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Systemic, cross-sectoral, or regulatory interventions to improve population nutrition and related global health challenges

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Systemic, cross-sectoral, or regulatory interventions to improve population nutrition and related global health challenges

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Editorial: Systemic, cross-sectoral, or regulatory interventions to improve population nutrition and related global health challenges

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Editorial on the Research Topic
Systemic, cross-sectoral, or regulatory interventions to improve population nutrition and related global health challenges

Malnutrition in all its forms is a leading cause for disability-adjusted life years (DALYs) globally (1). One in three people in the world suffers from at least one form of malnutrition, such as obesity or micronutrient deficiencies (2). Poor nutrition is driven by complex, interrelated environmental, social, cultural, political, economic, and behavioral factors (2). Regulatory and/or policy interventions across sectors are needed but face pushback from the system, i.e., vested interests (3). Methods from systems science have been advocated as useful tools to address this complexity and find sustainable solutions to malnutrition in all its forms (4). Although concepts and terminology of systems approaches have existed for many years, empirical knowledge about their application and effectiveness for public health nutrition remains very limited. Evidence is particularly lacking from low-and middle-income countries (LMICs). Uncertainty remains in terms of how an authentic systems approach can be applied in practice, how to engage non-academic partners – especially those who have the capacity and power to change health environments and policies – and how this relates to evidence standards.

In this special edition we sought contributions from international, national, and local health organizations, policymakers as well as academic authors working in population nutrition and related fields. It comprises 9 articles, representing contributions from 72 authors across institutions in 13 countries. The contributions provide insight into what these multiple partners are hoping to achieve from the application of systems approaches, how these projects might be conceived and presented as a research protocol, examples of their application in practice and proposed guidelines for the reporting of such studies.

Felmingham et al. reviewed the ways in which success has been characterized in the published literatures specifically around the use of system thinking in community prevention. The authors concluded that measures and concepts of success varied across the articles reviewed, ranging from level of community action, collaboration, changes in mental models, or cultural appropriateness, as well as shifts to a deeper understanding of complexity

within the population. The article introduced a recurring theme throughout this special edition, which is the definition and measurement of success and the need for guidelines and standards in the design and reporting of such initiatives.

Examples from empirical studies using a systems approach are presented in the form of protocols or case studies of completed work. In the case of Speich et al. they presented a research protocol for the development of projects targeting governance, policy and supply to improve food and nutrition security in several "secondary" cities in low income countries. They took a systems approach by proposing the development of a transdisciplinary intervention drawing on agriculture, food and health sectors to improve value chains with respect to six specific cities in Bangladesh, Kenya and Rwanda. In addition, they proposed working from a theory of change and focusing on elements of policy and advocacy, building of institutional capacity, data-driven planning and resource mobilization, workforce development and provision of feedback loops to support ongoing implementation.

A study by Allender et al. used participatory research methods in a co-creation study for enhancing policy to address diabetes in the Indian Ocean territories, a remote set of islands between Australia and Indonesia. The process itself used group model building (GMB), a technique prominent in systems science. The study provides an insight into adaptations required to such projects arising from travel restrictions during the COVID pandemic. Community perceptions were collected using methods from systems science and views were sought from a wide range of stakeholders across the islands. Participants described the systemic drivers of diabetes on the islands and potential policy solutions ranging from freight cost to food policy.

Work set in South Carolina (Calancie et al.) also brought multiple stakeholders together, using GMB to explicitly understand and intervene in the systemic drivers of child obesity. The participatory approach led to a range of priorities for interventions across multiple system levels, including food insecurity, empowering minority populations and advocacy for change across all sectors of the community.

Endevelt et al. called for better engagement with key stakeholders in design and implementation whether the context be LMIC or high-income countries. Their case study of attempts to implement policies for fortification of food in Israel emphasized the need for rigorous and structured engagement of all stakeholders and clear mechanisms for knowledge exchange across all levels to achieve optimal systems change. Key to this is capturing and sharing how these processes work, and what makes them effective, to create generalisable models for use worldwide.

Two studies addressed aspects of this multi-persepctive challenge in particularly in understanding the complexity of obesity and diabetes in Amsterdam and Qatar. Pinzon et al. aimed to identify and comprehend the fundamental system dynamics influencing obesity-related behaviors among adolescents. To achieve this, they constructed a Causal Loop Diagram (CLD) from a multi-actor viewpoint and then conducted a systems-based analysis to gain insights into the existing system, considering both its structural and functional aspects. The CLD presented in this study represented a synthesis of insights from academic researchers, adolescents, and stakeholders. Notably, adolescents made the most substantial contribution to the CLD, accounting for 74 out of 121 factors. A key finding was the ways in which existing structure worked to promote unhealthy behaviors among adolescents. When examining the emergent properties of the system from a macro perspective, it became evident that the functioning of several subsystems was oriented toward the objective of optimizing short- or long-term economic growth within the framework of a market-driven economy.

Analysis by Alareeki et al. developed deterministic models of public health interventions regarding the burden of diabetes burden among Qatari adults. The approach built on a mathematical model of the complexity of interacting modifiable and non-modifiable risks to assess the impact of a range of public health interventions, from lifestyle intervention to policy changes for active transport and in support of healthier food systems. A key finding was that multiple interventions at both individual and structural levels would deliver a greater impact than single interventions acting within one system alone.

Across this series, there are several commonalities, notably a focus on designing interventions that will have an impact and that will actively engage with the need for systemic action operating at multiple levels of risk and benefit. A second theme is trying to understand and engage the mechanisms by which interventions work or fail with the goal of identifying an optimal mix of interventions within a complex environment to provide the best return on investment. A third theme is the importance of putting key actors (e.g., community, healthcare professionals, educators, researchers, retailers, adolescents, etc) at the center of the design process: recognizing that change in these complex systems requires active engagement and co-creation with those who live and work within them.

A review by Li, Alharbi et al. found very few studies could claim rigid adherence to application of systems thinking or methods at all stages of the process, and the included studies were all conducted in high-income countries. Common features shared by the included studies were identified, such as measuring ongoing changes, in addition to endpoint outcomes, and supporting capacity building. Sub-optimal reporting might have explained the small number of studies meeting inclusion criteria, so Li, Allender et al. developed a list of practical questions (reporting guidance) to assist academic authors, journal editors and other interested stakeholders to design, report or review future interventions that apply a systems approach to tackle obesity or other public health challenges. These questions were developed based on the latest academic knowledge and are organized by the three broadly defined and interrelated stages of an intervention's life cycle: "development," "implementation/delivery" and "evaluation." The reporting guidance recognizes that in practice, the process of developing, implementing/delivering, and evaluating any complex intervention is often iterative and reflective, providing room for the main stages of the intervention's life cycle to occur simultaneously.

In summary, this Research Topic demonstrates a growing and comprehensive application of systems thinking principles in public health research. However, there is a pressing need for clearer definitions and better reporting of these approaches. We recommend that journals and authors adopt such standards, similar to those used for other methodologies such as randomized controlled trials (RCTs) or systematic reviews.

Author contributions

BL: Conceptualization, Formal analysis, Project administration, Resources, Visualization, Writing—original draft, Writing—review & editing. SA: Conceptualization, Formal analysis, Project administration, Resources, Visualization, Writing—original draft, Writing—review & editing. WW: Conceptualization, Formal analysis, Project administration, Resources, Visualization, Writing—original draft, Writing—review & editing.

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Improving the reporting of intervention studies underpinned by a systems approach to address obesity or other public health challenges

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reporting guidance, systems approach, obesity, public health intervention, system thinking, intervention development, intervention evaluation, intervention implementation

Introduction

A systems approach to obesity prevention is increasingly urged (1, 2). However, confusion exists on what a systems approach entails in practice, and the empirical evidence on this new approach is unclear. Several reviews (3–6) have tried to synthesize available evidence on a systems approach targeting obesity and other public health areas, but found that authentic, comprehensive application of this approach is scarce. We believe this is largely due to the uncertainty around the exact meaning of "a systems approach," and sub-optimal reporting.

Fully and transparently reported evidence can improve our understanding of how a systems approach is applied practically in different cultures and settings, support methodological development, and improve synthesis of emerging evidence on the effectiveness of this new approach.

Recommended questions to guide the reporting and review of future work

As a team of experts who have advocated and applied systems science to address obesity and other public health challenges with ongoing empirical studies across 16 countries, we developed a list of practical questions to assist academic authors, journal editors and other interested stakeholders to design, report or review future interventions that apply an authentic systems approach to tackle obesity or other public health

challenges. These questions were developed based on the latest academic knowledge, and comparative reflection on what were (or were not but self identified as) an authentic application of a systems approach published in public health journals (submitted to the collection of this journal).

Questions are organized by the three broadly defined and interrelated stages of an intervention's life cycle: "development," "implementation/delivery" and "evaluation." It is important to note that by "intervention(s)," we refer to interdepended programme of work containing multiple, coordinated actions aimed to stimulate, sustain, or re-orientate systemic changes. Moreover, in practice, the process of developing, implementing/delivering, and evaluating any complex intervention should be continuous, iterative and reflective (7). In a systems approach, the main stages of the intervention's life cycle may occur simultaneously (e.g., continuous monitoring and responding to changes while implementing agreed systemic actions).

Intervention development

1. Have the authors clearly defined the public health problem being addressed?
2. Have the authors specified the theoretical underpinning of the systems approach (e.g., System Dynamics) applied to develop the intervention and justified their choice? *Simply saying the intervention was developed using a systems approach is not sufficient.*
3. Have the authors specified the methods (e.g., Group Model Building) applied to develop the intervention and justified their choice? *Simply saying the intervention was developed using a systems approach is not sufficient.*
4. Have the authors made any adaptations or methodological innovations to the referred development process to suit local settings or cultures?
5. If the answer to the 4th question is YES, have the authors described such changes in sufficient detail to support methodological learning and advancement?
6. Have the authors clearly defined the targeted intervention community for each intervention in terms of its geographic/authoritative boundaries as well as the size and characteristics of the targeted population?
7. Have the authors described the environment (physical, cultural, socio-economic, and policy environments) within which the intervention was developed with sufficient detail to allow the readers to understand the development context? *Among others, this should include existing interventions/policies and how the local government and key stakeholders viewed the public health problem being addressed.*
8. Have the authors described in sufficient detail the process of identifying and choosing key subsystems/organizations/partners/decision-makers within the system prior to approaching them to develop a collective understanding of the system?
9. Have the authors described in sufficient detail the process of gaining support from senior leaders of those subsystems/organizations prior to developing a collective understanding of the system?
10. Have the authors described the subsequent steps involved in the intervention development process in sufficient detail? *To answer this question, consider whether the authors provided methodological information related to participants (and other individuals), activities/process, locations, duration, outputs, instruments, and materials? A flowchart is recommended in addition to the description in the text.*

Intervention delivery/implementation

1. Have the authors clearly defined each intervention community (if multiple communities/cities/regions were included in the study/project) in terms of the geographic/authoritative boundaries as well as the size and characteristics of each beneficiary population?
2. Have the authors described the intervention environment (physical, cultural, socio-economic, and political environments) of each intervention community/city/region with sufficient detail to allow the readers to understand the intervention context? *Among others, this should include existing interventions/policies and how the local government and key stakeholders viewed the public health problem being addressed.*
3. Have the authors specified who were involved in the delivery of jointly identified and prioritized intervention actions and their responsibilities?
4. Have the authors specified the responsibilities of all individuals and organizations involved in the delivery of jointly identified and prioritized intervention actions?
5. Have the authors described with sufficient detail how communication and aligned collective actions across diverse action groups/stakeholders were maintained and monitored?
6. Have the authors described how to ensure a shared feeling of joint ownership (of the intervention) across diverse stakeholders or action groups?
7. Have the authors described in sufficient detail what were delivered/implemented, including the initial plan and subsequent changes to the initial plan?
8. If any intervention actions were adjusted, re-designed or terminated in response to results of ongoing intervention monitoring or other causes (e.g., lack of funds or change of leadership), have the authors explained the reasons for such changes?

9. Have the authors reported the challenges/barriers and facilitators to deliver the intervention?
10. Have the authors described the nature/sources of funding allocated to support the interventions?

Intervention monitoring and evaluation

1. Have the authors defined the overall evaluation approach (e.g., stepped wedge design, natural experiment or routine data collection)?
2. Have the authors discussed how the chosen evaluation approach reflects features of systems thinking (e.g., complexities and dynamics)? *Following considerations may help to answer this question:*
    - *Have the authors described and justified methods used to assess how individual intervention actions worked together, interacted with each other and generated changes to the whole system?*
    - *Was ongoing monitoring of intervention impact included as part of the overall evaluation work (in addition to endpoint outcome measures)?*
    - *Have the authors measured and reported on unintended consequences? If yes, have they reported the methods and results with sufficient detail?*
    - *Have the authors described any attempt to understand how the system evolves over time?*
3. Have any of the evaluation outcomes been used to review and update stakeholders' understanding of the system gained prior to intervention delivery?
4. If the answer to the above question is YES, have the authors described what, when and how ongoing evaluation outcomes were used to support intervention delivery/implementation?
5. Have the authors reported on the challenges/barriers and facilitators to evaluation of intervention impact?
6. If the authors adapted/amended an existing evaluation approach/method or invented new methods, have these adaptations/innovations been described with sufficient detail to support methodological learning and advancement?
7. Have the authors described in sufficient detail what and when impact indicators/outcomes were measured and how?
8. If process and economic evaluations were included in a study/project, have the authors described the evaluation approach and methods in sufficient detail (within the same publication or elsewhere)?
9. If methodological adaptations or innovations were made to traditional process/economic evaluation approaches, have the authors described their approaches and methods in sufficient detail to support methodological learning and advancement?
10. Have the authors provided other information on study/project results (with reference to established reporting guidance if available) to allow readers to understand and assess results?
11. If any, have the authors identified, recorded, and reported major changes in the intervention environment (e.g., natural disasters, new public health crises and changes of national policies relevant to the public health problem being addressed) during the intervention delivery/implementation period that might influence accurate evaluation of the intervention outcomes?
12. If the answer to the 11th question is YES, have the authors discussed the potential impacts of those major changes in the intervention environment to help readers interpret the reported intervention results?

Discussion

This Opinion paper presents the first guidance for reporting public health interventions underpinned by a systems approach in the format of practical questions essential to intervention development, delivery/implementation and evaluation.

These questions will help researchers, editors, reviewers and policy makers to pay attention to, record and report information that have often been ignored in current practice but are valuable for the methodological advancement in this field. For example, we encourage authors to fully report contextual/cultural adaptations in applying a systems approach. We also ask authors to report any methodological adaptations or innovations made to traditional process/economic evaluation approaches. Moreover, unlike many interventions delivered in a controlled setting or design, the intervention context and setting in any system-level interventions is dynamic and constantly changing. Therefore, we encourage authors to identify, record and report major changes in the intervention environment (e.g., natural disasters, new public health crises and changes of national policies relevant to the public health problem being addressed) during the period of intervention delivery/implementation.

Some of the reporting suggestions are unique to complex, systemic public health interventions, and so have not been included in existing reporting guidance developed for general trial studies. For instance, we ask authors to report whether any evaluation outcomes have been used to review and update the system map drawn previously? We encourage authors to discuss how their chosen intervention evaluation approach reflects features of systems

thinking (e.g., complexities and dynamics). Several hint questions are also offered to assist this (e.g., have the authors described any attempt to understand how the system evolves over time?).

We hope these questions can assist the design, reporting and reviews of future public health interventions applying an authentic systems approach, and provide the first step toward developing a comprehensive reporting guidance for systemic interventions in public health. We welcome academic peers, journal editors and policy makers to share their thoughts about these questions, collectively making the first step toward developing a comprehensive guidance for reporting public health interventions underpinned by a systems approach.

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BL conceived the idea, provided the first draft of the manuscript, and wrote the guidance. SA, BS, and CF edited the manuscript. All authors read and approved the final version of the manuscript.

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Nutrition in City Ecosystems (NICE): Protocol of a multi-sectoral development project to improve food and nutrition security of secondary city populations in Bangladesh, Kenya and Rwanda

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Background: Secondary cities tend to be better linked with local food systems than primate cities, acting as important platforms to trade agricultural produce with rural surrounding. COVID-19, conflicts and climate change continue to expose inefficiencies in food systems and have further exacerbated malnutrition, calling for substantial food systems transformations. However, tackling current food systems' challenges requires new approaches to ensure food and nutrition security. Nutritious and agroecologically produced food offer the potential to transform food systems by improving diets and alleviating pressure on the environment, as well as by creating jobs and reducing poverty. This paper describes the design of a project by a Swiss public-private consortium to improve food and nutrition security and to reduce poverty in city ecosystems in six secondary cities in Bangladesh, Kenya and Rwanda through governance/policy and supply and demand side interventions.

