategy outlined in this thesis proposes to reduce fat (possibly as saturated fat) by 20% in manufactured and out-of-home (MOOH) food categories. To assess whether this is a feasible approach, the surveys will examine the extent of the variation of fat content within the cakes and biscuits products available on the UK market (primary objective). Cakes and biscuits (including pastries, buns, and fruit pies) cumulatively contribute to 9-15% of the UK population's total energy intake (200), and are also a major SFA source, contributing to 9-15% of total SFA intake in the population (200). The analyses of the NDNS data carried out in chapter 5 of this thesis showed that — among all the MOOH categories considered — biscuits and cakes were the top contributors of calories and were consumed by 68% and 46% of the NDNS population, respectively.

The surveys have also the secondary objectives of a) determining whether the products with less fat are those with a reduced energy density b) assessing the overall healthiness of MOOH food categories and c) establish if fat rather than sugar is the biggest contributor to energy density in MOOH food products. The latter is an important objective that has the aim of showing that in sweet categories, fat reformulation might be a more effective strategy for reducing energy density than sugar reformulation alone (275). The methods used to investigate each research objective have been detailed in chapter 3.

4.1 Results

4.1.1 Fat and energy density variation in cakes

There was a large variation of total and saturated fat content within each cake category (Table 4.1). One of the categories with the largest variation in total fat content was the Chocolate Swill Roll as the product with the minimum total fat content had 19.9 g of total fat/100g while the product with the highest fat content had 35.3 total fat/100g. One of the categories with the smallest variation in total fat content was the Iced Madeira as the product with the minimum total fat content had 14.4 g of total fat/100g while the product with the highest fat content had 18.2 total fat/100g. Total fat content varied considerably also in other categories. For example, in Bakewell products total fat content ranged from 4.3 to 18 g/100g whereas in Carrot cakes the total fat content spanned from 5.6 to 29.7 g. The saturated fat content varied widely within each category (Table 4.1). In Fruit Swiss Rolls, the amount of SFA per 100g spanned from 0.9 to 11g, and in Lemon cakes from 1.5g to 9.9g (Table 4.1). In chocolate cake, the category with the largest number of products, SFA varied from a minimum of 12.2 g/100g to a maximum value of 27.5 g/100g. Table 4.1 also shows the large variation in energy density within all the cake categories. In the Cupcakes/Fairy Cakes category, the calories per 100 g spanned from 380 to 502 and in Chocolate Swiss Rolls from 366 to 500.

Table 4.1 Total and saturated fat content and energy density in different categories of cakes, mean ± SD (range)

Category	N	Total fat (g/100g)	Saturated fat (g/100g)	Energy Density (kcal/100g)
Plain with chocolate	5	24.6±2.3 (21.0-27.0)	8.0±6.2 (3.0-18.0)	446±16 (421-457)
Coffee and Walnut	6	22.0±3.5 (16.8-26.4)	7.4±3.4 (4.0-13.8)	433±22 (403-460)
Chocolate	42	21.8±3.1 (12.2-27.5)	6.9±2.6 (2.0-14.1)	430±21 (365-475)
Cupcakes/Fairy Cakes	19	21.7±5.2 (14.6-28.3)	5.8±4.9 (1.3-15.4)	440±41 (380-502)
Chocolate Cake Bar	5	21.5±5.4 (13.9-26.8)	11.4±2.0 (8.2-13.5)	445±41 (376-484)
Brownies	5	20.8±3.7 (17.2-25.5)	8.4±3.1 (3.9-12.0)	430±23 (406-454)
Red Velvet	7	20.3±3.7 (17.7-27.7)	5.3±2.2 (3.1-9.1)	433±27 (411-489)
Chocolate Muffins	18	20.2±2.5 (14.0-26.0)	3.9±0.6 (2.6-4.6)	416±21 (369-475)
White Chocolate	6	19.5±1.2 (17.0-20.3)	6.6±2.0 (4.6-9.9)	423±12 (402-436)

Chocolate Swiss Rolls	18	19.4±5.2 (12.9-35.3)	10.0±3.6 (5.9-19.0)	420±36 (366-500)
Coconut	4	18.3±2.4 (17.5-22.0)	10.7±6.2 (7.3-20.0)	416±36 (394-470)
Walnut	6	17.8±2.1 (15.9-22.8)	6.0±1.1 (4.3-7.3)	405±11 (395-426)
Blueberry Muffins	6	17.5±2.4 (14.5-20.0)	1.5±0.2 (1.2-1.7)	378±28 (331-408)
Victoria	18	17.0±4.9 (8.5-24.7)	6.4±3.4 (2.9-13.8)	402±36 (346-456)
Carrot	16	16.8±3.5 (5.6-29.7)	3.8±1.4 (1.5-6.2)	389±20 (323-415)
Lemon	21	16.6±3.3 (16.7-22.3)	4.3±2.1 (1.5-9.9)	394±22 (358-439)
Coffee	5	16.3±3.7 (13.8-22.6)	7.2±2.4 (5.7-11.2)	403±19 (391-435)
Angel	12	16.1±2.6 (14.7-19.6)	4.9±0.8 (3.8-6.5)	398±16 (378-420)
Madeira	9	16.1±2.2 (13.6-19.1)	8.7±2.5 (3.3-11.0)	387± 9(367-395)
Iced Madeira	7	15.7±1.4 (14.4-18.2)	7.4±2.1 (3.1-9.1)	405±20 (391-445)
Almond	5	15.6±2.4 (13.4-18.5)	5.0±1.1 (3.1-5.9)	396±16 (379-411)
Bakewell	4	14.2±6.6 (4.3-18.0)	5.2±2.5 (1.8-7.9)	397±41 (335-422)
Fruited Madeira	6	13.2±5.3 (8.9-23.5)	5.0±0.8 (3.7-5.9)	380±51 (347-484)
Ginger	4	12.8±2.9 (17.4-17.5)	2.6±1.9 (1.0-4.9)	383±20 (362-406)
Lemon Swiss Roll	4	12.4±6.5 (8.3-22.0)	6.7±3.0 (4.5-11.0)	375±34 (349-425)
Fruit	17	11.9±5.4 (1.4-21.2)	4.4±2.0 (0.4-7.2)	367±39 (273-449)
Fruit Swiss Roll	13	11.4±5.7 (1.7-22.1)	5.3±2.9 (0.9-11.0)	365±36 (301-422)
Battenberg	4	10.8±7.9 (11.9-15.0)	3.5±0.7 (2.7-4.2)	401±22 (375-421)
Genoa	4	10.2±2.4 (8.8-13.8)	4.9±0.7 (4.2-5.6)	356±16 (344-380)

The average percentage total fat variation in cakes was 45% (Figure 4.1, red bar). Only two cakes categories — Battenberg and White Chocolate — presented a total fat variation >20% (Figure 4.1).

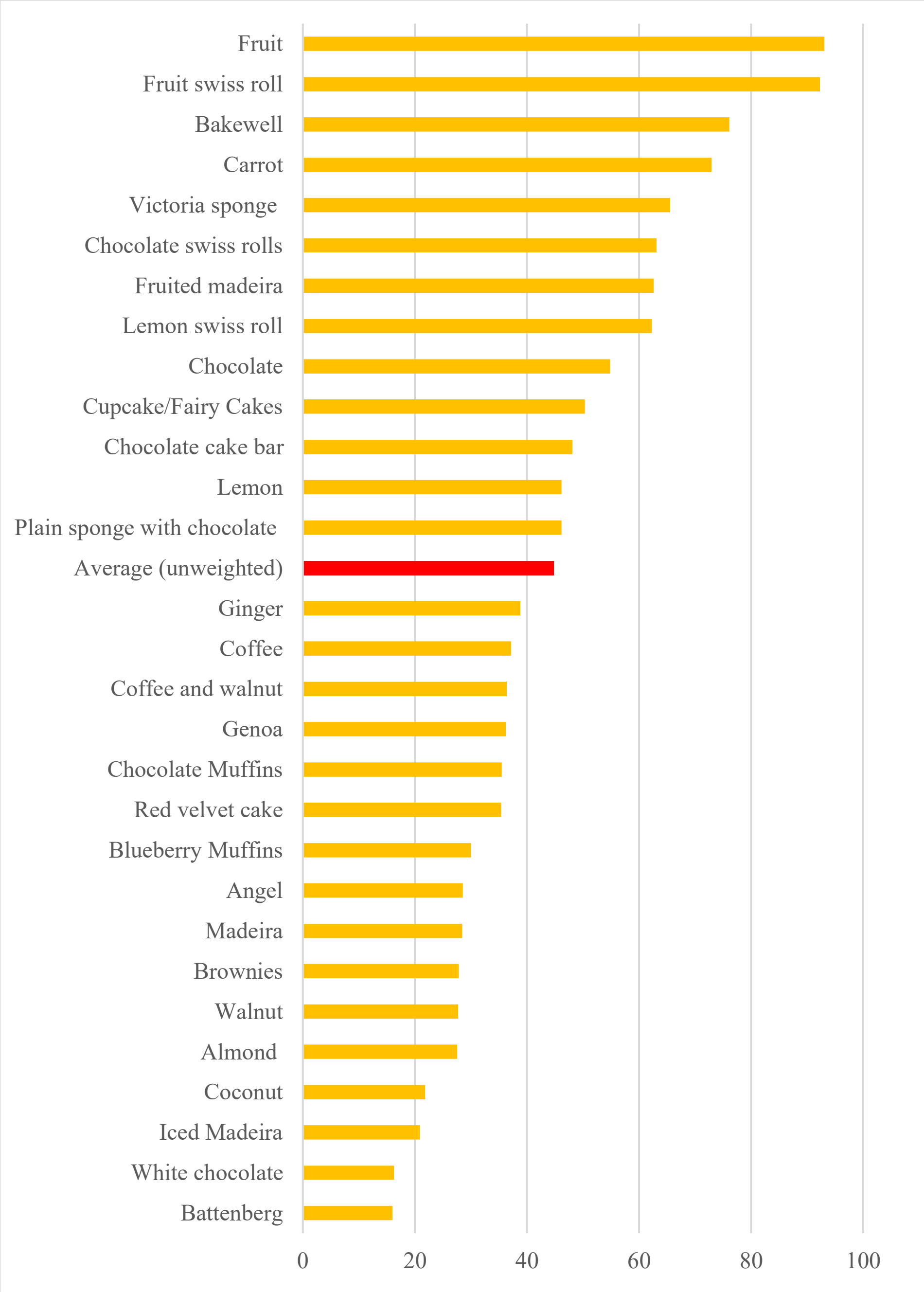


Figure 4.1 Percentage variation of total fat per 100g of product within each cake category.

4.1.2 Fat and energy density variation in biscuits

There was a considerable variation in the total fat content within each category. One of the categories with the largest variation in total fat content was the Wafer category, in which the product with the minimum total fat content had 0.7 g of total fat/100g while the product with the highest fat content had 38.9 total fat/100g. One of the categories with the most negligible variation in total fat content were Custard Cream biscuits as the product with the minimum total fat content had 20.9 g of total fat/100g while the product with the highest fat content had 22 g total fat/100g. Total fat content varied considerably also in other categories. For example, in Jam and Cream products total fat content ranged from 13.7 to 35.3 g/100g, whereas in Iced biscuits the total fat content spanned from 3.1 to 24.1 g/100g. Saturated fat content also varied considerably in most biscuit categories. For example, in Rich Tea biscuits, the amount of SFA/100g spanned from 1.2 to 7.2 g, while in Shortbread the SFA content spanned from 2.9 to 21.2 g/100g (Table 4.2). The Fruit and the Jam biscuits categories had the lowest SFA content with the smallest variation in SFA content (Table 4.2).

Table 4.2 Total and saturated fat content and energy density in different categories of biscuits, mean ± SD (range)

Category	**N**	**Total fat (g/100)**	**Saturated fat (g/100g)**	**Energy Density* (kcal/100g)**
Shortbread with additions	10	30.0±3.3 (25.0-34.9)	17.7±2.0 (15.4-21.7)	528±18 (496-554)
Shortbread	28	28.3±2.1 (24.4-33.5)	16.7±4.1 (2.9-21.2)	519±11 (497-553)
Flavoured shortbread	8	27.6±1.5 (25.5-29.5)	17.5±1.1 (15.1-18.5)	519±9 (595-532)
Chocolate-coated	7	25.8±3.4 (21.7-30.1)	15.3±2.4 (11.8-18.4)	505±23 (466-534)
Jam and cream	10	25.8±7.0 (13.7-35.3)	15.1±5.4 (6.5-22.3)	505±39 (425-558)
Wafer	10	24.7±14.1 (0.7-38.9)	13.3±8.0 (0.3-22)	498±89 (331-585)
Chocolate chip	29	24.4±1.8 (22.2-29.3)	13.1±2.0 (11-17)	498±10 (485-522)
Nice	5	23.1±1.4 (21.0-24.3)	12.2±1.9 (10-13.8)	497±7 (487-575)
Chocolate digestives	31	23.0±2.2 (15.8-26.1)	11.9±1.3 (8.2-13.6)	495±13 (456-512)
Shortcake	9	22.5±2.4 (17.0-25.4)	10.4±1.1 (7.7-11.6)	490±1 (458-532)
Custard cream	6	21.5±0.6 (20.9-22.0)	11.4±0.5 (10.8-11.8)	492±3 (487-494)
Malted milk	9	21.3±1.1 (19.4-23.5)	10.2±0.9 (9-12.3)	489±7 (476-597)
Oatmeal	8	20.7±1.3 (17.9-22.3)	9.8±2.2 (8-13.7)	478±11 (454-491)

Digestives	11	20.6±2.7 (14.4-23.4)	9.1±2.7 (1.5-11)	481±14 (447-498)
Bourbon	9	20.5±1.0 (19.0-21.6)	10.2±4.8 (1.2-14.2)	480±9 (469-487)
Ginger stem	7	19.7±4.3 (13.3-25.3)	10.2±4.8 (1.2-14.2)	466±28 (432-582)
Breakfast filled	7	16.8±2.9 (14.0-21)	5.6±2.5 (3.0-10)	455±22 (433-497)
Ginger	19	15.4±2.6 (9.0-19.5)	7.4±2.0 (3.8-12)	456±17 (421-489)
Rich Tea	16	14.1±1.1 (10.8-15.5)	5.8±1.8 (1.2-7.2)	454±7 (436-467)
Breakfast unfilled	22	13.9±2.4 (9.1-18)	2.9±2.1 (1.0-7.6)	432±19 (395-461)
Iced	7	13.0±7.1 (3.1-24.1)	7.7±6.1 (1.3-18.7)	451±38 (399-515)
Jam filled	5	12.7±2.4 (8.6-15.1)	6.0±1.2 (4.0-7.0)	426±18 (396-445)
Fruit filled	13	8.4±1.2 (7.0-10.2)	2.9±1.7 (0.7-4.6)	391±1 (375-411)

All the biscuit categories presented a large percentage variation in their total fat content (Figure 4.2). The average fat variation in biscuits was 35% (Figure 4.2). Out of 24 biscuit categories, seven — Custard Cream, Bourbon, Fruit Filled, Nice, Flavoured Shortbread, Oatmeal, Malted Milk — presented a total fat variation of <20% (Figure 4.2).

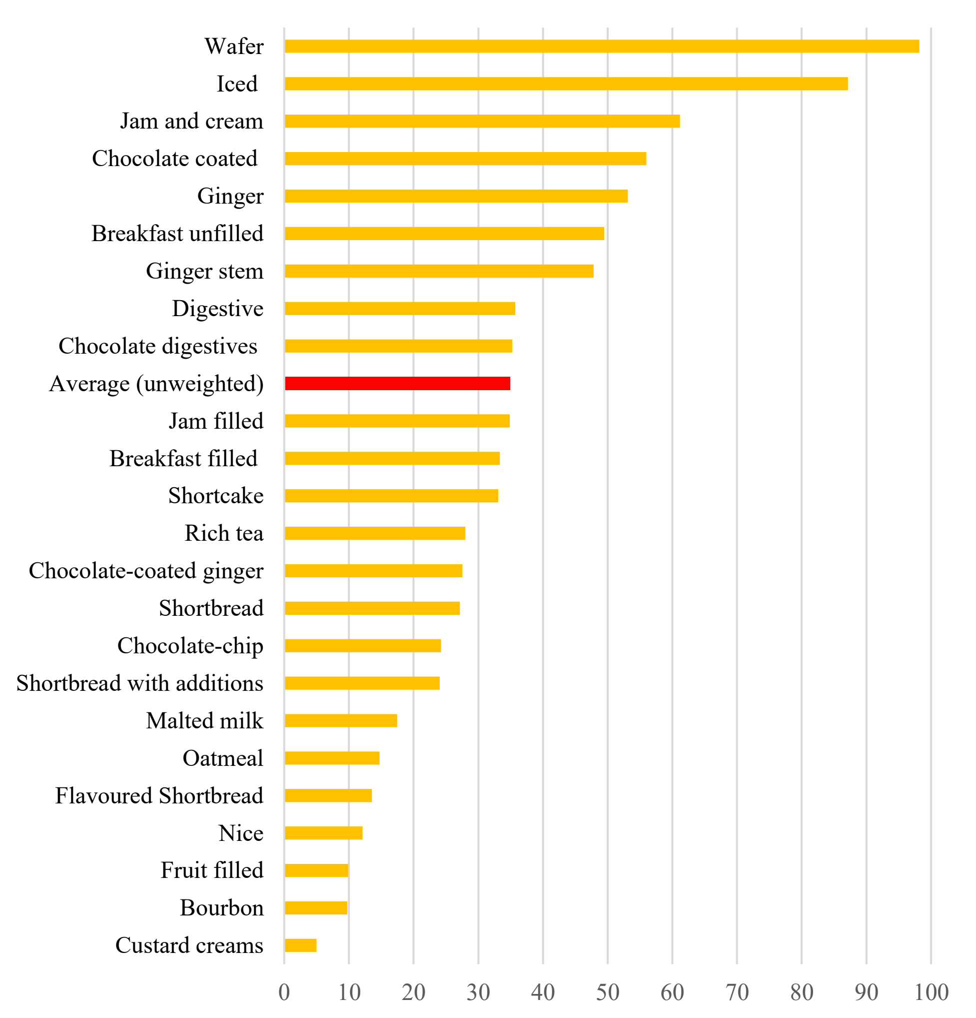


Figure 4.1 Percentage variation of total fat per 100 g of product within each biscuit category

4.1.3 Relationships between fat content and energy density

On average, the cakes (n = 381) had an energy density of 406 ± 37 kcal/100 g and an average total fat content of 17.9 ± 5.2 g/100 g, which contributed to 39% of the overall product energy (Table 4.3). The average sugar content was 36.6 g/100 g, which contributed to 34% of the overall product energy. The average saturated fat content was 5.9 ± 3.4 g/100 g, which contributed to 13% of the overall product energy (Table 4.3). On average, the biscuits (n = 481) had an energy density of 484 ± 38 kcal/100. The average total fat content was 21.8 ± 6.3 g/100 g, which contributed to 40% of the overall product energy. The average content of sugar was 30.0 ± 9.2 g/100 g, which contributed to 23% of the overall product energy. The average saturated fat content was 11.4 ± 4.9 g/100 g, which contributed to 23% of the overall product energy (Table 4.3).

Table 4.3 Energy density, total and saturated fat and sugar content (mean, SD), and their respective percentage energy contribution to overall product energy in cakes and biscuits

	N	**Energy(kcal/ 100g) ± SD**	**Fat and SFA (g/100) ± SD**	**% Energy from fat and SFA**	**Sugar (g/100) ± SD**	**%Energy from sugar**
Cakes	381	406±37	17.9±5.2 *of which SFA* 5.9±3.4	39 (13 from SFA)	36.6±7.6	34
Biscuits	481	484±38	21.8±6.3 *of which SFA* 11.4±4.9	40 (23 from SFA)	30.0±9.2	23

In both biscuits and cakes, there was a significant positive correlation between total fat content and energy density ($r=0.94$, $p<0.001$ and $r=0.89$, $p<0.001$) (Figure 4.3A and 4.3D). There was also a significant correlation between saturated fat content and energy density ($r=0.86$, $p<0.001$ and $r=0.49$, $p<0.001$ for biscuits and cakes respectively), (Figure 4.3B and 4.3E). The correlations between sugar content and energy density were weak and not significant ($r=-0.06$, $p=0.16$ and $r=0.12$ and $p=0.17$ for biscuits and cakes respectively), (Figure 4.3C and 4.3F).

