Impact of food environment policies and food insecurity on less healthy food consumption, obesity and health economic outcomes a model-based appraisal

NOURISH – **N**utrition, **O**besity and **U**nhealthy food **R**elationships in food **I**nsecure populations: **S**ystems modelling of **H**ealth-related policies and outcomes

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LIST of CONTENTS

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Sponsor	The University of Sheffield
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STUDY SUMMARY

Study Title	Impact of food environment policies and food insecurity on less healthy food consumption, obesity and health economic outcomes a model-based appraisal
Internal ref. no. (or short title)	NOURISH
Study Design	Secondary data analysis and computational modelling
Study Duration	3 years
Summary	Obesity and food insecurity are rising in the UK, and policy makers need to identify evidence-based strategies to reduce these. Both are strongly related to environmental factors influencing food access and availability. Policies that alter the food environment may reduce obesity, but they may have unintended consequences including differential effects on food secure versus insecure populations. Agent-based models (ABMs) are a promising tool for evaluating public health policies, considering the complexity of behaviour and individual-environment interactions. However, their application to dietary policy has been limited. The aim of this project is to assess the health, economic and inequality impact of food environment policies across localities using a categories of food insecurity lens. Research questions: RQ1: What conceptual model describes how food insecurity, alongside other factors within the food system, influences the impact of food environment policies on high fat, salt and sugar (HFSS) food consumption and obesity? RQ2. How can a combination of datasets inform the estimation of structural equation models and a synthetic population to examine how differential exposure to environment factors including deprivation affect household food insecurity and hence influence different food choices for individuals, households and communities? RQ3: What is the structure and parameter estimation for an agent-based model that incorporates how environment and food insecurity factors influence individuals' food choices so that the model is calibrated to the emergent, contrasting trends between 2018 and 2023 in HFSS consumption by food insecurity categories and obesity rates for population subgroups across local authorities in Greater Manchester? RQ4: What are the impacts of three food environment policies (advertising, outlet restrictions, accessibility of healthy food) on health outcomes, labour market outcomes and inequalities for population subgroups across Greater Manchester localities including those defined by food insecurity category? The study takes a multidisciplinary approach involving stakeholder engagement, conceptual modelling, data synthesis, structural equation modelling, and empirical ABM development including comprehensive model calibration and validation. We will integrate data from surveys and environmental databases to create a synthetic population. The ABM will be calibrated and validated using trends in obesity and HFSS consumption for 10 local authorities across Greater Manchester. We will use the ABM to simulate three dietary policies

	and quantify the impact on HFSS consumption, obesity, and health and economic costs and benefits.

FUNDING AND SUPPORT IN KIND

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ROLE OF STUDY SPONSOR AND FUNDER

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ROLES AND RESPONSIBILITIES OF STUDY MANAGEMENT COMMITEES/GROUPS & INDIVIDUALS

The Trial Steering Committee will have a majority independent representation, including the Chair. They will meet regularly and to provide overall supervision for the project on behalf of the Project Funder and to ensure that the project is conducted to the rigorous standards set out in the Department of Health's Research Governance Framework for Health and Social Care and the Guidelines for Good Clinical Practice.

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KEY WORDS: Public Health, Obesity, Food Insecurity, Agent-based modelling (ABM)

STUDY FLOW CHART

	Work Package 1 (month 1-20)	Work Package 2 (month 1-14)	Work Package 3 (month 7-25)	Work Package 3 (month 24-36)
Research question	What conceptual model describes how food insecurity, alongside other factors within the food system, influences the impact of food environment policies on high fat, salt and sugar (HFSS) food consumption and obesity?	How can a combination of datasets inform the estimation of structural equation models and a synthetic population to examine how differential exposure to environment factors including deprivation affect household food insecurity and hence influence different food choices for individuals, households and communities?	What is the structure and parameter estimation for an agent-based model that incorporates how environment and food insecurity factors influence individuals' food choices so that the model is calibrated to the emergent, contrasting trends (2018-2023) in HFSS consumption by food insecurity categories and obesity rates for population subgroups across local authorities in Greater Manchester?	What are the impacts of three food environment policies (advertising, outlet restrictions, accessibility of healthy food) on health outcomes, labour market outcomes and inequalities for population subgroups across Greater Manchester localities including those defined by food insecurity category?
Aim	Co-design modelling infrastructure, engaging with stakeholders throughout and drawing upon available evidence.	Generate a comprehensive synthetic database and structural equation model (SEM) to quantify the relationships between food environment factors, food insecurity, HFSS consumption and obesity (2018-2023)	Develop an empirical ABM of HFSS food choices and obesity, representing pathways and feedback loops between the food environment and food insecurity and dietary behaviour.	Offer evidence-based insights into the impact of interventions aiming to reduce obesity in the population, along with their associated costs, benefits and any unintended consequences
Method	Collaborative conceptual modelling and targeted literature searches	Iterative proportional fitting, spatial microsimulation, structural equation modelling	Agent-based modelling, approximate bayesian computation	Agent-based modelling Health economic modelling and analysis
Data		**Individual level:** National Diet and Nutrition Surveys 2008-, Understanding Society 2018-, Food and You 2018-, Living Costs and Food SurveyHealth Survey for England 2018-, Keenan et al. surveys 2020-. **Environment level:** E-food Desert Index, Priority Places for Food Index, Advertising Spend data, Ordnance Survey PoI	**Model population and calibration targets:** Integrated synthetic database from WP2. **Model mechanisms:** SEM from WP2. **Additional model parameters**; expert elicitation	**Model:** Agent-based model from WP3 linked to health economic model **Policy parameters**: Expert elicitation
Outputs	Specification for the final version of the conceptual model and path analysis, policies to model, model validation steps and sensitivity analyses	Synthetic database and SEM describing the individual, household and environment level drivers of food choice and food insecurity over time	An empirically informed ABM of food choices and obesity in local authorities in GM	A food policy evaluation including health and economic impacts for up to three policies.
PPI and stakeholder involvement	Regular meetings to receive feedback and input from a diverse group of people and stakeholders from local government and charity organisations			

2 BACKGROUND

National and local policy makers need to identify policies that improve population health outcomes, reduce health inequalities, and are cost-effective. Obesity and food insecurity are both complex public health challenges that require evidence-based approaches to address their underlying causes. Obesity and food insecurity are associated with numerous chronic health conditions, including hypertension and diabetes (1, 2), and are concentrated in the most disadvantaged populations, contributing to health inequalities in the UK (3, 4). Obesity and food insecurity are strongly influenced by environmental factors influencing food access, affordability and availability (5, 6). Policies to alter the food environment have been suggested as a strategy to reduce obesity (7). Interventions such as advertising restrictions for foods high in fat, salt and sugar (HFSS) have seen encouraging results, in terms of reduced household purchasing of HFSS foods (8). However the specific mechanisms underlying the effectiveness of these policies (i.e. how individual and societal level behaviours change due to policy influence) are unclear. These policies function within a complex system and, if not carefully implemented, may have unintended effects including increasing food insecurity in vulnerable populations. To understand the impact of different place-based interventions (e.g. food advertising restrictions) on obesity and food insecurity, we can develop models that explain the relationship between food policies and their effects, taking into account the complexity of the relationships and feedback loops. This project will synthesise the existing evidence base by establishing **empirically calibrated systems models to link modifiable environmental factors with HFSS consumption and food insecurity** to assess the **local impact of policy options** aiming to positively influence these relationships.