Methods: The Nutrition in City Ecosystems (NICE) project promotes well-balanced nutrition for city populations through interdisciplinary agricultural, food, and health sector collaborations along city-specific value chains. Adopting a transdiciplinary systems approach, the main interventions of NICE are (i) advocacy and policy dialogue, (ii) building of decentralized institutional capacity in multi-sectoral collaborations, (iii) support of data-driven planning, coordination and resource mobilization, (iv) anchoring of innovations and new approaches in city-level partnerships, (v) capacity building in the agricultural, retail, health and education sectors, as well as (vi) evidence generation from putting policies into practice at the local level. NICE is coordinated by in-country partners and local offices of the Swiss public-private consortium partners.

Discussion: The NICE project seeks to contribute to urban food system resilience and enhanced sustainable nutrition for city populations by (A) strengthening urban governance structures involving key stakeholders including women and youth, (B) generating income for producers along the supply chain, (C) triggering change in producers' and consumers' behavior such that nutritious and agroecologically produced foods are both in demand as well as available and affordable in urban markets, and (D) allowing a scale up of successful approaches to other national and international cities and city networks.

KEYWORDS

nutrition, diverse diets, secondary cities, food systems governance, agroecology, farmers' hubs, demand-side intervention

1. Introduction

Sixty-eight percent of the world's population will live in urban areas by 2050, and around 90% of this increase will occur in small cities and/or towns of Africa and Asia (1). Small cities and towns are also the areas where the majority of the world's poor live today (2). Degradation of natural resources and pollution are often going along with rapid and unplanned urbanization. Urbanization costs also arise from the wasteful way in which many city food systems operate, including the overuse of fertilizers, excessive use of antibiotics for animal growth and untreated human waste (3). With more than 720 million people suffering from hunger, 149 million children under 5 years of age stunted and over 2.3 billion people not having regular access to sufficient, safe, and nutritious food (4), radical transformation of today's food systems is required to address urgent challenges of food security and nutrition. Issues of food security and insufficient nutrition not only lead to undernutrition and micronutrient deficiency but also foster overweight and obesity in many urban areas (4).

Urban food systems have impacts beyond just food, and their reach extends beyond just urban and peri-urban areas (2). Effective governance of urban food systems making use of multisectoral collaboration is a first step toward food systems transformation and tackling malnutrition issues (2). However, lack of articulation on nutrition outcomes in relevant urban policies and strategies, weak coordination mechanisms among stakeholders acting in food systems, lack of relevant institutional leadership, and lack of monitoring systems still often persist in many urban areas, and especially in the fast-growing secondary cities of Asia and Africa (2). Nutrition and food systems are multi-sectoral by nature, requiring expertise from agriculture, (public) health, finance, social affairs, education and many more (5). Based on principles of participation, ownership, and commitment, mutual trust and collaboration, participatory processes, and system approaches contribute to beneficial prioritizations, leverage synergies and improve the likelihood of success and sustainability of implementations (5). Discussions between municipal government and informal food sector associations such as e.g. consumer groups, farmer cooperatives (unions), civil societies etc. have been shown to importantly contribute to designing actions to improve nutrition and livelihoods, create jobs, reduce poverty and improve food and nutrition security for a large segment of the urban population (6). Similarly, it has previously been shown that women empowerment encouraging spousal discussions about farming contributes to increases in dietary diversity and increased nutrition practices (7). Women and also youth often play a key, but under-recognized and often informal, role in food systems e.g. in production, processing, and selling at markets and food shops. However, their participation in decision-making is often low and they only have limited opportunities to influence food systems. Thus, to get fair benefits from a food system that largely depends on them to function, women and youth are a priority population to be strengthened through food systems transformations (8).

Cities other than a country's largest city (primate city, often the capital) are named secondary cities and are generally better linked with local food systems than primate cities, acting as important platforms to trade agricultural produce with the rural surroundings (9). As such, secondary cities are important contributors to a reduction of rural poverty while primate citites lead in contributing to the country's economic development (9). In order for consumers in fast growing secondary cities to change their food consumption behavior toward improved diets and more sustainable food systems, nutritious and agroecologically produced food need to be available, accessible, and affordable. Containing ecological as well as social components focused on empowering the local context, agroecology may serve as the key overarching concept for sustainable food systems transformation (10). Increased proximity and connectivity between consumers and producers can reduce the risk of food contamination and maintain food integrity compared with long-distance travel (11). Furthermore, increased proximity between food production and food consumption in secondary cities'

Abbreviations: COVID-19, Coronavirus disease caused by SARS-CoV-2; ETH, Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology); FAO, Food and Agriculture Organization of the United Nations; IFAD, International Fund for Agriculture Development; M&E, Monitoring and evaluation; NICE, Nutrition in City Ecosystems project; SAL, Sight and Life Foundation; SDC, Swiss Agency for Development and Cooperation; SDG, Sustainable Development Goals of the United Nations; SFSA, Syngenta Foundation for Sustainable Agriculture; SHARP, FAO's Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists tool; Swiss TPH, Swiss Tropical and Public Health Institute; UN, United Nations.

contexts can allow producers to earn a higher share of revenue and increase their margins due to lower investment e.g. into transport (11).

Particularly in the urban setting, many people currently experience a pronounced shift away from traditional staples such as rice, millet or pulses toward more convenient and often high-processed foods such as pasta, bread, or high-sugar foods (12–18). This is a result of changes in lifestyles including, but not limited to, moving out of a farming household, different relative prices for food, and often increased income (12). Urban households living in poverty tend to spend a large proportion (in some countries up to 70%) of their income on food, making them particularly vulnerable to food price crises (19–21). By forcing households to substitute nutritious food such as fruits and vegetables, nuts and seeds or animal products with less nutritious, less expensive, and less nutrient-dense staples, food price volatility immediately affects diet quality (9). Food and nutrition literacy emphasizing the ability of individuals to learn adequate food use, still seem to be insufficient to overcome these socio-economic obstacles. Hence, a systems approach combining the tackling of all health, environmental, and socio-economic factors to malnutrition is needed (22). Fragmented market structures contributing to the establishment of informal arrangements (street traders, home-based small retail stores) which are often not regulated, add another layer of complexity on the city food system (9, 23, 24). Still, it is not only physical and economic access shaping food and nutrition outcomes in urban contexts (25), but the consideration of how households utilize food together with clean water and sanitation and health care to reach adequate diets and achieve nutritional wellbeing, was found to be another important component in shaping households' abilities to ensure food security and dietary quality in Kisumu, Kenya (26).

It is in this context that a multi-country and multi-stakeholder project entitled "The Nutrition in City Ecosystems (NICE)" was conceived and provided with key funding by the Swiss Agency for Development and Cooperation (SDC). A public-private consortium comprising the Swiss Tropical and Public Health Institute (Swiss TPH), ETH Zürich (Sustainable Agroecosystems Group and World Food Systems Center), Sight and Life (SAL), and the Syngenta Foundation for Sustainable Agriculture (SFSA) is now implementing and co-financing the project to contribute to healthy nutrition through sustainable, local food production and more diverse and healthy dietary choices in urban food systems.

With its holistic approach addressing several sectors and layers of food systems, the NICE project aims to cut across six out of the 17 Sustainable Development Goals (SDGs) (27), namely:

- SDG 2—Zero Hunger through uncovering dietary patterns and promoting nutritious local food.
- SDG 3—Good Health and Well-being through diversified, micronutrient-rich food and nutrition.
- SDG 5—Gender Equity through the focus on women and youth.
- SDG 11—Sustainable Cities and Communities through the focus on urban and peri-urban populations.
- SDG 12—Responsible Consumption and Production through the promotion of agroecological food production and consumption.
- SDG 17—Partnerships for the Goals through the project's multi-stakeholder partnerships.

2. Methods/design

In this paper we describe the mixed-methods methodology system approach that is being used throughout the NICE project in city populations in Bangladesh, Kenya, and Rwanda. After an inception phase of 6 months, the project started in August 2021 and project phase I is currently ongoing until June 2025.

2.1. Study objectives and hypotheses

In alignment with SDC's thematic focus on food systems, the NICE project's primary objective is to improve the food and nutrition security of city populations and to reduce poverty by increasing the demand and supply of healthy, diverse diets consisting of nutritious and agroecologically produced food.

We hypothesize that:

IF city governments establish multisectoral platforms for nutrition planning and resource mobilization, and implementation is participatory with women and youth-led initiatives;

IF local food supply chains, built on a selection of food produced with improved knowledge on good agroecological farming practices, and supported by social business models along the value chain, are linked to urban markets;

IF knowledge about the importance of all aspects of diet (types of food, diversity, agroecological aspects) is generated and disseminated to urban, peri-urban and local consumers and producers (leaving no-one behind);

and

IF evidence from the project are not only shared among the participating cities and countries but also disseminated more broadly;

THEN NICE will contribute to (i) an increased demand for and supply of nutritious and agroecologically produced food, (ii) an improved nutrition situation of the whole city region population, (iii) strengthened governance of city food systems and the position of women and youth therein; and (iv) impacts that trigger a snow-ball effect beyond participating cities and countries.

All project activities will foster four outcomes (A–D) *via* 13 clearly defined, expected outputs as presented in Figure 1 and will have a special focus on the inclusion of women and youth as priority populations for food systems transformation.

2.2. Project sites

In line with SDC's global perspective for this project, three countries have been selected from among SDC's focus countries for project implementation. Main criteria for country selection was the availability of a local office and network of one of the public-private consortium partners, capable to take on project management. In each of the three selected countries, two secondary front-runner cities (six cities in total) were chosen for the implementation of the NICE project. Selection of the cities was based on previous work experience of different members of the NICE consortium and the city's interest to

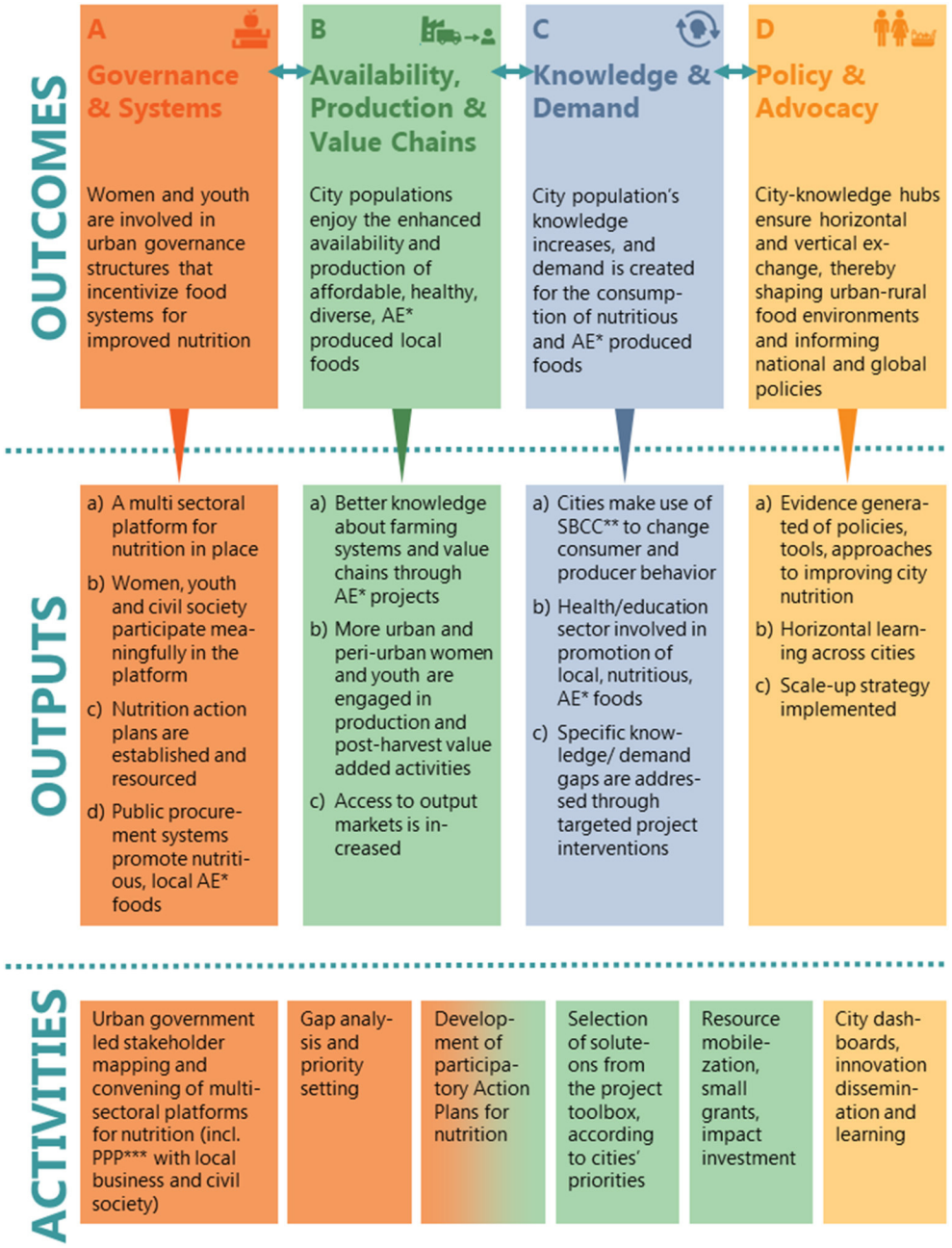

FIGURE 1
Theory of change of NICE with respective outcomes, outputs and underlying activities. In order to achieve its objectives to improve the food and nutrition security of city populations and to reduce poverty by increasing the demand and supply of healthy, diverse diets consisting of nutritious and agroecologically produced food, the NICE project works toward four outcomes **(A–D)** resulting from 13 outputs and their respective required activities. *AE, agroecology/agroecological/agroecologically; **SBCC, social behavior change communication; ***PPP, public-private partnership.

be involved. The main target populations for the project activities are the socio-economically worst-off city populations living in poverty pockets with high rates of malnutrition as well as small holder farmers in the city food sheds, with a particular focus on women and youth. Through demand and affordability side interventions that can contribute to the availability, accessibility, and affordability of more diverse diets and thus improved nutrition, the nutritional status of all these populations should be improved.

In Rwanda, the selected secondary cities, Rubavu and Rusizi, are part of the Government's Second Economic Development and Poverty Reduction Strategy 2013–2018 promoting six cities to serve as additional country growth poles besides Kigali developing into a regional hub. In Bangladesh, the selected cities are Dinajpur and Rangpur. Bungoma and Busia are the selected cities in Kenya. The health and agricultural sectors are quite strongly devolved to county-level in Kenya, but the extent of decentralization is more mixed in Bangladesh and Rwanda.

The two Bangladeshi project cities Dinajpur and Rangpur are both located in the north-western part of Bangladesh. During

consultation meetings with the city authorities in NICE's inception phase, the mayor of Dinajpur confirmed an estimated population size of ±300'000 for Dinajpur, with at least 45'000 of them living in one of the city's 69 slums where on average 8–9 households share one toilet (28). People in Dinajpur mainly belong to the ethnicities of Santal and Orao and Islam is their main religion while Bangla is their language. In terms of climate, Dinajpur faces few but heavy rains during the monsoon. Dinajpur City Context Analysis during NICE inception phase identified Dinajpur's economy to mainly depend on agriculture with a strong focus on rice production (28). Dinajpur has a governmental safety net program supporting people in need with food from the local storage depot. Furthermore, there are microcredit opportunities for women and youth and short-term (6–12 months) employment opportunities for unemployed youth at different government offices. As per the Rangpur City Context Analysis during NICE inception phase, Rangpur has a population of ±800'000 with at least 100'000 of them living in one of the city's 57 slums (29). People in Rangpur mainly belong to the ethnicities of Santal and Orao and Islam is their main religion. While Bangla is the formal language in the city, Rangpuri dialect is widely spoken in Rangpur's rural surroundings. Rangpur's climate is comparable to the one in Dinajpur; few but heavy rains during the monsoon. Assessed during NICE's inception phase, Rangpur city is a commercial hub that serves its surrounding districts. City dwellers are thus mostly involved in non-farming activities and Rangpur is one of the most important economic zones in Bangladesh, even though the city belongs to the most poverty-stricken regions of Bangladesh. Still, about 50–60% of agro-food products produced in the area are exported to the rest of the country. City dwellers usually purchase their food from local wet markets, where fish, rice, chicken, vegetables, and grocery items are available. Cereals, largely rice, are the main foods in Rangpur region (29). Also Rangpur has a governmental safety net program supporting people in need with food from the local storage depot.