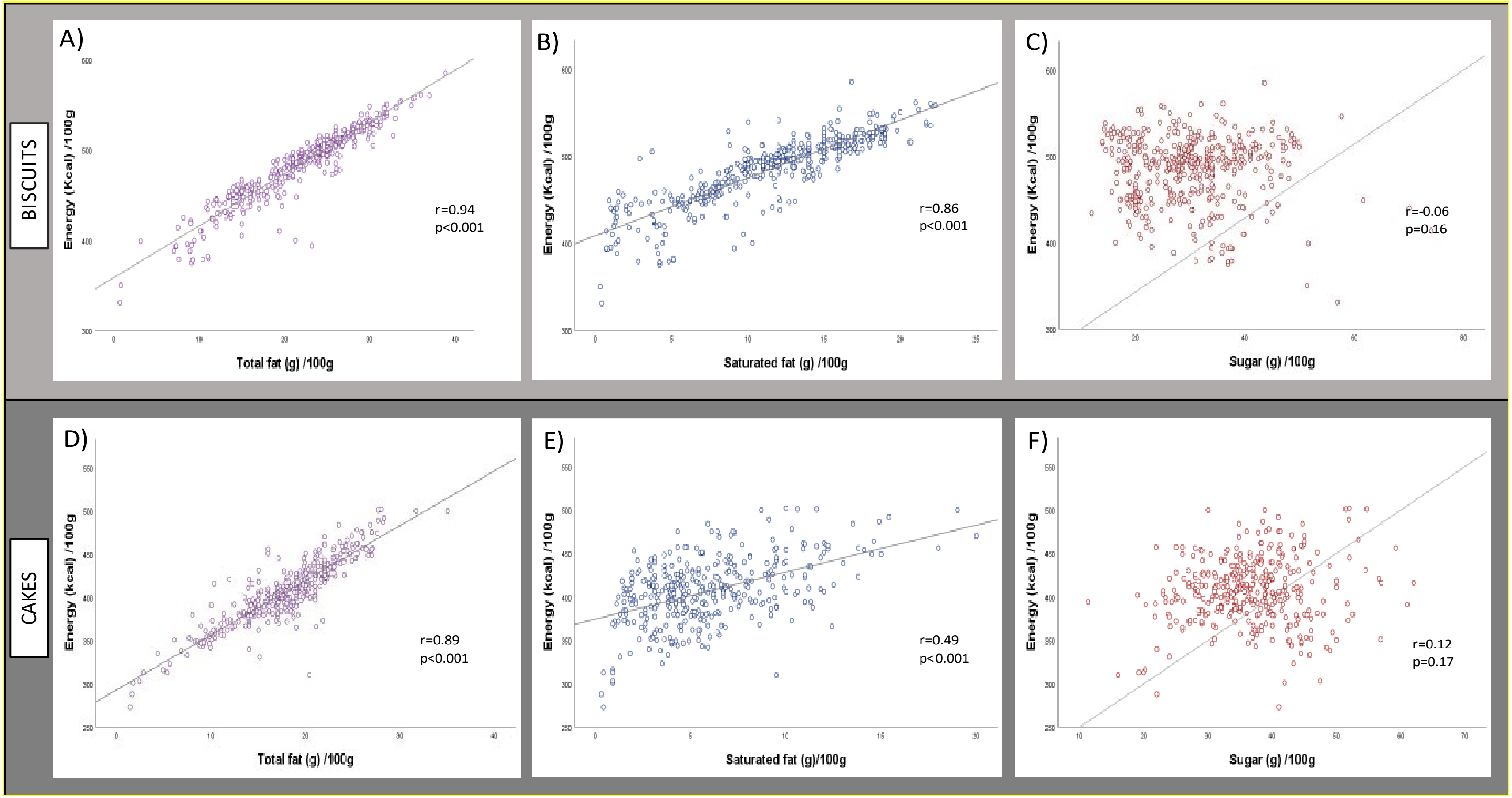


Figure 4.3 Energy density, total and saturated fat and sugar content (mean, SD), and their respective percentage energy contribution to overall product energy in cakes and biscuits

4.1.4 Comparison with the UK Front of Pack Labelling Guidelines

When looking at data for cakes, fifty-seven percent of the products would receive a red (high) color code for total fat, while only 1% would receive a green (low) color code (Figure 4.4A). Similarly, fifty-four percent would receive a red (high) color code for saturated fat, while only 6% would receive a green (low) color code (Figure 4.4C). Seventy-five percent of the biscuit products would receive a red (high) color code for total fat (Figure 4.4B), while only 0.41% (2 products, not shown in Figure 4.4B) would receive a green (low) color code. Eighty-eight percent of biscuit products would receive a red (high) color code for saturated fat, while only 5% would receive a green (low) color code (Figure 4.4D).

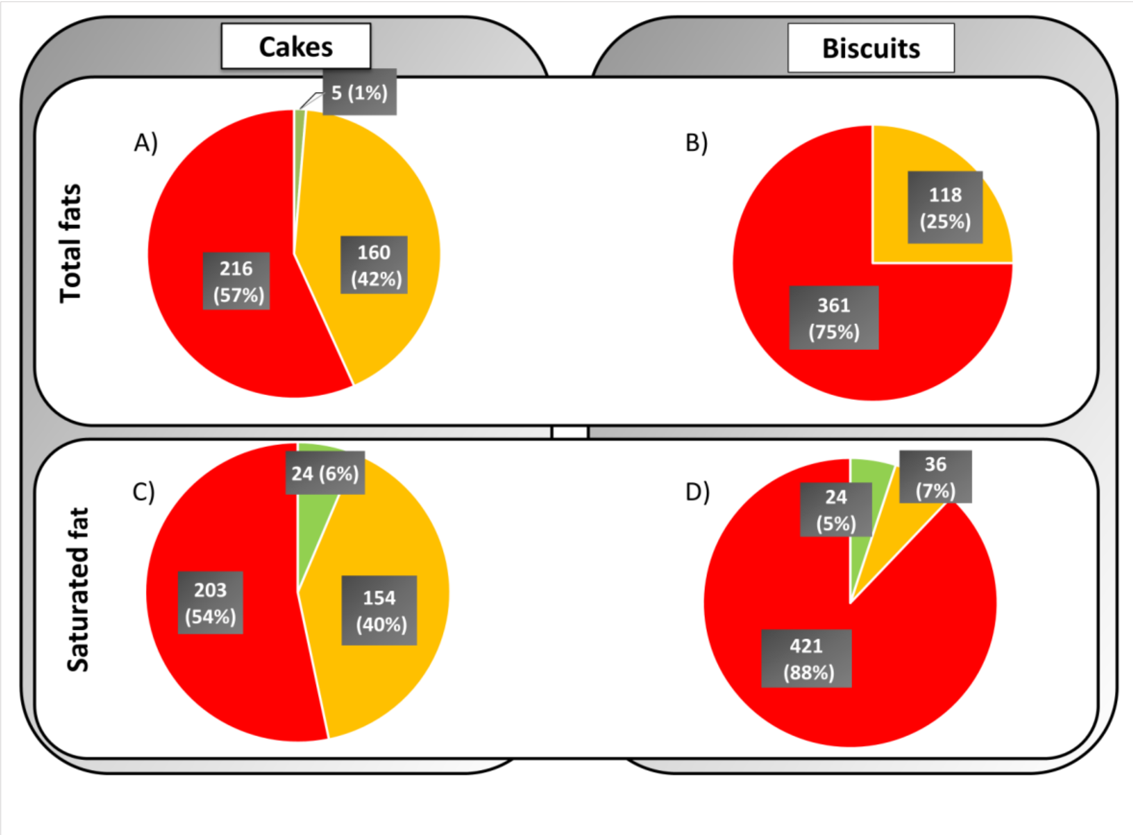


Figure 4.4 Percentage of cakes (A,C) and biscuits (B,D) that would receive a low/medium/high criteria for total fat (A,B) and saturated fat (C,D)

Chapter 5 | Results of the modelling study

The work undertaken in this chapter has contributed to the publication listed below:

- Roberta Alessandrini, Feng J He, Yuan Ma, Vincenzo Scrutinio, David S Wald, Graham A MacGregor, Potential impact of gradual reduction of fat content in manufactured and out-of-home food on obesity in the United Kingdom: a modeling study, The American Journal of Clinical Nutrition. Volume 113, Issue 5, May 2021, pages 1312-1321. https://doi.org/10.1093/ajcn/nqaa396.

This chapter present the results of the proposed fat reformulation strategy consisting of a gradual and stepwise reduction of fat (preferably SFA) by 20% in manufactured and out-of-home food (MOOH) consumed in the UK. As detailed in chapter 3, the main objective of the modelling study is to develop health impact data (obesity, type 2 diabetes, and CVD) resulting from the fat reformulation strategy with the aim of persuading policymakers to implement the policy. The secondary objectives of this study include a) the ranking of the MOOH food categories that contribute most to calorie and fat intake in the UK population and b) the determination of the population subgroup (income and age) that would benefit most the proposed fat reformulation strategy.

5.1 Results

5.1.1 Ranking of the MOOH categories

Out of almost hundred food categories used in the National Diet and Nutrition Survey (NDNS), forty-six were selected as manufactured and out-of-home (MOOH) food categories. Table 5.1 shows the ranking of the MOOH food categories according to their calorie contribution to the diet of the NDNS population. Table 5.1 also shows the percentage of consumers for each category. Biscuits, cakes ranked as top contributors of calories in the NDNS population followed by chocolate confectionery, chips, crisps, and other savoury snacks. The same categories were also widely consumed by a large proportion of the NDNS population. For example, biscuits were consumed in almost seventy percent of the population while chocolates, cakes, chips, and cheese by half of the NDNS population (Table 5.1). Manufactured fish products and ready meals based on processed meats were rarely eaten categories contributing to less than 1% of the calories consumed by the NDND population.

Table 5.1 Food categories included in the strategy ranked according to their contribution to total calorie intake in the NDNS population (n=2371). The fourth column shows the percentage of consumers in each category.

Ranking	**NDNS food category**	**Total kcal provided in NDNS population, by category**	**Share of consumers (%)**
1	Biscuits manufactured / retail	169630	68
2	Buns, cakes, pastries / manufactured	129283	46
3	Chocolate confectionery	112167	50
4	Chips purchased including takeaway	110727	48
5	Crisps, savoury snacks	100919	55
6	Pizza	97501	24
7	High fibre breakfast cereals	95782	44
8	Savoury sauces, pickles, gravies	93771	94
9	Cheddar cheese	91283	54
10	Other sausages, including homemade dishes	68504	39
11	Other breakfast cereals (not high fibre)	66605	37
12	Manufactured coated chicken/ turkey	61247	26
13	Manufactured meat pies and pastries	52562	17
14	White fish coated/ fried	46037	24
15	Ice cream	44752	27
16	Other cheese	38390	36
17	Burgers and kebabs purchased	34112	14
18	Sugar confectionery	32741	26
19	Pasta manufactured products & ready meals	26395	12
20	Other manufactured potato products	21515	15
21	Manufactured chicken products including ready meals	17895	14
22	Fromage frais, dairy desserts / manufactured	17183	17
23	Beans and pulses including ready meal & homemade dishes	16804	19
24	Sweet spreads fillings and icing	14878	12
25	Soup manufactured/ retail	13165	19
26	Manufactured beef products including ready meals	13081	6
27	Other meat products manufactured including ready meals	12590	10
28	Cereal based milk puddings / manufactured	12160	12
29	Other cereal-based puddings / manufactured	11284	5
30	Manufactured canned tuna products including ready meals	8902	12
31	Manufactured egg products including ready meals	8515	5
32	Manufactured oily fish products including ready meals	7689	6
33	Rice manufactured products & ready meals	7474	4

34	Fruit pies manufactured	6183	3
35	Meat alternatives including ready meals & homemade dish	5745	5
36	Other potato products & dishes / manufactured	4462	5
37	Other manufactured vegetable products including ready meals	4307	4
38	Liver and dishes	3982	3
39	Sponge puddings / manufactured	3521	2
40	Manufactured pork products including ready meals	2789	3
41	Manufactured lamb products including ready meals	1636	1
42	Cottage cheese	1165	1
43	Manufactured white fish products including ready meals	1088	1
44	Manufactured shellfish products including ready meals	1069	1
45	Ready meals based on sausages	1039	<1
46	Ready meals based on bacon and ham	136	<1

The Cheddar cheese category ranked as top contributor to SFA and total fat intake, followed by biscuits and chocolate confectionery (Supplementary Tables A1 and A2 in Appendix to chapter 5).

On average, the 46 food MOOH food categories included in the strategy contributed to 38.6% of the total energy intake (%E) of the NDNS participants (Figure 5.1, red bar). In the age groups of 6–11 and 12–18 years old, the selected categories contributed to 47.3% and 45% of the total energy intake, respectively (Figure 5.1).

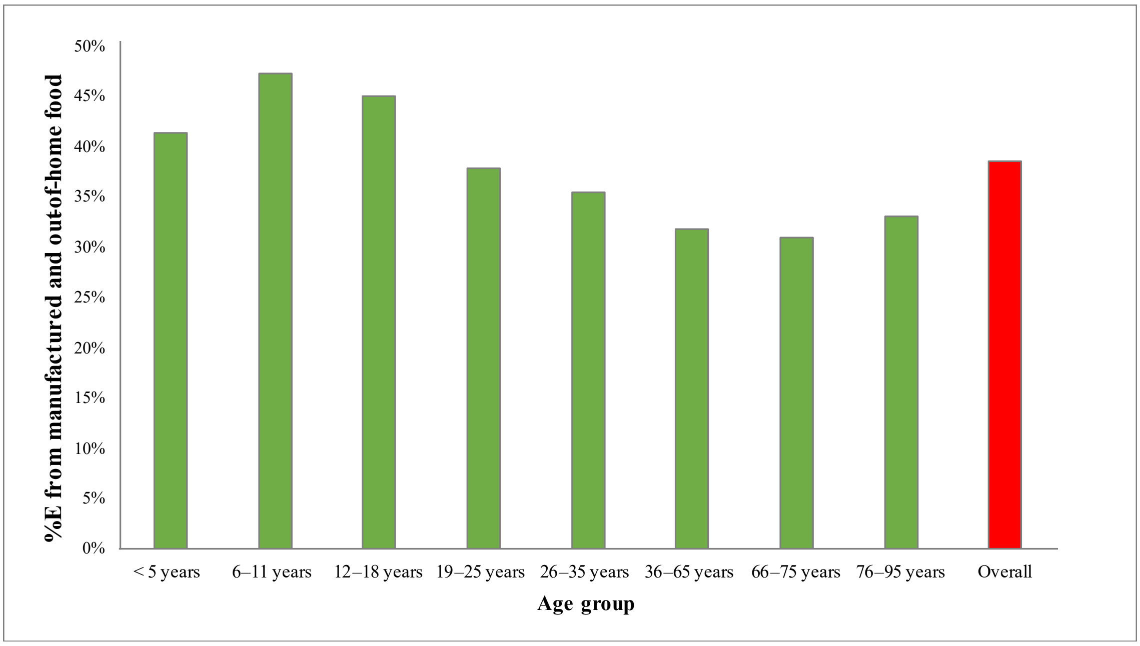


Figure 5.1 Contribution to %E from the 46 food categories considered

5.1.2 Health Impact of the (saturated) fat reformulation strategy

The fat reformulation strategy proposed in this PhD thesis would determine a gradual reduction in calorie intake in the NDNS population (Table 5.2). At the end of the first year, the mean energy intake reduction would be 14.7 (95% CI 14.4, 15.0), while at the end of the fifth year it would be 67.6 kcal/d/person (95% CI 66.1, 68.8), (Table 5.2). The predicted reduction in energy intake would lead to a gradual reduction in bodyweight in the long term. The average reduction in steady–state bodyweight in adults at the end of the fifth year is predicted to be 2.7 kg (95% CI 2.6, 2.8), (Table 5.3).

Table 5.2 Changes in energy intake and bodyweight (95% confidence interval) at the end of each year of the fat reduction strategy.

Cumulative fat reductions in the food products included	**Mean changes in energy intake (kcal/day), (95% CI)** (n=2371)	**Mean changes in bodyweight (Kg), (95% CI)** *(n=1348)*
1st year (↓4.4%)	-14.7 (-14.4, -15.0)	-0.58 (-0.56, -0.59)
2nd year (↓8.5%)	-28.8 (-28.2, -29.4)	-1.13 (-1.1, -1.17)
3rd year (↓12.5%)	-42.3 (-41.4, -43.1)	-1.67 (-1.62, -1.72)
4th year (↓16.4%)	-55.2 (-54.1, -56.2)	-2.18 (-2.11, -2.25)
5th year (↓20%)	-67.6 (-66.1, -68.8)	-2.67 (-2.59, -2.76)

When considering the effects of the fat reformulation strategy on the different age groups these would generate different results (Table 5.3). For example, if the strategy would be implemented, the energy intake in 11–18 years old would be reduced by 85.1 kcal/d/person (95% CI 81.6, 88.7), while in the 26–35 age group, energy intake would be reduced by 76.6 kcal/d/person (95% CI 71.0, 82.3) (Table 5.3). Children and older adults would be the age groups less affected by the fat reformulation strategy as this would result in around 50 calories less per person daily. The predicted mean reduction of bodyweight and energy intake at the end of the fifth year did not vary between the different income groups (p=0.494; p=0496, respectively) (Supplementary Table A3, Appendix to chapter 5).

Table 5.3 Mean changes in daily energy intake (95%CI) at the end of the fifth year, by age group.

Age group	Number of individuals	Mean kcal reduction (95%CI)
<5	405	-47.9 (-45.8, -50.8)
6 – 10	417	-73.9 (-71.1, -76.6)
11 – 18	484	-85.1 (-81.6, -88.7)
19 – 25	120	-75.9 (-69.1, -82.9)
26 – 35	230	-76.6 (-71.0, -82.3)
36 – 65	751	-64.9 (-62.4, -67.7)
66 – 75	162	-54.9 (-49.9, -60.0)
75+	154	-53.0 (-48.5, -57.6)

Sensitivity analysis

When I used the widely used "3500 kcal=1 lb" rule, the average reduction in bodyweight at the end of the fifth year would be 3.3 kg (95% CI 3.2, 3.4). Alternatively, when I used the model proposed by Christiansen and Garby, the average reduction at the end of the fifth year would be 3.5 kg (95% CI 3.2, 3.7).

Effect of the strategy on fat intake

At the end of the fifth year, the total daily calories from fat would fall from 33.5% to 31.2% resulting in an average reduction of 7.5 g/d/person in fat consumption. In the NDND population, SFA intake as %E would be reduced from 12.7% to 10.1% resulting in an average SFA reduction of 6.7g/d/person (95%CI 6.5, 6.9). The amount of fat reduced per 100g of product varied considerably; for sauces and chocolate confectionery the fat reduction would be around 6.5g/100 of product while in biscuits and sausages the reduction would be around 3.5g/100g of product (Figure 5.2). In contrast, the reduction in lower energy density foods such as breakfast cereals or soups it was only 0.2 grams. When considering regular portion size, the fat reduction would be very small; around three grams of fat for a wafer-style chocolate bar and <0.1gram of fat for a portion of breakfast cereals. Most of the fat reduced in the MOOH food categories included in the strategy would be saturated fat (shown as blue horizontal bars). In few categories (mainly potato-based products) it would not be possible to reduce fat by focussing only on saturated fats. In these categories, some of the fat reduced would be unsaturated fat (shown as orange horizontal lines).

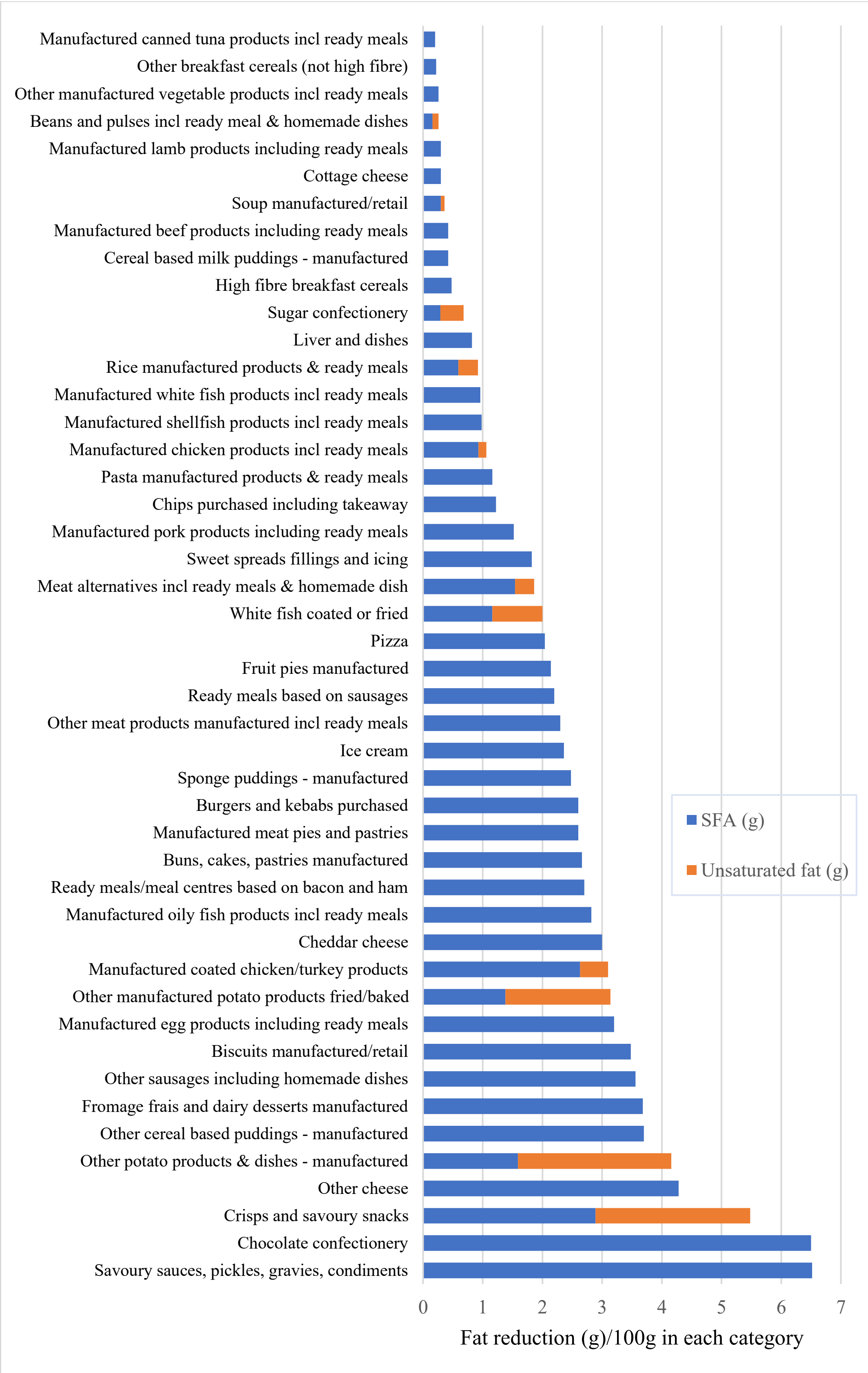


Figure 5.2 Mean reduction in SFA (g) and unsaturated fat (g) for 100g of product category. SFA content is shown in blue while unsaturated fat content in orange.