Obesity rates have been rising in the UK, particularly among disadvantaged populations, with two thirds of adults in the most deprived decile classified as overweight or obese in 2021 (4). Simultaneously, food insecurity has increased over the past decade and was further exacerbated by the COVID-19 pandemic (3). Food insecurity is defined by inadequate availability, accessibility, utilisation, and stability of nutritious food, and occurs when individuals cannot consistently access an adequate supply of nutritious food that meets their dietary needs (9). A recent survey estimated that in 2022, almost a fifth of UK households experienced moderate to severe food insecurity, which is consistently associated with negative health outcomes such as poor mental health and chronic diseases like hypertension and diabetes (1, 2). Food insecurity is associated with obesity in high income countries, including the UK, particularly in adult women (10). This relationship, often referred to as a paradox (11) is complex and is influenced by multiple factors such as dietary quality and environmental and neighbourhood level factors in disadvantaged areas, where healthy options are limited and unaffordable with low food secure households reporting less accessibility of healthy foods (12). Psychological distress and limited resources for adaptive coping mechanisms associated with increased consumption of unhealthy (HFSS type) foods are potentially important factors mediating this relationship (13). A combination of explanations is needed to understand the complex relationship between food insecurity and obesity, particularly when looking at differences between social groups (14). The proposed research will provide critical insights into how environmental factors interact with consumption of HFSS foods and how these interact with obesity and food insecurity. By building an integrated understanding of complex interactions between these factors and the food environment we can develop evidence-based policies and interventions that target disadvantaged populations, reduce health inequalities, and promote better access to healthy food options.

Food environment interventions, particularly food advertising restrictions, have been promoted as potentially effective policies for reducing consumption of unhealthy foods (15). Restricting TV advertising of foods has also been suggested to have the potential to reduce childhood obesity; and out of home advertising also targets both adults and children (16). Following a ban on HFSS advertising across London transport networks, purchasing of these foods reduced by 6.7%, with some differences between sociodemographic groups (8). A recent modelling study used purchasing data to explore potential health and economic impacts of this policy, finding significant improvements to obesity outcomes and potential savings to the NHS of £218m (17). Food advertising bans have also been implemented in other locations, including Bristol, and work is ongoing to quantify the impact of these interventions (Award ID:NIHR152114). Whilst this modelling approach can extrapolate the observed effects over time, it does not account for the complex behavioural mechanisms underlying decisions to purchase HFSS foods following the removal of advertising. This makes it more challenging to compare with alternative policies that have not undergone formal evaluation and predict the effect in other areas. These methods also do not allow for interactions between individuals or for the assessment of place-based interventions, as interactions between individuals and their environment are not represented. These approaches also do not allow for the modelling of the effects of a policy on unintended negative consequences, for example a worsening of food insecurity. An ideal next step for this modelling would be to be able to explicitly consider the underlying behavioural mechanisms and how these interact with environmental factors to better predict the differential outcomes by population groups.

Food choices are a complex problem that involve the interaction of multiple mechanisms at an individual and environmental level, and there have been calls for the use of complex methods in public health research (18). Complex systems modelling techniques such as agent-based models (ABMs) are well placed to represent the complexity of environmental interactions with food choices and allow for detailed population-level modelling including subgroups defined by deprivation. An ABM is a computer simulation that mimics real-world scenarios by representing individual entities (agents) and their interactions to understand complex systems and behaviours. A recent review identified 56 studies that used simulation models to evaluate the impact of dietary policies including taxation, labelling and reformulation (19), but no studies that were identified used an ABM. There is considerable scope to develop an ABM to evaluate the impact of dietary policies, representing realistic behavioural mechanisms and complex individual-environment interactions. Whilst no ABMs were identified in this review to explore the impact of dietary policies, several ABMs have been developed to explore dietary behaviours. We have reviewed these dietary behaviour ABMs to inform the development of this proposal.

Literature review (performed to inform proposal development)

Aim: To provide an overview of how ABMs have been previously used to explore dietary behaviours and obesity, with a focus on the underlying mechanisms that are used to determine dietary choices.

Method: We conducted a search of titles and abstracts in Web of Science to identify ABMs that have been used to explore dietary behaviours. Search terms combined “agent-based model” with dietary behaviour queries (dietary behav* OR food consumption OR dietary choices OR eating habits OR junk food OR fast food OR obesity).

Results: 182 articles were identified with 9 reviews and 119 articles (others were datasets, dissertations). Focusing initially on the 9 reviews – we identified two that had specifically investigated the way in which agent-based models have been used in obesity and dietary behaviour research.

One review (20) published in 2019 systematically reviewed the different computational models of obesity published up to 2018. This study included 38 studies reporting 30 different models. This review identified 14 agent-based models, with the rest being system dynamics models; most ABMs were based on a US setting with only one in a UK setting. The review highlighted that most of the mechanisms underlying behaviour in the models were based on social network influences with some exploring social norms.

Another review aimed to explore the way that agent-based models have been developed in obesity research and whether these have been done rigorously. This review identified 32 ABMs used in obesity research between 2013 and 2019, demonstrating that these methods offer considerable potential to incorporate the complexity of dietary behaviours into models (21). It highlighted promising avenues for future work, including utilising rich datasets to represent the food environment.

We restricted our search to studies that would not have been included in the previous reviews – those published in 2019 and later. This left 74 articles. 24 of these directly reported an agent-based model of food consumption or obesity and were published between 2019 and 2023.

Psychological mechanisms

Several psychological mechanisms were incorporated into the models including social norms and peer influence. However, only two studies made explicit references to psychological theory such as the theory of planned behaviour (22) and the “unhealthy food addiction hypothesis” (23).

The food environment and food insecurity

A minority of studies considered the food environment or food insecurity using real-world data but did not explicitly reference psychosocial theory. One study based on a cohort in Austin, Texas, integrated multiple data sources at individual and neighbourhood levels, incorporating food insecurity in a model examining the impact of a healthy food initiative (24). Another study conducted in Texas considered elements of the food environment such as supermarket and fast-food restaurant densities but did not explicitly consider food insecurity (25). The impact of policies to improve access to fruits and vegetables in rural areas was modelled, but results are not broken down by any measure of food insecurity or socioeconomic status. One other study (published since the (19) review) used an ABM to evaluate the impact of taxes, nutrition warning labels and food advertising on the purchasing of ultra-processed foods in Latin-American countries, but did not include any representation of the food environment (26).

Summary

This demonstrates that there is significant potential for the integration of complex behavioural mechanisms and individual-environment interactions in ABMs evaluating dietary behaviours and policies in a UK context. Although worsening food insecurity is a potential unintended consequence of dietary policies that aim to alter the food environment, this has not been considered in many agent-based models to date.

2 RATIONALE

This study will focus on modelling food environment policies that aim to enhance healthy food choices and reduce obesity, without worsening food insecurity. These policies include the regulation of food advertising, increasing healthier food options and reducing unhealthier food options. Our focus will be on HFSS foods, as these foods have significant policy attention and many regions across the UK have recently implemented restrictions on their advertising. We are working with policy stakeholders in Greater Manchester (GM) including Greater Manchester Combined Authority, they are most interested in policies targeting these foods.