The two Kenyan project cities, Bungoma and Busia, are both located in the western part of the country, close to the Ugandan border. Bungoma has a population of ±250'000 inhabitants (30) mostly belonging to the Luhya tribe (more precisely the Bukusu sub-tribe) with its own language, but Bungoma is becoming more and more cosmopolitan. Uncontrolled urban sprawl is gradually extending into prime agricultural land in the peri-urban areas of the town (31). In terms of climate, Bungoma faces a typically tropical climate with significant amounts of rainfall summing up in an average annual rainfall of 1,500 mm and an average annual temperature of 22.5°C (32). Maize covers 95% of the land under food crop production and 80% of the value of food crops produced annually in Bungoma county (33). Other crops are beans, sorghum, and millets as well as sugarcane, cotton, palm oil, coffee, tea and sunflower as cash crops (34). The main food processing value chains in Bungoma are maize into flour and animal feed, sugarcane into molasses and sugar, and coffee berries into coffee beans; most production is for local consumption (34). Busia has an estimated population of ±120'000 and rapidly growing informal settlements (35). The predominant ethnic groups in Busia town are Teso and Luhya with their own languages, while English and Kiswahili are widely spoken, and most inhabitants are Christians with also some Muslims especially in the urban center of the city (36). In terms of climate, Busia also faces a moisty tropical climate with a slightly higher amount of precipitation in the first half of the year compared to the second half summing up in an annual rainfall of 750–2,000 mm (37). Mean temperature is between 21 and 27°C in Busia (37). Besides agriculture and fishing, trade is another important economic activity in Busia (38). Agricultural production is mainly at a subsistence level. The main type of crops grown in Busia County include maize, cassava, finger millet, beans, sorghum, rice, sweet potato, cowpea, groundnuts, banana, green gram, sesame, soya beans, cotton, tobacco, sugarcane, oil palm, and pepper. The main value chains in the city-region are vegetables such as kales, cowpea, black nightshade, tomatoes, water melons, bananas, rabbit rearing, piggery and poultry rearing (39).

The two Rwandan project cities, Rusizi and Rubavu, are both located in the Western Province, the so-called food basket of Rwanda. Rubavu has a population of ±150'000 inhabitants (40). Main language in the area is Kinyarwanda and most people are Christians. In terms of climate, Rubavu faces an equatorial climate with an average temperature of 21.5°C as well as annual rainfalls of 1200–1300 mm fairly well distributed throughout the year except for the period of long dry season, which extends from June to mid-September (40). City Context Analysis during NICE inception phase highlighted Rubavu's high production volumes of potatoes, sweet potatoes, cassava, sorghum, maize, beans, vegetables, and fruits (mangoes and passion fruit) for subsistence and export to other regions of the country and beyond country's border to the Democratic Republic of Congo as well as of cash crops such as coffee, tea, and pyrethrum (41). Rubavu's economy is strongly dependent on cross border trade with Goma town in the Democratic Republic of Congo where 25% of Rubavu's population works. The tourism sector also fosters the economic development in the city and Rubavu is prominently mentioned in Rwanda's Tourism Policy (42), leading to a generally positive business environment in Rubavu. Less than 50% of the population are engaged in agricultural work in Rubavu, but just behind Kigali, Rubavu has the second most informal settlements among Rwandan cities, about 190 ha of the urban area are currently unplanned. Rusizi has a population of ±70'000 inhabitants (40). As for Rubavu, main language in the area is Kinyarwanda and most people are Christians. In terms of climate, Rusizi has an average temperature of 25°C, with hottest month being July. The average annual rainfall is 1200–1300 mm, fairly well distributed throughout the year except for the period of long dry season which extends from June to mid-September (40). City Context Analysis during NICE inception phase listed trade as another important economic activity besides agriculture, fishing, and forestry in Rusizi because the district shares borders with both the Democratic Republic of Congo and Burundi (40). Still, 57% of Rusizi's workforce are engaged in agriculture and 45% of Rusizi's population is categorized as poor or extreme-poor as per the Rwandan categorization system. Crops produced in the city include cassava, banana, sorghum, and peas. Other popular crops in Rusizi are avocadoes and French beans (41). In Rwanda, the socio-economically least well-off citizens are entitled to free health insurance while the wealthiest are paying premiums of USD $8 per adult per year (41).

As re-confirmed during City Context Analyses in the inception phase of the project, city-level nutrition data are scarce for all the selected cities, but Table 1 provides an overview on the most important nutrition indicators in the general urban context in the selected countries.

TABLE 1 Selected nutrition indicators to contribute to the big picture of cities in which the NICE project is implemented.

	Bangladesh	Kenya	Rwanda
<5 y stunting prevalence (%)[a]	26.3 [2019]	20.0 [2014]	19.8 [2020]
5–19 y female overweight prevalence (%)[b]	8.7 [2016]	16.2 [2016]	16.9 [2016]
18+ female overweight prevalence (%)[b]	22.2 [2016]	34.3 [2016]	33.5 [2016]
Prevalence of infants with low birth weight (%)[c]	27.8 [2015]	11.5 [2015]	7.9 [2015]

While nutrition data for specific cities are scarce, the Global Nutrition Report's Country Profiles (66) provide a brief overview about national nutrition situations, with data on stunting prevalence disaggregated for the urban context only. Data in brackets indicating year of data collection.

[a]UNICEF/WHO/World Bank. Joint Child Malnutrition Estimates Expanded Database: Stunting, Wasting and Overweight. Published online July 2020. Available at: https://data.unicef.org/resources/dataset/malnutrition-data.

[b]NCD Risk Factor Collaboration. Values for 2000 to 2016 Published online http://ncdrisc.org/data-downloads.html.

[c]UNICEF/WHO. Low birthweight estimates. Published online 2019. Available at: https://data.unicef.org/topic/nutrition/low-birthweight.

TABLE 2 Comprehensive set of 13 agroecological principles as per the High Level Panel of Experts of the Committee on World Food Security and Nutrition's framework of agroecology (47).

1. To improve resource efficiency
a. Recycling
b. Input reduction
2. To strengthen resilience
c. Soil health
d. Animal health
e. Biodiversity
f. Synergy
g. Economic diversification
3. To secure social equity / responsibility
h. Co-creation of knowledge
i. Social values and diets
j. Fairness
k. Connectivity
l. Land and natural resource governance
m. Participation

2.3. Project design

The NICE project follows a context-sensitive / system approach focusing on governance and acting through facilitation and leveraging of local stakeholder activities in close partnership with the respective city authorities. While nutrition for city populations is improved through participatory, agricultural, food and health sector collaborations along city-specific value chains, interventions may differ among the participating secondary cities based on the food system opportunities and bottlenecks each city prioritizes; nevertheless expected outcomes and outputs of the project remain fixed (Figure 1). The main overarching interventions of NICE are thus (i) advocacy and policy dialogue, (ii) building of decentralized institutional capacity in multi-sectoral collaborations, (iii) support of data-driven planning, coordination and resource mobilization, (iv) anchoring of innovations and new approaches in city-level partnerships, (v) capacity building in the agricultural, retail, health and education sectors, as well as (vi) evidence generation from putting policies into practice at the local level, all around the four main project outcomes (Figure 1).

In Project Outcome 1, city authorities are supported to better understand the dynamics of their respective food system. With technical support, cities will build participatory mechanisms in the form of functional, multisectoral food systems platforms for improved coordination among several food systems stakeholders. These functional multisectoral food systems platforms including not only governmental organizations but also the private sector and civil society then aim to contribute to data-driven strategic planning and resourcing and make city food systems more responsive to local ecological conditions and nutritional needs of its population in an inclusive manner (43, 44). The example of Brazil, which used to be an exemplary case of governmental support for agroecology but then was completely wiped out by a change in political leadership (45), illustrates the importance of strong and resilient/robust multisectoral, local level food systems ownership.

In Project Outcome 2, availability, accessibility and affordability of nutritious and agroecologically produced food shall be addressed through implementation and strengthening of farmers' hubs. Under the concept of farmers' hubs—an inclusive business model developed by SFSA—commercial one-stop service platforms create small holder farmers' access to quality inputs, agricultural machines, markets, finance and knowledge, ensuring them fair prices and assistance for increased farm productivity (46). Challenges of the agri-food chain including farming systems, food safety, supply chain (e.g., regarding intermediaries engaged in trading), and post-harvest handling shall be addressed (e.g., in the form of trainings and study tours) in line with the complex and dynamic concept of agroecology defined by the framework of the High Level Panel of Experts (HLPE) of the Committee on World Food Security and Nutrition (47). The framework bases on a comprehensive set of 13 agroecological principles as presented in Table 2. Value chains which the NICE project should focus on will be selected in a collaborative and participatory approach focusing on (i) government buy-in, (ii) nutrition-improvement potential, (iii) production feasibility, (iv) market potential, (v) income generation potential, (vi) agroecology potential and (vii) consumer buy-in. The UN Food and Agriculture Organization's (FAO) Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists (SHARP) tool will be adapted to the needs of the project to understand the agroecological status of each value chain, allowing a thorough gap assessment and challenges identification in the farming system (48, 49). After prioritization of the main value chain-related challenges, project interventions will be decided in consultations with key stakeholders following the International Fund for Agriculture Development (IFAD)'s guide for project design in nutrition-sensitive value chains (48).

In Project Outcome 3, demand for nutritious and agroecologically produced food should be fostered through social behavior change communication influencing evidence-based decision-making by local actors on food production and

consumption behaviors. Social behavior change communication increasing the nutrition literacy and thus the demand for nutritious and agroecologically produced food will include a range of media campaigns and social marketing interventions informed by evidence from a qualitative formative research through stakeholder interviews, in-home observations and group discussions. Consumers should become participants rather than just "beneficiaries" of food system transformation and the project's focus will be on nutritious and agroecologically produced food across selected city food regions emphasizing on ensuring access for women, youth and people living in informal settlements.

Finally, in Project Outcome 4, robust monitoring and evaluation (M&E) of the whole NICE project is ensured and lessons learned are recorded to be shared within and across countries. Data on urban population-specific food systems indicators are essential to guide city authorities' decision-making and to monitor change: As an example, egg hub models, where eggs are produced safer and more efficiently through collaboration, and support low market prices, are a true success story of social business implementation by SAL (50). Hence, they acted as an inspiration for the systematic approach in NICE (50): Increased egg production to lower market prices not only made eggs more accessible for those most in need of nutritious food—women and children—but also raised the incomes of smallholder (women) farmers in SAL's experience (50). Food systems data collected in the NICE project will be made publicly available in due time through (peer-reviewed) publications, local outreach documents such as case studies, good practices or technical briefs, and on city-owned online urban food system fora to further inform food systems transformation. Food systems data to be collected in the NICE project include baseline and endline data on NICE's impact and outcome indicators (Figure 2), data of the formative research on consumer and farmer behavior to build the evidence for social marketing and agroecology interventions as well as qualitative findings from food systems governance experience.

2.4. Project governance

City-level partnerships are at the core of NICE's context-sensitive / system approach and facilitation is a key component of the project. With assistance from the NICE project, city authorities (mainly from the departments of health and agriculture, but also departments of development, social welfare, education, finance etc.) and other food system stakeholders (farmers' cooperatives, local small and medium size enterprises, women and youth associations, nutrition counselors and primary health care points, local NGOs etc.) are leading the implementation of activities that support both overarching city-led priorities, as well as the project goals and outcomes. Innovations and new approaches, especially regarding agroecology and social behavior change communication, are foreseen to be anchored in the city-level partnerships.

Local SFSA offices in Bangladesh and Kenya, and the SAL and Swiss TPH offices in Rwanda backstop project implementers on the ground. All project activities are managed across several levels (Figure 3). On a first level, there is overall coordination and steering of the project by a leadership board consisting of the project leader from Swiss TPH and one team mate from each consortium member. On a second level, city-led actions are facilitated by the country-level project coordinators and their teams consisting of city-based coordinators as well as assisting staff. On a third level, backstopping and crosscutting technical support across cities and countries are provided by the global outcome teams bringing in the specific expertise of all four consortium partners: As a prominent institute in global health and nutrition, with experience in working with local governments and expertise in systems strengthening, Swiss TPH is responsible for Outcome 1. SFSA with its farmers' hubs model and wide expertise in agriculture, agribusiness, value chains, and markets is backstopping Outcome 2, strongly supported by ETH Zurich with its deep knowledge on agroecology and implementing impactful supply side interventions and analyses to improve food security, income, and resilience. SAL, a global nutrition think tank, with a wide set of expertise in nutrition, behavior change, and brokering public-private partnerships, backstops Outcome 3 while Outcome 4 is backstopped by ETH Zurich with its Sustainable Agroecosystems Group and the World Food System Center globally recognized for their expertise in agriculture, agroecology, food systems, and city region resilience.

An Advisory Board of food systems, nutrition, agroecology and urbanization experts as well as country experts from policymaking, academia, and project partners including SDC, guides the strategic direction of the project by meeting twice a year to oversee study progress in an independent manner, giving feedback and making recommendations.

Finally, a comprehensive, results-oriented M&E system based on a logframe supports the steering of the project and the generation of evidence to contribute to policy dialogue and wider learning. Indicators for M&E are presented in Figure 2.

Baseline data on impact and outcome indicators have been collected through a baseline investigation by independent local academic partners (Bangladesh, Kenya) and Swiss TPH (Rwanda) from April to June 2021 in all the cities involved and will be published separately. These information guide the value-chain selection and the identification of future study beneficiaries (priority populations). Similarly, a respective endline investigation is planned for the end of the project to assess improvements. Data on output indicators are generally collected on an on-going or bi-annual base by the country project management teams through focus group discussions and key informant interviews as well as respective observations and document collections. Furthermore, latest at the midpoint of the project, an internally arranged review will be conducted to confirm the relevance, efficiency, and effectiveness of the interventions, to gather project beneficiaries' experiences, and examine progress with the scale-up strategy.

A conflict-sensitive program management approach is implemented for planning, facilitating, and evaluating project interventions as the project has the potential to disrupt the status quo, potentially triggering conflict between local partners.

2.5. Data management and ethics

All project data will be collected electronically in this study. As agreed in any study protocols submitted for ethical clearance in the NICE project, raw data will be uploaded onto encrypted, secure servers of the Swiss headquarters of the respective academic

FIGURE 2
Monitoring and Evaluation indicators of NICE. A comprehensive, results-oriented M&E system based on a logframe supports the steering of the project and the generation of evidence to contribute to policy dialogue and wider learning *via* impact, outcomes (A–D referring to outcomes in Figure 1), and output indicators (A.a–D.c referring to outputs in Figure 1). HFIAS, Household Food Insecurity Access Scale; HDDS, Household Dietary Diversity Score; MDD-W, Minimum Dietary Diversity for Women.

partners, and will be rapidly curated, anonymized and cleaned before storage. All data will always be deleted from devices used in the field after upload to the main respective server. Data cleaning will be undertaken in respective statistical programs such as STATA or R, and various checks will be run on quantitative data to check for outliers, inconsistencies and potential mistakes.

Local authorities will be closely involved in all activities in their municipalities, or wider districts, including in the development of annual workplans and sharing of budgets. Informed by the fact that different malnutrition problems in urban centers tend to be clustered by residential neighborhoods, areas that have high rates of malnutrition are identified and particularly supported for and by the different project interventions, in close consultation with the local authorities.

Ethical clearance for any data collection and surveys will be carried out as requested by national bodies and regulations, especially given that some data collection will involve vulnerable population groups, and include any personal data and anthropometric

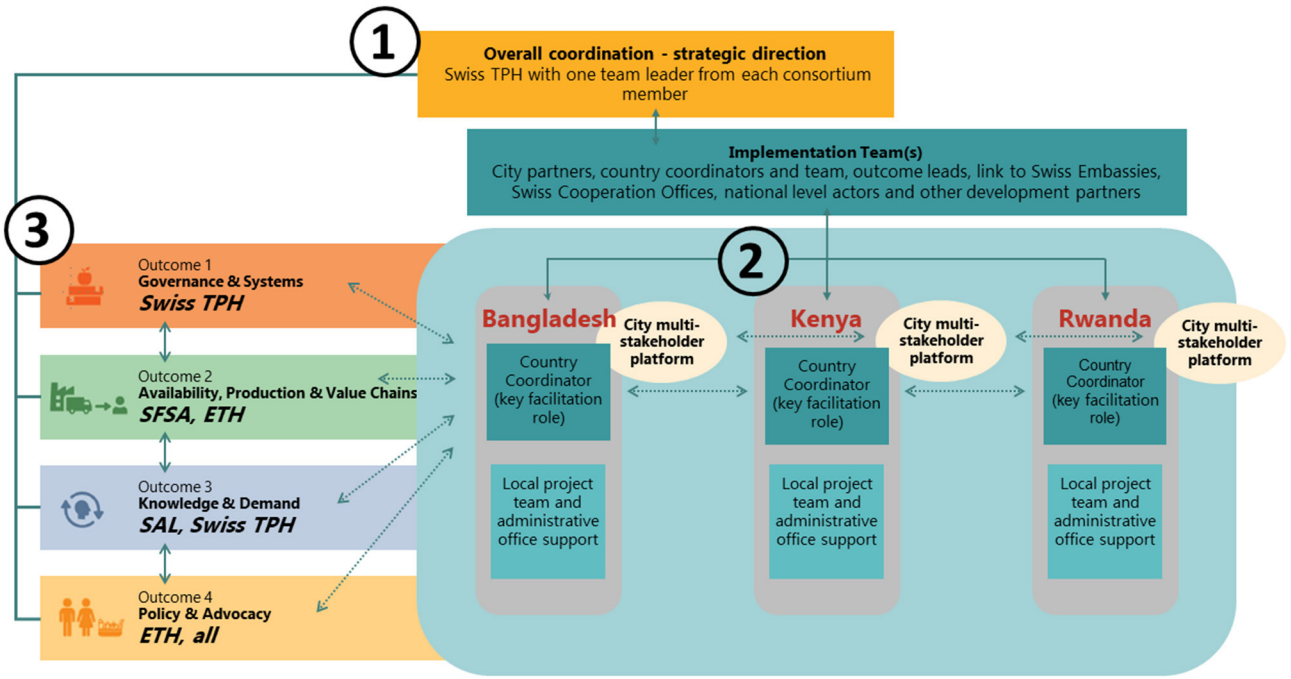

FIGURE 3
Overall set-up of NICE. NICE is set-up around 3 levels of governance: (1) overall coordination and steering of the project by a leadership board consisting of the team leader from Swiss TPH and one team leader from each consortium member; (2) country-led implementation through country-level project coordinators and their teams consisting of city-based coordinators as well as assisting staff; (3) cross-cutting technical support and quality assurance across cites and countries by global outcome teams bringing in the specific expertise of all four consortium partners. Swiss TPH, Swiss Tropical and Public Health Institute; SFSA, Syngenta Foundation for Sustainable Agriculture; ETH, Eidgenössische Hochschule Zürich; SAL, Sight and Life.

measurements. The NICE project will work with local academic partners and involve them in dissemination of findings. Survey results will always be fed back to local authorities and the involved communities in the cities concerned.