Impacts of the strategy on obesity prevalence

In the NDNS population, the average bodyweight reduction of 2.7 kg would reduce the prevalence of overweight by 1.5 percentage points (from 36.7% to 35.2%) and obesity by 5.3 percentage points (from 29.9 % to 23.2%). This reduction would amount to approximately 1 million cases of overweight and 3.5 million cases of obesity being reduced in the UK population. The average BMI of the UK adult population is predicted to be reduced by 0.96 kg/m^2 (from 27.44 kg/m^2 to 26.48 kg/m^2). According to the calculations by Wang and colleagues, the predicted BMI reduction could, in turn, prevent 183,000 (95%CI 171,000; 194,000) incident cases of type 2 diabetes over 20 years (i.e. roughly 9100 per year) (267).

Impacts of the strategy on LDL and CVD risk

According to the regression coefficient published by Yu-Poth and colleagues, a reduction of 1% in energy from SFA would result in a decrease in serum LDL cholesterol of 0.05mmol/L (268). The strategy proposed in this PhD thesis — which would lead to an average reduction of 2.6%E from SFA — would reduce the population average LDL cholesterol by 0.13mmol/L. According to the estimations by Law and colleagues, a 1.8mmol/L reduction in LDL would reduce the risk of IHD and stroke events by 61% (95%CI 51, 71) and 17% (95%CI 9%, 25%), respectively (269). When considering the reduction of LDL by 0.13mmol/L the risk of IHD events would be reduced by 6.6% (95%CI 6.2%, 8.5%) while the risk of stroke would be reduced by 1.3% (95%CI 0.6%, 2.0%). When applying the 6.6 % risk reduction to the 66, 341 IHD deaths occurring every year in the UK, I estimated that the proposed strategy would prevent 4378 IHD deaths (95% CI 4113; 5638) per year. For strokes, when I applied the 1.3% risk reduction to the 36,628 stroke deaths occurring every year in the UK, I estimated that the strategy would prevent 476 stroke deaths (95% CI 220; 733) per year. If the strategy would be implemented, the number of deaths prevented would be of 87,560 (95%CI 82,260; 112,760) for IHD and 9520 (95%CI 4400; 14,660) for strokes over 20 years.

Chapter 6 | General discussion

The present chapter discusses the research findings reported in the preceding chapters and brings together the findings within the context of the aims of this PhD research and within the current policies on solutions to solve the obesity problem.

6.1 Main findings

Evidence shows that changes in the food environment have fuelled the current global obesity epidemic (276). Energy-dense foods are heavily promoted and widely available, contributing to excessive energy intake and thereby obesity. Often, these foods are also high in saturated fat, free sugars, and salt. The overarching goal of this thesis was to show that fat reformulation is a feasible and effective approach to reduce calorie density in food and therefore obesity prevalence. More specifically, this research had two aims. The first aim was to show that a 20% fat reformulation in MOOH foods is a realistic and feasible public health nutrition policy. The second aim was to predict the health impacts of a nationwide reformulation strategy of 20% reduction in fat focussing on MOOH food categories.

The cakes and biscuits surveys (chapter 4) showed a 35% and 45% variation in fat content in biscuits and cakes, respectively. The findings clearly indicate that a 20% fat reformulation is a realistic and feasible public health nutrition policy as some manufacturers are already producing the same type of cakes and biscuits with less fat and calories. The research findings presented in chapter 4 show that fat contributes more to calories than sugar, thus policy makers should focus also on fat reformulation as a tool to reduce calories in sweet food products. This research also showed that among all the surveyed products, only a tiny percentage would receive a green label for total or saturated fat content indicating that there is ample room for the improvement of these products.

The modelling part of the present PhD research (chapter 5) provided a detailed impact evaluation of a nationwide fat reformulation strategy. The findings showed that a 20% reduction in fat content in 46 MOOH categories could reduce the average body weight by 2.7Kg and the average energy intake by 68 kcal/person/day at the end of the fifth year from implementation. This would reduce overweight and obesity prevalence by 6.8%, corresponding to approximately 4.5 million cases of obesity and overweight being prevented. This body weight reduction would prevent around 183,000 incident cases of type 2 diabetes over 20 years. Reducing SFA in the selected food categories to the 20% target would bring SFA intake within the limits recommended by the WHO, reduce LDL cholesterol, and prevent 97,000 CVD deaths in 20 years.

The analysis of the NDNS data (chapter 5) showed that the 46 MOOH food categories selected within this research contributed to around 40% of the UK population's energy intake. This percentage was higher in the 6–11 and 12–18 years old, in which the selected categories contributed to 47.3% and 45% of the total energy intake, respectively. Biscuits, cakes, chocolate confectionery, chips, crisps, and savoury snacks ranked as top contributors to energy intake and were widely consumed. The cheddar cheese category ranked as a leading contributor to SFA and total fat intake, followed by biscuits and chocolate confectionery. Pizza, sauces, and sausages were other top contributors of energy, total and saturated fat intake. This analysis also showed that 20% fat reduction in the MOOH food categories considered would be minimal and therefore unlikely to be noticed by consumers.

6.2 Implications

The results of this thesis have important implications for the UK and global public health nutrition policy. Since the 1980s, the prevalence of obesity and its related disease burden has been steadily growing (12). Experts agree that to effectively tackle obesity, countries need to implement a mix of policies in different sectors (18, 112, 277). This research shows that the implementation of a fat reformulation strategy alone would reduce obesity and overweigh prevalence by 6.8% and address saturated fat overconsumption (which is another important public health issue). This research proposes a tiered fat or energy density levy as a mechanism to promote fat reformulation.

6.2.1 A fiscal approach to promote fat reformulation

In recent years, some countries have started implementing policies to reduce the energy density and the unhealthy nutrient content in foods and drinks (see chapter 1). The most popular policy is the taxation of sugar-sweetened beverages (SSBs) implemented in about 40 countries (114). A recent evaluation showed that since the announcement of the UK's sugary drinks industry levy (SDIL), the sugar content in SSBs had been reduced by 42% (115), meaning many manufacturers reformulated their products to avoid paying the levy. The policy's health impacts are yet to be observed because it might take years to observe tangible reductions in obesity prevalence due to other important factors at play. For example, the sugar-sweetened drinks industry might increase the marketing and advertising of lower sugar options which could lead to increased sales. In this case the overall sugar consumption in the population might increase thus hampering the policy's effect (116). Nevertheless, in the UK, SSBs contribute only to 1-4% of the total dietary calories (200), and the SDIL impacts on obesity and overweight might be limited. The results of the present thesis showed that focusing on MOOH food categories, which provide around 40% of the total energy intake in the population, is a crucial strategy to reduce the obesity and overweight prevalence.

Recently, the UK Government implemented voluntary programmes to reduce salt, sugar, and calories in the food supply chain (chapter 1). While the salt reduction programme, despite its voluntary nature, has successfully led to a salt reduction in food and salt intake in the population (136), the sugar programme has been mostly unsuccessful in reducing sugar and calorie content in most of the target food categories (275). An explanation might be that while salt reformulation consists of removing milligrams of salt from foods (with minimal impact on product weight), sugar and fat contribute to the weight of food products. Thus, the removal of sugar from solid foods might be more technologically complex. The unsuccess of the sugar programme could also be attributable to the to its poor design; sugar has the same energy density as starch and protein and reducing calories density only through sugar reduction is problematic. Combining targets for sugar, calories, and fat simultaneously within the programme could have led to more meaningful results. The other central issue of the sugar programme lied in its voluntary nature. Evidence shows that mandatory approaches such as fiscal policies work better than voluntary initiatives even if these are monitored and managed by governments (278-280). Manufactures also seem to prefer mandatory approaches as these ensure a level playing field for the industry (105). The UK SDIL, for example, has resulted in substantial reductions of both calories and sugar content in sugar-sweetened drinks as manufacturers quickly adapted to the new policy (115).

Fiscal approaches are gradually gaining popularity as a policy solution to solve the obesity problem. The National Food Strategy commissioned by the UK Government recommended a salt and sugar tax to improve the health of the population and generate revenue to invest in the provision of free fruit and vegetables to low-income families (105). Countries which have implemented tiered tax approaches (e.g. based on several levels of nutrient/100g) reported positive impacts because the tax can simultaneously promote reformulation and incentivise consumers to buy healthier alternatives (86). To date, only Hungary and Mexico have implemented taxes covering solid manufactured food categories. The Hungarian tax covers — besides SSB and energy drinks— salty snacks, pre-packed sweets, powdered soups, and salty condiments (278, 281). The tax considers sugar, salt, and caffeine content in the selected categories. An evaluation of the Hungarian tax led by the WHO found that of 69 companies paying the tax, 40% reported to have reformulated their products, 30% had removed unfavourable components in their products, and 70% had decreased the quantity of unfavourable components in their products (86, 281). The Mexican tax considers four "non-essential" food categories (salty snacks, cereal-based sweets, ready-to-eat cereals, non-cereal based sweets) with an energy density greater than 275kcal/100g. Some studies evaluated the tax's impact in terms of changes of purchases of the taxed products (279, 280, 282); however, no study assessed whether the Mexican tax promoted reformulation in the targeted food products and reduced energy intake. Between 2011 and 2013, Denmark implemented the first-ever tax on saturated fat content in meat, dairy products, extracted animal fat, edible oils and fats, margarine, and spreads. Some studies report that the tax reduced saturated fat intake and NCD mortality (283, 284). However, no study has evaluated whether the tax promoted reformulation of the target categories.

One of the critical issues around designing an energy-density levy is the choice of foods to which the levy applies (86). The WHO recommends using a nutrient profiling model to define the food categories to include (86). However, the countries which have implemented the tax did not follow the recommendation and chose the categories to tax arbitrarily. In Mexico, "non-essential foods" had been defined before implementing the tax. The approach has raised criticism because the tax does not include ice-creams, flour chips and puddings, commonly considered unhealthy foods. The Hungarian tax has also raised similar criticism. It targets mainly sweet and chocolate-based foods and some salty snacks, but leaves out other categories that are high in unhealthy nutrients such as processed meat and cheese (278). The reformulation strategy outlined in this thesis (chapter 5) includes all the MOOH food categories that consumers could buy in restaurants and supermarkets and excludes all the minimally processed food categories typically used to prepare homemade meals (e.g. vegetable oil or pasta). This comprehensive approach could be considered fairer to food manufactures and actors operating in the out-of-home sector.

The reformulation strategy outlined in this thesis could also be incentivised by other mandatory nutrition policies such as warning labels, mandatory front-of-pack nutrition labelling, or calorie and nutrient labelling in the out-of-home sector. Evidence shows that in Chile, since the implementation of the black warning labels, manufacturers have significantly reduced unhealthy nutrients to avoid the warning labels (285). Similarly, a comprehensive review showed that mandatory calorie and nutrient menu labelling have resulted in a reduction in calories by reducing the unhealthy nutrient content of the foods on the menus (286). In England, calorie labelling in the out-of-home sector has been implemented since April 2022. An evaluation of the policy has yet to be available, but it is very likely that the policy will promote calorie reformulation (287).

6.3 Strengths and limitations

This research modelled the health impacts of a gradual and unobtrusive fat reduction strategy in manufactured and out-of-home foods. The proposed strategy has many strengths. First, the 20% fat reduction proposed can be easily achieved by the food industry. The cakes and biscuit survey (chapter 4) showed that there is a wide variation in the fat content of each category examined. The average variation of fat per 100g in biscuits was greater than 30% while in cakes was greater than 40% (chapter 4). These findings show that it is possible to produce a certain type of biscuit (e.g. angel cake, shortbread biscuits) with less fat and a lower energy density.

Second, with the proposed strategy, the absolute reduction in fat content would be very small. For example, in the cakes and biscuits categories, a 20% fat reformulation would lead to an average fat reduction of only 2.6g for 100g of cakes and 3.5g for 100g of biscuits (chapter 5). According to the same set of results, the average fat reduction in the chocolate confectionery category would be of 6.5g per 100g of product. Conversely, the reduction in lower energy density foods such as breakfast cereals was only 0.2g per 100g of product. When considering the fat reduction per portion, this would be minimal; around 3g of fat for a portion of a wafer-style chocolate bar, and less than 0.1g of fat for breakfast cereals. When applying the 20% fat reduction to the average UK person's dietary intake, the mean fat consumption would be reduced by 7.5g/person/day. This quantity of fat is equivalent to about half a tablespoon of oil or an individually wrapped small butter portion. This reduction is unlikely to be noticed by the consumers as the reduction will spread across many food categories and would be implemented gradually.

Third, a 20% fat reduction would not mean converting all foods to reduced-fat foods. A common misconception around reducing fat and calories in foods is the assumption that all the products included would be converted into reduced-fat foods or low-fat foods. According to the EU and the US law, a "reduced-fat" claim on the food label can be used when the product in question has 30% less fat than the reference product (288, 289). Conversely, the claim "low-fat" can be used when products contain less than 3g of fat per 100g (288, 289). In the 1980s and 1990s, swapping regular manufactured products with their low-fat and reduced-fat versions was advocated as a strategy to lose weight, particularly in the US. Some qualitative analyses and ecological observations showed that obesity prevalence and consumption of low/reduced-fat foods increased concurrently (290-292). However, no quantitative analysis showed a direct causation between the two. As described in chapter 1, a variety of factors cause obesity, and it is unlikely that consumption of low/reduced-fat foods alone is responsible for the high prevalence of obesity and overweight observed today. An analysis of trends of obesity and overweight in US between 1971 and 2006 indicated that an increase in energy intake could be the most important driver of increased obesity prevalence (292). The idea that reduced-fat products may increase the risk of obesity may be rooted in the evidence from some trials that showed that a low/reduced-fat label on a product could induce overconsumption in obese individuals (293, 294). However, a comprehensive review showed that energy overconsumption might be due to low/reduced-fat label on products rather than the effect of reduced-fat food on satiety (274). Another common misconception around reduced-fat food or food with less fat is that their lower fat content gets compensated by an increase in sugar content; a phenomenon commonly referred as "sugar-fat see-saw". Public Health England (PHE) led an investigation to assess the presence of the “sugar-fat see-saw” in widely consumed products including biscuits, desserts, cake bars, cereal bars, yoghurts, dips, mayonnaise, coleslaw, and ready meals. The investigation included 94 standard products and their corresponding reduced-fat, low-fat or fat-free equivalents. PHE concluded that although there was a substantial variation between categories and manufacturers and within individual categories, there was no overall trend for reduced-fat products to contain more sugar than their standard equivalents (295). This demonstrates that it is entirely possible to reformulate food products by gradually reducing their fat content without increasing their sugar content (i.e. without worsening their nutritional quality). Additionally, this research proposes a 20% fat reduction; the reformulated products would not qualify as “reduced-fat” and use the "reduced-fat" claim, thus avoiding the unintended consequence of leading consumers to eat more food than usual.

Fourth, the strategy outlined in this thesis considers the possibility of focussing on SFA reduction. Although a reduction of total fat or SFA would lead to the same energy reduction (as they both provide 9 kcal per gram), focussing on SFA would have additional benefits on the population's cardiovascular health. As described in chapter 2, both the recent WHO draft guidelines and the SACN recommendations indicate the %E from SFA should be reduced to less than 10%. According to the NDNS (years 2014/2016), the SFA intake in the UK population exceeds the 10% recommendation, with the average percentage of dietary energy (%E) from SFA being 12.5 %E in all adults, and 14.5%E in individuals aged 75 and over (chapter 2). SFA intake exceeds the recommended intake also in other countries (204). Any country implementing the proposed strategy could address two public health nutrition problems at once, i.e. reducing the prevalence of obesity and overweight, and reducing the disease burden related to an excessive intake of SFA.

Fifth, a fat reformulation strategy would be a more cost-effective intervention for countries to implement compared to behaviour change approaches. Educating populations to make healthy choices has been shown to be costly requiring permanent input and a high level of individual agency (108, 146). Moreover, behaviour change approaches may widen health inequalities gaps as people with lower socio-economic status tend to benefit less from these interventions (147) An economic evaluation of the UK salt reduction policies in England showed that either voluntary or mandatory reformulation were more cost-effective than Change4Life, a governmental health promotion campaign (296). The Department of Health and Social Care's Calorie Model estimates that any policy reducing energy intake by 20 kcal per day would save the UK National Healthcare System (NHS) £1.4 million and prevent 10,500 deaths over 25 years (297). When applying these findings to the results of the present PhD research, the strategy I proposed (which reduces the average calorie intake by 68 kcal per day) could save the NHS £4.7million and prevent 35,175 deaths over 25 years. These figures did not include the potential additional CVD reduction if the strategy was focussed on SFA. The strategy outlined in this thesis could result in even greater health benefits if the fat reduced would be replaced with high-fibre ingredients as the average fibre intake would be increased to be closer to the population target of 30g per day as recommended by SACN (256, 262, 298). The latest NDNS data showed that in the UK, the average fibre intake was low; in people aged 19-64 years it was 19g per day and only 9% of people in this age group met the SACN recommendation of consuming 30g of fibre per day (262). Evidence suggests that fibre dilutes food energy density, and it has a beneficial effect on satiety and appetite regulation (299)

Another advantage of the proposed reformulation strategy lays in the potential of benefiting the entire population, with a greater impact on individuals with obesity and overweight (300). The modelling study considers the frequency of consumption at the participant level and those consuming very often or large quantities of the selected food categories (i.e. individuals with obesity and overweight) would gain the most benefit in terms of calorie and bodyweight reduction. Therefore, if implemented, the proposed strategy would have a more considerable impact on those who need most to reduce their body weight. The strategy would not cause any energy reduction in those whose diet is based on home cooked meals made with minimally processed ingredients. Interestingly, the modelling study shows that people from different income groups would have a similar calorie and bodyweight reduction, thus demonstrating that the proposed strategy would benefit the entire population.

Lastly, another strength of the proposed reformulation strategy is that it includes all manufactured and out-of-home solid food categories, and excludes foods typically used for meal preparations such as grains, vegetables and fruit, oils and fats, and unprocessed meat. This comprehensive approach has the advantage of ensuring a level-playing field for the industry. A frequent criticism of current food and nutrition policies is the exclusion of the out-of-home sector. For example, calorie labelling is compulsory in the UK for manufactured foods but is only voluntary for the out-of-home sector (calorie labelling in the out-of- home is a relatively recent policy). Partly because of this, some investigations have reported higher calories and unhealthy nutrient content in in out-of-home foods compared with equivalents sold in retail (139, 140).

The studies included in this thesis have some limitations. The survey of fat content was limited to manufactured cakes and biscuits available in the UK's retail. Due to time and resources constraints, it was impossible for me to carry out surveys which systematically assessed the fat content in all the 46 food categories included in the modelling study. Nevertheless, as shown in chapter 5, cakes and biscuits are among the top contributors of calories, total fats and SFA. Additionally, the NGO Consensus Action on Salt, Sugar, and Health (CASSH) regularly carries out surveys looking at the nutrient variation present within many product categories. Their data are publicly available and often include information about the total and saturated fat content variation found within product categories. For example, a CASSH survey carried out in 2017 looked at the nutrient variation in manufactured sausages available in UK supermarkets (301). The survey showed a large variation of the total and saturated fat content within each sausage type (Table 6.1). The percentage variation of fat was greater than 50%. A similar variation could be observed from the 2016 CASSH survey data looking at dips such as hummus and taramasalata (Table 6.2), (302). The minimum per cent variation within the same type of dip was 20%. Another CASSH investigation found a considerable variation of the SFA content within the same type of cheese (Table 6.3), (303). These data show the feasibility of reducing fat content in the other MOOH food categories included in the reformulation strategy proposed in this thesis.

Table 6.1 Total and SFA content per 100g of some types of sausages
Reduced-fat products were excluded.

Type of sausage	**Minimum total fat g/100g**	**Maximum total fat g/100g**	**Variation total fat (%)**
Cumberland	10.6 *of which* 3.6 SFA	29.0 *of which* 11.1 SFA	63.5
Chipolatas	11.8 *of which* 5.3 SFA	26.4 *of which* 9.4 SFA	55.0
Lincolnshire	12.0 *of which* 4.4 SFA	28.0 *of which* 9.4 SFA	57.1

Table 6.2 Total and SFA content per 100g of some types of dips.
Reduced-fat products were excluded.