Following our discussions with stakeholders and the public and our review of evidence, we have decided it is important to consider the role of food insecurity in the relationship between food environment policies and eating behaviours. There are numerous complex factors influencing food choices in food insecure populations, with a potential role for food environment factors such as availability of healthy food options as well as distress and eating to cope. Therefore, people may make different food choices when they are food secure versus not secure and these could be influenced differently by policy. It is important to consider impacts on food insecure populations as a potential unintended consequence of food environment policies.

Using data from the Trussell Trust (27) and Office for Health Improvement and Disparities (4) we observed substantial differences and diverging patterns over time in areas within the GM region in terms of obesity and one potential indicator of food insecurity – food parcel distribution. For example, in Rochdale adult obesity has consistently risen alongside higher food parcel distribution. Wigan exhibits similar high obesity rates but with lower food parcel distribution. These distinct regional dynamics form an ideal dataset for developing an agent-based model to disentangle the mechanisms driving these different trends. This project will aim to identify factors such as concentration of food outlets and exposure to food advertising that might contribute to these variations. Food parcel distribution is not an ideal measure of food insecurity, and food insecurity data is not widely available at the local authority level. By focusing on GM and partnering with stakeholders in GM we can access two surveys that would otherwise be unavailable: The Greater Manchester Residents Survey and The Bread and Butter Thing (TBBT) annual members surveys to give us insights into how the dynamics of food insecurity have changed across the region, within each of the 10 local authorities.

Existing simulation models evaluating dietary policies often lack the capacity to represent complex behavioural mechanisms and individual-environment interactions (19). There are limited previous ABMs that consider food insecurity as an unintended consequence of dietary policies, or comprehensively explore the psychological mechanisms underlying food choices, or consider environmental influence, particularly in a UK context (20).

Our approach will use collaborative conceptual modelling to develop a shared understanding of the relationships between the food environment and HFSS food consumption and how these might differ by different factors, particularly food insecurity. We will use literature searches and develop a comprehensive synthetic database of the relationships between these factors to inform the parameters of our model. We will comprehensively validate our findings against trends in HFSS food consumption and obesity patterns across 10 areas of Greater Manchester.

3 RESEARCH QUESTIONS

This project aims to develop and utilise an ABM that can evaluate the health, inequalities, and economic impacts of place-based food interventions. The model will capture the relationship between individual and environmental level factors, with a focus on exploring modifiable factors that could be influencing this relationship and be amenable to policy interventions. We focus on the role of food insecurity, to explore its role in the relationship between place-based food interventions and consumption and quantify any unintended effects these interventions may have on food insecurity.

The project has four work packages, described in detail below, each aim to answer a specific research question:

- RQ1: What conceptual model describes how food insecurity, alongside other factors within the food system, influences the impact of food environment policies on high fat, salt and sugar (HFSS) food consumption and obesity? (WP1)
- RQ2. How can a combination of datasets inform the estimation of structural equation models and a synthetic population to examine how differential exposure to environment factors including deprivation affect household food insecurity and hence influence different food choices for individuals, households and communities? (WP2)
- RQ3: What is the structure and parameter estimation for an agent-based model that incorporates how environment and food insecurity factors influence individuals' food choices so that the model is calibrated to the emergent, contrasting trends (2018-2023) in HFSS consumption by food insecurity categories and obesity rates for population subgroups across local authorities in Greater Manchester? (WP3)
- RQ4: What are the impacts of three food environment policies (advertising, outlet restrictions, accessibility of healthy food) on health outcomes, labour market outcomes and inequalities for population subgroups across Greater Manchester localities including those defined by food insecurity category? (WP4)

4 STUDY DESIGN

WP1: Stakeholder engagement: mapping the food system, conceptual modelling, policy identification and prioritisation for quantitative analysis. (Months 1-20) Lead: Squires

Aim: The aim of WP1 is to co-design the modelling infrastructure, engaging with stakeholders throughout and drawing upon available evidence.

Objective 1: Develop a shared understanding of the complex problem and determine the model scope, including policy scenarios to be implemented in the ABM and useful model outcomes.

Objective 2**:** Develop and justify the model structure, including (i) finalising a systems model setting out the relationship between sociodemographic, psychological, environmental and behavioural variables, to be implemented in the ABM, (ii) agreeing on calibration targets and data and (iii) describing how the ABM integrates with the existing health economic model.

Objective 3: Obtain feedback on the realism and practical implications of the model results, refine appropriately, and agree on sensitivity analyses.

Preliminary findings: Co-applicant Squires published a conceptual modelling framework for developing the structure of public health economic models (28), which is now widely used. It sets out four key principles of good practice which will be followed, including that: 1. a systems approach to public health modelling should be undertaken; 2. a documented understanding of the problem is important before and alongside developing and justifying the model structure to develop valid, credible and feasible models; 3. strong communication with stakeholders is essential throughout model development; and 4. a systematic consideration of the determinants of health is central to identifying key impacts of the interventions. More recently, several co-applicants (alongside other multidisciplinary experts) developed a toolbox of methods for incorporating the influences on behaviour into public health economic models (29). This includes a decision algorithm for choosing which methods are appropriate and sets out some novel but impactful methods which have not been widely used in this field. One such method draws upon systems mapping but uses it to incorporate both behavioural theory and social structures. A case study around smoking uptake and cessation is currently underway which is utilising the integration of both frameworks to inform the development of an agent-based model to assess the effectiveness and cost-effectiveness of a set of policy interventions [award number PRCRPG-Nov21\100002]. The conceptual modelling has successfully provided tools for communication with a range of collaborators and allowed us to be able to discuss complex issues within a multidisciplinary team. We plan to utilise a similar approach within this project.

Design: We will conduct collaborative conceptual modelling with project stakeholders from GM including Greater Manchester NHS and The Bread and Butter Thing (TBBT), a charity based in GM who provide fresh, healthy food to families with low disposable income. We will include national stakeholders, Sustain, a charity advocating for healthy and sustainable food systems. We will use Sustains extensive networks of local authorities to identify stakeholders outside of GM to participate in workshops. We will use the above frameworks to discuss and document our understanding of this complex problem, agree the model scope to be most useful to stakeholders, and determine which sociodemographic, psychological and environmental factors are important to include in such a model. We will design the final version of the systems model that will be assessed using the agent-based model. We will develop a technical specification document for the ABM, setting out all modelling methods, data and assumptions. We will also work with our PPI co-applicant and PPI panel to produce summaries that can be understood and presented to a wider audience.

Building on a baseline systems map, we will conduct targeted literature searches and consult with stakeholders to develop our understanding of the issue to be modelled and the initial systems maps. We will hold three workshops with our stakeholders (Greater Manchester Combined Authority, Sustain, TBBT) and all academic partners over the course of the project to collaboratively develop the ABM and ensure maximum policy relevance, including the potential to have an impact on residents in different areas in GM. Stakeholders will be invited to participate if they meet one or more of the following inclusion criteria: (1) they have expertise in obesity, food insecurity, food systems or food policy, they represent organisations with a particular focus on Greater Manchester, they represent local authorities outside of Greater Manchester to bring a national perspective. Stakeholders will be excluded if they have a potential conflict of interest, such as financial links to unhealthy food brands or the advertising industry. We will produce output documents from the workshops which will be shared with all stakeholders for comment following the workshops to ensure all views are represented.