An assessment of the main contextual, programmatic and institutional risks of the NICE project as well as an in-depth consultation process have been carried out during project preparation. The consortium partners are well networked in all three countries and specifically with the local municipalities in all the cities.

3. Discussion

Suboptimal diet is responsible that one-third of the world's population suffers from malnutrition (4). Current food systems cannot guarantee sustainable availability, accessibility and affordability of nutritious and agroecologically produced food for all city dwellers in many urban areas (4, 51). Man-made conflicts, climate change and COVID-19 are further accentuating the burden of malnutrition and food insecurity, and the global community, therefore, recognizes an urgent need for food systems transformation toward more sustainable ways of producing and consuming food (52). By signing initiatives such as the Milan Urban Food Policy Pact or the C40 Cities Climate Leadership Group, many cities around the world already acknowledge the strong potential cities and urban regions can play for successful implementation of beneficial food systems transformations: By participating in large multisectoral networks with common aims and objectives, cities support each other through peer-to-peer exchange and direct technical assistance as well as knowledge sharing and efforts management and take their responsibility to integrate sustainable food systems into social, economic and environment policies, programs and initiatives (53, 54). The recent United Nations (UN) 2021 Food Systems Summit combined crucial elements of food safety, nutrition, poverty and inequalities in the context of climate and environmental change to ensure that all people have access to a safe and nutritious diet (55, 56). The UN 2021 Food Systems Summit thus aimed to catalyze a shift in consumer behavior that will create and build demand for sustainably produced agri-food products (55, 56). The NICE project is directly in line with Action Track 1 and Action Track 2 of the UN 2021 Food Systems Summit.

Sustainability is a key requirement of the NICE project, particularly fostered through interventions in the field of agroecology and social businesses (47, 57). Agroecology, by promoting sustainable farming practices in different categories has increasingly gained scientific and policy recognition as a way to address environmental and social issues within food systems (58). With investments in systems research, innovation, capacity building, market linkages, and the realization of fair prices, a huge potential can be exploited from agroecology to transform food systems in low-income countries (59). There is also a body of evidence on how women's participation in agroecological networks (especially in short supply chains) helped them to lift themselves out of violent situations of isolation and to affirm their own identity and knowledge (60, 61). Social businesses are another promising approach for improved sustainability and women engagement (57): Rural employment and entrepreneurship are key potential drivers of economic growth,

as well as being vital for food and nutrition security. Acting as aggregators for input buying and output sales, as well as providing good agricultural practice know-how and machinery, Farmers' Hubs are promising examples for the social business model and are particularly strengthened by the NICE project. Young people want opportunities and incentives, the chance to learn new skills, use new tools and earn a decent income in new markets. Farmers' Hubs are mostly driven by young entrepreneurs linking farmers in their communities to modern agricultural technologies and practices.

Work in nutrition and food systems is multisectoral by nature as it requires expertise from agriculture, public health, nutrition, education and beyond (5). Tight collaboration between supply and demand side as well as food systems governance guarantees affordable availability and accessibility of nutritious and agroecologically produced products, and nutrition-literate consumers' demand. Through widely-disseminated, well-timed and designed social behavior change communications on several media, nutrition literacy and maturity of city populations are improved, influencing city populations' dietary patterns.

Literature has shown that by involving a broad base of stakeholders and basing the policy and planning processes on principles of participation, ownership, commitment, mutual trust, and collaboration, municipal authorities are more likely to develop policies and programs that meet the needs of both the municipality and its constituents, and are thus more inclusive and successful in implementation (5, 62). Dubbeling et al. (2010) summarized the benefits of applying a participatory and multisectoral approach in transformation processes as follows: (i) More participatory governance and encouraged public-private partnerships help overcome distrust, and bridge the gap between citizen groups and the local government; (ii) A better understanding of priority issues and the needs of different food systems stakeholders empower respective quality analyses and decision-making; (iii) Enhanced acceptance and ownership of the transitions improve likelihood of success and sustainability of implementation, and (iv) Problem-solving and political lobbying capacities of the participating institutions are strengthened, and citizen's groups are empowered (5, 63, 64). Still, participatory, multisectoral approaches also have their challenges that need to be tackled, including amongst others a higher time investment compared to conventional top-down approaches or the danger of undue increases in the influence of some stakeholders with higher capacity to actively participate in the process and to convince other stakeholders (5, 63, 65). Through continued awareness-raising and information dissemination among and toward multiple stakeholders feeling ownership for the local urban food system, the NICE project will contribute to institutionalization of more sustainable food systems providing affordable nutritious and agroecologically produced food to all city dwellers, even the ones most at risk for malnutrition due to cultural and socio-economic shortcomings. Active strengthening of the organizational, managerial, technical, and networking capacities of all food system stakeholders, particularly focusing on women and youth, is key for making transitioned food systems more inclusive. The prioritization of women and youth as important beneficiaries of improved food systems but also key actors within them, challenges current power imbalances and inequities in access to resources and decision-making.

Through its context-sensitive / system approach fostering human-centered, participatory, agricultural, food, and health sector collaborations, the NICE project will improve and transition food systems by (A) strengthening urban governance structures involving key stakeholders including women and youth, (B) generating income for the producers along the supply chain, (C) triggering change in producers' and consumers' behavior such that nutritious and agroecologically produced food are both in demand, available and affordable in urban markets, and (D) scaling up successful approaches to other cities within the countries, as well as internationally. By channeling experiences into national policies and exchanges, city-level and national level project ownership as well as social accountability are strengthened. The front-runner project cities in each country are expected to share their experiences and findings with four additional cities per country during this project phase. In a potential second phase of the project, the findings and interventions should also be transferred to other countries, focusing on an involvement of also francophone contexts, and more fragile contexts, potentially with links to humanitarian aid.

Author contributions

CS supported the development of country-specific protocols, coordinates and monitors the study implementation, and drafted the manuscript. TB-J, KZ, and HP co-designed the project, supported the development of country-specific protocols, coordinate and monitor the study implementation, and drafted the manuscript. CM, SE, VJ-C, CT, and FS co-designed the project. CH, CN, EG, FZ, SB, and MP supported the development of country-specific protocols and coordinate and monitor the study implementation. JS, KK, MS, PT, SW, BG-S, and DB co-designed the project, supported the development of country-specific protocols, and coordinate and monitor the study implementation. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Challenges and obstacles implementing evidence-based food fortification policy in a high-income country

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The World Health Organization (WHO) recognizes food fortification as one of the most cost-effective and beneficial public health measures available. Mass fortification policies and regulations can reduce health disparities, including in high-income countries, by improving micronutrient intake among food-insecure or high-risk populations without changing their diet or behavior. While international health organizations have traditionally prioritized technical assistance and grants to medium and low-income countries, it is important to recognize that micronutrient deficiencies may also pose an important yet underappreciated public health problem in many high-income countries. Nevertheless, some high-income countries, including Israel, have been slow to adopt fortification, due to a variety of scientific, technological, regulatory, and political barriers. Overcoming these barriers requires an exchange of knowledge and expertise among the all stakeholders to achieve cooperation and broad public acceptance within countries. Similarly, sharing the experience of countries where the matter is in play may help inform efforts to advance fortification globally. Here we share a perspective on progress and barriers to achieve this goal in Israel, to inform efforts made to avoid the regrettable waste of unrealized human potential from prevalent yet preventable nutrient deficiency conditions, in Israel and beyond.

KEYWORDS

folate (folic acid), iodine, micronutrients, vitamin B12, calcium, vitamin D, NTD (neural tube defect), fortification

Perspective

Food fortification has been a safe and cost-effective method of preventing prevalent micronutrient deficiencies for over a century (1, 2). As of 2020, 143 countries around the world have adopted mandatory food fortification policies (3). Along with vaccinations, the World Health Organization (WHO) recognizes food fortification as one of the most cost-effective and beneficial public health measures available, and as a safe, effective, and inexpensive public health measure to prevent the harms associated with pernicious micronutrient deficiencies (4). Mass fortification can reduce health disparities including in high-income countries by improving micronutrient intake among food-insecure or high-risk populations without changing their diet or behavior (1, 5–8). Indeed, on January 31, 2023, the World Health Organization Executive Board decided to recommend that

the World Health Assembly adopt a resolution calling to accelerate efforts for preventing micronutrient deficiencies and their consequences, including spina bifida and other neural tube defects, through safe and effective food fortification (9). The Executive Board recommendation is supported by Australia, Brazil, Canada, Chile, Colombia, Ecuador, Malaysia, Paraguay, the European Union and its 27 Member States, and by Israel. Nevertheless, some high-income countries, including in Europe and Israel, have been slow to adopt fortification.

Growing evidence indicates that micronutrient deficiencies in Israel present a significant public health challenge. Over the past two decades, the Israel Ministry of Health (MOH) established three panels, in 1996, 2010 and 2015; all recommended mandating food fortification. The latest panel recommended fortifying salt with iodine, milk with vitamin D and flour with iron, B-complex, including but not limited to folic acid and vitamin B12, using the Canadian approach of mandatory fortification, accompanied by national biomonitoring of the population's micronutrient status. This as recommended by the WHO and public health best practice (2, 4, 10–13). In late 2018, the Minister of Health, and MOH Director-General, endorsed the recommendations and authorized steps to implement appropriate regulations (14). A subsequent Regulatory Impact Assessment (RIA) recommended harmonizing Israeli requirements with the European rather than Canadian guidance on fortification, to require mandatory fortification of selected staples, while permitting industry-driven voluntary fortification of other food products, on condition that claims and marketing of voluntarily fortified food are restricted.

Although knowledge of the benefits of food fortification are over a century old, countries like Israel that wish to fortify their food face a variety of scientific, technological, regulatory, and political barriers, including achieving public acceptance (1, 15). For example, implementing a sustainable fortification program requires adequate evidence of the populations' nutritional status; knowledge of the population consumption patterns of the intended fortification vehicle (e.g. salt, milk, or flour); setting technical standards for fortified foods; a willing and technically capable food industry; consideration of the effect on trade export and import of fortified foods; enacting appropriate regulations and laws; establishing procedures for fortified food quality control and for monitoring the effect of the policy on the populations' nutrition and health; providing appropriate funding; and of course, a supportive public and public health community. All this requires an exchange of knowledge and expertise among the all stakeholders to achieve cooperation and broad public acceptance (1).

To this end, the MOH, Israel Association of Public Health Physicians and the Ashkelon Academic College, convened a conference in November 2019, to discuss evidence of micronutrient deficiencies in Israel and the MOH decision to fortify food [see (16)]. Participants included relevant stakeholders, government officials, the public health community, academic researchers, industry representatives, and the public at large. Presentations reviewed evidence of prevalent micronutrient deficiencies of vitamins A, C, D, and E, folate, iodine, calcium, magnesium and iron, and of neural tube defects, anemia, thyroid disease and rickets, based on dietary intake data (from Israel Center for Disease Control's MABAT (Nutrition and Health) surveys of representative samples of children, adults, and the elderly), clinical laboratory data (from the major Health Management Organizations), and academic studies (from the peer-reviewed medical literature). The meeting concluded with a round table exchange, indicating broad official and stakeholder support for fortifying food in Israel.

The main obstacles to mandate fortification are neither scientific nor technological (16). Rather, the challenge has been to gain the political motivation needed to draft and pass legislation designed to regulate, enforce and fund fortification, according to the specific health and nutrition needs of the Israeli population. The delay in doing so partly reflects concern over those significant regulatory, budgetary and political efforts that are necessary to give public health priority over competing interests. Unfortunately, the onset of the COVID-19 pandemic diverted MOH attention and resources from this important issue, and progress toward implementation has slowed. Nevertheless, at the urging of the MOH the Israel Standards Institute has begun to revise the salt and milk standards, to meet the intended requirements for local production and importation of iodized salt and iodine and vitamin D fortified milk (Personal communication, Endevelt, R.). Theoretically, market-driven, voluntary fortification might improve the dietary intakes of some Israelis, but extensive international experience shows that uncontrolled voluntary fortification is less effective, more prone to promote risk of excessive intake, and more likely to increase health disparities than mandatory, regulated food fortification. Thus, it is crucial that in addition to revising the food standards, Israel enacts regulations specifying the fortificants and food vehicles that must be fortified, while restricting the use of voluntary fortification for marketing purposes. The regulations should allow for periodic evaluation and adjustment to the fortification program to allow for possible changes in the populations' nutritional status and food intake. WHO guidelines on food fortification and extensive international experience can provide reassurance and guide Israel's response to these concerns.

Other concerns that mandatory fortification might restrict free trade, particularly with Europe, should be allayed by acknowledging that the World Trade Organization allows countries to create their own national food standards in accordance with the CODEX Alimentarius, and to legislate mandatory fortification of locally produced and imported food, when required for public health (17). Indeed, the European Union does not require harmonized food fortification standards. Rather, each European Member State regulates fortification based on the health needs of its own population: Ten states allow salt to be fortified with either potassium or sodium iodide (KI or NaI), two states permit potassium iodate only (KIO_3), and nine states permit both iodide and iodate. In seven of twenty-five European states, salt iodization is mandatory (18). Furthermore, the required iodine concentrations differ between member states based on each population's iodine status, and none of this prevents European trade. Simply stated, trade considerations do not trump mandatory fortification, provided the legislation is necessary to ensure public health.

The MOH should also address the drafting of fortification legislation in the MOH work plan; perform cost-utility analyses; strengthen public support through information campaigns; make arrangements to sustain fortification; establish a steering committee with a mandate to design, oversee and enforce the program; and provide for the periodic monitoring of the population's nutrient intake and status.

The MOH should continue to place public health policy over competing interests and balance political pressures in order to affirm an effective and equitable policy. Doing so will ultimately improve the well-being of the Israeli public, by helping to lessen health and social disparities, reduce health system costs to the Israeli economy, and avoid the regrettable waste of unrealized human potential from these prevalent yet preventable deficiency conditions.

International implications

While international health organizations have traditionally prioritized technical assistance and grants to medium and low-income countries, it is important to recognize that micronutrient deficiencies may also pose an important yet underappreciated public health problem in many high-income countries. Thus, national governments of high-income countries should prioritize preventing this "silent hunger" that causes birth defects and negatively impacts child development and the realization of human potential and health at all ages. Countries that fortify their food can provide positive examples of public health best practice to those, that have yet to do so (4, 19, 20).

Based on this international experience with micronutrient deficiencies and fortification, and the current situation in Israel, we draw the following conclusions:

With regard to Israel

1. Micronutrient deficiencies can and do occur in Israel at levels which may harm vulnerable groups in the population that require public health action. Excess risk micronutrient deficiencies may be prevented by eradicating their antecedent deficiencies through evidence-based, mass food fortification.
2. Mandate fortification of salt with iodine, milk with vitamin D, flour with iron, vitamin B-complex including folic acid and vitamin B12, making it an integral element in Israel's health-promoting nutrition policy.

Global public health recommendations

3. Micronutrient intake and status of the general and high-risk populations should be monitored on a regular basis.
4. Health funds and the MOH must promote awareness of the vital role of micronutrients for vulnerable populations: women, pregnancies, newborns, children, adolescents, adults and the elderly.
5. Medical, nursing, nutrition professional training programs should place nutrition public health among the highest priority messaging and competencies required for their professional training.
6. High, medium, and low-income countries should all be encouraged to consider mandatory fortification of common foods to promote health of their populations. The ongoing COVID-19 pandemic underscores the urgency of these measures.
7. WHO. UNICEF, UNDP, World Bank and other leading international organizations should make the elimination of the silent hunger of micronutrient deficiencies a high priority, and a key element of the Sustainable Development Goal of "Zero Hunger".

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

RE, TT, ZS, and AT conceived of and drafted this manuscript. All authors contributed to revising it critically for important intellectual content and approved of the final version to be published.