Type of dips	**Minimum total fat g/100g**	**Maximum total fat g/100g**	**Variation total fat (%)**
Houmous	13.7 *of which* 1.7 SFA	31.0 *of which* 1.0 SFA	55.8
Taramasalata	46.0 *of which* 1.3 SFA	58.0 *of which* 2.2 SFA	20.7
Guacamole	13.1 *of which* 1.0 SFA	20.2 *of which* 3.7 SFA	35.1

Table 6.3 SFA/100g of some types of cheese at the same ripening level.
Reduced-fat products were excluded.

Type of cheese	**Minimum SFA g/100g**	**Maximum SFA g/100g**	**Variation SFA (%)**
Feta	8.5	17.8	54.8
Blue	16.0	26.5	39.6
Emmental	16.9	20.5	17.6
Wensleydale	15.7	21.1	25.6
Gouda	20.0	24.3	17.8
Mozzarella	6.0	18.0	66.6

Another limitation of the present thesis was that I could not perform surveys of out-of-home categories (e.g. burger, fries, pizza). In the UK, calorie labelling in the out-of-home sector has been implemented in 2022. By then, I had already completed the data collection part of this PhD research. Before April 2022, the determination of the fat and calorie content of out-of-home products would have required the purchasing the products and an analytical assessment by a specialised laboratory. Performing all these steps requires substantial funding and time resources which were unavailable for the completion of the present PhD research. Some evidence supporting the proposed reformulation strategy in the out-of-home comes from a study that comprehensively assessed the SFA content in UK popular takeaway such as pizza, chicken and chips, and kebabs (140). The study found a considerable variation of the SFA of these products; for example, the minimum SFA/100g in a standard pizza margherita was 4.72g while the maximum content was 7.22g (35% variation) (140).

The limitation of the modelling study is that it relies on several assumptions. Some assumptions were based on empirical evidence. For example, I assumed that all individuals underreported a third of their food intake, as showed by doubly labelled water studies (263). Another assumption is that consumers would not change their food consumption habits once the reformulation would be implemented. Some evidence discussed earlier on in this chapter shows that consumers may increase the consumption of reduced-fat foods due to low-fat labels rather than the effect of reduced-fat foods on satiety (174, 293, 294); however, this strategy encourages a silent reformulation and discourages the use of reduced-fat claims. I also assumed that every gram of fat reduced in the target food categories would be replaced by fibre-based ingredients, or that appropriate food technologies would compensate for the fat reduction. Some evidence shows that it is possible to successfully reduce fat and energy density through different means in many widely consumed food categories. A summary of the available evidence will be briefly discussed in the next section focussing on case studies.

Another limitation is that to calculate the body weight reduction and the CVD reduction, I have used some published equations, and therefore these results would depend on the quality of the equations used. However, I carried out some sensitivity analyses by using different weight loss equations which have showed consistent findings. Despite some evidence indicating that different types of saturated fatty acids may have different impacts on LDL cholesterol and CVD risk, I assumed that all different saturated fatty acids had the same impact on CVD. Both the WHO and the SACN acknowledged this body of evidence. However, for public health purposes and for simplifying the messages around the need to reduce SFA consumption, both organisations refer to SFA as a "single nutrient" (179, 187). To conclude, assumptions are a common feature of all modelling studies, and I took all the possible actions to minimise uncertainty and produce robust results.

Due to the lack of weight loss equations specific for children and adolescents, I have not been able to model a bodyweight reduction in these age groups. However, the modelling part quantifying the energy intake reduction relative to the proposed strategy, shows that adolescents would be the age group in which the strategy would result in the biggest calorie reduction because they consume more energy from the selected food categories. Tackling childhood obesity is a priority for the UK Government and many other countries, and the proposed strategy has the potential of addressing this problem particularly in children and adolescents (304).

Finally, a frequent issue around reformulation is that manufacturers generally describe product reformulation as a long and costly process. The increased costs may arise from the use of more expensive ingredients or changes in processing and machinery. Manufacturers also report concerns that reformulation might lead to sales loss because consumers might not like the reformulated products (149); however, this has not been the case for salt reduction in the UK. As explained in chapter 1, obesity is a costly issue for society as it leads to increased NHS costs, loss of productivity and reduced quality of life. A report published in 2022, estimated that the annual cost of obesity in the UK is £58 billion, an amount of equivalent magnitude to around 3% of the 2020 UK's GDP (10). The proposed fat reformulation strategy, which could be easily implemented, could reduce part of these costs by saving the NHS £4.7million over 25 years.

6.4 Feasibility of the reformulation strategy from the technological perspective

The reformulation strategy outlined in this PhD thesis involves a gradual fat reduction and a concurrent increase in fibre-rich ingredients to compensate for the small fat reduction and to keep products' taste acceptable for consumers. The term fibre-rich ingredients include various non-digestible carbohydrates such as cellulose, inulin, oligofructose or only fibre from grains, fruit, and vegetables. These ingredients are often used as fat replacers which the American Dietetic Association defines as "ingredients that can be used to provide some or all of the functions of fat, yielding fewer calories than fat" (305). Most fibre-rich ingredients used as fat replacers have very low energy density (0-1.5kcal/g) (306). Some other fat replacers such as starches and protein-based replacers have a higher energy density; around 4kcal/g. From the technological perspective, fat replacers' most important function is to keep the product acceptable for consumers while fat content is being reduced (306, 307). Table 6.4 details some examples taken from the literature in which fat and energy density have been reduced by adding fibre-based fat replacers. All the experiments reported resulted in products deemed acceptable for consumers. For example, a study reported that it is possible to reduce the fat content by 49% in muffins (i.e. a type of cake) by using an emulsion of sunflower oil and cellulose (308). In another experiment, the authors reduced fat and added dietary fibre from oat, wheat, and fruit to dry-cured sausages. The reformulated sausages had up to 75% less fat, energy density was reduced by 35%, while dietary fibre content increased (309). In another investigation, the authors reported a 40% fat reduction in biscuits through the addition of corn fibre and lupin extract (310). In ice-creams, apart from protein-based fat replacers and starches, common fibre-based fat replacers include inulin, oligofructose, and cereal and fruit-based dietary fibre (311).

In some food categories, fat can be reduced without replacement, i.e. only through category-specific food technologies (Table 6.4). For example, in chips, fat can be reduced through air frying or microwave processing (312, 313). The latter can lead to chips with 30% less fat compared to regular chips (313). Reduced-fat cheese can be manufactured through the removal of the fat from milk before the cheese making. This process is less suitable for more aged cheese varieties such as mature cheddar; however, a study showed that half of the initial fat could be removed after the ripening process. This process ensured the flavour intensity of the regular product (314). Similarly, meat-based products such as meatballs can be produced through the physical removal of fat or, to keep products acceptability high, through fat replacers such as inulin or rice bran (315).

Table 6.4 Examples of available food technologies used to produce reduced-fat foods.

Product category	Technology used to produce reduced-fat products
Biscuits	Maltodextrin, lupin extract and corn fibre (310); rice starches (316)
Cakes & baked goods	Cellulose and peach fibre to replace fat in muffins (308, 317); polydextrose, guar guar in baked goods (307)
Chocolate confectionery	Fruit juice to replace milk and fat (318)
Fried potatoes	Air frying (312); microwave processing(313)
Cheddar cheese	Fat extraction after ripening (314)
Sausages	Addition of fruit-fibre (309); high-pressure processing (222)
Ice cream	Inulin, oligofructose, maltodextrin, polydextrose, milk proteins, soy proteins, cereal and fruit-based dietary fibre, starches (311)
Meatballs, mincemeat	Rice bran, inulin (315)

One of the most critical issues around fat replacers is that they make the products ingredient list longer. Evidence suggests that some consumers prefer products with "clean labels" that have, among others, a shorter ingredient list made of fewer familiar names (319). Longer ingredient lists might discourage the purchase of the reformulated products particularly in the higher socio-economic groups (319). In the present PhD research, I suggested replacing fat with fibre-based ingredients from whole foods such as fruit, vegetables, and whole grains. Evidence shows that fibre from these foods has beneficial effects on health (320). Besides, consumers might be more likely to buy products that have more familiar names (e.g. fibre from apples) rather than more unfamiliar names such as cellulose or inulin (321).

6.5 Case studies of successful reformulation

Other evidence in support of the feasibility of proposed fat reformulation strategy comes from some reformulation cases studies described by the Institute of Grocery Distribution (IGD). According to the IGD, Tesco reduced SFA content in their Chicken and Bacon sandwiches by 30% solely by removing butter and swapping mayonnaise with its reduced-fat version (Table 6.4). The reformulation resulted in products with reduced calories (322). Tesco reported to have reduced butter from over a hundred of their high selling sandwich products and that targeting butter was the easiest way to reduce calories and SFA without compromising products' flavour and consistency (322).

Table 6.5 Changes in total fat and SFA (g/100g) in the reformulated Tesco chicken sandwiches

	Chicken & bacon sandwich	**Reformulated Chicken % bacon sandwich**	**% change**	**Chicken, bacon & stuffing sandwich**	**Reformulated Chicken, bacon & stuffing sandwich**	**% change**
Total fat g/100g	24.4	22.3	-6.8	23.8	23.3	-2.1
SFA g/100g	3.2	2.6	-31.5	3.7	2.7	-27
kcal/100g	476	445	-4.7	545	533	-2.2

Another successfully reformulated product is Mr Kipling Viennese Whirl by Premier Foods. The IGD reported that the SFA content had been reduced from 12.4g/100g in 2016 to 10.6g/100g in 2020 (-14.5%), while total fat was reduced from 30.2g/100g to 28.5g/100g in 2020 (-5.7%) (Figure 6.1 and Figure 6.2). It is worth noting that the sugar content/100g has also been reduced, while fibre content/100g content has increased. From the ingredient list of the product in 2016 and 2020 (Figure 6.3 and Figure 6.4 respectively), it is clear that the only difference is the addition of a few ingredients such as inulin, and "soluble maise fibre" and few other fat replacers such as whey powder and milk protein. Soluble maise fibre, also known as resistant maltodextrin, is an ingredient that is widely used for the production of reduced-sugar and reduced-fat products (323).

Figure 6.1 Nutrition information of Mr Kipling Viennese Whirl in 2016 (before reformulation). Image taken on 25/08/2016 and available from the FoodSwitch database.

Figure 6.2 Nutrition information of Mr Kipling Viennese Whirls in 2020 (after reformulation). Available at https://www.mrkipling.co.uk/our-ranges/favourites/viennese-whirls last accessed 10/02/2021.

Figure 6.3 Ingredient list of Mr Kipling Viennese Whirls in 2016
Image available from the FoodSwitch database taken on 25/08/2016.

Wheat Flour (with added Calcium, Iron, Niacin, Thiamin), Vegetable Oils (Palm, Rapeseed), Icing Sugar, Raspberry Jam (Glucose-Fructose Syrup, Raspberry Purée, Humectant (Vegetable, Glycerine), Gelling Agent (Pectin), Acid (Citric Acid), Acidity Regulator (Sodium Citrates), Flavouring, Colour (Anthocyanins), Vegetable Margarine (Vegetable Oils, (Palm, Rapeseed), Emulsifier (Mono- and Diglycerides of Fatty Acids), Flavouring, Colour (Beta-Carotene), Invert Sugar Syrup, Soluble Maize Fibre, Salt, Maize Starch, Raising Agents (Disodium Diphosphate, Sodium Bicarbonate), Fructose, Maltodextrin, Sucrose, Humectant (Vegetable Glycerin), Inulin, Sugar, Flavourings, Emulsifiers (Polyglycerol Esters of Fatty Acids, Mono- and Diglycerides od Fatty Acids), Whey Powder (**Milk**), Colour (Curcumin), **Milk** Proteins

Figure 6.4 Ingredient list of Mr Kipling Viennese Whirls in 2020 (after reformulation). Available at https://www.mrkipling.co.uk/our-ranges/favourites/viennese-whirls%20last%20accessed%2010/02/2021 (last accessed 10/02/2021).

Finally, governments around the world are understanding the importance of reformulation and are starting to support businesses to successfully reformulate their products. For example, the Department of Agriculture, Environment and Rural Affairs in Northern Ireland has recently gathered small and medium sized food business in a conference providing guidance on reducing calories, saturated fat and sugar in cheesecake, a widely consumed dessert in the region (324). The use of 5% low fat cream cheese resulted in products with less saturated fat and calories. Other reformulation tips included using biscuits crumble with a coarser texture, do not over-melting the butter as this leads to the evaporation of water, and trying to incorporate a good amount of air in the cream as this adds volume and reduces energy density.

According to the taste panellists involved in the event, the reformulated products “tasted fresher” and had better “overall taste, aroma, and appearance” (324).

Chapter 7 | Conclusions

This final chapter provides a reflection on what has been presented throughout this thesis, the main research findings, and the implications of these findings. This chapter also reflects on the doctoral research process and makes some recommendations for future research in this area.

7.1 Research trajectory

7.1.1 The initial idea for this research

The idea for this research emerged from an interaction with experts from CASSH, who are world experts in nutrient reformulation. In the UK, CASSH had a pivotal role in designing and implementing the salt reduction strategy, which has been in operation since 2003. The salt strategy has been a successful nutrition policy in the UK, and based on this, I decided to explore fat reformulation as a potential solution to help solve the obesity problem. At the beginning of my doctoral studies in 2018, the concept of reformulation as a strategy to tackle obesity was not new. The UK Government was running the salt and sugar reduction programme and developing the calorie reduction programme. Thanks to the support of CASSH, I could attend (in person) Public Health England (PHE)'s presentation of the calorie reduction programme to all interested stakeholders, including civil society groups and the food industry. During the meeting, I reflected on several elements of the calorie reduction programme (including its monitoring and evaluation) and understood the practical implications for the industry when removing a fifth of the calories from their products. Based on these observations, I decided to develop a saturated fat reformulation strategy, as compared to the 20% calorie reduction proposed by PHE, a strategy focussing on saturated fat could yield more advantages. First, a 20% fat reduction would have a minimal impact on manufactured and out-of-home (MOOH) food recipes. Second, if implemented, MOOH food producers would have to focus only on saturated fat reduction (not on sugar, fat, and calories simultaneously), thus providing more specific reformulation targets. Third, compared to calorie reformulation alone, focusing on saturated fat would provide additional public health benefits as the latter would reduce LDL cholesterol and CVD at the population level.

7.1.2 Development of the research questions and methods

The broader definition of a saturated fat reformulation strategy led to the development of the research questions, aims, objectives and methods for the present PhD research. It became clear that one of the aims of my research was to provide health impact data to convince policymakers to implement an improved version of the calorie reformulation strategy. Mathematical modelling was the only study design that allowed the production of health impact data of a saturated fat reformulation strategy (also considering the time and resources available during my PhD). As I did not have the skills or knowledge to carry out a modelling study, I enrolled in many courses focussing on data analysis. I asked for the support of senior researchers outside my group who are experts in mathematical modelling methods. In parallel, I also started evaluating the feasibility of the proposed strategy by talking with the experts at CASSH and by analysing data for the cakes and biscuits categories.

7.2 Summary of the main findings

The present PhD research showed a wide variation in the fat and energy content within the same category of products, such as cakes and biscuits. The findings provide policymakers with evidence regarding the feasibility of fat and calorie reformulation, as some manufacturers are already producing the same type of cakes and biscuits with less fat, calories, and an overall healthier nutrient profile. This PhD research produced important data to persuade policymakers to implement a fat reformulation strategy in the UK and in other countries. The modelling study showed that a gradual (saturated) fat reduction by 20% in 46 manufactured and out-of-home food categories, which together contribute to more than one-third of the UK population's daily calories, could reduce calorie intake and reduce overweight and obesity in the population. Reducing SFA in the selected food categories to the 20% target would bring SFA intake within the recommended intakes, reduce LDL cholesterol, and improve the population's cardiovascular health. If implemented, the proposed strategy alone would reduce obesity and overweight prevalence, reduce cases of type 2 diabetes, and prevent IHD and stroke deaths.

7.3 Fitting the findings in the bigger picture

The literature summarised in chapter 1 indicated that obesity is a complex societal problem. This condition is caused by many factors, many of which are attributable to the food and physical activity environment in which people live. In the past 30 years, the UK Government has made many deliberations about solutions to solve the obesity crisis and implemented some important policies. However, the policies available in the UK did not stop or reduce obesity meaningfully. Bolder governmental actions are urgently needed. The findings of this PhD research showed that implementing a fat reformulation strategy alone would substantially reduce obesity prevalence. If implemented, the strategy could reduce the prevalence of overweight from 36.7% to 35.2%, and obesity from 29.9 % to 23.2%. Additionally, there would be a reduction of approximately 183,000 type 2 diabetes-related death over 20 years, and 97, 000 CVD deaths if the fat reformulation strategy would be focussed on saturated fat. The health gains would be substantial; governments should implement the proposed strategy immediately as fat reformulation is entirely feasible (chapter 4). Of course, fat reformulation should not be considered as the only obesity prevention policy. The proposed strategy could reduce obesity but not eliminate it completely. Other policies changing the built and the food environment in which people live are strongly needed to solve the obesity crisis.

7.4 Considerations for policymakers

The results of the present research led to another important set of questions. How to make the saturated fat strategy operative? Should policymakers use a voluntary or a mandatory approach to fat reformulation? At the beginning of this research, voluntary reformulation (based on the previous success of the salt strategy) seemed to be a viable policy option. However, in 2019 sugar reduction programme results showed disappointing results for most of the categories included in the programme. As explained in chapters 1 and 6, removing sugar (a bulk ingredient in many food recipes) might be more technologically challenging than removing a few milligrams of salt. On the other hand, part of the unsuccess of the sugar strategy can be attributed to the unwillingness of the food industry to voluntarily reformulate their food products in the absence of penalties for non-compliance. Many analyses highlighted the success of the

Sugary Drinks Industry Levy as since its announcement in 2016, sugar had almost been halved in many sugar-sweetened beverages (115). This led to the reflection that governments need to consider mandatory approaches based on fiscal instruments to incentivise the food industry and consumers to produce and choose healthier food. Contrary to common sense, mandatory approaches are a better and fairer option for the industry. Recently, the chief executives of the UK's major food retailers have stated that they cannot act without legislation to ensure all competitors are making similar investments in reformulation (104, 105). As discussed in chapter 6, a tiered energy density levy focusing on manufactured foods could be a helpful tool to promote fat reformulation (325). Countries which have implemented tiered tax approaches (e.g. based on several levels of nutrient/100g of product) reported positive impacts because the tax can simultaneously promote reformulation and incentivise consumers to buy healthier alternatives (86).

7.5 Considerations for scientists and future research

The results of the present PhD research showed that reducing fat by 20% in MOOH foods is possible and that if this reduction were applied to all the MOOH foods available on the UK market, the health gains for the population would be considerable. Researching this topic led to new research questions that should be considered for future research. The first question is how to structure a mandatory approach using financial tools. Could a tiered levy on calorie density in MOOH foods promote saturated fat reformulation? Alternatively, would it be better to implement a tiered levy based on fat content (i.e. "a fat tax")? Which kind of food producers (in terms of numbers of employees) should be subjected to the levy? Should the tiers of the levy be the same for all product categories? Could the levy be implemented in both manufactured and out-of-home food products? What other types of complementary policies be needed to aid the development and implementation of an energy-density levy (e.g. mandatory nutrient labelling in the out-of-home sector)?

The other important set of questions concerns the technical feasibility of (saturated) fat reformulation in all MOOH food categories included in the present PhD research. While the surveys showed a wide variation in fat content in many manufactured food categories, only few case studies show that reducing fat within the same product would be feasible and affordable for all food producers (see chapter 6). Developing new case studies and making the results freely available could help small food companies (which usually do not have considerable resources to invest in research and development) to reformulate their products.

7.6 Transferability of reformulation as an intervention goal

Reformulation as a public health intervention to improve population health has many advantages. The most important is that, as shown in this research, making minimal changes in the way food is produced can lead to huge population health gain without changing individuals' behaviour. The critics of reformulation point out that reformulation legitimises the existence and consumption of manufactured foods such as biscuits and chocolates which should not be consumed within a healthy diet (326). On the contrary, reformulation reduces the harm from excessive unhealthy nutrient consumption, thus reducing the disease risk associated with unhealthy diets. Most nutrition scientists agree that changing how people choose, prepare, and consume food is complex and ineffective from the public health point of view (247-249). Thus reducing, but not eliminating completely the negative factor, might be a winning strategy that could work much better for governments, the food industry, the healthcare sector, and consumers.

Many similar strategies have been used worldwide and share the same principles of reformulation. For example, in Sweden, the reduction of the alcoholic strength of beer has been implemented as a way to reduce the harmful use of alcohol (327). Similar approaches have been implemented in other policy areas, such as transport. For example, in the European Union car manufacturers need to comply with a set of production standards to reduce polluting emissions and mitigate the effects of the current climate crisis (249). In both cases, alcohol and polluting cars are not completely eliminated, but their availability and manufacturing are modified to reduce the relative disease burden in the population.

Product reformulation can also be used as an intervention in many policy areas. Products can be reformulated to be more environmentally sustainable and more in line with higher animal welfare standards. Some examples include meat and dairy products containing fewer animal-based ingredients and more plant-based ingredients (i.e. the

50/50 burger with half meat and half vegetables). Some other examples include plastic bottles made with a proportion of recycled plastics or even leathers made from non-food crops (e.g. apple or pineapple skin). The list of examples could be very long as companies continuously seek to develop products for the growing population of conscious consumers. However, as shown by the success of the SDIL and the unsuccess of the PHE reformulation programmes, government action is critical for implementing initiatives aimed at increasing the availability of healthier and environmentally sustainable products for the entire population.