Workshop 1. Purpose: Deliver objective 1

Outline:

- Presentation and discussion of our understanding of the problem to be addressed by the model, including mechanisms and pathways between food environment factors and food insecurity to HFSS consumption, considering socioeconomic inequalities and health and cost outcomes.
- Defining the model boundaries - prioritisation exercise to agree on the essential components of the model for policy relevance. Agree on key policies to be assessed in the model, comparators, subgroups to be included, model outcomes, modelling perspective and timeframe.
- Presentation of key elements of existing smoking cessation case study to demonstrate the modelling process and outputs.
- Discussion and development of a systems model, setting out the relationship between sociodemographic, psychological, environmental and behavioural variables to inform WP2.
- Discussion of how this systems model applies within the GM context, and it’s generalisability.

Outputs: Documented understanding of the problem, outlining pathways and interactions between food insecurity, obesity, HFSS consumption, the food environment and health and costs. Agreed model scope. Initial systems map to inform WP2.

Workshop 2. Purpose: Deliver objective 2

Outline:

- Presentation of results from WP2 and discussion of how this could impact the systems model and ABM.
- Presentation of the SPHR diabetes prevention health economic model and how this will integrate with the ABM and the purpose of model calibration and validation – to ensure that model findings are robust and representative of the target phenomena.
- Discussion of data that can be used for calibrating and validating the model.
- Agree on a series of calibration and validation data targets (for example, obesity or HFSS consumption patterns across local authorities in Greater Manchester over time).
- Critical review of model assumptions.
- Presentation of underlying assumptions in the ABM and systems model.
- Stakeholder input to validate, modify or refine assumptions based on real-world insights and policy relevance.

Outputs: A systems map setting out the relationship between sociodemographic, psychological, environmental and behavioural variables, to be implemented in the ABM. A technical specification document for the ABM.

Workshop 3. Purpose: Deliver objective 3.

Outline:

- Presentation of initial model outputs, showing simulation results for patterns in obesity and food insecurity across GM.
- Gather stakeholder insights into model outputs and obtain feedback on the realism and practical implications of the initial results, including identifying areas where the model outputs diverge significantly from real-world observations or stakeholder expectations.
- Discuss how the model might apply to other UK contexts (e.g., rural, or coastal communities)
- Discuss potential modifications or enhancements to model structure, mechanisms or assumptions.
- Prioritise the suggested refinements based on their potential impact in addressing policy questions.
- Agree on sensitivity analyses and final model validation steps.

Outputs: An updated specification for the final version of the model. Agreed sensitivity analyses and final model validation steps. One publication describing the conceptual modelling for a computer decision tool to assess the impact of food environment policies on dietary behaviours.

WP2: Food system data analysis and construction of a synthetic population. Lead: Buckley

Aim: Generate a comprehensive synthetic database and structural equation model (SEM) to quantify the relationships between food environment factors, food insecurity, HFSS consumption and obesity.

Objective 4: Generate a synthetic database integrating data at the environmental, individual and household level for the factors influencing food choice, food insecurity and obesity.

Objective 5**:** Based on the systems map produced in WP1, generate a SEM to describe the relationships between food environment factors and HFSS consumption and how these differ by food insecurity status.

Preliminary findings: Co-applicant Keenan has recently conducted psychological surveys that provide insights into individual-level factors involved in food-related decisions by those experiencing food insecurity. This work builds on evidence showing robust associations between obesity and food insecurity (10) and psychological factors underpinning dietary patterns including emotional eating (30). This research reveals a critical role for distress. In one study, the relationship between food insecurity and diet quality was mediated by psychological distress and eating to cope (31). If individuals reported distress in response to food insecurity and using food as a coping mechanism, they were more likely to consume a less nutritious diet (i.e. less fresh produce and more HFSS type foods). Another study (13) found that food insecurity related distress and eating to cope was associated with higher BMI. Combined, these studies highlight a pathway (Attachment 3) through which food insecurity might influence both increased consumption of HFSS foods and BMI via distress and using foods as a coping mechanism. This project will further exploit this psychological data by synthesising it with a rich range of other data to create a comprehensive synthetic database. This will help identify if distress is a driver of consuming more HFSS foods in different regions and could potentially reveal areas where higher distress and greater availability of HFSS combine to drive weight gain.

Design: For objective 4, we will gather and combine evidence on connections between the food environment and psychological factors underlying eating behaviours such as distress. Individual-level data from surveys (incl. National Diet and Nutrition Surveys, Health Survey for England) and published research and geographic information (incl. exposure to food advertising, proximity to healthy and unhealthy food outlets) will be merged to create a comprehensive database. For objective 5 we will use SEM, to identify correlations mechanisms and effect sizes, and generate calibration targets for modelling in WP3.

Setting: The initial synthetic database will be developed at the national (UK) level, integrating 6 national datasets (National Diet and Nutrition Surveys, Food and You 2, Health Survey for England, Understanding Society, Living Costs and Food Survey and Food Foundation) on dietary patterns and BMI, food insecurity and psychological factors that can influence food choices by detailed sociodemographic indicators including index of multiple deprivation. This will be supplemented with additional data which will provide greater detail on psychological mechanisms underlying food insecurity (Keenan et al.), the relationship between dietary behaviours and food insecurity in food insecure populations (Shinwell et al. (32)), and patterns of food insecurity and related sociodemographic factors across Greater Manchester (The Bread and Butter Thing Surveys and GM Residents Surveys).

Data: Developing an empirical ABM requires a comprehensive database, including information about individual behaviours and characteristics, the population, and the environment. Behavioural data is important for informing the initial agent population and its development over time. This data will provide insights into individual behaviours (e.g. HFSS consumption) sociodemographic factors (e.g. household income) and other factors influencing behaviours such as stress and emotional eating. Geographic data is important for contextualising individuals in particular geographic settings over time. Geographic data is used in two ways in an agent-based model. First, to provide an initial realistic population for the model using Census or population count data, to ensure that the number of agents in the model are representative of real people in that geographic locality in that time-period by the key sociodemographic factors that we are interested in for the modelling. Second, to estimate individual exposure to different environmental factors over time, by having an estimate of what each individual in the model's local area looks like (e.g. food advertising exposure, access to food outlets). Finally, it is good practice to reserve data that is not used directly in model development for model calibration and validation. **As surveys are designed for specific purposes, there is no single database that covers all the requirements for an agent-based model.** Therefore, WP2 will focus on generating a comprehensive synthetic database that can be used to extract data for each of these purposes. Additionally, this database can be used to extract correlations and relationships that form the initial mechanisms in the agent-based model. Table 1 provides a summary of the data that will be integrated in WP2 and below we have set out how this data will be used to inform each aspect of the modelling. These datasets were selected based on inclusion and exclusion criteria related to whether they would be suitable to inform the modelling. Datasets were included if they were valid, received appropriate ethical approval and focused on at least one key topic related to the modelling (i.e., food insecurity, dietary behaviours, psychological distress, food advertising, commuting time, food environment, local area information about GM) in suitable target populations (i.e., national data on UK adults, adults in GM). Datasets were excluded if they lacked appropriate ethical approval or if the raw data were unavailable for reuse. Other datasets of relevance might be integrated if they are identified during the conceptual modelling in WP1 and they meet the inclusion and exclusion criteria.