Conflict of interest

RE directs the Division of Nutrition, Public Health Services, Israel Ministry of Health. ZS is former director of the Division of Nutrition in the Israel Ministry of Health and current member of the Health Promotion Department, the Southern District Health Office of the Israel Ministry of Health. HL is the current Chair and Davidovich is the former Chair of the Israel Association of Public Health Physicians. ZM is the Director of Research at the Tel Aviv Department of Health. RE, TT, ZS, and AT were members of the 2015 Ministry of Health Committee on Micronutrient Fortification. RE, TT, ZM, ND, HL, and AT were on the steering committee of the 2019 Micronutrient Conference. ZM and ZS are members in the National Council for Health Promotion in Israel.

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Success of community-based system dynamics in prevention interventions: A systematic review of the literature

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Systems thinking approaches are increasingly being used to help communities understand and develop responses to preventing complex health problems. Less is known about how success is characterized and what influences success in these approaches. We present a systematic review of how concepts of success are understood and evaluated in the peer reviewed literature of studies using systems thinking in community prevention. We searched five databases for peer-reviewed literature published between 2000 and 2022, with search terms related to systems thinking, prevention and community. Studies were included if they; reported using community-based systems thinking to prevent a public health problem; described the engagement and empowerment of community members to address a public health issue; and, were published in English. Thirty-four articles were identified from 10 countries. Twenty-one aimed to prevent a chronic disease (e.g., obesity) and 16 measured success using specific tools, 10 of which used semi-structured interviews or surveys. Measures of success included implementation processes, cultural appropriateness, the number or type of actions implemented, effectiveness of community action, and changes in individual thinking or mental models, population health outcomes, data collected, or systems level measures. Implementation factors influencing success included the capacity to engage participants, composition and experience of facilitators, strength of coordination teams, allocation of resources, adaptation to participant feedback, use of multiple systems approaches, workshop process providing time and methods to allow new insights, flexible delivery, and diversity of perspectives. Findings from each of the articles indicated that approaches increased a range of outcomes including community action, strategic thinking, future planning and evaluation, community buy-in, community voice, contribution and leadership, in addition to developing shared visions and goals and creating new, ongoing collaborations, among many others. Measures of success varied, suggesting more empirical reporting of proposed outcomes of system science in communities would be valuable. While the measurement of success in the use of systems thinking in community-based prevention efforts is limited, there are helpful examples we can look to for future measurement of success.

KEYWORDS

systems thinking, community-based system dynamics, systematic review, success, evaluation, prevention

1. Introduction

The application of systems thinking to address complex community and social problems is gaining momentum (1, 2), particularly in community settings (3, 4). A range of methods have emerged within systems thinking that are used to help capture and engage with complexity inherent in many modern problems (5). According to Ison (p. 142) (5), systems thinking (or systemic thinking) in this instance is considered to be '*the understanding of a phenomenon within the content of a larger whole; to understand things systemically literally means to put them into context, to establish the nature of their relationships*.'

There are a wide range of systems thinking approaches, which are shaped by the various historical influences of systems practice across different disciplines (6). Common techniques to work with communities using system thinking include participatory system dynamics (PSD), group model building (GMB), soft systems methodology (7), critical systems heuristics (8) and community-based system dynamics (CBSD) (9, 10). While there is overlap between methods, there are also key distinctions, which generally span the level of involvement participants have in the process, the ownership participants have over the diagram developed and overall capacity built as a result of participant engagement (10). Most examples of systems thinking studies in the public health literature provide in-depth descriptions of the community's understanding of a complex problem, but few provide insights on the effectiveness of the method, nor the implications of these methods for the success of attempts to address the problem overall. GMB stands out as one form of systems thinking with a greater amount of documented evaluation in the literature (3, 11, 12).

Long before systems thinking gained momentum in public health, community participation and engagement have been called for as a critical element in prevention efforts (13, 14). CBSD is an application of GMB that emphasizes participation and engagement alongside systems thinking (10). A key aspect of CBSD is engaging community or stakeholders in an agreed problem to gain shared insights and identify corresponding community-led action through the use of GMB (9, 10). This typically involves stakeholders in a series of workshops or consultations who create a diagram (in public health, often a causal loop diagram (CLD)) which helps visualize a complex problem from the community's perspective. CBSD builds community capacity to recognize key feedback loops in a system's structure that drive a system's behavior, mobilizing action for systems change.

The concept of success can be contentious, and for the purpose of this review, success (or not) of an approach is considered in light of the authors conclusions within each article. While an approach is not considered completely 'successful' or 'unsuccessful', it is important to draw from past experiences that may have included components that helped facilitators get closer to their outcome, or those that may have created challenges.

Abbreviations: CBSD, Community based system dynamics; GMB, Group model building; CLD, Causal loop diagram.

While there are numerous descriptions of the use of CBSD to identify causal factors, interrelationships and actions to address a problem, much less literature describes the effectiveness or success of the approach. Within the literature that is available, findings are fragmented. No study has systematically searched the literature to examine success of CBSD across multiple studies, nor identified factors that influence success.

This systematic review assesses the current evidence describing success of CBSD and examines implementation factors that influence this success by asking the following research questions:

1. How is success in community-based system dynamics understood and measured in public health?
2. What implementation factors influence success of community-based system dynamics efforts in public health?

2. Methods

This review was registered with PROSPERO in January 2021 (CRD42021212817). Reporting of results was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (15).

Our review focused on systems thinking approaches that specifically brought the community together to address the prevention of a public health or social problem, specifically using CBSD, or where a participatory method of visualization, modeling or causal diagram creation was applied to empower or mobilize a community in response to a complex problem. Definitions of CBSD by Hovmand (9) and descriptions by Király and Miskolczi (10) have been used to define the boundaries of this review.

2.1. Search strategy

The search was inclusive of empirical research published between January 2000 and October 2022. Both qualitative and quantitative study designs were included in our review. Only articles published in English were included.

Studies were searched using the MEDLINE complete, PsycInfo, CINAHL, Global Health and SocIndex databases. Search terms focused on three primary areas: community (population), systems thinking (intervention), prevention (outcome). Terms from the three areas were combined with the operator 'AND'. Within the primary search areas, more specific search terms were combined with the operator "OR" (Table 1). The broad term of "systems thinking" was included as pilot literature searching identified there were few published studies that measure success of CBSD when using these terms alone.

The search strategy was adapted to the syntax requirements of each database. Reference lists of all included articles, and other relevant review articles identified, were additionally scanned for relevant studies.

All retrieved references were exported into the Endnote reference management software and transferred to Covidence, an online review platform, where duplicates were removed and articles were screened for inclusion.

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TABLE 1 Search term concepts and variations.

Search term concept	Search term variation
Systems thinking	"system* science" OR "system dynamics" OR "system* thinking" OR "system* change*" OR "system* approach*" OR "system* initiative*" OR "system* theor*" OR "system* model*" OR "system* action*" OR (MH "systems theory") OR "complex problem*" OR "complex adaptive system*" OR "complex system*" OR "group model building" OR "causal loop diagram*" OR "participatory system*" OR (MH "Nonlinear Dynamics")
Prevention	"public health" OR "health promotion" OR "early intervention" OR "population health" OR "rural health" OR "urban health" OR prevent* OR "mental health" OR obesity OR alcohol OR "food system*" OR (MH "Public Health") OR (MH "Preventive Medicine") OR (MH "Primary Prevention") OR (MH "Health Promotion")
Community	communit* OR stakeholder*

2.2. Study selection

Use of CBSD terminology is sporadic. For the purpose of this paper, we will use the term CBSD when describing success, implementation and measures for all included articles in our review, even if the term has not been stated in the included article. This provides recognition of those articles using methods that encompass the principles of CBSD, as described in the following inclusion criteria.

Articles were included if they reported projects that; described collaboration or coalitions within specified communities; used, or described using an approach to systems thinking in the community setting (stated they were using CBSD, or alternatively, GMB, participatory systems or described building/using a qualitative CLD with the community); described engaging with stakeholders to apply systems thinking; focused on prevention of a public health issue; described a process that intended to empower individuals from a community (to take action, mobilize, or advocate); and had participation of community members across all stages of problem definition, diagram development, testing and transferring insights back into community. Studies were excluded if they did not consider community-level outcomes. An end point for the CBSD process was not defined in the criteria, as this varied and was highly dependent on what facilitators intended to see change as a result of using CBSD.

2.3. Screening process

The titles and abstracts of retrieved articles were independently screened by two members of the review team (TF, ADB or PNS) and discrepancies were resolved through discussion with a third reviewer (ADB or PNS). Before starting full text review, three authors involved in the screening process (TF, ADB, PNS) reviewed a subset of articles to ensure application of criteria were consistent. The remaining full text articles were reviewed by two independent authors (TF with ADB or PNS) with conflicts discussed and resolved between three authors (TF, ADB, PNS). Reasons for article exclusion at this stage were recorded. The most common reasons for exclusion were articles that were the wrong study type, wrong systems approach, or wrong health issue.

2.4. Data extraction and synthesis

Two reviewers (TF, ADB or PNS) independently extracted relevant data from 20% of articles (selected in alphabetical order, by first author) using a pre-specified and agreed upon data extraction template which included study title, intervention title (if specified), country or region of study/implementation, year of publication and implementation, author (s)/organization (s), study design, aim, nature of complex problem, lead implementation organization, collaborations, number and type of stakeholders involved in implementation (community members, professionals, others), details of the implementation process, method of data collection for success, and authors conclusions of the success of the process. Discrepancies were discussed within this sample to ensure consistency across the remainder of articles. Remaining data extraction was completed by one reviewer (TF).

The number of studies screened, assessed and included in the final review were recorded and reported using the PRISMA flowchart (Figure 1). As our study aimed to better understand the varying concepts of what constituted success in CBSD, a summary of the findings across the literature is presented (Supplementary Table 3). Results are grouped into studies that have used author observation to report on success and those that have used non-observation data collection methods.

2.5. Quality assessment

We did not undertake an assessment for the risk of bias as this was a systematic review with narrative synthesis intended to summarize the current state of the literature. We did however apply a standard approach to assessing the quality of studies returned by the review.

Study quality was assessed using the Critical Appraisal Skills Programme (CASP) Checklists (16). Quality appraisal was conducted by the primary investigator (TF) with 20% of articles cross-checked by one member of the review team to ensure consistency (ADB or PNS). Although no literature was excluded based on quality, discussion on quality of studies is included.

2.6. Analysis

A narrative synthesis, guided by Popay and Roberts (17), was used in this review due to the varying nature of study designs employed by those using CBSD. This involved; developing a preliminary synthesis of findings of included studies, exploring relationships in the data, and assessing the robustness of the synthesis (for example, quality

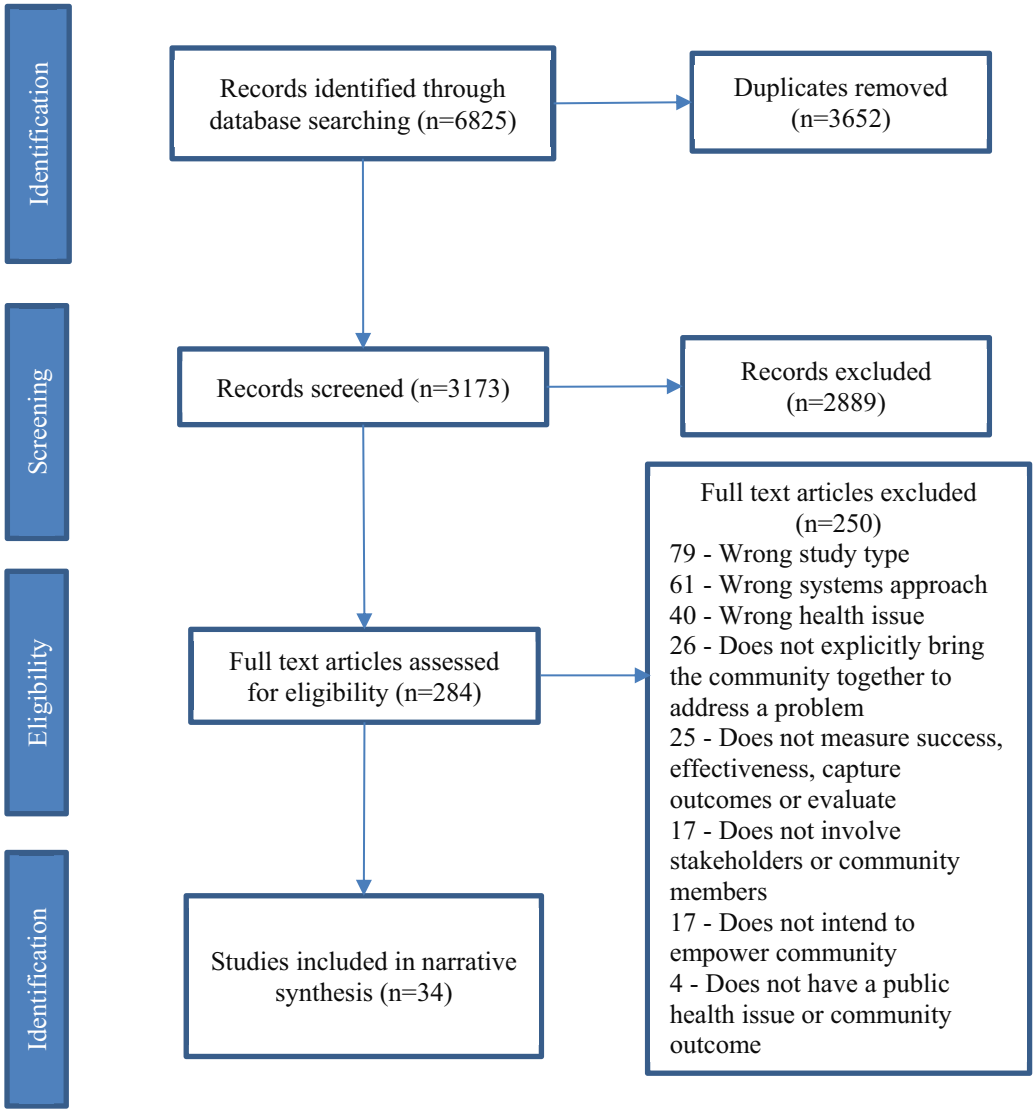

FIGURE 1
PRISMA flow chart.

assessments and quantity, of included articles, and minimizing bias by including multiple reviewers at each stage).

Descriptions provided by authors of each article were used to identify interventions (if they were named), regions where approaches occurred, the nature of the complex problem identified, and how systems thinking was used with each community.

Inductive thematic analysis (18) was used by one reviewer (TF) to explore themes within three subsets of the data extracted, specifically where; data related to concepts of success, identification and descriptions of implementation factors, and, overall findings (for example, how an implementation factor increased or decreased perceived success). The reviewer (TF) identified codes and categories as they emerged, and where codes or categories were identified as similar, themes emerged. The main, reoccurring or most important concepts were identified across all included studies by identifying those that occurred most often or were described by authors as having a critical influence on results. Results for this analysis are presented in sections 3.5 and 3.6.

3. Results

The search of all databases yielded 6,825 articles, before 3,652 duplicates were removed. A total of 3,173 titles and abstracts were screened, with 284 articles identified eligible for full-text review. Of these, 34 articles met the inclusion criteria and were included in this review (Supplementary Table 3).

3.1. Sample characteristics

The 34 articles represented 12 different interventions. Twenty articles did not specify an intervention name. Two articles related to The Whole of Systems Trial of Prevention Strategies for Childhood Obesity (WHOSTOPS) (19, 20), with three additional articles focused on subset interventions within WHOSTOPS [GenR8 Change (21)], Sustainable Eating Activity Change Portland [or SEA Change Portland (22) and Portland, a WHO STOPS pilot community (23)]. Two

articles related to Healthy Families Waitākere (HFW) (24, 25), and the remaining seven articles described a single intervention (Campbelltown - Changing our Future (Change4Campbelltown) (26), Nourishing Hawke's Bay: He wairua tō te kai (27), Prevention Impacts Simulation Model (PRISM) (28), Shape Up Under 5 (SUU5) (29), Derby: a City on the Move (DaCotM) (30), Urban Health in Latin America ("Salud Urbana en América Latina," or SALURBAL) (31), and the Food & Fitness (F&F) Initiative (32).

The articles reviewed were of mixed quality and value, based on the Critical Appraisal Skills Programme (CASP) Checklists (16) (Table 2). One article was assessed as low value (33), 23 moderately valuable (21, 23, 24, 27, 28, 30, 34–50) and 10 were of high value (19, 20, 22, 25, 26, 29, 31, 32, 51, 52).