7.7 Lessons for CASSH

The present PhD research has been made possible thanks to the input and support of CASSH, a group of specialists concerned with dietary salt and sugar consumption and its effects on health. CASSH also carries out campaigns in many areas to reduce salt and sugar content in manufactured and out-of-home food products as well as salt and sugar added to cooking and at the table in the UK and worldwide. Over the past years, CASSH has gradually started to focus more on the determinants of obesity and the overall nutrient profile of food products, as foods high in sugar and salt are often also high in calories and saturated fat. The present PhD research aimed to provide to CASSH an impact evaluation for a calorie reduction strategy (focussed on saturated fat) to persuade policymakers and gain public support for the strategy.

This research taught CASSH many important lessons. The most important is that focusing on sugar reformulation only is not enough to tackle obesity. This research shows that fat must be part of the equation when reducing the energy density of foods. The cakes and biscuit surveys clearly showed that fat (and not sugar) is the biggest contributor of calories in these categories. However, it must be noted that reducing sugar in the population is also essential for reducing the burden of tooth decay and for adapting the population's taste to reduced levels of sweetness.

The other lesson learnt regards the technical feasibility of reducing fat in foods. While from a technological point of view, salt reduction is more straightforward, the same cannot be said about fat reduction. Fat is a bulk ingredient in many food categories; if fat is reduced, another ingredient must be used to replace the weight and volume of fat in the product (e.g. vegetables, fat replacers). This was a new concept for CASSH. The group is now better placed to discuss calorie and fat reformulation with the food industry and other stakeholders.

7.8 Reflections on the research process

Through this research, I learned many new concepts and skills, which led me to become a more mature and competent public health nutritionist. This research also helped me to cultivate my critical thinking and to develop less polarised views about complex situations, not only in the field of public health nutrition. For example, at the beginning of this PhD, I supported the theory of Monteiro and colleagues stating that ultra-processed foods (i.e. "industrial formulation of ingredients") should not be part of a healthy diet and that these foods should be avoided entirely (326, 328). However, I later pondered that the definition of ultra-processed food is not a very helpful concept. Advising people to refrain from consuming these foods or asking governments to ban these foods is not a feasible and politically appealing solution, as ultra-processed foods are an integral part of our food system. Instead, I found out that ameliorating the nutritional quality of food products through reformulation could be a much more useful and feasible approach. In parallel, this PhD research needed a working definition to describe all the foods to include in the fat reformulation strategy. After much reflection, I decided that the definition of manufactured and out-of-home foods (used by the National Diet and Nutrition Survey) perfectly described the kind of products to include in the proposed reformulation strategy. Initially, I was reluctant to include products such as cheese and processed meat in this category as I believed that reformulating these products was not entirely possible. However, after many discussions with my supervisors, reading the relevant literature, and noticing that cheese and processed meat presented a wide variation of fat content, I felt confident about including these products in the fat reformulation strategy.

This PhD research also led me to consider more in detail the role and responsibility of the government, civil society, and the food industry. I learned that the food industry is a very important part of almost every country's economy, as it creates jobs and allows everyone to worry less about food and focus on other important aspects of life. At the same time, the main aim of the food industry is to generate profits. The civil society must therefore act to pressure the food industry to produce food that is not only safe and affordable but also healthy and sustainable. On the other hand, governments have the dual role of protecting the health of the population (as well as the health of the planet) while ensuring that the food industry contributes to the economy by making profits. Understanding these complexities is useful to understand one's own role as a researcher and also to have more fruitful conversations with the food industry and government representatives.

When I started my PhD, my analysis skills were very limited. To develop the modelling part of the present research I spent a considerable amount of time learning data analysis through formal courses organised by the Doctoral College at Queen Mary University but also through the help of more experienced quantitative researchers such as Dr Vincenzo Scrutinio. Through the modelling part of this thesis, I learned the strengths and the limitations of mathematical models as well as the challenges of determining the right model assumptions. Modellers often say that "no model is perfect", and after carrying out this research, I can also state the same. However, at the end of the research process, I can also state that models are a very useful tool to answer important public health nutrition questions that would otherwise remain unanswered.

To conclude, throughout the PhD journey I have gained many new skills, developed my critical thinking, and contributed with new knowledge to the ongoing policy discussion about how to fix the obesity problem.

References

1. World Health Organization. Obesity and overweigh factsheets Geneva: World Health Organization; 2020 [updated 01/04/2020. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

2. National Institute for Health and Care Excellence. Obesity: identification, assessment and management. Clinical guideline [CG189]. Available at https://www.nice.org.uk/guidance/cg189/chapter/Recommendations#identifying-and-assessing-overweight-obesity-and-central-adiposity (updated 2022). 2014.

3. Afshin A, Sur PJ, Fay KA, Cornaby L, Ferrara G, Salama JS, et al. Health effects of dietary risks in 195 countries, 1990-2013; a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2019;393(10184):1958-72.

4. Ellulu MS, Patimah I, Khaza'ai H, Rahmat A, Abed Y. Obesity and inflammation: the linking mechanism and the complications. Arch Med Sci. 2017;13(4):851-63.

5. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K. Body Fatness and Cancer — Viewpoint of the IARC Working Group. New England Journal of Medicine. 2016;375(8):794-8.

6. Public Health England. Excess Weight and COVID-19, Insights from new evidence London Public health England; 2020.

7. Cohen AK, Rai M, Rehkopf DH, Abrams B. Educational attainment and obesity: a systematic review. Obesity Reviews. 2013;14(12):989-1005.

8. Nickson D, Timming AR, Re D, Perrett DI. Subtle Increases in BMI within a Healthy Weight Range Still Reduce Womens Employment Chances in the Service Sector. PLOS ONE. 2016;11(9):e0159659.

9. Brewis AA. Stigma and the perpetuation of obesity. Social Science & Medicine. 2014;118:152-8.

10. Bell M, Deyes K, Vitello E. The annual social cost of obesity in the UK. London: Frontiers Economics; 2022.

11. Xiling L, Xu Y, Xu J, Pan X, Song X, Shan L, et al. Global burden of noncommunicable disease attributable to high body mass index in 195 countries and territories, 1990–2017. Endocrine. 2020;69.

12. Abarca-Gómez L, Abdeen ZA, Hamid ZA, Abu-Rmeileh NM, Acosta-Cazares B, Acuin C, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. The Lancet. 2017;390(10113):2627-42.

13. The Health and Social Care Information Centre. Statistics on Obesity, Physical Activity and Diet - England Leeds (UK): The Health and Social Care Information Centre; 2018 [Available from: https://digital.nhs.uk/data-and-information/publications/statistical/statistics-on-obesity-physical-activity-and-diet/statistics-on-obesity-physical-activity-and-diet-england-2018.

14. The Organization for Economic Cooperation and Development (iLibrary). Overweight or obese population (indicator) 2022 [Available from: https://www.oecd-ilibrary.org/social-issues-migration-health/overweight-or-obese-population/indicator/english_86583552-en.

15. Bodirsky BL, Dietrich JP, Martinelli E, Stenstad A, Pradhan P, Gabrysch S, et al. The ongoing nutrition transition thwarts long-term targets for food security, public health and environmental protection. Scientific Reports. 2020;10(1):19778.

16. Butland B, Jebb S, Kopelman P, McPherson K, Thomas S. Foresight tackling obesities: Future choices – project report. 2nd edition. London Department for Innovation, Universities and Skills; 2007.

17. Swinburn B, Sacks G, Hall K, McPherson K, Finegood DT, Moodie M, et al. The Global Obesity Pandemic: Shaped by Global Drivers and Local Environments. Lancet (London, England). 2011;378:804-14.

18. Brinsden H, Lobstein T, Landon J, Kraak V, Sacks G, Kumanyika S, et al. Monitoring policy and actions on food environments: rationale and outline of the INFORMAS policy engagement and communication strategies. Obes Rev 2013 Oct;14 Suppl 1:13-23 Epub ahead of print; DOI: doi: 101111/obr12072). 2013.

19. Swinburn B, Egger G. Preventive strategies against weight gain and obesity. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2002;3(4):289-301.

20. Société Francaise de Santé Publique. Health and Human Nutrition: Element for European Action. Paris: French Presidency of the European Union; 2000.

21. Griffith R, Jin W, Lechene V. The decline of home-cooked food. Fiscal Studies. 2022;43(2):105-20.

22. Robertson A, Lobstein T, Knai C. Obesity and socio-economic groups in Europe: Evidence review and implications for action. 2007.

23. Nielsen. Nielsen's Global Ingredient and Dining-Out Trends Report New York: The Nielsen Company; 2016 [Available from: https://www.nielsen.com/wp-content/uploads/sites/3/2019/04/global-ingredient-and-out-of-home-dining-trends-aug-2016.pdf.

24. Saskena MJ, Okrent AM, Anekwe TD, Cho C, Dicken C, Effland A, et al. America's Eating Habits: Food Away From Home. Washington (DC): United States Department for Agriculture, USDA Economic Research Service; 2008.

25. Stephens J, Miller H, Militello L. Food Delivery Apps and the Negative Health Impacts for Americans. Frontiers in Nutrition. 2020;7.

26. Theis DRZ, Adams J. Differences in energy and nutritional content of menu items served by popular UK chain restaurants with versus without voluntary menu labelling: A cross-sectional study. PLOS ONE. 2019;14(10):e0222773.

27. Roberts SB, Das SK, Suen VMM, Pihlajamäki J, Kuriyan R, Steiner-Asiedu M, et al. Measured energy content of frequently purchased restaurant meals: multi-country cross sectional study. BMJ. 2018;363:k4864.

28. Livingstone MBE, Pourshahidi LK. Portion Size and Obesity. Advances in Nutrition. 2014;5(6):829-34.

29. Monteiro CA, Cannon G, Levy RB, Moubarac J-C, Louzada MLC, Rauber F, et al. Ultra-processed foods: what they are and how to identify them. Public Health Nutrition. 2019;22(5):936-41.

30. Drewnowski A. Nutrient density: addressing the challenge of obesity. British Journal of Nutrition. 2018;120(s1):S8-s14.

31. Cairns G, Angus K, Hastings G, Caraher M. Systematic reviews of the evidence on the nature, extent and effects of food marketing to children. A retrospective summary. Appetite. 2013;62:209-15.

32. Boyland EJ, Nolan S, Kelly B, Tudur-Smith C, Jones A, Halford JC, et al. Advertising as a cue to consume: a systematic review and meta-analysis of the effects of acute exposure to unhealthy food and nonalcoholic beverage advertising on intake in children and adults1,2. The American Journal of Clinical Nutrition. 2016;103(2):519-33.

33. Pombo-Rodrigues S, Hashem KM, He FJ, MacGregor GA. Salt and sugars content of breakfast cereals in the UK from 1992 to 2015. Public Health Nutrition. 2017;20(8):1500-12.

34. EU Science Hub. Health Promotion and Disease Prevention Knowledge Gateway. Whole Grain. Brussels: European Commission; 2017 [Available from: https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/whole-grain_en.

35. Watson C, Reckling M, Preissel S, Bachinger J, Bergkvist G, Kuhlman T, et al. Grain Legume Production and Use in European Agricultural Systems. Advances in Agronomy. 2017;144:235-303.

36. Bittman M, Cleary E, Wilkinson-Bibicos C, Gershuny J. The social disorganization of eating: a neglected determinant of the Australian epidemic of overweight/obesity. BMC Public Health. 2019;19(S2).

37. de la Torre-Moral A, Fàbregues S, Bach-Faig A, Fornieles-Deu A, Medina FX, Aguilar-Martínez A, et al. Family Meals, Conviviality, and the Mediterranean Diet among Families with Adolescents. Int J Environ Res Public Health. 2021;18(5).

38. Chae W, Ju YJ, Shin J, Jang S-I, Park E-C. Association between eating behaviour and diet quality: eating alone vs. eating with others. Nutrition Journal. 2018;17(1):117.

39. La Marra M, Caviglia G, Perrella R. Using Smartphones When Eating Increases Caloric Intake in Young People: An Overview of the Literature. Frontiers in Psychology. 2020;11.

40. Lemke M, Schifferstein HNJ. The use of ICT devices as part of the solo eating experience. Appetite. 2021;165:105297.

41. Mozaffarian D, Rosenberg I, Uauy R. History of modern nutrition science—implications for current research, dietary guidelines, and food policy. BMJ. 2018;361:k2392.

42. Swire-Thompson B, Lazer D. Public Health and Online Misinformation: Challenges and Recommendations. Annual Review of Public Health. 2020;41(1):433-51.

43. Crockett RA, King SE, Marteau TM, Prevost AT, Bignardi G, Roberts NW, et al. Nutritional labelling for healthier food or non-alcoholic drink purchasing and consumption. Cochrane Database Syst Rev. 2018;2:Cd009315.

44. Feng W, Fox A. Menu labels, for better, and worse? Exploring socio-economic and race-ethnic differences in menu label use in a national sample. Appetite. 2018;128:223-32.

45. Sørensen K, Pelikan JM, Röthlin F, Ganahl K, Slonska Z, Doyle G, et al. Health literacy in Europe: comparative results of the European health literacy survey (HLS-EU). European Journal of Public Health. 2015;25(6):1053-8.

46. Newton S, Braithwaite D, Akinyemiju TF. Socio-economic status over the life course and obesity: Systematic review and meta-analysis. PLOS ONE. 2017;12(5):e0177151.

47. Cooksey Stowers K, Marfo NYA, Gurganus EA, Gans KM, Kumanyika SK, Schwartz MB. The hunger-obesity paradox: Exploring food banking system characteristics and obesity inequities among food-insecure pantry clients. PLOS ONE. 2020;15(10):e0239778.

48. Bell Z, Scott S, Visram S, Rankin J, Bambra C, Heslehurst N. Food insecurity and the nutritional health and well-being of women and children in high-income countries: protocol for a qualitative systematic review. BMJ Open. 2021;11(8):e048180.

49. Hirvonen K, Bai Y, Headey D, Masters WA. Affordability of the EAT–Lancet reference diet: a global analysis. The Lancet Global Health. 2020;8(1):e59-e66.

50. Nelson M, Erens B, Bates B, Church S, Boshier T. Low income diet and nutrition survey. London: Food Standard Agency; 2007.

51. National Energy Action and the Food Foundation. Impacts of food insecurity and fuel poverty on child health this winter. London: National Energy Action and the Food Foundation, ; 2022 [Available from: https://foodfoundation.org.uk/sites/default/files/2022-09/FF_NEA%20Joint%20Briefing%20Sept%202022%20FINAL_2.pdf.

52. Drewnowski A, Specter SE. Poverty and obesity: the role of energy density and energy costs. Am J Clin Nutr. 2004;79(1):6-16.

53. Jin H, Lu Y. Evaluating Consumer Nutrition Environment in Food Deserts and Food Swamps. Int J Environ Res Public Health. 2021;18(5).

54. Cooksey-Stowers K, Schwartz MB, Brownell KD. Food Swamps Predict Obesity Rates Better Than Food Deserts in the United States. Int J Environ Res Public Health. 2017;14(11).

55. Garawi F, Devries K, Thorogood N, Uauy R. Global differences between women and men in the prevalence of obesity: is there an association with gender inequality? European Journal of Clinical Nutrition. 2014;68(10):1101-6.

56. Papas MA, Alberg AJ, Ewing R, Helzlsouer KJ, Gary TL, Klassen AC. The built environment and obesity. Epidemiol Rev. 2007;29:129-43.

57. Congdon P. Obesity and Urban Environments. Int J Environ Res Public Health. 2019;16(3):464.

58. Dixon BN, Ugwoaba UA, Brockmann AN, Ross KM. Associations between the built environment and dietary intake, physical activity, and obesity: A scoping review of reviews. Obesity Reviews. 2021;22(4):e13171.

59. Lovasi GS, Hutson MA, Guerra M, Neckerman KM. Built Environments and Obesity in Disadvantaged Populations. Epidemiologic Reviews. 2009;31(1):7-20.

60. Zhang H, Yin L. A Meta-analysis of the Literature on the Association of the Social and Built Environment With Obesity: Identifying Factors in Need of More In-Depth Research. Am J Health Promot. 2019;33(5):792-805.

61. Li F, Harmer P, Cardinal BJ, Bosworth M, Johnson-Shelton D. Obesity and the built environment: does the density of neighborhood fast-food outlets matter? Am J Health Promot. 2009;23(3):203-9.

62. Fleischhacker SE, Evenson KR, Rodriguez DA, Ammerman AS. A systematic review of fast food access studies. Obesity Reviews. 2011;12(5):e460-e71.

63. Sarwer DB, Polonsky HM. The Psychosocial Burden of Obesity. Endocrinol Metab Clin North Am. 2016;45(3):677-88.

64. Torres SJ, Nowson CA. Relationship between stress, eating behavior, and obesity. Nutrition. 2007;23(11-12):887-94.

65. van der Valk ES, Savas M, van Rossum EFC. Stress and Obesity: Are There More Susceptible Individuals? Curr Obes Rep. 2018;7(2):193-203.

66. Kyle TK, Dhurandhar EJ, Allison DB. Regarding Obesity as a Disease: Evolving Policies and Their Implications. Endocrinology and metabolism clinics of North America. 2016;45(3):511-20.

67. Heshka S, Allison DB. Is obesity a disease? International Journal of Obesity. 2001;25(10):1401-4.

68. Kopelman PG, Finer N. Reply: Is obesity a disease? Int J Obes Relat Metab Disord. 2001;25(10):1405-6.

69. Lobstein T, Brinsden HC, Gill TP, Kumanyika SK, Swinburn B. Comment: obesity as a disease – some implications for the World Obesity Federation's advocacy and public health activities. Obesity Reviews. 2017;18:724 - 6.

70. Stoner L, Cornwall J. Did the American Medical Association make the correct decision classifying obesity as a disease? Australas Med J. 2014;7(11):462-4.

71. Bray GA, Kim KK, Wilding JPH. Obesity: a chronic relapsing progressive disease process. A position statement of the World Obesity Federation. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2017;18(7):715-23.

72. James WPT. Research on obesity. Nutrition Bulletin. 1977;4(3):187-90.

73. James WPT. WHO recognition of the global obesity epidemic. Int J Obes. 2008;32 Suppl 7:S120-6.

74. Bray G. Obesity in perspective, Fogarty International Center Series on Preventive Medicine. Washington, DC: Government Printing Office; 1973.

75. McCarthy M. A brief history of the World Health Organization. Lancet (London, England). 2002;360(9340):1111-2.

76. Nishida C, Uauy R, Kumanyika S, Shetty PS. The Joint WHO/FAO Expert Consultation on diet, nutrition and the prevention of chronic diseases: Process, product and policy implications. Public Health Nutrition. 2004;7(1A):245-50.

77. World Health Assembly. Fifty-fifth World Health Assembly, 13-18 May 2002: summary records of committees and ministerial round tables; reports of committees. Genev: World Health Organization; 2002.

78. WHO Expert Meeting on Childhood Obesity. Annual Report. Kobe, Japan: WHO Centre for Health Development; 2005.

79. Robertson A, Tirado C, Lobstein T, Jermini M, Knai C, Jensen JH, et al. Food and health in Europe: a new basis for action. Copenhagen: World Health Organization. Regional Office for Europe; 2004 2004.

80. Branca FNH, Nikogosian H, Lobstein T. WHO. The Challenge of Obesity in the WHO European Region and the Strategies for Response. WHO European report: Denmark2007.

81. World Health Organization. Global action plan for the prevention and control of noncommunicable diseases 2013-2020. Geneva: World Health Organization; 2013 2013. Report No.: 9789241506236.

82. World Health Organization. WHO European Childhood Obesity Surveillance Initiative (COSI) [Available from: https://www.who.int/europe/initiatives/who-european-childhood-obesity-surveillance-initiative-(cosi).

83. World Health Organization. Report of the Commission on Ending Childhood Obesity: implementation plan: executive summary. Geneva: World Health Organization; 2017 2017. Contract No.: WHO/NMH/PND/ECHO/17.1.

84. European Commission. EU Action Plan on Childhood Obesity 2014–2020. Brussels: European Commission; 2014.

85. World Health Organization. European food and nutrition action plan 2015–2020. Copenhagen: World Health Organisation Regional Office for Europe; 2015. Report No.: 928905123X.

86. World Health Organization. Fiscal policies for diet and prevention of noncommunicable diseases: technical meeting report, 5-6 May 2015. Geneva: World Health Organization 2016.

87. World Health Organisation. Policy Brief: Producing and promoting more food products consistent with a healthy diet. Geneva: World Health Organisation; 2014.

88. World Health Organization Regional Office for Europe. Eliminating trans fats in Europe: A policy brief. Copenhagen, Denmark: World Health Organization; 2015. Contract No.: 23/03.

89. James WPT. Research on Obesity: A Report. London: HM Stationary Office 1976.

90. Department of Health. The health of the Nation - a strategy for health in England. London: HMSO; 1992.

91. Jebb SA, Aveyard PN, Hawkes C. The evolution of policy and actions to tackle obesity in England. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2013;14 Suppl 2:42-59.

92. Department of Health. Saving Lives: Our Healthier Nation. London, England: Department of Health; 1999.

93. National Audit Office. Tackling Obesity in England. London: National Audit Office; 2001.

94. Kopelman P, Jebb SA, Butland B. Executive summary: Foresight 'Tackling Obesities: Future Choices' project. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2007;8 Suppl 1:vi-ix.

95. Department of Health and Department of Children SaF. Healthy weight, healthy lives: a cross-government strategy for England. Cross-Government Obesity Unit. Gateway reference: 9204 2008. 2008.