Data source	Years	Design	Population	Purpose	Geographic granularity
National Diet and Nutrition Survey	2018-2023	Cross-sectional	UK National	Dietary behaviours, BMI and food insecurity (2019 onwards)	Government Office Region
Food and You / Food and You 2	2018-2023	Cross-sectional	UK National	Food insecurity, diet quality	Grouped Region
Health Survey for England	2018-	Cross-sectional	England	Psychological distress	Government Office Region
Understanding society	2009-2022	Longitudinal	UK National	Time spent commuting, food insecurity, diet quality	Local authority (restricted use)
Living Costs and Food Survey	2017-2022	Cross-sectional	UK National	Expenditure on food	Government Office Region
Food Foundation	2020-2023	Cross-sectional	UK National	Food insecurity and diet quality	Grouped Region
Keenan et al. Liverpool surveys	2021-2023	Cross-sectional	Adults in Liverpool	Food insecurity, psychological factors (incl. eating to cope), diet quality	Partial Postcode
Shinwell et al. survey	2021	Cross-sectional	UK Adults	Dietary behaviours, food insecurity	None
The Bread and Butter Thing Surveys	2018-2023	Cross-sectional	Adults in Greater Manchester (TBBT users)	Food insecurity for GM	Local authority
Greater Manchester Residents Survey	2020-2023	Cross-sectional	Adults in Greater Manchester	Health, food insecurity, household finances for GM	Local authority
Nielsen Advertising Spend data	2018-2023	Aggregate finance data	UK National	Estimate advertising exposure over time	Region
E-food Desert Index	2020	Aggregate environmental data	UK National	Estimate accessibility of food for small geographic areas	LSOA
Priority Places for Food Index	2022	Aggregate environmental data	UK National	Estimate environmental indicators of food insecurity for small areas	LSOA
Ordnance Survey Points of Interest	2018-2022	Aggregate environmental data	UK National	Estimate exposure to fast-food takeaway outlets	Partial postcode

Table 1. Summary of data sources to be combined in synthetic database in WP2.

Baseline agent population

In this project we are interested in how various factors influence individual's food choices, particularly for HFSS foods. We are also interested in the interaction between the psychological factors that affect these food choices and how these may also influence or be influenced by food insecurity. We aim to understand how these factors interact with detailed sociodemographic variables and may impact feedback loops in our model. We have identified several key individual-level datasets that can be combined to generate a database incorporating all these factors. First, the National Diet and Nutrition Surveys (2018-2023) will form the foundation of our baseline agent population, as this contains detailed information about individuals sociodemographic characteristics including age, gender, ethnicity, index of multiple deprivation (IMD), household income and information about employment in addition to detailed dietary patterns and body mass index (BMI). From 2019 this survey includes information that asks explicitly about food insecurity to allow us to estimate the relationship between food insecurity and dietary behaviours. The food insecurity measure is derived from the United States Department of Agriculture (USDA) standardised questionnaire that is used globally to measure food insecurity (33). This groups households into four categories ranging between high and very low food security (high, marginal, low and very low). We will use these categories throughout the project to divide individuals into subgroups to explore how mechanisms differ by food insecurity categories. The NDNS data does not include any psychological factors involved in decision making about foods including psychological distress. As the NDNS data is not designed to be representative of food insecure populations, food insecurity and additional diet quality variables (e.g. fruit and vegetable consumption) will be supplemented from several sources, including the Food and You / Food and You 2 surveys, that contain detailed sociodemographic characteristics about individuals and households and a food insecurity measure (USDA questionnaire). Understanding Society will also be used to supplement the database with data on the relationship between diet quality and food insecurity and includes an 8-item UN food insecurity scale compatible with the USDA scale. A survey by Shinwell et al. (32) will also be used to supplement the database with detailed dietary information in food insecure populations. This will also be supplemented with data from the Food Foundation (34), which tracks food insecurity regularly in the UK and contains detailed information about sociodemographic factors and diet quality. Psychological factors influencing food choices will also be supplemented from multiple sources. First, the national survey The Health Survey for England will be used to estimate psychological distress for adults by sociodemographic categories and BMI using the GHQ-12 score. It will also be used to estimate other external factors that could be influencing food choices or BMI (e.g., physical activity) that will be used to inform data-driven components of the modelling. Understanding Society also contains information about the length of time spent travelling on public transport, including buses and trains, and commuting to work. This will be used to adjust individual exposures to food environment variables including food advertising. This will be further supplemented with the surveys by Keenan et al. (2021, 2022, as yet unpublished data from 2023) that have detailed information on eating to cope as well as psychological distress and dietary behaviours. The Greater Manchester Residents Survey and TBBT surveys will be used to further supplement the database with detailed information about food insecurity dynamics across local authorities in GM. We will use the Living Costs and Food Surveys to estimate expenditure on food to account for the cost of food and income in the population.

Environmental data

Food outlets and accessibility

Data on the food environment will come from several sources. First, we will use aggregate data from the Consumer Data Research Centre including the Priority Places for Food Index (35) available under a UK Open Government Licence (OGL). This will be used to provide detailed estimates of the environmental drivers of food choices and food insecurity. Information in this dataset is broken down by detailed geographic area (Lower Super Output Area), allowing for differentiation by socioeconomic factors. This dataset builds on the earlier E-Food desert index and contains different indicators of the food environment that may indicate that a neighbourhood is at risk of food insecurity. This includes information about access to cheap, healthy, and sustainable sources of food. For example, it includes measures of access and proximity to supermarket retail facilities and online deliveries as well as indicators of socioeconomic barriers such as car access. Ordnance Survey Points of Interest data, freely available under an educational license, will be used to classify the density of different types of food outlets in the GM region over time. This will be classified into the density of fast-food and takeaway outlets (i.e., those likely to be selling HFSS foods). This data is available at postcode district level, and we will use ONS data to lookup the LSOA associated with each postcode district to estimate an exposure to fast-food and takeaway outlets for each LSOA.

Advertising exposure data

Advertising exposure is particularly challenging to estimate for individuals due to the proprietary nature of this information held by the advertising industry, limiting our access to such detailed data. This detailed data contains estimates of advertising impressions, how many individuals are expected to have seen any given advert as well as geolocation and behavioural targeting data. As a cost-effective alternative, we are proposing to use the only industry measure that academic researchers can feasibly gain access to: advertising spend data by category over time and integrate this with other data sources to estimate an individual exposure to advertising, stratified by sociodemographic characteristics.

We will purchase Nielsen data (£21,336) which provides estimates of out of home advertising spend for different types of foods and brands over time (2018-2023). Foods are categorised into product categories (e.g., “chocolate”). They then provide detailed information about the advertiser and brand (e.g., “Cadburys – Crème Egg”). For each product, we will look up the nutritional composition and compare that to the Nutrient Profile Model to establish whether the product is considered HFSS or not. We will then calculate total advertising spend for HFSS foods. This data also contains information about the format (e.g. large digital, bus) and environment (e.g. retail, roadside, transport). The limitation of this data is that it is only available in broad regions (North West, North East, etc.) therefore it is not possible to perform detailed geographic linkage to estimate individual exposure to advertising. We will integrate this data with literature on differential exposure to advertising exposure by different sociodemographic categories.