3.2. Region or country

Articles described interventions that were implemented across 10 different countries or regions, with 26 articles describing interventions conducted within high income countries [13 from the United States (28, 29, 32, 35–37, 40, 44, 46–49, 52) with one article each related to PRISM and SUU5, with the remaining interventions not described, seven from Australia (19–23, 26, 51) with five articles connected to WHOSTOPS or subset interventions, one article related to the Change4Cambelltown intervention, and one intervention not described. There were three articles from New Zealand (24, 25, 27) two of which were related to the HFW intervention and one connected to Nourishing Hawke's Bay: He wairua tō te kai. Three articles were from the United Kingdom (30, 34, 45)], one of which was connected to the DaCotM intervention, with the remaining two interventions not described. Four articles described interventions in upper middle income countries, in Lebanon (38, 39, 43) and Thailand (50), with all focused on refugee communities (it is worth noting that all interventions in Lebanon occurred in areas with high disadvantage, including those areas with newly arrived Syrian refugees, and the intervention in Thailand was related to those living in refugee camps), none of which identified a name for their interventions. One article described an intervention in Fiji (42), a middle income country, while two articles described interventions in lower middle income countries [one from India (33), one from the Latin American region (31)]. Of these, all were unnamed interventions, with the exception of the SALURBAL intervention in Latin America. One article described an unnamed intervention in Afghanistan (41), one of the world's lowest income countries (53).

3.3. Complex problems

Of the articles included, 10 described interventions focused on childhood obesity (19–22, 27, 29, 40, 45, 48, 52), two on childhood fruit and vegetable intake (24, 25), and one on childhood overweight and obesity (26). The articles reported on findings from seven interventions: SUU5 (29), WHOSTOPS (19, 20), two additional interventions connected to WHOSTOPS (GenR8 Change (21) SEA Change Portland (22)), HFW (24, 25), Change4Campbelltown (26) and Nourishing Hawke's Bay: He wairua tō te kai (27). Four articles that focused on childhood obesity described interventions that were unnamed (40, 45, 48, 52).

In addition, eight articles reported findings on CBSD approaches that focused on some aspect of chronic disease. This includes the following topics: chronic disease as an outcome (44), burden of chronic disease (28), non-communicable disease (43)), and changing environments to encourage physical activity and healthy eating (physical inactivity (30), availability of healthy foods in low income communities (36), use of evidence in food related policy making (42), water and sugar sweetened beverage consumption (23) and healthy eating and active living (32)) for the population overall.

Three articles reported on interventions that focused on mental health of refugee and local communities (38, 39, 41), all of which occurred in Lebanon and Afghanistan. Three articles focused on equity (racial inequity (47), health equity (31), and inequities experienced by Indigenous women in relation to intimate partner violence and alcohol misuse (46)). Two articles focused on housing (housing, energy and wellbeing (34) and family homeless shelter use (35)).

Other complex problems reported include; community violence (49), road traffic safety and pedestrian deaths (37) and sustained adoption of cleaner cooking technologies (33). One article did not describe the focus of interventions specifically, as its aim was to explore the use of CBSD in Indigenous communities in Australia across various interventions (51).

3.4. Use of systems thinking with the community

Twenty-six of the 34 articles used CBSD in the community in addition to testing or refining the systems method used. Four articles used CBSD in the community alone, without intention to test or refine the method, nor use it as part of evaluation. Three articles described using systems thinking to test and refine the method and the remaining article used systems thinking as an evaluation technique. Twelve articles described using CBSD as part of a wider intervention, with 20 articles describing stand alone interventions. In two articles it was unclear whether the CBSD approach was stand alone or part of a wider intervention.

Eighteen articles did not describe the composition of the facilitation team, eight articles identified that facilitation team members included a mix of academics and community leaders or professionals, seven stated facilitation teams comprised of academic researchers, and one identified a consultancy led facilitation.

Authors used terminology other than CBSD to describe their method of community or stakeholder engagement and qualitative model development (Table 3). Thirteen articles (13 interventions) explicitly describe using CBSD (20, 23, 27, 31, 33, 35, 36, 38, 40, 41, 46, 50, 51). The remaining 21 articles (20 interventions) use other descriptions to explain the methods they use. Five articles (five interventions) describe using GMB with the community to build a causal loop diagram (22, 24, 37, 42, 43), and three articles (three interventions) describe using GMB with the community (25, 29, 49). Three articles (three interventions) describe building a causal loop diagram with the community (26, 30, 48), two articles (two interventions) describe using system dynamics (SD) with the community (28, 44) and two articles (two interventions) describe using participatory GMB (21, 39).

TABLE 2 Summary of quality assessment for included articles.

Articles	Qualitative studies (CASP Qualitative Studies Checklist)									
	1. Was there a clear statement of the aims of the research?	2. Is a qualitative methodology appropriate?	3. Was the research design appropriate to address the aims of the research?	4. Was the recruitment strategy appropriate to the aims of the research?	5. Was the data collected in a way that addressed the research issue?	6. Has the relationship between researcher and participants been adequately considered?	7. Have ethical issues been taken into consideration?	8. Was the data analysis sufficiently rigorous?	9. Is there a clear statement of findings?	Overall comments 10. How valuable is the research?
Allender et al., 2020	Yes	Yes	Yes	Cannot tell	Cannot tell	Yes	No	Yes	Yes	Excellent - very valuable
Bolton et al., 2022	Yes	Yes	Yes	Cannot tell	Yes	Cannot tell	Yes	Cannot tell	Yes	Moderately valuable
Brown et al., 2022	Yes	Yes	Yes	Cannot tell	Yes	Cannot tell	Yes	Cannot tell	Yes	Moderately valuable
Browne et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Excellent - very valuable
Burke et al., 2014	Yes	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	No	Cannot tell	Yes	Moderately valuable
Calancie et al., 2022	Yes	Yes	Yes	Yes	Yes	Cannot tell	No	Yes	Yes	Excellent—very valuable
Calancie et al., 2020	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Excellent - very valuable
Cavill et al., 2020	Yes	Yes	Yes	No	Yes	Cannot tell	Cannot tell	Yes	Yes	Moderately valuable
Chavez-Ulgade et al., 2022	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Moderately valuable
Deutsch et al., 2021	Yes	Yes	Yes	Cannot tell	Yes	Yes	No	Cannot tell	Yes	Moderately valuable
Egbuonye et al., 2022	Yes	Yes	Yes	Cannot tell	Yes	Cannot tell	No	No	Yes	Moderately valuable
Frerichs et al., 2018	Yes	Yes	Cannot tell	Cannot tell	Yes	Cannot tell	No	Yes	Yes	Moderately valuable
Frerichs et al., 2016	Yes	Yes	Yes	Yes	Cannot tell	Yes	No	Cannot tell	Yes	Moderately valuable
Gerritsen et al., 2020	Yes	Yes	Yes	Yes	Cannot tell	Cannot tell	Yes	No	Yes	Excellent - very valuable
Gerritsen et al., 2019	Yes	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	Yes	No	Yes	Moderately valuable

(Continued)

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TABLE 2 (Continued)

Articles	Qualitative studies (CASP Qualitative Studies Checklist)									
	1. Was there a clear statement of the aims of the research?	2. Is a qualitative methodology appropriate?	3. Was the research design appropriate to address the aims of the research?	4. Was the recruitment strategy appropriate to the aims of the research?	5. Was the data collected in a way that addressed the research issue?	6. Has the relationship between researcher and participants been adequately considered?	7. Have ethical issues been taken into consideration?	8. Was the data analysis sufficiently rigorous?	9. Is there a clear statement of findings?	Overall comments 10. How valuable is the research?
Haroz et al., 2021	Yes	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	No	Cannot tell	Yes	Moderately valuable
Jacobs et al., 2021	Yes	Yes	Cannot tell	No	Yes	Yes	Yes	No	Yes	Excellent - very valuable
Jenkins et al., 2020	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Excellent - very valuable
Kumar et al., 2016	Yes	Yes	Yes	Cannot tell	Cannot tell	No	No	No	No	Not valuable for this review
Loyo et al., 2013	Yes	Yes	Yes	Yes	Yes	No	no	Cannot tell	Yes	Moderately valuable
Macmillan et al., 2016	Yes	Yes	Yes	yes	Yes	No	Yes	yes	Yes	Moderately valuable
Maitland et al., 2021	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Excellent - very valuable
Marcal et al., 2021	Yes	Yes	Yes	Yes	Yes	No	No	Cannot tell	Yes	Moderately valuable
McKelvie-Sebileau et al., 2022	Yes	Yes	Yes	Yes	Cannot tell	Yes	Yes	Cannot tell	Yes	Moderately valuable
Morais et al., 2021	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Excellent - very valuable
Mui et al., 2019	Yes	Yes	Yes	Cannot tell	Cannot tell	yes	Cannot tell	Cannot tell	Yes	Moderately valuable
Naumann et al., 2020	Yes	Yes	Yes	Yes	Cannot tell	No	Cannot tell	Cannot tell	Yes	Moderately valuable
Noubani et al., 2020	Yes	Yes	Yes	Yes	Cannot tell	Yes	Cannot tell	Cannot tell	Yes	Moderately valuable
Noubani et al., 2021	Yes	Yes	Yes	Yes	Cannot tell	Yes	Yes	Cannot tell	Yes	Moderately valuable

(Continued)

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TABLE 2 (Continued)

Articles	Qualitative studies (CASP Qualitative Studies Checklist)									
	1. Was there a clear statement of the aims of the research?	2. Is a qualitative methodology appropriate?	3. Was the research design appropriate to address the aims of the research?	4. Was the recruitment strategy appropriate to the aims of the research?	5. Was the data collected in a way that addressed the research issue?	6. Has the relationship between researcher and participants been adequately considered?	7. Have ethical issues been taken into consideration?	8. Was the data analysis sufficiently rigorous?	9. Is there a clear statement of findings?	Overall comments 10. How valuable is the research?
Sweirad et al., 2020	Yes	Yes	Yes	Yes	Cannot tell	No	No	Cannot tell	Yes	Moderately valuable
Trani et al., 2016	Yes	Yes	Yes	Cannot tell	Cannot tell	Yes	No	Cannot tell	Yes	Moderately valuable
Waqa et al., 2017	Yes	Yes	Yes	Yes	Cannot tell	Yes	Yes	Cannot tell	Yes	Moderately valuable
Zablith et al., 2021	Yes	Yes	Yes	Yes	Cannot tell	Yes	Cannot tell	Cannot tell	Yes	Moderately valuable
Zurcher et al., 2018	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Excellent - very valuable
	Cluster control trial (CASP RCT Checklist)									
	1. Did the study address a clearly focused research question?	2. Was the assignment of participants to interventions randomized?	3. Were all participants who entered the study accounted for at its conclusion?	4. Were the participants 'blind' to intervention they were given? • Were the investigators 'blind' to the intervention they were giving to participants? • Were the people assessing/ analyzing outcome/s 'blinded'?	5. Were the study groups similar at the start of the randomized controlled trial?	6. Apart from the experimental intervention, did each study group receive the same level of care (that is, were they treated equally)?	7. Were the effects of intervention reported comprehensively?	8. Was the precision of the estimate of the intervention or treatment effect reported?	9. Do the benefits of the experimental intervention outweigh the harms and costs?	10. Can the results be applied to your local population/in your context? 11. Would the experimental intervention provide greater value to the people in your care than any of the existing interventions?
Jacobs et al., 2021	Yes	Yes	Yes	Cannot tell, No, No	Yes	Yes	Yes	Yes	Yes	Yes, Yes, Excellent, very valuable

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TABLE 3 Summary of articles and interventions.

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Allender et al. (20)	The Whole of Systems Trial of Prevention Strategies for Childhood Obesity (WHOSTOPS)	Childhood obesity	Using systems in community and testing the method	Methods inspired by CBSD and GMB to build a CLD	Leaders including health services, school principals, local government, councilors, retail leaders, business leaders, and key community figures.	Author reflection	Excellent—very valuable
Bolton et al. (21)	GenR8 Change, part of WHOSTOPS	Childhood obesity	Using systems in community and testing the method	GMB's plus additional community workshops	Community leaders and members who designed and implemented interventions on behalf of children. Participants varied across workshops. Data session—15 community leaders, 5 working group members (local shire council representing 15% of the overall group), health and medical services (35%), PCP (15%), state government (5%), local and regional sporting organizations (10%), employment agency (5%), and the education sector (15%). GMB 1- not stated. GMB2 - not stated. GMB3–171 participants	Causal loop diagram with highlighted areas of action in GenR8 Change 12 months post-GMB3.	Moderately valuable
Brown et al. (23)	Portland, a WHO STOPS pilot community	Water and sugar sweetened beverage consumption	Using systems in community and testing the method	CBSD to build a SD model	11 key stakeholders from Portland with an interest or role in consumption of SSBs or water and included representatives from the Primary Care Partnership, local government, health service, sporting clubs, the local water authority, and community members	Author reflection	Moderately valuable
Browne et al. (51)	Various	Not described - various interventions	Testing or refining systems as a method	CBSD and GMB	Not described - various interventions	Qualitative semi-structured telephone/ video conference interviews (individual and small group interviews)	Excellent—very valuable
Burke et al. (28)	Prevention Impacts Simulation Model (PRISM)	Burden of chronic diseases	Testing or refining systems as a method	System dynamics model to inform community-level policy decisions.	Members of both the local public health department and community members participated in building the model	Case studies - comparison of systems methods using RE-AIM	Moderately valuable

(Continued)

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Calancie et al. (52)	Not described	Obesity	Using systems in community and testing the method	Stakeholder-Driven Community Diffusion (SDCD) -informed intervention that uses GMB	12 key stakeholders selected from the Early Ages Healthy Stages (EAHS) Coalition, EAHS leaders identified 10 Committee members, with input from the research team on sector representation. The 2 remaining positions were chosen by coalition-wide nomination. The Committee represented 8 sectors: nutrition assistance programs, early education, center-based childcare, home-based childcare, public health department, community-based organization, private business, and philanthropy.	Online surveys and interviews to assess Committee member perspective shifts, and a follow-up survey to identify actions taken by the EAHS following the SDCD-informed intervention with the Committee. Surveys were administered during months 5 and 9 of Committee meetings. Interviews with Committee members at baseline and at the conclusion of the study. The same interview questions were asked at both points. Follow-up action survey - Fourteen months after the conclusion of Committee meetings, the research team distributed another online survey to all members. This survey was different than the one used to assess shifts in perspectives.	Excellent—very valuable
Calancie et al. (29)	Shape Up Under 5	Childhood obesity	Using systems in community and testing the method	Community-based process for using GMB	The SUU5 Committee was composed of 16 professionals from early childhood education and care (n = 5), parks and recreation (n = 2), the local health department (n = 2), health care (n = 3), food assistance programs (n = 1), and the public schools (n = 3)	Exit survey at the end of each meeting (measuring knowledge, engagement, and trust). In addition, measuring perspective shifts using two formats: an online survey at 3 time points (1 year, 18 months, and 2 years from the beginning of the project) and semi structured interviews at 2 time points (1 and 2 years after baseline)	Excellent - very valuable
Cavill et al. (30)	'Derby: a City on the Move (DaCotM)'	Physical inactivity	Using systems in community and testing the method	Systems mapping with communities to build CLDs	The DaCotM consortium - local government organizations, registered charities and further and higher education providers	Semi-structured interviews approximately 6 months after systems maps had been drafted and discussed. Meeting notes and written comments from the mapping sessions (approximately 12–15 attendees per session) were used to corroborate the findings from the interviews where possible.	Moderately valuable

(Continued)

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Chavez-Ugalde et al. (45)	Not described	Obesity	Using systems in community and testing the method	GMB adapted online	GMB's - 11 adolescents, 10 from Bristol Young People's Advisory Group (YPAG) and 1 from Avon Scouts. Additional workshop - Public health practitioners and policymakers	Brief anonymous online feedback survey	Moderately valuable
Deutsch et al. (46)	Not described	Intimate partner violence (IPV) and alcohol misuse (AM), with a focus on inequities experienced by Northern Plains Indigenous women.	Using systems in community and testing the method	A case study from a CBSD project	Northern Plains Indigenous Women. Stakeholder partners include both those with personal and professional experience, and public, non-profit and grassroots organizations. Participants receiving services from Group 1: a faith-based re-entry programs for women who were previously incarcerated; Group 2: a substance use treatment program for pregnant women and mothers; and Group 3: a domestic violence shelter. One modeling session held within each organization. Group 1 – five women, Group 2–20 women, Group 3 - four women. Did not collect identifying information from participants for anonymity. However, learned during the sessions that majority of participants in each group self-identified as Indigenous (although this was never asked explicitly by the session facilitators).	Author reflection	Moderately valuable
Egbuonye et al. (47)	Not described	Equity	Using systems in community and testing the method	A participatory action approach of dynamic system mapping and systemic strategy design	76 stakeholders, including representatives from health care, mental health, education, economic development, faith, human services, and government.	Author reflection	Moderately valuable
Frerichs et al. (48)	Not described	Childhood obesity	Testing or refining systems as a method	Produce visual diagrams that highlighted system structures. Youth produced two types of systems diagrams: (a) graphs over time and (b) CLDs	Twenty-one adolescent African American youths	Survey at baseline and immediately after each of the four sessions. Semi structured interviews with youth postintervention with both high and low levels of participation.	Moderately valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Frerichs et al. (49)	Not described	Community violence	Using systems in community and testing the method	Develop, adapt, and apply GMB methods	6-member core planning team plus 27 individuals: 11 from academic research settings, 16 community partners representing law enforcement, schools, housing, grassroots community organizations, religious institutions, and prior gang-involved youth. Participants were diverse in gender and race.	Adaptations to GMB on advice from diverse community members, in addition to post-satisfaction survey and qualitative feedback	Moderately valuable
Gerritsen et al. (25)	Healthy Families Waitākere (HFW)	Fruit and vegetable intake among children	Using systems in community and testing the method	A GMB process that engaged members of a diverse urban community	17 participants (14 of whom attended all three workshops)	Informal feedback or meetings at three times points - during and immediately after implementation of workshops (informal feedback), three months after the final workshop (partnership meeting held), and 12 months after workshops (met with staff from HFW to discuss what had happened in the interim with the purpose of evaluating the benefits and impact of the GMB process)	Excellent - very valuable
Gerritsen et al. (24)	Healthy Families Waitākere (HFW)	Fruit and vegetable intake among children	Using systems in community and testing the method	GMB to create a CLD	Local retailers, health promoters, schools and the wider community, with a minimum of two from each of these sectors. Secondary school students were included if they were over 16 years of age. A total of 17 community members participated in the three workshops. All main ethnic groups (Māori, Pacific, Asian and NZ European) were represented, with over half of participants identifying as Māori or Pacific	Author reflection	Moderately valuable