96. Department of Health. Healthy Lives, Healthy People: A Call to Action on Obesity in England. 2011.

97. MacGregor GA, He FJ, Pombo-Rodrigues S. Food and the responsibility deal: how the salt reduction strategy was derailed. BMJ. 2015;350:h1936.

98. Knai C, James L, Petticrew M, Eastmure E, Durand MA, Mays N. An evaluation of a public-private partnership to reduce artificial trans fatty acids in England, 2011-16. Eur J Public Health. 2017;27(4):605-8.

99. HM Government. Childhood Obesity, A Plan for Action. 2016. London HM Government; 2016. Contract No.: 24/03.

100. Public Health England. Sugar reduction: from evidence into action. London: Public Health England 2015. Contract No.: 24/03.

101. Department of Health and Social Care: Global Public Health Directorate: Obesity FaN. Childhood obesity: a plan for action. Chapter 2. London: Public Health England; 2018.

102. HM Government. Advancing our health: prevention in the 2020s. London: HM Government; 2019.

103. Department of Health and Social Care. Tackling obesity: empowering adults and children to live healthier lives London: HM Government 2020 [Available from: https://www.gov.uk/government/publications/tackling-obesity-government-strategy/tackling-obesity-empowering-adults-and-children-to-live-healthier-lives.

104. Burt HE, Brown MK, He FJ, MacGregor GA. Salt: the forgotten foe in UK public health policy. BMJ. 2022;377:e070686.

105. Dimbleby H. National food strategy independent review: the plan. London: National Food Strategy; 2021.

106. Theis D, White M. Is Obesity Policy in England Fit for Purpose? Analysis of Government Strategies and Policies, 1992–2020. The Milbank Quarterly. 2021;99(1):126-70.

107. Hawkes C, Jewell J, Allen K. A food policy package for healthy diets and the prevention of obesity and diet-related non-communicable diseases: the NOURISHING framework. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2013;14 Suppl 2:159-68.

108. Adams J, Mytton O, White M, Monsivais P. Why Are Some Population Interventions for Diet and Obesity More Equitable and Effective Than Others? The Role of Individual Agency. PLoS Med. 2016;13(4):e1001990.

109. Beauchamp A, Backholer K, Magliano D, Peeters A. The effect of obesity prevention interventions according to socioeconomic position: a systematic review. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2014;15(7):541-54.

110. Strassmann A, Çolak Y, Serra-Burriel M, Nordestgaard BG, Turk A, Afzal S, et al. Nationwide indoor smoking ban and impact on smoking behaviour and lung function: a two-population natural experiment. Thorax. 2022:thoraxjnl-2021-218436.

111. Tan CE, Glantz SA. Association Between Smoke-Free Legislation and Hospitalizations for Cardiac, Cerebrovascular, and Respiratory Diseases. Circulation. 2012;126(18):2177-83.

112. World Cancer Research Fund International. The NOURISHING policy database London: World Cancer Research Fund International,; 2022 [Available from: https://policydatabase.wcrf.org/level_one?page=nourishing-level-one.

113. World Health Organization. Regional Office for Europe. WHO European Regional Obesity Report 2022. World Health Organization. Regional Office for Europe; 2022.

114. Obesity Evidence Hub. Countries that have implemented taxes on sugar-sweetened beverages (SSBs): Cancer Council 2021 [Available from: https://www.obesityevidencehub.org.au/collections/prevention/countries-that-have-implemented-taxes-on-sugar-sweetened-beverages-ssbs#:~:text=About%2040%20countries%20have%20implemented,rates%20depending%20on%20sugar%20content.

115. Hashem KM, He FJ, MacGregor GA. Labelling changes in response to a tax on sugar-sweetened beverages, United Kingdom of Great Britain and Northern Ireland. Bulletin of the World Health Organization. 2019;97:789-856.

116. Scarborough P, Adhikari V, Harrington RA, Elhussein A, Briggs A, Rayner M, et al. Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis. PLOS Medicine. 2020;17(2):e1003025.

117. Colchero MA, Salgado JC, Unar-Munguía M, Molina M, Ng S, Rivera-Dommarco JA. Changes in Prices After an Excise Tax to Sweetened Sugar Beverages Was Implemented in Mexico: Evidence from Urban Areas. PLoS One. 2015;10(12):e0144408.

118. Devaney B. WIC Turns 35: Program Effectiveness and Future Directions. Childhood Programs and Practices in the First Decade of Life: A Human Capital Integration. 2010:29-48.

119. Dhar T, Baylis K. Fast-Food Consumption and the Ban on Advertising Targeting Children: The Quebec Experience. Journal of Marketing Research. 2011;48(5):799-813.

120. Potvin Kent M, Dubois L, Wanless A. A nutritional comparison of foods and beverages marketed to children in two advertising policy environments. Obesity (Silver Spring). 2012;20(9):1829-37.

121. Song J, Brown MK, Tan M, MacGregor GA, Webster J, Campbell NRC, et al. Impact of color-coded and warning nutrition labelling schemes: A systematic review and network meta-analysis. PLOS Medicine. 2021;18(10):e1003765.

122. Darnton-Hill I, Nishida C, James W. A life course approach to diet, nutrition and the prevention of chronic diseases. Public health nutrition. 2004;7(1a):101-21.

123. Baird J, Jacob C, Barker M, Fall CHD, Hanson M, Harvey NC, et al. Developmental Origins of Health and Disease: A Lifecourse Approach to the Prevention of Non-Communicable Diseases. Healthcare. 2017;5(1):14.

124. Waterlander WE, Luna Pinzon A, Verhoeff A, den Hertog K, Altenburg T, Dijkstra C, et al. A System Dynamics and Participatory Action Research Approach to Promote Healthy Living and a Healthy Weight among 10-14-Year-Old Adolescents in Amsterdam: The LIKE Programme. Int J Environ Res Public Health. 2020;17(14):4928.

125. Sawyer A, den Hertog K, Verhoeff AP, Busch V, Stronks K. Developing the logic framework underpinning a whole-systems approach to childhood overweight and obesity prevention: Amsterdam Healthy Weight Approach. Obes Sci Pract. 2021;7(5):591-605.

126. Nuffield Council on Bioethics. Public health: ethical issues. London: Cambridge Publishers Ltd; 2007.

127. Mouratidou T, Livaniou A, Saborido CM, Wollgast J, Louro Caldeira S. Trans fatty acids in Europe: where do we stand? A synthesysis of the evidence 2003-2013. European Commission Joint Reseach Centre; 2019.

128. Department of Health. Nutrient Profiling Technical Guidance. London: Department of Health 2011.

129. Hospital vending machines to dispens their last chocolate bar. http://www.wales.nhs.uk/documents/W080302-Hlt.pdf [press release]. NHS Wales 2008.

130. Food Standards Agency. Salt reduction targets. London, UK: Food Standard Agency; 2006. Contract No.: 22/03/2021.

131. Public Health England. Salt reduction targets for 2024. London: Public Health England 2020.

132. NHS. School Fruit and Vegetable Scheme London: NHS; 2015 [Available from: https://www.nhs.uk/Livewell/5ADAY/Documents/SFVS%20Factfile%20Newsletter%20May%202015.pdf.

133. Egnell M, Talati Z, Galan P, Andreeva VA, Vandevijvere S, Gombaud M, et al. Objective understanding of the Nutri-score front-of-pack label by European consumers and its effect on food choices: an online experimental study. International Journal of Behavioral Nutrition and Physical Activity. 2020;17(1):146.

134. Department of Health. Guide to creating a front of pack (FoP) nutrition label for pre-packed products sold through retail outlets. London: Department of Health,; 2016.

135. UK Statutory Instruments. The Calorie Labelling (Out-Of-Home sector) (England) London: Legislation.gov.uk; 2021 [Available from: https://www.legislation.gov.uk/uksi/2021/909/contents/made.

136. He FJ, Brinsden HC, MacGregor GA. Salt reduction in the United Kingdom: a successful experiment in public health. Journal of Human Hypertension. 2014;28:345-52.

137. Public Health England. Health matters–Obesity and the food environment. London (UK): Public Health England 2017. Contract No.: 15/03.

138. Government Office for Science. Tackling obesities: future choices - project report (2nd edition). Department of Innovation Universities and Skills; 2007.

139. Lachat C, Nago E, Verstraeten R, Roberfroid D, Van Camp J, Kolsteren P. Eating out of home and its association with dietary intake: a systematic review of the evidence. Obesity Reviews. 2012;13(4):329-46.

140. Davies IG, Blackham T, Jaworowska A, Taylor C, Ashton M, Stevenson L. Saturated and trans-fatty acids in UK takeaway food. International journal of food sciences and nutrition. 2016;67(3):217-24.

141. Alessandrini R, He FJ, Hashem KM, Tan M, MacGregor GA. Reformulation and Priorities for Reducing Energy Density; Results from a Cross-Sectional Survey on Fat Content in Pre-Packed Cakes and Biscuits Sold in British Supermarkets. Nutrients. 2019;11(6):1216.

142. van Raaij J, Hendriksen M, Verhagen H. Potential for improvement of population diet through reformulation of commonly eaten foods. Public Health Nutrition. 2009;12(3):325-30.

143. Institute of Medicine. Food Marketing to Children and Youth: Threat or Opportunity? Washington DC: The National Academies Press; 2006.

144. Cruz-e-Silva D, Goiana-da-Silva F, Morais Nunes A, Gregório M, Calhau C, Lopes C, et al. Improving dietary intake and achieving food product improvement: Policy opportunities and challenges for the WHO European Region in reducing salt and sugar in the diet. Copenhagen, Denmark: World Health Organisation Regional Office for Europe; 2020.

145. Alonso S, Tan M, Wang C, Kent S, Cobiac L, MacGregor GA, et al. Impact of the 2003 to 2018 Population Salt Intake Reduction Program in England. Hypertension. 2021;77(4):1086-94.

146. Gressier M, Sassi F, Frost G. Healthy Foods and Healthy Diets. How Government Policies Can Steer Food Reformulation. Nutrients. 2020;12(7):1992.

147. Coupe N, Cotterill S, Peters S. Tailoring lifestyle interventions to low socio-economic populations: A qualitative study. BMC Public Health. 2018;18.

148. Vlassopoulos A, Masset G, Charles VR, Hoover C, Chesneau-Guillemont C, Leroy F, et al. A nutrient profiling system for the (re)formulation of a global food and beverage portfolio. European Journal of Nutrition. 2016:1-18.

149. van Gunst A, Roodenburg AJC, Steenhuis IHM. Reformulation as an Integrated Approach of Four Disciplines: A Qualitative Study with Food Companies. Foods. 2018;7(4):64.

150. Brinsden HC, He FJ, Jenner KH, MacGregor GA. Surveys of the salt content in UK bread: progress made and further reductions possible. BMJ Open. 2013;3(6):e002936.

151. Food Standards Agency. Saturated Fat and Energy Intake Programme. London: Food Standards Agency; 2008. Contract No.: 03/11/2022.

152. Agency. FS. Reduction of Saturated fat in Bakery Products: A Report to the Biscuits, Cakes and Pastries Stakeholder Group. London, United Kingdom. 2002 London: United Kingdom; 2002.

153. Public Health England. Sugar Reduction: Achieving the 20%. A technical report outlining progress to date, guidelines for industry, 2015 baseline levels in key foods and next steps. London: Public Health England; 2015. Contract No.: 24/03.

154. Public Health England. Sugar Reduction: Achieving the 20%. London: Public Health England; 2017. Contract No.: 24/03.

155. O'Sullivan M. Salt, Fat and Sugar Reduction; Sensory Approaches for Nutritional Reformulation of foods and beverages. United Kingdom: Woodhead Publishing LtD.; 2020.

156. Amies-Cull B, Briggs ADM, Scarborough P. Estimating the potential impact of the UK government's sugar reduction programme on child and adult health: modelling study. BMJ. 2019;365:l1417.

157. Public Health England. Calorie reduction Technical report: guidelines for industry, 2017 baseline calorie levels and the next steps. Public Health England; 2020. Contract No.: 24/03.

158. Public Health England. Calorie reduction: the scope and ambition for action. 2018. London: Public Health England; 2018. Contract No.: 24/03.

159. Kolstoe S. Changes to public health bodies must be based on evidence and reflection, not scapegoating. 2020.

160. Wenham C. A distraction from the biggest public health challenge we have faced in a century: six problems with scrapping PHE. British Politics and Policy at LSE. 2020.

161. Hunter DJ, Littlejohns P, Weale A. Reforming the public health system in England. Lancet Public Health. 2022;7(9):e797-e800.

162. Department of Health and Social Care. New Office for Health Promotion to drive improvement of nation's health: Department of Health and Social Care; 2021 [Available from: https://www.gov.uk/government/news/new-office-for-health-promotion-to-drive-improvement-of-nations-health.

163. Danish Veterinary and Food Administration. Trans-fatty Acid Content in Food. Danish legislation on industrially produced trans-fatty acids: Ministry of Environment and Food of Denmark 2015 [Available from: https://www.foedevarestyrelsen.dk/english/Food/Trans%20fatty%20acids/Pages/default.aspx.

164. Willett WC, Stampfer MJ, Manson JE, Colditz GA, Speizer FE, Rosner BA, et al. Intake of trans fatty acids and risk of coronary heart disease among women. Lancet (London, England). 1993;341(8845):581-5.

165. Stender S, Dyerberg J, Astrup A. Consumer protection through a legislative ban on industrially produced trans fatty acids in foods in Denmark. Scandinavian Journal of Food and Nutrition. 2006;50(4):155-60.

166. Hyseni L, Bromley H, Kypridemos C, O'Flaherty M, Lloyd-Williams F, Guzman-Castillo M, et al. Systematic review of dietary trans-fat reduction interventions. Bulletin of the World Health Organization. 2017;95(12):821-30G.

167. European Parliament. Commission Regulation amending Annex III to Regulation (EC) No 1925/2006 of the European Parliament and of the Council as regards trans fat, other than trans fat naturally occurring in fat of animal origin Bruxelles: European Commission; 2019 [Available from: https://ec.europa.eu/food/safety/labelling_nutrition/trans-fat-food_en.

168. Erdman JW, MacDonald IA, Zeisel SH. Present Knowledge in Nutrition. Tenth ed. Ames, Iowa: Wiley Blackwell; 2012.

169. Perez-Escamilla R, Obbagy JE, Altman JM, Essery EV, McGrane MM, Wong YP, et al. Dietary energy density and body weight in adults and children: a systematic review. Journal of the Academy of Nutrition and Dietetics. 2012;112(5):671-84.

170. Stelmach-Mardas M, Rodacki T, Dobrowolska-Iwanek J, Brzozowska A, Walkowiak J, Wojtanowska-Krosniak A, et al. Link between Food Energy Density and Body Weight Changes in Obese Adults. Nutrients. 2016;8(4):229.

171. Arango-Angarita A, Shamah-Levy T, Rodríguez-Ramírez S. Dietary energy density is associated with body mass index-for-age in Mexican adolescents. Maternal & Child Nutrition. 2019;15(2):e12664.

172. Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal-weight women. The American Journal of Clinical Nutrition. 1998;67(3):412-20.

173. Leahy KE, Birch LL, Rolls BJ. Reducing the energy density of multiple meals decreases the energy intake of preschool-age children. The American Journal of Clinical Nutrition. 2008;88(6):1459-68.

174. Rolls BJ. The Role of Energy Density in the Overconsumption of Fat. The Journal of Nutrition. 2000;130(2):268S-71S.

175. Rolls BJ, Roe LS, Meengs JS. Reductions in portion size and energy density of foods are additive and lead to sustained decreases in energy intake. The American Journal of Clinical Nutrition. 2006;83(1):11-7.

176. EFSA Panel on Dietetic Products N, Allergies. Scientific Opinion on Dietary Reference Values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol. EFSA Journal. 2010;8(3):1461.

177. Food and Agriculture Organization of the United Nations. Fats and fatty acids in human nutrition; Report of an expert consultation. Geneva, Switzerland; 2010.

178. Committee on Medical Aspects of Food Policy. Dietary Reference Values for Food Energy and Nutrients for the United Kingdom. London: TSO; 1991. Contract No.: 16/03.

179. Scientific Advisory Committee on Nutrition. Saturated fats and health. London: Public Health England 2019.

180. Scientific Advisory Committee on Nutrition. The nutritional wellbeing of the British population. London: TSO; 2008.

181. Hooper L, Abdelhamid A, Bunn D, Brown T, Summerbell CD, Skeaff CM. Effects of total fat intake on body weight. Cochrane Database of Systematic Reviews. 2015(8):Cd011834.

182. World Health Organization. Healthy diet fact sheet Geneva: World Health Organization; 2020 [Available from: https://www.who.int/news-room/fact-sheets/detail/healthy-diet.

183. Keys A, Anderson JT, Grande F. Prediction of serum-cholesterol responses of man to changes in fats in the diet. Lancet (London, England). 1957;273(7003):959-66.

184. Forouhi NG, Krauss RM, Taubes G, Willett W. Dietary fat and cardiometabolic health: evidence, controversies, and consensus for guidance. BMJ. 2018;361:k2139.

185. Hooper L, Martin N, Abdelhamid A, Davey Smith G. Reduction in saturated fat intake for cardiovascular disease. Cochrane Database of Systematic Reviews. 2015(6):CD011737.

186. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990–2019: Update From the GBD 2019 Study. Journal of the American College of Cardiology. 2020;76(25):2982-3021.

187. World Health Organization. Draft guidelines on Saturated fats and Trans Fatty Acids. Geneva, Switzerland: World Health Organization 2018.

188. Committee on Medical Aspects of Food Policy. Nutritional aspects of cardiovascular disease. London: HMSO; 1994. Contract No.: 26/03.

189. National Institute for Health and Care Excellence. Cardiovascular disease: risk assessment and reduction, including lipid modification (Clinical guideline CG181) 2022 [Available from: https://www.nice.org.uk/guidance/cg181/chapter/1-recommendations#identifying-and-assessing-cardiovascular-disease-cvd-risk-2.

190. Wolfram G, Bechthold A, Boeing H, Ellinger S, Hauner H, Kroke A, et al. Evidence-Based Guideline of the German Nutrition Society: Fat Intake and Prevention of Selected Nutrition-Related Diseases. Annals of Nutrition and Metabolism. 2015;67(3):141-204.

191. Australian Government Department of Health and the New Zealand Ministry of Health. Macronutrient Balance 2013 [Available from: https://www.nrv.gov.au/chronic-disease/macronutrient-balance.

192. Dietary Guidelines Advisory Committee. Scientific Report of the 2015 Dietary Guidelines Advisory Committee:Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service,; 2015.

193. Nordic Co-operation. Nordic Nutrition Recommendations: Integrating nutrition and physical activity Copenhagen, Denmark: Norden; 2012 [Available from: http://norden.diva-portal.org/smash/get/diva2:704251/FULLTEXT01.pdf.

194. Piepoli MF, Hoes AW, Agewall S, Albus C, Brotons C, Catapano AL, et al. 2016 European Guidelines on cardiovascular disease prevention in clinical practice: The Sixth Joint Task Force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in Clinical Practice (constituted by representatives of 10 societies and by invited experts)Developed with the special contribution of the European Association for Cardiovascular Prevention & Rehabilitation (EACPR). European heart journal. 2016;37(29):2315-81.

195. Reiner Z, Catapano AL, De Backer G, Graham I, Taskinen MR, Wiklund O, et al. ESC/EAS Guidelines for the management of dyslipidaemias: the Task Force for the management of dyslipidaemias of the European Society of Cardiology (ESC) and the European Atherosclerosis Society (EAS). European heart journal. 2011;32(14):1769-818.

196. French Agency for Food Environmental and Occupational Health & Safety (ANSES). Étude individuelle nationale des consommations alimentaires 3 (INCA 3) Maisons-Alfort Cedex: Anses; 2017 [Available from: https://www.anses.fr/fr/content/inca-3-evolution-des-habitudes-et-modes-de-consommation-de-nouveaux-enjeux-en-mati%C3%A8re-de.

197. Vannice G, Rasmussen H. Position of the academy of nutrition and dietetics: dietary fatty acids for healthy adults. Journal of the Academy of Nutrition and Dietetics. 2014;114(1):136-53.

198. Eckel Robert H, Jakicic John M, Ard Jamy D, de Jesus Janet M, Miller Nancy H, Hubbard Van S, et al. 2013 AHA/ACC Guideline on Lifestyle Management to Reduce Cardiovascular Risk. Circulation. 2014;129(25_suppl_2):S76-S99.

199. Trumbo P, Schlicker S, Yates AA, Poos M. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. Journal of the American Dietetic Association. 2002;102(11):1621-30.

200. Public Health England and Food Standard Agency. NDNS results from years 7 and 8 (combined): data tables. London Public Health England 2018. Contract No.: 10/01/2021.

201. Lafay L, Mennen L, Basdevant A, Charles MA, Borys JM, Eschwège E, et al. Does energy intake underreporting involve all kinds of food or only specific food items? Results from the Fleurbaix Laventie Ville Santé (FLVS) study. International journal of obesity and related metabolic disorders. 2000;24(11):1500-6.

202. Heitmann BL, Lissner L. Dietary underreporting by obese individuals-is it specific or non-specific? British Medical Journal. 1995;311:986-9.

203. Goris A, Westerterp-Platenga M, Westerterp K. Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. The American Journal of Clinical Nutrition. 2000;71:130–4.