In a study using a machine learning workflow to classify street-level images into categories such as food and alcohol they find that more deprived areas have a higher concentration of food adverts and report the number of adverts for food in each deprivation decile (36). Another study conducted in Scotland estimated advertising exposure using children’s mobility data, finding similarly, that children in more deprived areas had more contact with the transport network and had higher exposure to unhealthy food and drink product advertising (37). Information from these studies can be used directly to partition the Nielsen advertising spend into advertising exposure by Index of Multiple Deprivation. We will conduct an updated literature search to check for new evidence on the sociodemographic patterning of advertising exposure to ensure we use the most up to date evidence on individual level advertising exposures.

Merging individual and environmental data to create the synthetic database

Lower Super Output Areas (LSOA) are statistical units each comprising approximately 1500 people, developed by the Office for National Statistics (ONS). The Index of Multiple Deprivation (IMD) compares each LSOA to measure the relative deprivation of each. As almost all individual surveys described above contain a measure of IMD for individuals, this will act as the main variable by which the datasets will be merged.

<u>Statistical analysis:</u>

For objective 4, the synthetic database will be generated by combining the data sources (Table 1) using several data integration, imputation and spatial microsimulation techniques including multiple imputation (38) and iterative proportional fitting (39). We will perform descriptive statistics on the synthetic database to estimate individuals’ exposure to different food environment factors conditional on different characteristics (incl. food insecurity categories and deprivation). For objective 5, a SEM for the prioritised structure identified in WP1 will be specified. These will quantify how differential exposure to food environment factors (food advertising exposure, accessibility and availability of healthy and unhealthy foods) is related to HFSS consumption, and how this may differ and be influenced by food insecurity and deprivation.

<u>Outputs</u>: A synthetic database linking national food environment indicators including food advertising exposure and healthy and unhealthy food availability, food insecurity and HFSS consumption and obesity. We will release the synthetic database in an open-source repository (GNU GPL v3 license) to aid other researchers in bringing together these constructs for modelling and exploratory purposes. One publication describing the construction of the synthetic dataset, including highlighting where the processes are generalisable to other areas and what additional data would be needed to do this. One publication describing the results from the SEM.

WP3: Empirical agent-based modelling of the food system to explain recent trends in adult obesity prevalence at local authority level. Lead: Buckley

Aim: Develop an empirical ABM of HFSS food choices and obesity, representing pathways and feedback loops between the food environment and food insecurity and dietary behaviour.

Objective 6: Produce an empirically informed agent-based model incorporating environmental factors that can generate local patterns in HFSS consumption and obesity over time (2018-2023)

Preliminary findings: We recently developed the Mechanism-Based Social Systems Modelling (MBSSM) conceptual framework for population health modelling (40) and have used this to develop several open-source ABMs of alcohol use behaviours integrating mechanisms from social norm theory (41), social role theory (42), the theory of planned behaviour and dual-process theory (43) and novel combinations of these theories (44). MBSSM is a flexible modelling framework that explicitly represents the actions and interactions of entities at the macro (society) and micro (individual) level and is ideally suited to represent the actions of the food industry in terms of food advertising and the decisions of individuals to consume foods. In a study funded by the Population Health Agent Based Simulation Network (PHASE) consortium, a proof-of-concept ABM was developed using MBSSM to explore mechanisms underlying the relationship between exposure to food advertising and HFSS consumption (award number: MR/S037594/1).

Components from behavioural theories were combined in an ABM to simulate daily consumption of HFSS foods for a representative synthetic population of Greater London using the National Diet and Nutrition Surveys (2000 – 2019). Model parameters were calibrated to recent empirical evidence estimating a reduction in HFSS purchasing following advertising restrictions on London transport. The model was used to test alternative explanations for the patterns in diet. This pilot ABM serves as an important first step in developing a modelling platform that explores the different mechanisms linking environmental food cues and HFSS consumption. It demonstrates that the proposed methods are feasible and can be used to develop theories of food consumption and evaluate food policies.

This project utilises and enhances substantial past investment in agent-based and health and economic modelling at Sheffield. The proposed research will further enhance this modelling infrastructure and will provide a novel link between existing modelling developed at Sheffield - the SPHR diabetes prevention model (henceforth the SPHR model) (17) and the MBSSM architecture (40).

Design: A description of a prototype systems map is in Attachment 3. The final version of this will be agreed in WP1 and will be informed by quantitative analysis in WP2. Modelling will have a local focus, using the database generated data in WP2 to empirically calibrate the model to different patterns in obesity and HFSS consumption observed across GM using Approximate Bayesian Computation (45). We will implement the three structures of the model identified in WP1 and quantified in WP2 to explore which mechanisms best combine to generate the emergent, contrasting trends in obesity rates and HFSS consumption in different sub populations across GM, including those defined by food insecurity.

Data:

Baseline agent population

The individual-level synthetic database generated in WP2 will be reweighted to population data from GM to generate a representative synthetic baseline agent population for the whole of Greater Manchester, that is representative of each of the 10 local authorities within GM.

The data to reweight the synthetic database will come from the Office for National Statistics population estimates. We will use the data from mid-2018 to generate our initial population. This data contains the total number of people in each location by age, gender, and LSOA. LSOA will allow us to reweight each individual based on their IMD position to enable a detailed breakdown of socioeconomic status. We will also use additional data from the 2021 Census to make sure that the number of individuals in different race and ethnicity groups, employment status and income are all generally reflective of the population they are weighted to. In WP3 we will add BMI as a health outcome by linking calorie consumption to weight using established relationships (46) as demonstrated in the SPHR model (17).

Agent population over time

For the model, we need to maintain a representative set of agents, and therefore need to consider births and deaths by replenishing and removing agents in each year. The minimum age of the agents will be 18 and these will be replenished using the corresponding mid-year population estimates for 18-year-olds in each LSOA by gender. We will use all-cause annual mortality rates from the Office for National Statistics by age, sex and local authority to remove the appropriate number of individuals in each year due to death. We will also need to update key characteristics in the model that are not involved in a mechanism in the ABM (external factors in Attachment 3, systems map). Rather than modelling these factors in the ABM in a mechanism-based way, we will ensure our data inputs to the model include these influences to accurately capture their impact on the model outcomes. For example, if the conceptual modelling in WP1 highlights household budgets as an important wider influence on food consumption, we will include a data-driven model to update these budgets in each year (using methods such as multiple regression).

Target data

We will agree on the final target data for the model with our policy stakeholders in Workshop 2 to ensure the model has maximum relevance for real-world policy making. We expect to use data from the Office for Health Improvement and Disparities on the prevalence of overweight and obesity in the adults by local authority. The first calibration target will be this prevalence over time (2018 – 2023) for each local authority within Greater Manchester (Oldham, Tameside, Bolton, Bury, Manchester, Rochdale, Salford, Stockport, Trafford, Wigan). The second calibration target will be nutritional intake data (calories from HFSS foods) generated under WP2 for each local authority within GM, based on reweighting of the National Diet and Nutrition Survey.