(Continued)

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Haroz et al. (50)	Not described	Suicide prevention	Using systems in the community	CBSD	Two refugee camps on the border of Thailand and Myanmar. Towns of Mae Sot which is close to Mae La camp and Umphang - the western border of Thailand. Local stakeholders from organizations working with displaced populations in Thailand, along with experts on systems modeling, suicide prevention, health systems, humanitarian contexts, and global mental health. Summaries from each workshop were presented in three languages (Karen, Burmese and English). The first workshop was held in Mae Sot, and included 21 participants representing organizations working with refugee, internally displaced person (IDP), and migrant populations. The second workshop was held in Umphang and included eight participants representing organizations working with refugee populations. A third workshop was held, which included nine participants with expertise in systems approaches, suicide prevention, global mental health, and humanitarian contexts. Many of the workshop participants were from the displaced and migrant communities in the area (representing Karen and Burman ethnicities). A final workshop was held in Mae Sot, and consisted of 14 stakeholders from organizations working with refugee populations.	Author reflection	Moderately valuable

(Continued)

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Jacobs et al. (19)	WHOSTOPS	Childhood obesity	Using systems in community and testing the method	A systems-based CBI approach, to develop a causal loop diagram	Leaders in the five intervention communities	Three monitoring waves (2015, 2017 and 2019). School participation rates, Height and weight data, weight-related behaviours and HRQoL of Grade 4 and 6 students were collected by self-report questionnaire. The Index of Community Socio-Educational Advantage (ICSEA) scores for each school were used as an indicator of SEP. The average of height and weight measures was used to calculate body mass index z-scores (BMI-z). Data on gender and age were collected for Year 2 students. Year 4 and 6 students were guided through questionnaires - gender, date of birth, language usually spoken at home, Aboriginal and/ or Torres Strait Islander background, residential postcode, and country of birth. The Core Indicators and Measures of Youth Health – Physical Activity & Sedentary Behaviour Module questionnaire was used to assess PA and sedentary behaviour and active transport. The Simple Dietary Questionnaire, which is based on the Australian Dietary Guidelines, was used to assess dietary behaviours. Health related quality of life was assessed using the 23-item Paediatric Quality of Life Inventory 4.0 (PedsQL)	Excellent - very valuable
Jenkins et al. (22)	Sustainable Eating Activity Change Portland (SEA Change Portland), part of WHOSTOPS	Childhood obesity	Using systems in community and testing the method	GMB to develop CLD's with community participation	Not described	Semi-structured interviews and a focus group	Excellent - very valuable
Kumar et al. (33)	Not described	Sustained adoption of cleaner cooking technologies	Using GMB as an evaluation technique	A CBSD modeling approach	Number of participants not identified. GMB sessions were primarily conducted with women.	Author reflection	Not valuable for this review

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Loyo et al. (44)	Not described	Chronic disease	Using systems in community and testing the method	A system dynamics model shared with stakeholders in the context of a multistakeholder "action lab"	56 participants attended the action lab, representing a range of public health, health care, nonprofit, advocacy groups, businesses, and schools. There was comprehensive representation across intervention areas except for air quality, which was represented indirectly by people working in the area of tobacco or asthma. Each participant also belonged to at least one community-based coalition, and many were key leaders.	Informal feedback – on completion participants were asked to rate their perceived levels of commitment, influence, and confidence in making the changes they had identified as most necessary.	Moderately valuable
Macmillan et al. (34)	Not described	Housing, energy and wellbeing	Using systems in community and testing the method	Participatory system dynamics modelling. A combination of primary and secondary data was used to develop a CLD and included individual semi-structured interviews with participants using cognitive mapping.	Over 50 stakeholders, representing 37 organizations. These included six national government departments; five representatives from local government; 14 non-government organizations; a group of six minority-ethnicity housing leaders (community roots group); five industry organizations; and eight academic institutions. Some stakeholders represented more than one sector.	Author reflection	Moderately valuable
Maitland et al. (26)	Campbelltown - Changing our Future (Change4Campbelltown)	Childhood overweight and obesity	Using systems in community and testing the method	A stakeholder-informed CLD.	Not described	Action register, stakeholder engagement database, GANTT chart for timeline and grant reporting requirements, actions represented on a CLD, communication log	Excellent - very valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Marçal et al. (35)	Not described	Family homeless shelter use	Using systems in community and testing the method	A CBSD study, that utilized GMB and key informant interviews to develop a causal feedback theory of factors	37 homeless clients with children. Participants were overwhelmingly female (91%) and Black (87%), and two-thirds were first-time shelter clients (65%). The mean age was 39.6 (SD ¼ 13.0) years. Families on average included 2.5 children (SD ¼ 1.8), family size ranged from 1 to 5 children. Staff participants were all female and primarily Black (83%). Agency employment tenures ranged from five to 24 years. Interviews were conducted with an executive director, a shelter manager, and a case manager who offered perspectives on client experiences of shelter stays and their own experiencing as providers.	Author reflection	Moderately valuable
McKelvie-Sebileau et al. (27)	Nourishing Hawke's Bay: He wairua t ¯o te kai	Childhood obesity	Using systems in the community	CBSD	Hawke's Bay region – Key stakeholders - District Health Board, Iwi (tribal group), school principals and Ministry of Education. Over the three workshops, 19 rangatahi (youth) from five regional high schools, and 26 community stakeholders participated. The high schools comprised of two low decile (1–3) schools (low community advantage) and three mid-decile (4–7) schools (mid community advantage). Community stakeholders represented 24 organizations including - District Health Board, Ministry of Education, kaupapa M ¯aori health providers and trusts, Iwi, Heart Foundation, Eastern Institute of Technology School of Health Science, Hawke's Bay Community Fitness Centre Trust, Sport Hawke's Bay, food rescue charity, local food production business representatives and a supermarket owner,	Author reflection	Moderately valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
					as well as teachers from Early Learning Services and low advantage primary schools. Of the 26 adults participating, approximately half were of M¯aori ethnicity. No demographic information was taken and individuals to ensure privacy and confidentiality.		
Morais et al. (31)	Urban Health in Latin America ("Salud Urbana en América Latina," or SALURBAL)	Health equity in Latin America	Using systems in community and testing the method	CBSD workshops	24 experts (São Paulo workshop) in food systems and transportation sectors working primarily in Brazil, with regional, national, and international influence, including "elected and administrative policy-makers, members of civil society (e.g., nonprofits), and academics."	Semi-structured interviews, 12 months after the São Paulo workshop	Excellent - very valuable
Mui et al. (36)	Not described	Availability of healthy foods in low income urban communities	Using systems in community and testing the method	CBSD to elicit perspectives from diverse stakeholders	18 participants, representing a diverse group comprising: 3 chain and local storeowners, 8 community residents, 3 representatives from city government agencies, and 4 representatives from local non-profit organizations.	Author reflection	Moderately valuable
Naumann et al. (37)	Not described	Road traffic safety - pedestrian deaths	Using systems in community and testing the method	A systems mapping technique (ie, CLDs) within a GMB context to identify a wide range of 'mental models'.	41 stakeholders, participants represented: pedestrian and bicycle advocacy, law enforcement, automobile industry, academia/research, health department, medical professions, local government, city planning, transit department, department of transportation and social services.	Author reflection	Moderately valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Noubani et al. (38)	Not described	Mental health	Using systems in community and testing the method	CBSD, through GMB workshops or semi- structured interviews.	89 participants from both contexts and communities. A diverse gender-and age-balanced group of both Syrian refugees and Lebanese host community members. General community members (adults aged over 18) and caretakers of people affected by MHPSS issues (e.g., parents of children aged 10–18). Lebanese community - 2 GMB workshops (Beirut - 9 females, 7 males; Beqaa - 9 females, 3 males), 18 semi-structured interviews (Beirut - 5 females, 4 males; Beqaa - 6 females, 3 males). Syrian refugees - 2 GMB workshops (Beirut - 10 females, 6 males; Beqaa - 2 females, 7 males) 18 semi-structured interviews (Beirut - 5 females, 4 males; Beqaa - 5 females, 4 males).	Author reflection	Moderately valuable
Noubani et al. (39)	Not described	Mental health	Using systems in the community	Participatory GMB workshops	36 health care providers active in mental health service provision (at least 1 year) from Beirut and Beqaa regions, 15 semi structured interviews conducted with psychologists, nurses, social workers and general practitioners across genders, 21 participants participated in two GMB workshops	Author reflection	Moderately valuable
Swierad et al. (40)	Not described	Childhood obesity	Using systems in community and testing the method	CBSD	16 Chinese American adults. All participants were aged between 20 and 60 years, and 43.8% (7/16) were male. Six participants were born overseas. Participants represented a variety of occupations including nurses, school guidance counselors, restaurant owners, community health workers, and housewives.	Author reflection	Moderately valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Trani et al. (41)	Not described	Mental health	Using systems in community and testing the method	A CBSD-informed GMB workshop	Initial sessions - three male and three female community based rehabilitation workers from the Mazar-e-Sharif region and four male CBR workers from Jalalabad. Four participants in the follow-up sessions were from Mazar-e-Sharif, Taloqan, Ghazni and Jalalabad, four regional program offices of the partner NGO.	Author reflection	Moderately valuable
Waqa et al. (42)	Not described	Evidence use in food-related policymaking	Using systems in community and testing the method	GMB and a system dynamics approach	18 participants from the MoHMS (n = 9) and the MOA (n = 9). The majority of participants (72%) were senior managers (such as National Advisors, Directors and Principal level officers) directly involved in policymaking, 28% were middle with potential to share evidence that influences the policymaking process. The majority (72%) were male.	Author reflection	Moderately valuable
Zablith et al. (43)	Not described	Non-communicable diseases	Using systems in the community	Semi-structured interviews followed by GMB workshops.	67 participants. 30 semi-structured interviews: 10 health care providers (physicians, pharmacists, nurses, PHCC managers, 5 male) in the Beqaa, 10 Lebanese (3 men, age range overall 23–60) and 10 Syrian refugee (3 men, age range overall 30–60) community members. All community participants suffered from a chronic condition or self-identified as being at risk of NCD development. First GMB - 10 health care providers (one physician, two pharmacists, six nurses, one PHCC manager); participants had between 3 and 15 years' experience of working in the Beqaa. Second and third GMB 12 Lebanese community members (41% male, age range 20–50), 15 Syrian refugees (13% male, age range 24–55). All community participants self-identified as having an NCD or a risk factor.	Author reflection	Moderately valuable

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TABLE 3 (Continued)

Author/s	Title of intervention	Nature of the complex problem	Context for use of systems thinking	Implementation process reported by authors	Participants/stakeholders involved in the intervention	Method of data collection for success of systems thinking approach	Quality check (CASP) How valuable is the research?
Zurcher et al. (32)	Food & Fitness (F&F) Initiative	Healthy eating and active living	Using systems in community and testing the method	Five key frameworks and a systems mapping process with community and initiative leaders - Core Theory of Success (CTS), Creative Tension Model (CTM), Hierarchy of Choices (HOC), Levels of Perspective (LoP), Ladder of Inference (LoI), causal loop diagramming	24 grassroots and institutional members of the six final grantee communities, 10 TA providers, and four WKKF staff participated in structured conversations at the conference. An additional 12 individuals for interviews, ranging from grassroots community members to local evaluators and project directors.	Structured conversations and in-depth phone interviews.	Excellent - very helpful

Other methods described include; participatory system dynamics modeling (SDM) with the community (34), systems frameworks including CLD's (32), Stakeholder-Driven Community Diffusion (SDCD) using GMB (52), GMB online with community (45), a participatory action approach of dynamic system mapping and systemic strategy design (47), and a systems-based community-based intervention (CBI) approach, to build a CLD (19).

3.5. Measuring success

All articles reported on more than one outcome (Table 4), identifying 14 themes, which included measuring contribution, engagement and collaborative experience, cultural appropriateness, the implementation process, ownership, trust and relationships, implementation of action, ongoing community engagement and community voice, and unintended consequences. Changes in individual thinking, insights, ideas or mental models, organizational commitment, the system or social norms, data collection, data sources or measurement of change, individual health outcomes, prevention practice, and support for action were also measured.

Of the 34 articles, 18 describe the success of their intervention through subjective author observation and reflection (20, 23, 24, 27, 33–43, 46, 47, 50), that is, where authors describe the success of the intervention, in the absence of additional data collection. The remaining 16 articles use a range of other methods to measure success or effectiveness of the intervention.

The 18 articles that describe their success through author observation and reflection include four named interventions across four articles, WHOSTOPS (20) HFW (24), Portland, a WHOSTOPS pilot community (23) and Nourishing Hawke's Bay: He wairua tō te kai (27). Fourteen articles did not identify a named intervention.

The remaining 16 articles measured success or effectiveness of their approach using semi-structured interviews at different timepoints (22, 29–31, 48, 51, 52), surveys or questionnaires at different timepoints (19, 29, 45, 48, 49, 52), informal qualitative feedback at different timepoints (25, 44, 49), project documentation (for example meeting minutes) (26, 30), action tracking (action register or on CLD) (21, 26), health measures and population health or education datasets (19), comparative systems thinking case studies (28), stakeholder engagement database (26) and structured conversations and in-depth interviews (32) (Table 5).

3.6. What influences success

There were numerous implementation factors influencing findings from across the studies. Nineteen themes emerged during the analysis of implementation factors. Of the articles describing success through author observation, the following themes describing implementation factors influenced success: the development of CLD's; the overall process (including workshops or interviews, CBSD, GMB and other methods); the time allocated to the process (for example, categories included the length of a workshop or the length of the process overall) alongside the timing of different parts of the process (for example, categories included the time taken between workshops, or the time allowed for participants and facilitators to adapt to momentum); the participants who were engaged, methods of engagement and ongoing

TABLE 4 Measures of success by author for 16 articles that measure success.

Author	Bolton et al., 2022	Browne et al., 2021	Burke et al., 2014	Calancie et al., 2022	Calancie et al., 2020	Cavill et al., 2020	Chavez-Ugalde et al., 2022	Frerichs et al., 2018	Frerichs et al., 2016	Gerritsen et al., 2020	Jacobs et al., 2021	Jenkins et al., 2020	Loyo et al., 2013	Maitland et al., 2021	Morais et al., 2021	Zurcher et al., 2018
Measuring success by…																
Measuring contribution, engagement and collaborative experience	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Measuring cultural appropriateness		✓							✓							
Measuring the implementation process		✓				✓	✓	✓	✓	✓				✓	✓	✓
Changes in individual thinking / insights/ideas/ mental models		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	
Measuring ownership, trust and relationships	✓	✓		✓	✓		✓		✓	✓		✓		✓	✓	✓
Support to take action	✓		✓		✓			✓		✓			✓			
Changes in organizational commitment	✓				✓											
Changes in the system/social norms	✓					✓					✓					✓
Changes in data collection, data sources and measurement of change	✓					✓								✓		✓
Changes in health outcomes						✓					✓					

(Continued)

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TABLE 4 (Continued)

Author	Bolton et al., 2022	Browne et al., 2021	Burke et al., 2014	Calancie et al., 2022	Calancie et al., 2020	Cavill et al., 2020	Chavez-Ugalde et al., 2022	Frerichs et al., 2018	Frerichs et al., 2016	Gerritsen et al., 2020	Jacobs et al., 2021	Jenkins et al., 2020	Loyo et al., 2013	Maitland et al., 2021	Morais et al., 2021	Zurcher et al., 2018
Measuring implementation of action	✓			✓						✓			✓	✓		✓
Measuring ongoing community engagement and community voice	✓									✓		✓		✓		
Changes in prevention practice												✓		✓	✓	✓
Measuring unintended consequences																✓

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TABLE 5 Evaluation method by author for 16 articles that measure success.