204. Micha R, Khatibzadeh S, Shi P, Fahimi S, Lim S, Andrews KG, et al. Global, regional, and national consumption levels of dietary fats and oils in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys. British Medical Journal. 2014;348:g2272.

205. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020-2025. Washington D.C.: U.S. Department of Agriculture and U.S. Department of Health and Human Services; 2020.

206. Public Health England. National Diet and Nutrition Survey: Years 1 to 9 of the Rolling Programme (2008/2009 – 2016/2017): Time trend and income analyses London Public Health England 2019.

207. Smith LP, Ng SW, Popkin BM. Trends in US home food preparation and consumption: analysis of national nutrition surveys and time use studies from 1965–1966 to 2007–2008. Nutrition Journal. 2013;12(1):45.

208. EU Science Hub. Health Promotion and Disease Prevention Knowledge Gateway. Dietary fats. Available at https://ec.europa.eu/jrc/en/health-knowledge-gateway/promotion-prevention/nutrition/fats

209. Federici C, Detzel P, Petracca F, Dainelli L, Fattore G. The impact of food reformulation on nutrient intakes and health, a systematic review of modelling studies. BMC Nutrition. 2019;5(1):2.

210. Johnson BJ, Grieger JA, Golley RK, Wycherley TP. Evaluation of Simulation Models that Estimate the Effect of Dietary Strategies on Nutritional Intake: A Systematic Review. The Journal of Nutrition. 2017;147(5):908-31.

211. International Choices criteria. A global standard for healthier food: Choices International Foundation; 2019 [Available from: www.choicesprogramme.org.

212. Leroy P, Requillart V, Soler LG, Enderli G. An assessment of the potential health impacts of food reformulation. European Journal of Clinical Nutrition. 2016;70(6):694-9.

213. Vyth EL, Hendriksen MAH, Roodenburg AJC, Steenhuis IHM, van Raaij JMA, Verhagen H, et al. Consuming a diet complying with front-of-pack label criteria may reduce cholesterol levels: a modeling study. European Journal Of Clinical Nutrition. 2011;66:510.

214. Roodenburg AJ, van Ballegooijen AJ, Dotsch-Klerk M, van der Voet H, Seidell JC. Modelling of usual nutrient intakes: potential impact of the choices programme on nutrient intakes in young dutch adults. PLoS One. 2013;8(8):e72378.

215. Roodenburg AJC, Schlatmann A, Dötsch-Klerk M, Daamen R, Dong J, Guarro M, et al. Potential Effects of Nutrient Profiles on Nutrient Intakes in the Netherlands, Greece, Spain, USA, Israel, China and South-Africa. PLOS ONE. 2011;6(2):e14721.

216. Temme EHM, van der Voet H, Roodenburg AJC, Bulder A, van Donkersgoed G, van Klaveren J. Impact of foods with health logo on saturated fat, sodium and sugar intake of young Dutch adults. Public Health Nutrition. 2011;14(4):635-44.

217. Gressier M, Privet L, Mathias KC, Vlassopoulos A, Vieux F, Masset G. Modeled dietary impact of industry-wide food and beverage reformulations in the United States and France. The American Journal of Clinical Nutrition. 2017;106(1):225-32.

218. Patterson E, Warnberg J, Kearney J, Sjostrom M. Sources of saturated fat and sucrose in the diets of Swedish children and adolescents in the European Youth Heart Study: strategies for improving intakes. Public Health Nutrition. 2010;13(12):1955-64.

219. Combris P, Goglia R, Henini M, Soler LG, Spiteri M. Improvement of the nutritional quality of foods as a public health tool. Public Health. 2011;125(10):717-24.

220. Schickenberg B, van Assema P, Brug J, Verkaik-Kloosterman J, Ocké MC, de Vries NK. Replacing foods high in saturated fat by low-saturated fat alternatives: a computer simulation of the potential effects on reduction of saturated fat consumption. British Journal of Nutrition. 2009;102(3):478-83.

221. Vieira SA, McClements DJ, Decker EA. Challenges of Utilizing Healthy Fats in Foods. Advances in Nutrition. 2015;6(3):309S-17S.

222. Bolumar T, Toepfl S, Heinz V. Fat Reduction and Replacement in Dry-Cured Fermented Sausage by Using High Pressure Processing Meat as Fat Replacer and Olive Oil. Polish Journal of Food and Nutrition Sciences. 2015;65(3):175-82.

223. Vijay V, Pimm SL, Jenkins CN, Smith SJ. The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss. PLOS ONE. 2016;11(7):e0159668.

224. Kadandale S, Marten R, Smith R. The palm oil industry and noncommunicable diseases. Bulletin of the World Health Organization. 2019;97(2):118-28.

225. Sun Y, Neelakantan N, Wu Y, Lote-Oke R, Pan A, van Dam RM. Palm oil consumption increases LDL cholesterol compared with vegetable oils low in saturated fat in a meta-analysis of clinical trials. The Journal of nutrition. 2015;145(7):1549-58.

226. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science. 2018;360(6392):987--92.

227. Pickup B. Supermarkets' sustainable palm oil not fully traceable: BBC News; 2019 [Available from: https://www.bbc.co.uk/news/business-47201336.

228. Lockyer S, Stanner S. Coconut oil – a nutty idea? Nutrition Bulletin. 2016;41(1):42-54.

229. Meijaard E, Abrams JF, Juffe-Bignoli D, Voigt M, Sheil D. Coconut oil, conservation and the conscientious consumer. Current Biology. 2020;30(13):R757-R8.

230. Poore J, Nemecek T. Reducing food’s environmental impacts through producers and consumers. Science. 2018;360(6392):987-92.

231. Liao X, Gerichhausen MJW, Bengoa X, Rigarlsford G, Beverloo RH, Bruggeman Y, et al. Large-scale regionalised LCA shows that plant-based fat spreads have a lower climate, land occupation and water scarcity impact than dairy butter. The International Journal of Life Cycle Assessment. 2020;25(6):1043-58.

232. Nilsson K, Flysjö A, Davis J, Sim S, Unger N, Bell S. Comparative life cycle assessment of margarine and butter consumed in the UK, Germany and France. The International Journal of Life Cycle Assessment. 2010;15(9):916-26.

233. Doody O, Bailey ME. Setting a research question, aim and objective. Nurse Res. 2016;23(4):19-23.

234. Richardson WS, Wilson MC, Nishikawa J, Hayward RS. The well-built clinical question: a key to evidence-based decisions. ACP J Club. 1995;123(3):A12-3.

235. Doran GT. There's SMART way to write management's goals and objectives. Management review. 1981;70(11):35-6.

236. Swinburn BA. Obesity prevention: the role of policies, laws and regulations. Aust New Zealand Health Policy. 2008;5:12.

237. Rose G. Sick individuals and sick populations. International Journal of Epidemiology. 2001;30(3):427-32.

238. McLaren L. In defense of a population-level approach to prevention: why public health matters today. Can J Public Health. 2019;110(3):279-84.

239. Magnusson RS. Case studies in nanny state name-calling: what can we learn? Public Health. 2015;129(8):1074-82.

240. Cullerton K, Donnet T, Lee A, Gallegos D. Playing the policy game: a review of the barriers to and enablers of nutrition policy change. Public Health Nutr. 2016;19(14):2643-53.

241. National Harm Reduction Coalition. Principles of Harm Reduction New York: National Harm Redution Coalition; 2020 [Available from: https://harmreduction.org/about-us/principles-of-harm-reduction/.

242. Charlet K, Heinz A. Harm reduction—a systematic review on effects of alcohol reduction on physical and mental symptoms. Addiction Biology. 2017;22(5):1119-59.

243. Levengood TW, Yoon GH, Davoust MJ, Ogden SN, Marshall BDL, Cahill SR, et al. Supervised Injection Facilities as Harm Reduction: A Systematic Review. American Journal of Preventive Medicine. 2021;61(5):738-49.

244. Nichols T, M. Craike, I. Thevios & R. Calder,. Nutrition policy in Australia: adopting a harm minimisation approach. Policy evidence brief 2020-01. Melbourne: Victoria University, Mitchell Institute; 2020.

245. Gressier M, Swinburn B, Frost G, Segal AB, Sassi F. What is the impact of food reformulation on individuals' behaviour, nutrient intakes and health status? A systematic review of empirical evidence. Obesity Reviews. 2021;22(2):e13139.

246. Hashem KM, He FJ, MacGregor GA. Effects of product reformulation on sugar intake and health-a systematic review and meta-analysis. Nutrition reviews. 2019;77(3):181-96.

247. Swinburn B, Kraak V, Rutter H, Vandevijvere S, Lobstein T, Sacks G, et al. Strengthening of accountability systems to create healthy food environments and reduce global obesity. The Lancet. 2015;385(9986):2534-45.

248. Food and Agriculture Organization of the United Nations. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. . Rome: FAO; 2020.

249. Mulholland E, Miller J, Bernard Y, Lee K, Rodríguez F. The role of NOx emission reductions in Euro 7/VII vehicle emission standards to reduce adverse health impacts in the EU27 through 2050. Transportation Engineering. 2022;9:100133.

250. Al-Saadi H. Demystifying Ontology and Epistemology in Research Methods. 2014.

251. Watson R. Quantitative research. Nurs Stand. 2015;29(31):44-8.

252. Harris AD, McGregor JC, Perencevich EN, Furuno JP, Zhu J, Peterson DE, et al. The use and interpretation of quasi-experimental studies in medical informatics. J Am Med Inform Assoc. 2006;13(1):16-23.

253. Uauy R. Understanding public health nutrition. The Lancet. 2007;370(9584):309-10.

254. Vitolins MZ, Case TL. What Makes Nutrition Research So Difficult to Conduct and Interpret? Diabetes Spectr. 2020;33(2):113-7.

255. Sutherland J, Edwards P, Shankar B, Dangour AD. Fewer adults add salt at the table after initiation of a national salt campaign in the UK: a repeated cross-sectional analysis. British Journal of Nutrition. 2013;110(3):552-8.

256. Canene-Adams K, Laurie I, Karnik K, Flynn B, Goodwin W, Pigat S. Estimating the potential public health impact of fibre enrichment: a UK modelling study. British Journal of Nutrition. 2022:1-7.

257. O'Flaherty M, Bandosz P, Critchley J, Capewell S, Guzman-Castillo M, Aspelund T, et al. Exploring potential mortality reductions in 9 European countries by improving diet and lifestyle: A modelling approach. Int J Cardiol. 2016;207:286-91.

258. Caro JJ, Briggs AH, Siebert U, Kuntz KM. Modeling good research practices--overview: a report of the ISPOR-SMDM Modeling Good Research Practices Task Force-1. Med Decis Making. 2012;32(5):667-77.

259. Hashem KM, He FJ, Alderton SA, MacGregor GA. Cross-sectional survey of the amount of sugar and energy in cakes and biscuits on sale in the UK for the evaluation of the sugar-reduction programme. BMJ Open. 2018;8:e019075.

260. Kantar. Grocery Market Share, Great Britain. 2020 [Available from: https://www.kantarworldpanel.com/en/grocery-market-share/great-britain/snapshot/26.01.20/.

261. Department of Health. Technical guidance on nutrition labelling. 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/595961/Nutrition_Technical_Guidance.pdf.

262. Public Health England and Food Standards Agency. NDNS: years 7 and 8 (combined). Results of the National Diet and Nutrition Survey (NDNS) rolling programme for 2014 to 2015 and 2015 to 2016. 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699241/NDNS_results_years_7_and_8.pdf.

263. Public Health England. Misreporting in the National Diet and Nutrition Survey Rolling Programme (NDNS RP): summary of results and their interpretation (Appendix X) https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined. 2018.

264. Hall KD, Jordan PN. Modeling weight-loss maintenance to help prevent body weight regain. American Journal of Clinical Nutrition. 2008;88(6):1495-503.

265. Ma Y, He FJ, Yin Y, Hashem KM, MacGregor GA. Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study. The Lancet Diabetes & Endocrinology. 2016;4(2):105-14.

266. Office for National Statistics. Office for National Statistics. Overview of the UK population 2019. 2019.

267. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. The Lancet. 2011;378(9793):815-25.

268. Yu-Poth S, Zhao G, Etherton T, Naglak M, Jonnalagadda S, Kris-Etherton PM. Effects of the National Cholesterol Education Program's Step I and Step II dietary intervention programs on cardiovascular disease risk factors: a meta-analysis. American Journal of Clinical Nutrition. 1999;69(4):632-46.

269. Law MR, Wald NJ, Rudnicka AR. Quantifying effect of statins on low density lipoprotein cholesterol, ischaemic heart disease, and stroke: systematic review and meta-analysis. British Medical Journal. 2003;326(7404):1423-.

270. Wald NJ, Law MR. A strategy to reduce cardiovascular disease by more than 80%. British Medical Journal. 2003;326:1419-23.

271. Townsend N, Williams J, Bhatnagar P, Wickramasinghe K, Rayner M. Cardiovascular disease statistics. British Heart Foundation: London (2014).

272. Bland JM, Altman DG. Statistics Notes: Bootstrap resampling methods. British Medical Journal. 2015;350:h2622.

273. Christiansen E, Garby L. Prediction of body weight changes caused by changes in energy balance. European journal of clinical investigation. 2002;32(11):826-30.

274. Oostenbach LH, Slits E, Robinson E, Sacks G. Systematic review of the impact of nutrition claims related to fat, sugar and energy content on food choices and energy intake. BMC Public Health. 2019;19(1):1296.

275. Public Health England. Sugar reduction: report on progress between 2015 and 2019. London: Public Health England; 2020.

276. Public Health England: Strategies for Encouraging Healthier 'Out of Home' Food Provision https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604912/Encouraging_healthier_out_of_home_food_provision_toolkit_for_local_councils.pdf. 2017.

277. Vandevijvere S, Swinburn B. Towards global benchmarking of food environments and policies to reduce obesity and diet-related non-communicable diseases: design and methods for nation-wide surveys. BMJ Open. 2014;4(5):e005339.

278. Bíró A. Did the junk food tax make the Hungarians eat healthier? Food Policy. 2015;54:107-15.

279. Batis C, Rivera JA, Popkin BM, Taillie LS. First-Year Evaluation of Mexico's Tax on Nonessential Energy-Dense Foods: An Observational Study. PLoS Med. 2016;13(7):e1002057.

280. Taillie LS, Rivera JA, Popkin BM, Batis C. Do high vs. low purchasers respond differently to a nonessential energy-dense food tax? Two-year evaluation of Mexico's 8% nonessential food tax. Preventive medicine. 2017;105s:S37-s42.

281. National Institute for Food and Nutrition Science Directorate General. Assessment of the impact of a public health product tax. Budapest: World Health Organization, Regional Office for Europe; 2015.

282. Pedraza LS, Popkin BM, Salgado JC, Taillie LS. Mexican Households' Purchases of Foods and Beverages Vary by Store-Type, Taxation Status, and SES. Nutrients. 2018;10(8).

283. Smed S, Scarborough P, Rayner M, Jensen JD. The effects of the Danish saturated fat tax on food and nutrient intake and modelled health outcomes: an econometric and comparative risk assessment evaluation. European Journal of Clinical Nutrition. 2016;70(6):681-6.

284. Tiffin R, Arnoult M. The public health impacts of a fat tax. European Journal of Clinical Nutrition. 2011;65(4):427-33.

285. Reyes M, Smith Taillie L, Popkin B, Kanter R, Vandevijvere S, Corvalán C. Changes in the amount of nutrient of packaged foods and beverages after the initial implementation of the Chilean Law of Food Labelling and Advertising: A nonexperimental prospective study. PLOS Medicine. 2020;17(7):e1003220.

286. Rincón-Gallardo PS, Zhou M, Da Silva Gomes F, Lemaire R, Hedrick V, Serrano E, et al. Effects of Menu Labeling Policies on Transnational Restaurant Chains to Promote a Healthy Diet: A Scoping Review to Inform Policy and Research. Nutrients. 2020;12(6).

287. Kaur A, Briggs A, Adams J, Rayner M. New calorie labelling regulations in England. BMJ. 2022;377:o1079.

288. Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods, (2006).

289. US Food and Drug Administration. Specific Requirements for Nutrient Content Claims 2020 [Available from: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=101.62.

290. Walker TB, Parker MJ. Lessons from the War on Dietary Fat. Journal of the American College of Nutrition. 2014;33(4):347-51.

291. La Berge AF. How the Ideology of Low Fat Conquered America. Journal of the History of Medicine and Allied Sciences. 2008;63(2):139-77.

292. Austin GL, Ogden LG, Hill JO. Trends in carbohydrate, fat, and protein intakes and association with energy intake in normal-weight, overweight, and obese individuals: 1971-2006. American Journal of Clinical Nutrition. 2011;93(4):836-43.

293. McCann MT, Wallace JM, Robson PJ, Rennie KL, McCaffrey TA, Welch RW, et al. Influence of nutrition labelling on food portion size consumption. Appetite. 2013;65:153-8.

294. Mullie P, Godderis L, Clarys P. Determinants and nutritional implications associated with low-fat food consumption. Appetite. 2012;58(1):34-8.

295. Public Health England. Sugar Reduction, The evidence for Action, Annex 5D. London: Public Health England 2015.

296. Collins M, Mason H, O'Flaherty M, Guzman-Castillo M, Critchley J, Capewell S. An Economic Evaluation of Salt Reduction Policies to Reduce Coronary Heart Disease in England: A Policy Modeling Study. Value in Health. 2014;17(5):517-24.

297. Global and Public Health Group. Technical Consultation Document: Department of Health and Social Care (DHSC) Calorie Model. London: Department of Health and Social Care; 2018.

298. Scientific Advisory Committee on Nutrition. Carbohydrates and Health London: TSO; 2015 [Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf.

299. Hervik AK, Svihus B. The Role of Fiber in Energy Balance. Journal of nutrition and metabolism. 2019;2019:4983657.

300. Monteiro CA, Moubarac JC, Levy RB, Canella DS, Louzada M, Cannon G. Household availability of ultra-processed foods and obesity in nineteen European countries. Public Health Nutrition. 2018;21(1):18-26.

301. Action on Salt. Sausage Survey: Queen Mary University of London; 2017 [Available from: http://www.actiononsalt.org.uk/media/action-on-salt/news/surveys/2017/sausages-/Sausages-Survey-2017---Full-Data.pdf.

302. Action on Salt. Dips Survey: Queen Mary University of London; 2016 [Available from: http://www.actiononsalt.org.uk/media/action-on-salt/news/surveys/2016/dips/CASH_Salt,-Fat-&-Saturates-Data-for-Dips-Press-Release.pdf.

303. Action on Salt. Cheese Survey Queen Mary University of London 2012 [Available from: http://www.actiononsalt.org.uk/media/action-on-salt/news/surveys/2012/cheese/Cheese-Data-2012.pdf.

304. HM Government. Childhood Obesity, A Plan for Action. Chapter 2. 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/718903/childhood-obesity-a-plan-for-action-chapter-2.pdf.

305. Richard D. Position of the American Dietetic Association fat replacer. Journal of the American Dietetic Association. 1998;98:463-8.

306. Peng X, Yao Y. Carbohydrates as Fat Replacers. Annual Review of Food Science and Technology. 2017;8(1):331-51.

307. Colla K, Costanzo A, Gamlath S. Fat Replacers in Baked Food Products. Foods. 2018;7(12):192.

308. Martínez-Cervera S, Salvador A, Sanz T. Cellulose ether emulsions as fat replacers in muffins: Rheological, thermal and textural properties. LWT - Food Science and Technology. 2015;63.

309. García ML, Dominguez R, Galvez MD, Casas C, Selgas MD. Utilization of cereal and fruit fibres in low fat dry fermented sausages. Meat Science. 2002;60(3):227-36.

310. Forker A, Zahn S, Rohm H. A Combination of Fat Replacers Enables the Production of Fat-reduced Shortdough Biscuits with High-sensory quality. Food and Bioprocess Technology. 2012;5(6):2497-505.

311. Akbari M, Eskandari MH, Davoudi Z. Application and functions of fat replacers in low-fat ice cream: A review. Trends in Food Science & Technology. 2019;86:34-40.

312. Teruel Mdel R, Gordon M, Linares MB, Garrido MD, Ahromrit A, Niranjan K. A comparative study of the characteristics of French fries produced by deep fat frying and air frying. Journal of Food Science. 2015;80(2):E349-58.

313. Joshi A, Rudra SG, Sagar VR, Raigond P, Dutt S, Singh B, et al. Development of low fat potato chips through microwave processing. Journal of food science and technology. 2016;53(8):3296-303.

314. Nelson BK, Barbano DM. Reduced-fat cheddar cheese manufactured using a novel fat removal process. Journal of Dairy Science. 2004;87(4):841-53.

315. Kumar Y. Development of Low-Fat/Reduced-Fat Processed Meat Products using Fat Replacers and Analogues. Food Reviews International. 2019:1-17.

316. Lee Y-T, Puligundla P. Characteristics of reduced-fat muffins and cookies with native and modified rice starches. Emirates Journal of Food and Agriculture. 2016:311-6.

317. Grigelmo-Miguel N, Carreras-Boladeras E, Martín-Belloso O. Development of high-fruit-dietary-fibre muffins. European Food Research and Technology. 1999;210(2):123-8.

318. Skelhon TS, Grossiord N, Morgan AR, Bon SAF. Quiescent water-in-oil Pickering emulsions as a route toward healthier fruit juice infused chocolate confectionary. Journal of Materials Chemistry. 2012;22(36):19289-95.