Data on model mechanisms

The baseline parameter values for model mechanisms (e.g., the relationship between psychological distress and emotional eating) will be derived from the conceptual modelling in WP1 and SEM in WP2. These will form the tentative prior beliefs for the effect sizes for the mechanisms in the ABM. Where data is unavailable from the SEM, we will review literature and conduct expert elicitation (47) with stakeholders in Workshop 1 and 2.

<u>Statistical Analysis:</u>

Baseline agent population generation

Iterative proportional fitting (IPF) will be used to calculate a weight for each individual in the synthetic database generated in WP1 for each local authority in GM (39). IPF is a technique used to iteratively adjust the weights of individuals within a dataset to match target distributions. In this case, the target distributions will be the number of people in each local authority in GM by age and gender and index of multiple deprivation. We will also match to additional targets on ethnicity, employment, and the number of households with children.

Model validation plan

We will use the new best-practice protocol for validating agent-based models (48). The 10 local authorities in GM provide target data for empirical calibration and validation of model parameters *and* model structures. The data will be used over two waves of validation activity. An indicative split of the LA targets across the waves is shown in Table 2 – this decomposition is based on the obesity data and will be reviewed once the target data has been confirmed with stakeholders in WP1 Workshop 2.

Wave 1

		Overall obesity trend since 2018	
		Upward trend	Flat trend
2018 baseline	Lower prevalence	Stockport	Trafford
	Medium prevalence	Salford	Bolton
	Higher prevalence	---	Wigan

Wave 2

		Overall obesity trend since 2018	
		Upward trend	Flat trend
2018 baseline	Lower prevalence	Bury	Manchester
	Medium prevalence	Oldham	Rochdale
	Higher prevalence	---	Tameside

Table 2: Indicative organisation of GMCA local authorities for model validation

For the family of model structures prioritised for analysis from WP1 Workshop 2, we will run a 5-fold cross-validation analysis using Wave 1 LA data. Using a ‘leave-one-out’ approach, we run parameter inference on combined target data from 4 LAs and validate the results on the 5th LA. We do this for each of the 5 ‘folds’, or combinations, that leave out a different LA and average the validation results across all folds.

The cross-validation gives us a ranking of the performance of the different model structures on unseen data that we can use to inform stakeholder discussion and further model structure prioritisation in WP1 Workshop 3. At this point, we will have a second, updated family of models to analyse. To avoid the possibility of overfitting of models to the already seen validation results, we now deploy the Wave 2 LA data in a second round of cross-validation. Again, we will achieve a ranking of model structures. For the model that provides the best generalisation to unseen data, we then estimate its parameters using target data from all 10 local authorities. This model is the engine for policy analysis in WP4.

Model parameter inference

The cross-validation activities and final policy model both require inference of model parameters. Each ABM structure considered will contain several parameters describing the magnitude and direction of the effect between different variables. Our prior beliefs about the values of these parameters will come from the SEM in WP2, literature and expert opinion. We will use standard Approximate Bayesian Computation (ABC) methods, e.g. history matching (45), for estimating the parameters of each agent-based model. We will use ‘implausibility’ as the likelihood estimator for ABC, taking account of uncertainties in the LA target data and ABM stochasticity (49).

Outputs: An empirically informed ABM of food choices and obesity in local authorities in GM, with outputs aggregated by food insecurity categories and deprivation. Two publications describing the model’s ability to reproduce dynamics in obesity in GM, and one publication describing the mechanisms identified in the model that drive HFSS consumption by food insecurity categories.

WP4: Policy modelling to estimate health, health inequalities, and economic impacts of HFSS food environment interventions. Lead: Breeze

Aim: Offer evidence-based insights into the impact of interventions aiming to reduce obesity in the population, along with their associated costs, benefits and any unintended consequences.

Objective 7: Run up to 3 policy scenarios (advertising restrictions, availability of healthy and unhealthy food) identified in WP1 to get differences in HFSS and calorie consumption for groups defined by food insecurity and sociodemographic factors compared with a do-nothing scenario.

Objective 8: Use the SPHR model to conduct a full impact assessment for all policy scenarios assessing the lifetime cost-effectiveness in terms of health, health inequalities and economic impacts.

Design: The three policy scenarios to be run will be finalised in WP1. After our initial conversations with stakeholders, we anticipate that these scenarios will be (1) Restricting advertising for HFSS foods across the GM region, (2) Restricting the availability of unhealthy food – e.g., reducing the number of takeaways, (3) Increasing the availability and accessibility of healthy food options.

For each policy scenario and do nothing counterfactual we will use the ABM developed in WP3 to run the model forwards in time for 5 years to estimate the difference in calories and nutritional intake for each modelled individual. The final time horizon of the ABM will be agreed with stakeholders, with consideration for policy decision-making, dynamic changes, and modelling uncertainties. The model will estimate the impact of policies on nutritional intake and BMI.

We will import individual trajectories for calories and nutrients into the SPHR model to estimate long-term health impacts through changes to BMI and other cardiometabolic risk factors. The SPHR model allows for the calculation of several health outcomes including projections for the prevalence of overweight and obesity within the population, estimates for the occurrence rates of diabetes, cardiovascular disease, cancers, congestive heart failure, osteoarthritis, depression and dementia, calculations related to disease-specific mortality rates and the subsequent gained life years and Quality Adjusted Life Years (QALYs), assessment of disease-specific expenses within the NHS for treatments and associated social care costs. The SPHR model will report short-term return on investment and long-term cost-effectiveness estimates with costs and QALYs discounted at a rate of 3.5%. The impact of the policies on wider societal impact such as informal care costs and labour market impacts such as work participation and social benefits receipts will be reported separately.

Socioeconomic position and inequalities

In our ABM developed in WP3, individuals will have different exposures to factors influencing their dietary behaviours, including the food environment and food insecurity and may therefore have different responses to policies. We will analyse the health and economic consequences of policies across different social groups. This involves measuring how each policy affects health outcomes and NHS costs within different groups. We plan to offer evaluations for each of the 10 local authorities in GM, with further breakdowns based on socioeconomic status (IMD quintile) and food insecurity across and within these areas. We will be receptive to feedback from our stakeholders and PPI panel members in terms of incorporating additional demographic divisions. In the SPHR model individual trajectories for calorie and nutrient intake will be included in the model. This will allow the short and long-term health economic outcomes to be stratified by socioeconomic groups.

Sensitivity analysis and uncertainty quantification

The calibration and validation of the ABM performed under WP3 will give us a posterior distribution for each model parameter to fit the observed trends in obesity and food insecurity across GM. We will repeatedly sample from this posterior distribution to run each policy scenario to present uncertainty intervals around the central estimates. We will also perform additional sensitivity analyses as advised by stakeholders in WP1. In the SPHR model the posterior distributions for calorie and nutrient trajectories will allow for uncertainty in the policy scenarios to be characterized. This will be combined with probability distributions specified for all other model input parameters to enable probabilistic sensitivity analysis.