319. Asioli D, Aschemann-Witzel J, Caputo V, Vecchio R, Annunziata A, Næs T, et al. Making sense of the "clean label" trends: A review of consumer food choice behavior and discussion of industry implications. Food Research International. 2017;99:58-71.

320. EU Science Hub. Health Promotion and Disease Prevention Knowledge Gateway. Dietary Fibre. Brussels: European Commission; 2017 [Available from: https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/dietary-fibre_en.

321. O'Sullivan MG. Chapter three - Reduced-fat products and challenges. Salt, Fat and Sugar Reduction: Woodhead Publishing; 2020. p. 63-96.

322. The Institute of Grocery Distribution. Reformulation Case studies; Tesco: reducing 'reds' in Food-To-Go 2017 [Available from: https://www.igd.com/social-impact/health/reformulation/case-studies/article-viewer/t/tesco-reducing-reds-in-food-to-go/i/16174.

323. Tate and Lyle Nutrition Centre. Soluble corn fibre: health benefits and products applications. Hoffman Estates, IL , (US): Nutrition Centre Tate and Lyle; 2021.

324. Department of Agriculture EaRA. Cheesecake Reformulation Technical Guidance Belfast: Department of Agriculture, Environment and Rural Affairs, ; 2022.

325. Stubley P. Government urged to impose 'calorie tax' on unhealthy food 2019 [Available from: https://www.independent.co.uk/news/uk/politics/calorie-tax-campaign-health-food-levy-sugar-soft-drinks-a9044521.html.

326. Scrinis G, Monteiro CA. Ultra-processed foods and the limits of product reformulation. Public Health Nutr. 2018;21(1):247-52.

327. Rehm J, Lachenmeier DW, Llopis EJ, Imtiaz S, Anderson P. Evidence of reducing ethanol content in beverages to reduce harmful use of alcohol. The Lancet Gastroenterology & Hepatology. 2016;1(1):78-83.

328. Monteiro CA, Moubarac JC, Cannon G, Ng SW, Popkin B. Ultra-processed products are becoming dominant in the global food system. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2013;14 Suppl 2:21-8.

Appendix I | Chapter 5

Supplementary Table 1. Food categories included the in the strategy ranked according to their contribution to SFA intake in the NDNS population (n=2371). The fourth column shows the percentage of consumers of each category.

Ranking	NDNS food category	Total grams of SFA provided by category in the NDNS population	Share of consumer s (%)
1	Cheddar cheese	4727	54
2	Chocolate confectionery	3458	50
3	Biscuits manufactured/retail	3372	68
4	Buns cakes & pastries manufactured	2369	46
5	Other cheese	1962	36
6	Other sausages including homemade dishes	1860	39
7	Pizza	1602	24
8	Manufactured meat pies and pastries	1489	17
9	Ice cream	1470	27
10	Savoury sauces pickles gravies & condiments	1040	94
11	Burgers and kebabs purchased	838	14
12	Chips including takeaway	696	48
13	Crisps and savoury snacks	613	55
14	Manufactured coated chicken/turkey products	559	26
15	White fish coated or fried	525	24
16	Pasta manufactured products & ready meals	430	12
17	Fromage frais and dairy desserts manufactured	389	17
18	Other meat products manufactured including ready meals	377	10
19	High fibre breakfast cereals	335	44
20	Other cereal based puddings - manufactured	330	5
21	Sweet spreads fillings and icing	279	12
22	Manufactured beef products including ready meals	213	6
23	Manufactured chicken products including ready meals	203	14

24	Other breakfast cereals (not high fibre)	203	37
25	Manufactured egg products including ready meals	200	5
26	Cereal based milk puddings - manufactured	188	12
27	Sugar confectionery	147	26
28	Other manufactured potato products fried/baked	143	15
29	Fruit pies manufactured	122	3
30	Soup manufactured/retail	110	19
31	Manufactured oily fish products including ready meals	96	6
32	Liver and dishes	95	3
33	Sponge puddings - manufactured	84	2
34	Beans and pulses including ready meal & homemade dishes	75	19
35	Other manufactured vegetable products including ready meals	53	4
36	Manufactured pork products including ready meals	45	3
37	Meat alternatives including ready meals & homemade dish	43	5
38	Manufactured canned tuna products including ready meals	35	12
39	Other potato products & dishes - manufactured	33	5
40	Manufactured lamb products including ready meals	30	1
41	Rice manufactured products & ready meals	24	4
42	Cottage cheese	21	1
43	Manufactured white fish products including ready meals	19	1
44	Ready meals based on sausages	17	<1
45	Manufactured shellfish products including ready meals	7	1
46	Ready meals based on bacon and ham	2	<1

Supplementary Table 2. Food categories included in the strategy ranked according to their contribution to fat intake in the NDNS population (n=2371). The fourth column shows the percentage of consumers of each category.

Ranking	NDNS food category	Total grams of SFA provided by category in the NDNS population (n=2371)	Share of consumers (%) (n=2371)
1	Cheddar cheese	7597	54
2	Biscuits manufactured/retail	7179	68
3	Chocolate confectionery	6153	50
4	Savoury sauces pickles gravies & condiments	5997	94
5	Crisps and savoury snacks	5615	55
6	Buns cakes & pastries manufactured	5597	46
7	Chips including takeaway	4869	48
8	Other sausages including homemade dishes	4853	39
9	Pizza	3710	24
10	Manufactured meat pies and pastries	3432	17
11	Manufactured coated chicken turkey products	3279	26
12	Other cheese	3055	36
13	White fish coated or fried	2251	24
14	Ice cream	2184	27
15	Burgers and kebabs purchased	1907	14
16	High fibre breakfast cereals	1179	44
17	Other meat products manufactured including ready meals	930	10
18	Pasta manufactured products & ready meals	869	12
19	Other manufactured potato products fried/baked	842	15
20	Sweet spreads fillings and icing	826	12
21	Manufactured chicken products including ready meals	743	14
22	Other breakfast cereals (not high fibre)	691	37
23	Beans and pulses including ready meal & homemade dishes	661	19
24	Other cereal based puddings - manufactured	610	5

25	Fromage frais and dairy desserts manufactured	594	17
26	Manufactured egg products including ready meals	527	5
27	Manufactured oily fish products including ready meals	484	6
28	Manufactured beef products including ready meals	475	6
29	Sugar confectionery	474	26
30	Soup manufactured/retail	429	19
31	Cereal based milk puddings - manufactured	306	12
32	Liver and dishes	289	3
33	Fruit pies manufactured	259	3
34	Other manufactured vegetable products including ready meals	243	4
35	Meat alternatives including ready meals & homemade dish	238	5
36	Manufactured canned tuna products including ready meals	222	12
37	Manufactured pork products including ready meals	178	3
38	Other potato products & dishes - manufactured	165	5
39	Sponge puddings - manufactured	158	2
40	Rice manufactured products & ready meals	108	4
41	Manufactured lamb products including ready meals	69	1
42	Manufactured white fish products including ready meals	49	1
43	Ready meals based on sausages	46	<1
44	Cottage cheese	39	1
45	Manufactured shellfish products including ready meals	35	1
46	Ready meals based on bacon and ham	8	<1

Supplementary Table 3. Mean body weight ± SD (kg) and energy intake (kcal/day) change by income group at the end of the fifth year of the strategy.

Household income in the past 12 months	Body weight change ±SD at the end of the fifth year (n=1171)	Energy intake change (kcal/day) at the end of the fifth year (n=2371)
<£5,000	-2.8 ± 1.51*	-70.3 ± 35.07**
£5,000 - £19,000	-2.6 ± 1.60*	-60.4 ± 37.97**
£20,000 - £49,000	-2.8 ± 1.56*	-57.5 ± 30.93**
>£50,000	-2.7 ± 1.35*	-70.3 ± 34.50**

*Kuskal-Wallis non-parametric test, p=0.49; **Kuskal-Wallis non-parametric test, p=0.49

Appendix I | Publications related to this thesis

- ***Roberta Alessandrini, Feng J He, Kawther M Hashem, Monique Tan, Graham A MacGregor. Reformulation and Priorities for Reducing Energy Density; Results from a Cross-Sectional Survey on Fat Content in Pre-Packed Cakes and Biscuits Sold in British Supermarkets. Nutrients 2019, 11, 1216.***

Background: *Cakes and biscuits are among the most widely consumed manufactured food categories which contribute to calories and fat intake in UK diets.*
Objectives: *To assess whether fat reformulation is possible in cakes and biscuits*
Design: *Cross-sectional survey of the fat content of cakes and biscuits available in nine UK supermarket chains.*
Results: *In cakes (n = 381), the mean total fat content was 17.9 ± 5.2 g/100g (39% of the overall energy); range (1.4–35.6 g/100g) and the average saturated fat content in cakes was 5.9 ± 3.4 g/100g (13% of the overall energy); range (0.3–20 g/100g). In biscuits (n = 481), the mean total fat content was 21.8 g ± 6.3 g/100g (40% of the overall energy); range (0.7–38.9 g/100g) and the average saturated fat content was 11.4 ± 4.9 g/100g (23% of the overall energy); range (0.3–22.3 g/100g). In both cakes and biscuits, total and saturated fat content was positively correlated with energy density.*
Conclusions: *Cakes and biscuits sold in UK supermarkets are high in total and saturated fat, and that fat content contributes substantially to product energy density. Fat reformulation in these products would effectively reduce energy density, calorie intake and help prevent obesity. Fat reformulation should be implemented simultaneously with sugar reformulation and be focused on saturated fat, as this will have the additional effect of lowering LDL cholesterol.*

- ***Roberta Alessandrini, Feng J He, Yuan Ma, Vincenzo Scrutinio, David S Wald, Graham A MacGregor, Potential impact of gradual reduction of fat content in manufactured and out-of-home food on obesity in the United***

Kingdom: a modeling study, The American Journal of Clinical Nutrition, 2021; *https://doi.org/10.1093/ajcn/nqaa396*. ***Online ahead of print.***

Background: *Manufactured and out-of-home foods contribute to excessive calories and have a critical role in fueling the obesity epidemic. We propose a 20% fat reduction in these foods.*
Objectives: *To evaluate the potential impact of the proposed strategy on energy intake, obesity, and related health outcomes in the population.*
Methods: *We used the National Diet and Nutrition Survey rolling program (NDNS) data to calculate fat and energy contributions from 46 manufactured and out-of-home food categories. We considered a gradual fat reduction—focusing on SFA—in these categories to achieve a 20% reduction in 5 years. We estimated the reduction in energy intake in the NDNS population and predicted the body weight reduction using a weight loss model. We scaled up the body weight reduction to the UK adult population. We estimated reductions in overweight/obesity and type 2 diabetes cases. We calculated the reductions of LDL, ischemic heart disease (IHD), and stroke deaths that could be prevented from the SFA reduction.*
Results: *The selected categories contributed to 38.6% of the population's energy intake. By the end of the fifth year, our proposed strategy would reduce the mean energy intake by 67.6 kcal/d/person (95% CI: 66.1–68.8). The energy reduction would reduce the mean body weight by 2.7 kg (95% CI: 2.6–2.8). The obesity prevalence would be reduced by 5.3% and the overweight prevalence by 1.5%, corresponding to 3.5 and 1 million cases of obesity and overweight, respectively, being reduced in the United Kingdom. The body weight reduction could prevent 183,000 (95% CI: 171,000–194,000) cases of type 2 diabetes over 2 decades. Energy from SFA would fall by 2.6%, lowering LDL by 0.13 mmol/L and preventing 87,560 IHD deaths (95% CI: 82,260–112,760) and 9520 stroke deaths (95% CI: 4400–14,660) over 20 years.*
Conclusions: A modest fat reduction (particularly in SFA) in widely consumed foods would prevent obesity, type 2 diabetes, and cardiovascular disease

Appendix II | Other publications, posters, and training

Publications

- ***Temme, Elisabeth H.M.; Vellinga, Reina E.; de Ruiter, Henri; Kugelberg, Susanna; van de Kamp, Mirjam; Milford, Anna; Alessandrini, Roberta; Bartolini, Fabio; Sanz-Cobena, Alberto; Leip, Adrian. 2020. A. Demand-Side Food Policies for Public and Planetary Health.*** **Sustainability** ***2020,*** **12*,*** ***5924.*** [***https://doi.org/10.3390/su12155924***](https://doi.org/10.3390/su12155924)

<u>Background:</u> The current food system has major consequences for the environment and for human health. Alignment of the food policy areas of mitigating climate change and public health will ensure coherent and effective policy interventions for sustaining human health and the environment.

<u>Objective:</u> This paper explores literature on demand-side policies that aim to reduce consumption of animal-based foods, increase plant-based foods, and reduce overconsumption.

<u>Methods:</u> We searched for publications, published between January 2000 and December 2019, considering the above policy domains. Articles were distinguished for type of policy instrument, for topic via keywords and examples were given.

<u>Results:</u> Most demand-side policies focus on preventing overweight and obesity, using all types of policy instruments including more forceful market-based policies. Hardly any examples of public policies explicitly aiming to lower animal-based foods consumption were found. Policies combining health and sustainability objectives are few and mainly of the information type.

<u>Conclusions:</u> Moving towards environmentally sustainable and healthy diets is challenging as the implemented demand-side policies focus largely on human health, and not yet on environmental outcomes, or on win-wins. Policies targeting foods from the health perspective can contribute to lower environmental impacts, by indicating suitable animal-based food replacers, and aiming at avoiding overconsumption of energy dense-nutrient poor foods. Working solutions are available to ensure coherent

and effective demand side food policies aligning public health and environmental aims. Implementation of aligned and effective policy packages is urgent and needed.

- ***Alberto Sanz-Cobena, Roberta Alessandrini, Benjamin Leon Bodirsky, Marco Springmann, Eduardo Aguilera, Barbara Amon, Fabio Bartolini, Markus Geupel, Bruna Grizzetti, Susanna Kugelberg, Catharina Latka, Xia Liang, Anna Birgitte Milford, Patrick Musinguzi, Ee Ling Ng, Helen Suter & Adrian Leip. Research meetings must be more sustainable. Nature Food 2020, 1, 187. https://www.nature.com/articles/s43016-020-0065-2***

This paper was originated from the conversations had during the second meeting of the Expert Panel of Nitrogen and Food held in Cercedilla (Spain) in 2018. The paper (i.e. the Cercedilla Manifesto) states how scientific meetings should be organized in the spirit of responsible consumption and production, including the prioritization of plant-based meals for reduced nitrogen loss. The Cercedilla Manifesto is linked to an online petition which was signed by 300 researchers across the globe: https://www.openpetition.eu/petition/online/cercedilla-manifesto-research-meetings-must-be-more-sustainable

Posters

- ***Food futures: Storylines of dietary megatrends along the Shared Socioeconomic Pathways (SSPs). Roberta Alessandrini and Benjamin L Bodirsky. Proceedings of the Nutrition Society, 2020, 79(OCE2), E327. doi:10.1017/S002966512000275X***

Diet shapes human health and has been a major driving force of global change during the 21st century. The establishment of narratives encompassing patterns of dietary change is therefore crucial for exploring visions of future development, harmonising scenario-based assessments within the scientific community, and facilitating communication between scientists, policymakers, and other stakeholders. The Shared Socioeconomic Pathways (SSPs) have recently been established as a focal point of scenario analysis. However, they remain vague with respect to food systems and, in particular, to the development of dietary drivers, patterns, and outcomes.

This article formulates and discusses five plausible dietary narratives compatible with the SSPs, each unique with respect to its main actors, policy framework, food supply chain organisation, consumer context, dietary composition, and health outcomes in cases of under- and overnutrition. This approach allows for a more comprehensive study of food system dynamics than is possible via quantitative approaches and enables researchers to investigate more explorative futures compared to model-derived scenarios.

I presented the above poster at the Oxford's Livestock, Environment, and People 2019 conference and at the 13th European Nutrition Conference 2019 held in Dublin. The publication has been submitted and it is now under revision.

- ***Nutritional quality of plant-based meat products available in the UK: a cross-sectional survey. Roberta Alessandrini, Mhairi K Brown, Sonia Pombo-Rodrigues, Sheena Bhageerutty, Feng J He, Graham A MacGregor.***

Background: Plant-based diets have been gaining popularity in the UK due to concerns over the health, animal welfare, and environmental issue linked to animal-based foods. The objective of this study is to compare the nutrient profile of plant-based meat with equivalent meat products.

Methods: We conducted a cross-sectional survey of plant-based meat products available from 14 retailers in the UK and collected data for the equivalent meat products. We extracted data on energy density, total and saturated fat, protein, fibre, sugar, and salt content per 100g from product labels. We calculated the nutrient profile score (NPS) for all products using the UK Nutrient Profiling Model and compared meat products with plant-based meat through Wilcoxon tests. We calculated the percentage of products that would get at least one high (red) label for fat, saturated fat, or salt using the UK's front of pack colour coded labelling criteria. We calculated the proportion of plant-based products that would meet the UK salt reduction targets.

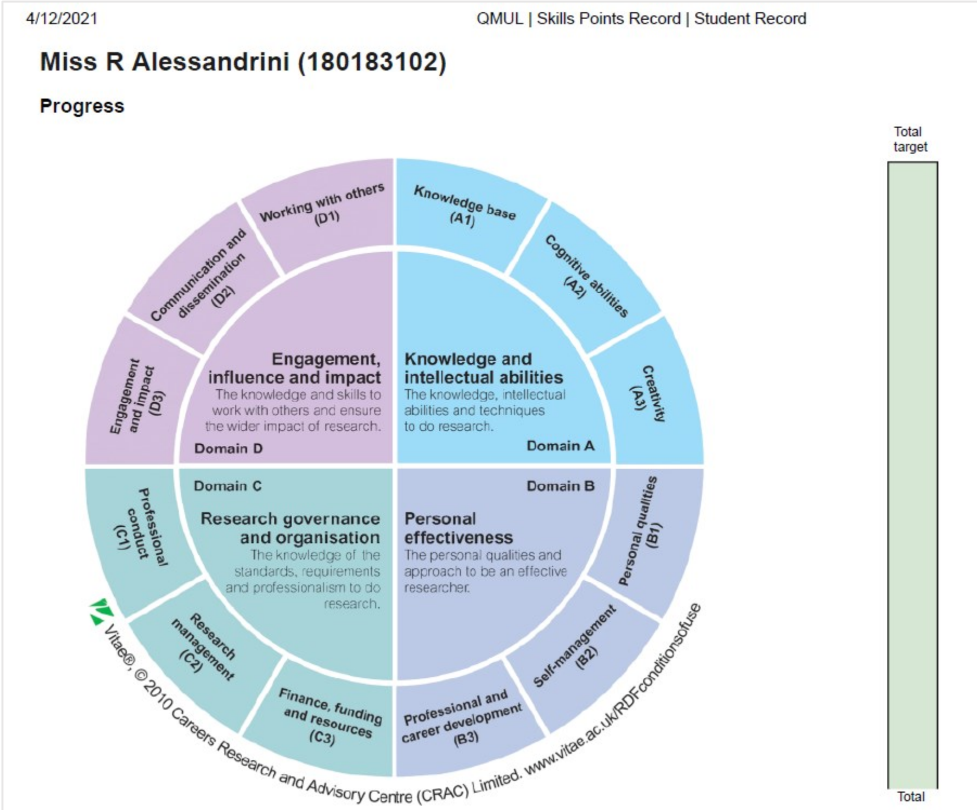
Results: We collected data for 207 plant-based meat and 226 meat products. Compared to meat, plant-based meat had significantly lower energy density, total fat, saturated fat, and protein and significantly higher fibre per 100g of products. Salt content in plant-based meat was significantly higher in four out of six categories. Plant-based meat had *a significantly lower NPS (i.e. healthier) in five out of six categories. Around 20% of the plant-based meat and 46% of the meat products had at least one high/red label for either total fat, saturated fat, or salt ($p<0.001$). Two thirds of the plant-based products did not meet the current UK salt targets.*

Conclusions: *Plant-based meats have a better nutrient profile compared to meat. However, more progress is needed to reduce salt in these products.*

I presented the results of the above study at the Oxford's Livestock, Environment, and People 2020 conference (oral presentation). The paper has now been submitted.

Training

Since enrolment in my current PhD programme, I have attended 273 hours of development activities (the minimum is 220) under the four domains specified by the UK Research Councils (knowledge and Intellectual abilities; personal effectiveness; research governance and organisation; engagements, influence, and impact). Most of the training courses attended were provided by the Researcher Development Team at Queen Mary University of London.



The figure shows that I have achieved the minimum number of skills points for each researcher development domains.

In 2020. I was given the opportunity to enrol and complete a deveopment course for women researchers provided by the Springboard Consultancy.


Researcher Development | Queen Mary University of London

springboard work and personal development for women

This is to certify that

Roberta Alessandrini

has completed the

Springboard Women's Development Programme

run by

Researcher Development

at

Queen Mary University of London

Signed by

Dr. Anna Price,

Head of Researcher Development

19th May, 2020

Springboard certificate of attendance.

Lastly, I took part in the mentorship programme supported by Queen Mary University. My mentor is Dr Anna Birgitte Milford based at the Norwegian Institute for the Bioeconomy.

Teaching

Over the past two years, I have tutored first and second year medicine students during their problem-based learning sessions and marked their assignments. I also gave a lecture on my research project to the Global Health Master's students at Queen Mary University of London.

Conference presentations

I was invited to present my research at the *Oxford's Livestock, Environment, and People 2020 conference*, at the *VegMed Conference 2021*, and at *Food Matters Live 2021*.