Data: The effects of each of the policy scenarios will be developed in collaboration with stakeholders and utilising the conceptual framework developed in WP1. This will enable a shared understanding of the mechanisms through which the policy will impact model outcomes and identify data requirements to programme the policy effects. Where possible the policy effects will be informed by published evidence and the mechanisms of the agent-based model. We will use expert elicitation to inform any gaps in the evidence for the policy scenarios (50). We will work with stakeholders to identify costs for existing services or conduct micro-costing of interventions. Unit costs will be estimated from external sources (e.g., suppliers of relevant products, national healthcare databases (51).

We will review existing sources of data used in the SPHR model for updates to parameter inputs. The SPHR model is an individual level simulation based on trajectories of metabolic factors including body mass index (BMI), systolic blood pressure, cholesterol and HbA1c. The trajectories for BMI are programmed to reflect demographic patterns in national surveys (Health Survey for England), and other cardiometabolic trajectories are informed by longitudinal cohort studies (English Longitudinal Study of Ageing and Whitehall II). The model simulates incidence of cardiovascular disease using the QRISK2 risk equations (52) and other diabetes related complications (e.g. renal failure, blindness, foot ulcers) using the UKPDS outcome model version 2 risk equations (53).

Outputs: A food policy evaluation including health and economic impacts for up to three policies for 10 local authorities across GM, with effects aggregated by IMD and food insecurity categories. Two publications 1) reporting the findings of the impacts of food policies in GM on health and food insecurity by socioeconomic groups, and 2) the health economic impacts of food policies in GM.

5 ETHICAL AND REGULATORY CONSIDERATIONS

5.1 Research Ethics Committee (REC) and other Regulatory review & reports

Ethical approval is not required for WPs 2, 3 and 4. NRES ethics approval is not required for WP1. We have followed and complied with the Economic and Social Research Council's research ethics framework and have obtained ethical approval for WP1 workshops through the internal ethics review process in the Institute of Population Health, University of Liverpool (ref: 15683) and Sheffield Centre for Health and Related Research, University of Sheffield. Prior to the workshops, participants will be asked to read an information sheet and sign a consent form.

5.2 Peer review

The research plan has been reviewed by the funding committee and has undergone peer review. The protocol will undergo further review post-award from the funder.

The study steering committee is yet to be appointed, but will provide overall supervision for the project on behalf of the Project Funder and ensure that the project is conducted according **to the rigorous** standards set out in the Department of Health's Research Governance Framework for Health and Social Care and the Guidelines for Good Clinical Practice.

5.3 Patient & Public Involvement

We actively engaged with a diverse Public and Patient Involvement (PPI) panel to develop the research plan. The panel provided valuable perspectives on the aims and scope of the study.

We will form a public advisory group for the study to inform the methods, interpretation of data and dissemination of findings. We aim to recruit 8-10 people with representation from diverse population groups including populations at high risk of food insecurity via third sector organisations (incl. The Bread and Butter Thing), and via the Sheffield 'DeepEnd' PPI network and the Greater Manchester Poverty Action Group. The target characteristics of the public panel will ensure representation across gender, age, race and ethnicity, employment status, parental status and individuals with long term health conditions. We will focus on recruiting individuals who are food insecure or at risk of food insecurity. Overall, we aim to build a well-rounded PPI panel that reflects the various realities of food insecurity in the UK.

We will meet with the PPI group during each of the four work packages in order to explain the work being undertaken, ensure that it is still applicable and to check that the outputs are clear. We will meet initially with the PPI group to (i) identify training needs, (ii) understand preferences for meeting and communicating and (iii) to get feedback on how PPI could be best incorporated within each stage.

Members of the public will contribute to informing the design of the conceptual model in WP1, including model scoping, the interpretation of outputs and dissemination of the research. Kelly (PPI co-applicant) will attend all workshops in WP1, offer guidance across all WPs and help to prepare materials for PPI workshops to improve accessibility. She will also support dissemination strategies for the project.

Squires (Professor, Sheffield) is the PPI lead on this proposal and will be the main point of contact for the panel. Her doctoral research highlighted the importance of stakeholder involvement in model development, including input from members of the public. PPI members will be paid according to INVOLVE recommendations.

5.4 Protocol compliance

Protocol compliance will be monitored by the principle investigators and deviations from the protocol will be documented and communicated to the study steering committee for approval. • prospective, planned deviations or waivers to the protocol are not allowed under the UK regulations on Clinical Trials and must not be used e.g. it is not acceptable to enrol a participant if they do not meet the eligibility criteria or restrictions specified in the study protocol • accidental protocol deviations can happen at any time. They must be adequately documented on the relevant forms and reported to the Chief Investigator and Sponsor immediately. • deviations from the protocol which are found to frequently recur are not acceptable, will require immediate action and could potentially be classified as a serious breach.

5.5 Financial and other competing interests for the chief investigator, PIs at each site and committee members for the overall study management.

The project PIs have no financial and other competing interests. The competing interests of the study steering committee will be reported once the committee have been recruited.

5.6 Amendments

Amendments to the protocol will be submitted to the study steering committee who will have the responsibility to approve or reject the amendment with a 2/3 majority

6 DISSEMINATION POLICY

We plan to submit 7 papers to peer-reviewed scientific journals describing the methodological contributions and the findings of our research. All papers will be published open access. We will target a combination of health, nutrition, and modelling journals.

Manuscript 1 – Conceptual modelling of a decision tool to assess the impact of food environment policies on dietary behaviours and health and economic outcomes (target journal: Journal of Public Health)
Manuscript 2 – Introducing a comprehensive database for food environment policy analysis. Linking food environment indicators with HFSS consumption, food security and psychological and sociodemographic factors at the individual and household level (target journal: Health and Place)
Manuscript 3 – Quantifying the relationships between the food environment and HFSS consumption, differences by food insecurity and deprivation (target journal: Appetite).
Manuscript 4 - Modelling dynamics in obesity in GM: an agent-based model (target journal: Journal of Artificial Societies and Social Simulation).
Manuscript 5 – Using agent-based modelling to explore the mechanisms driving HFSS consumption and differences by food insecurity status (target journal: The Journal of Nutrition or International Journal of Behavioural Nutrition and Physical Activity).
Manuscript 6 – Nutritional, health and food insecurity impact of dietary policy options for the Greater Manchester area using Agent-based Modelling (target journal: Public Health Nutrition)
Manuscript 7 – A health economic assessment of dietary policy options for the Greater Manchester area using lifetime microsimulation (target journal: Lancet Public Health)

The research will develop modelling infrastructure for agent-based modelling of food environment policies in a UK context, building on significant modelling infrastructure that has been developed at Sheffield. This work will provide a framework to extend the modelling to studying other food-related policies or other health behaviours including alcohol and smoking and how these could be altered by policies.

We will develop policy briefing documents with our public involvement group, PPI co-applicant Kelly and with input from our stakeholder group to identify key messages and findings and communicate findings in an accessible format, such as social media.
Briefing Document 1: The potential impact of three food environment policies in 10 local authorities in Greater Manchester: health and economic impacts. We will schedule a webinar with stakeholders at month 29 to discuss the final policy analyses.

We will work with PPI members and PPI co-applicant Kelly to identify clear, meaningful messages for the public, develop communication materials and identify appropriate outlets for dissemination.

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