Author		Bolton et al., 2022	Browne et al., 2021	Burke et al., 2014	Calancie et al., 2022	Calancie et al., 2020	Cavill et al., 2020	Chavez-Ugalde et al., 2022	Frerichs et al., 2018	Frerichs et al., 2016	Gerritsen et al., 2020	Jacobs et al., 2021	Jenkins et al., 2020	Loyo et al., 2013	Maitland et al., 2021	Morais et al., 2021	Zurcher et al., 2018
Data collection method																	
Qualitative semi-structured interviews (individual or small group)	Before implementation (baseline)				✓												
	During implementation												✓				
	At delayed timepoint/s post implementation		✓		✓	✓	✓		✓							✓	
Surveys or questionnaires	Before implementation (baseline)				✓				✓			✓					
	During implementation				✓	✓			✓			✓					
	Immediately post implementation				✓			✓		✓		✓					
	At delayed timepoint/s post implementation				✓	✓											
Informal qualitative feedback	During implementation to adapt scripts and workshops									✓	✓						
	Immediately post implementation										✓						
	At delayed timepoint/s post implementation										✓			✓			
Individual health measurements and demographics												✓					

(Continued)

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TABLE 5 (Continued)

Author	Bolton et al., 2022	Browne et al., 2021	Burke et al., 2014	Calancie et al., 2022	Calancie et al., 2020	Cavill et al., 2020	Chavez-Ugalde et al., 2022	Frerichs et al., 2018	Frerichs et al., 2016	Gerritsen et al., 2020	Jacobs et al., 2021	Jenkins et al., 2020	Loyo et al., 2013	Maitland et al., 2021	Morais et al., 2021	Zurcher et al., 2018
Population health and education datasets											✓					
Structured conversations and in-depth interviews																✓
Tracking actions (action register or on CLD)	✓													✓		
Stakeholder engagement database														✓		
Project documentation						✓										
Comparative systems thinking case studies			✓													

commitment; and the composition, skills and experience of the facilitation team (Table 6). While one article (20) touched on these issues, it included a focus on building capacity of the use of CBSD in prevention more broadly. As such, this paper identified additional factors as important to outcomes of the approach: supporting a strong process, including utilization of existing structures and ensuring strong collaborative relationships between practice and academia; and using a capacity building approach.

Descriptions of the effects of implementation factors varied across articles, for example, where time and timing influenced success, one article (48) stated participants:

> *"found the diagramming activities acceptable, but indicated they needed more time because they were only beginning to understand the concepts when the session ended."*

Another article (26) identified:

> *"Actions operated on differing timescales, for many there was some delay between the initial planning and the implementation and following there was often adaptation of the action."*

While a third article (32) stated:

> *"Every group and every individual interviewed emphasized that systems change in communities takes more time than people are accustomed to."*

Additional implementation factors that influenced success in the 16 articles that used non-observation methods were; the role of coordination teams with the opportunity to shape the approach; the ability for a group to come together to implement collective action; providing opportunities for participant feedback on the process; leveraging workshop outputs; the use of systems thinking methods; the strength and quality of relationships and collaboration; the opportunity to combine multiple approaches simultaneously; and a flexible delivery model (accommodating for differences in language, number and timing of workshops, literacy, numeracy, computer literacy or confidence using technology) (Table 6).

Findings from the 16 articles are presented alongside implementation factors in Table 6 with 23 themes identified. Findings included increased community action, increases in strategic thinking, future planning and evaluation, increasing community buy-in and community voice, developing shared visions and goals and creating new, ongoing collaborations. Findings also included building momentum, increasing community contribution and leadership, acknowledging the time required to develop new partnerships and collective thinking, increased understanding of feedback and how it contributes to understanding problems and corresponding action, among many others.

4. Discussion

4.1. Summary of main findings

Measures and concepts of success varied across the articles reviewed, often comprising subjective observations and reflections of

TABLE 6 Key implementation factors and how they affected findings in 16 studies that measured success.

Implementation factors that were identified as important	Findings from 16 articles that measure success	
The overall workshop/diagram approach	• Increased shared learning and story telling • Uncovered complexities, interconnections, changed thinking and created new insights • Increased cultural appropriateness • Increased focus on collaboration and shared vision • Allowed flexible delivery • Increased community voice • Increased knowledge, engagement and an awareness of who else should be 'in the room'	• Changed prevention practice • Changed data collection and measurement approaches • Format and concepts were a challenge • Increased local capacity • Increased community-led action • Further development of methods • Community CLD was not used to its potential • Built trust and ownership • Increased shared learning and story telling
CLD's and other diagrams	• Uncovered complexities, interconnections, changed thinking and created new insights • Increased community-led action • Increased focus on collaboration and shared vision • Test local scenarios and change decisions • Participation in evaluation was positive	• Changed data collection and measurement approaches • Further development of methods • Increased knowledge, engagement and an awareness of who else should be 'in the room' • Increased local capacity
Participants and engagement	• Built trust and ownership • Increased knowledge, engagement and an awareness of who else should be 'in the room' • Changed prevention practice • Increased focus on collaboration and shared vision	• Increased local capacity • Increased community-led action • Limited interest, capacity, time and miscommunication of the approach Uncovered complexities, interconnections, changed thinking and created new insights
Facilitation team	• Increased local capacity • Increased community voice	• Built trust and ownership
Flexible delivery	• Allowed flexible delivery	• Increased cultural appropriateness
Coordination group or meetings	• Created new, ongoing networks • Increased knowledge, engagement and an awareness of who else should be 'in the room' • Increased community-led action	• Uncovered complexities, interconnections, changed thinking and created new insights • Changed prevention practice • Competing priorities limited engagement • Built trust and ownership
Implementing collective action	• Uncovered complexities, interconnections, changed thinking and created new insights • Increased community-led action • Increased knowledge, engagement and an awareness of who else should be 'in the room' • Changed data collection and measurement approaches	• Created systems change • Format and concepts were a challenge • Participation in evaluation methods and/or measuring change was difficult • Allowed flexible delivery • Built trust and ownership • Strong foundation for change
Time and timing	• Increased knowledge, engagement and an awareness of who else should be 'in the room'	• Limited the opportunity to discuss ideas
Obtaining participant feedback	• Participation in evaluation methods and/or measuring change was difficult	
Leveraging workshop/diagram development outputs	• Increased community voice	• Increased community-led action
Use of systems thinking methods	• Community CLD was not used to its potential • Created systems change • Changed data collection and measurement approaches • Changed prevention practice	• Increased knowledge, engagement and an awareness of who else should be 'in the room' • Increased focus on collaboration and shared vision
Relationships and collaboration	• Strong foundation for change • Increased knowledge, engagement and an awareness of who else should be 'in the room' • Reduced unintended consequences	• Uncovered complexities, interconnections, changed thinking and created new insights • Increased focus on collaboration and shared vision • Increased community-led action

(Continued)

TABLE 6 (Continued)

Implementation factors that were identified as important	Findings from 16 articles that measure success	
Multiple approaches combined	• Changed prevention practice • Created systems change	• Increased focus on collaboration and shared vision • Further development of methods
Flexible project evolution	• Allowed flexible delivery • Built trust and ownership	• Strong foundation for change
Resources	• Increased knowledge, engagement and an awareness of who else should be 'in the room'	• Strong foundation for change
Data collection	• Participation in evaluation methods and/or measuring change was difficult • Increased knowledge, engagement and an awareness of who else should be 'in the room'	• Increased focus on collaboration and shared vision Built trust and ownership • Changed prevention practice • Changed data collection and measurement approaches
A shared vision	• Increased community-led action	• Increased knowledge, engagement and an awareness of who else should be 'in the room'
Aligning new and existing efforts	• Increased knowledge, engagement and an awareness of who else should be 'in the room'	
Diverse perspectives	• Uncovered complexities, interconnections, changed thinking and created new insights	

study authors, or resulting from semi-structured interviews with key stakeholders. Typical measures of success included community action, collaboration, changes in mental models, or cultural appropriateness. It is difficult to determine specific effects of each implementation factor theme as this was reported to vary across studies (for example, where one had a reported effect in one study, the same factor may have had the opposite effect in another study), which was also reportedly influenced by the characteristics of participants and the context of each approach. We found variation in methods to achieve the same outcome and variation in outcomes sought using the same method describing an emerging field trialing multiple alternate approaches.

Our review builds on reviews by Carey (1), Rusoja (2), and Wilkinson (54) who aimed to investigate the use of systems science or systems thinking in public health or health generally. All three reviews identified various systems methods and terms, with modeling, specifically causal loop diagrams, featuring as one of the most common systems methods used in health. Wilkinson found that although there were many calls to use systems thinking methods, there were few published examples. Our review shows growth in the application of systems thinking, specifically CBSD, and while example evaluations are limited, they are also beginning to grow. Calls from Carey (1) Rouwette (55) and Scott (11) highlight the important stretch beyond model creation as an outcome, to draw attention to research that examines the quality and effectiveness of systems science as a method, with Rouwette specifically calling for examination of successful and unsuccessful efforts (in GMB).

Our review supports findings in a review by Bagnall, Radley (56) that identifies barriers and enablers to implementation of whole systems approaches (WSA's), noting that leadership, engagement, paying attention to partnerships and building trust (and allowing the time required to do so), governance and shared values, and developing collaborative teams all influenced success. Building on Bagnall's review, Jayasinghe, Soward (57) found that WSA's need to include as many domains of capacity building as possible. Domains identified the importance of leadership, in all its forms, alongside partnerships, community engagement and mobilization of resources, all of which were echoed as important implementation factors for success of CBSD approaches in our review. Cilenti, Issel (3) and Littlejohns, Hill (58) have also conducted helpful reviews that explore how system dynamics and CLD's can be used by communities to realize community action. They found, as in our review, there are times when success may be defined in ways other than community action. This should be considered in future systematic reviews of CBSD and other community-based systems thinking methods.

A recent review (59) developed a framework for measuring success of participatory modeling in systems approaches, and though the study was not focused on community intervention alone, clear similarities were observed between the findings of the current study. Specifically they consider four categories (feasibility, value, change and action, and sustainability) to guide evaluation design of participatory modeling programs. Further parallels exist outside the use of system science, and the findings of this review are supported by other reviews of community capacity and readiness, for example Nagorcka-Smith, Bolton (60) reviewed 26 studies and found shared decision making, resourcing, leadership and facilitation were critical to successful implementation of community initiatives that involved community coalitions. This is echoed by Brush, Mentz (61) who identified the strength of relationships, characteristics and composition of the group influenced success.

4.2. Strengths and limitations

A limitation of this review was the wide variability of terms within systems thinking and the ability to identify those explicitly intending to empower and mobilize a community (as identified in descriptions by Hovmand (9) and Király and Miskolczi (10)). For this reason, the search terms 'community' and 'stakeholder' were applied to narrow the field of articles down to those most relevant in the community setting, although this may prove overly simplistic without the inclusion of alternatives (for example, using the term 'participant'). In addition, systems thinking does not include other participatory

modeling techniques such as 'concept mapping' or 'group concept mapping' (62) which were excluded from this review. Other systems methods, such as social network analysis (63), and agent-based modeling (64), were also excluded.

This review did not explore the grey literature as it was anticipated there would be far less empirical measurement of outcomes meaning several examples of CBSD may have been excluded from this review. The review is also limited to articles in the English language. Of 34 papers, few set out to actively evaluate their approach and only 16 had data extracted that could provide insights into implementation factors and measures of success. While some articles collected data at multiple timepoints, others did not, which proved challenging during analysis.

Strengths of this review include the systematic review of all published literature, with all titles, abstracts and full text screened by at least two authors. Analysis was conducted in line with the recommended process for narrative synthesis by Popay and Roberts (17), and in line with PRISMA guidelines (15). An additional strength was the breadth of terms used, which ensured inclusion of findings of other studies that may not have explicitly identified CBSD in their methodology. Adaptation of methods and scripts to apply CBSD is critical to the success of the practice (9). This review captures variations in the approach and compares these against adaptations to measure success based on the direction of the intervention.

4.3. Implications for policy and practice

Despite limited evidence for measurement of success CBSD, our systematic review shows that success is influenced by early design decisions, for example, identifying key stakeholders, composition of the facilitation team/s, timing of workshops, and perceived influence of the process by community members. This indicates it is not only crucial to consider and plan for measurement of success early in the application of CBSD, but that this planning will directly influence implementation, potentially influencing longer term outcomes for the community involved in the approach.

While this review focuses on the use of CBSD in prevention, findings may also be helpful to inform design, implementation and evaluation of other methods that aim to empower community to address complex problems, specifically measures of success, data collection methods, and implementation factors that influence success.

Summarizing the findings from this review for practice, we have developed the following considerations, with each informing the next:

- Consider why you are using CBSD with the community, and be clear on its purpose. What are you aiming to do? What is your end point?
- Identify what change to measure. What will change as a result of you using this approach? Is it community action, individual thinking, change in policy, approach to planning, increased collaboration, increased engagement, or another measure?
- Identify the most appropriate data collection tools. What data collection tools will you use to measure the change you are aiming for? If using surveys, are validated or tested surveys or questionnaires available? If the tool used is novel, is it described in enough detail that it can be replicated by others?
- Consider strategies that will support empowerment of the community after diagram development is complete. How will you care for participants and their contribution after diagram development is complete?

4.4. Future research

In the absence of extensive literature that measures success in CBSD, future research may benefit in looking to studies from other disciplines that have measured effectiveness of group model building (for example, organizational management and organizational change (65)) to draw on other existing and tested frameworks and tools. Examples include Rouwette's previously developed questionnaire designed to measure communication quality, consensus and commitment to conclusions for those studies aiming to measure insight or collaboration (66), or Fokkinga's mental model survey (67) for those aiming to measure changes in individual thinking. Measurement frameworks and tools required will vary and will be shaped by the original purpose and setting of the work.

Future attempts to measure success of CBSD should ensure insights are collected from community members and stakeholders at multiple timepoints, including at delayed timepoints after workshops or a CLD has been first developed. This will help determine how community members have applied new insights from the process, and help identify changes in actions, policy or planning at the local level. Evaluation frameworks applied in other participatory modeling approaches may also be helpful. Our review echoes calls from Lee, Hickie (59), emphasizing that evaluation is planned and budgeted for, extending beyond the development of the diagram or CLD. In the case of CBSD, it is important studies plan to capture impacts that stretch beyond modeling and explore impacts within the community.

5. Conclusion

Greater emphasis on measurement of success of future CBSD approaches is required. The use of CBSD and other community-based systems approaches in prevention is growing rapidly. Continuing to synthesize and apply evidence from this research as it emerges will be critical to improve population health. Research teams, alongside the communities they are working with, must articulate what they are seeking to change by using CBSD. Defining success in this way will help identify what will be measured, how it may be measured (including identifying appropriate data collection methods and tools) and will provide a clearer understanding of success.

There are helpful attempts to measure success and effectiveness of CBSD approaches in the published literature. These examples show the importance of design, facilitation strengths and ongoing community engagement as key factors in implementation.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

TF completed the original search, contributed to article screening, full text assessment, data extraction, analysis, preparing initial and ongoing drafts of manuscript, and editing final manuscript. KB contributed to research design, draft manuscripts, and editing final manuscript. EH contributed to draft manuscripts and editing final manuscript. AB and PN-S contributed to article screening and assessment of full texts, draft manuscripts and final manuscript. SA contributed to final research design, provided ongoing supervision, draft manuscripts and editing final manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1103834/full#supplementary-material

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Implementing a stakeholder-driven community diffusion-informed intervention to create healthier, more equitable systems: a community case study in Greenville County, South Carolina

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This case study describes the application of a theory-informed, stakeholder-driven intervention with a group of 19 multi-sector stakeholders from an existing coalition to promote whole-of-community change that supports childhood obesity prevention. The intervention applied community-based system dynamics to design and implement activities that promoted insights into the systems driving childhood obesity prevalence and helped participants prioritize actions to influence those systems. This led to three new priority areas for the coalition: addressing food insecurity; building power among historically marginalized voices within the community; and supporting advocacy efforts to promote community-wide change beyond the coalition's previous focus on organizational-level policy, systems and environment change. The intervention spurred the application of community-based system dynamics to other health issues and in partner organizations, which demonstrates paradigm shifts about how to address complex public health issues in the community.

KEYWORDS

community coalition, systems change, childhood obesity, diffusion, systems dynamics, policy, systems and environmental changes, multi-sector stakeholders, group model building

Introduction

Excess weight gain during childhood is a complex, serious public health issue. It increases the risk of obesity in adulthood and associated chronic diseases such as diabetes, hypertension, and cardiovascular disease (1). In Greenville County, South Carolina, surveillance data from youth in grades two and five indicates that 35.7% experience overweight or obesity, which is similar to national prevalence estimates (2, 3). Prevalence is disproportionately higher among

Greenville's African American (41.4%) and Hispanic youth (50.4%) (4). Equitably and sustainably reducing childhood overweight and obesity requires a comprehensive approach that addresses multiple drivers of excess weight gain simultaneously, including socioeconomic factors and issues of racism that systematically disadvantage communities of color (5, 6). Community coalitions are an approach for promoting equity and mobilizing childhood obesity efforts across sectors and organizations within a community (7, 8). Coalitions provide an arena for developing relationships, pooling resources, gaining knowledge and skills, identifying community needs and strengths, and empowering members as agents of change (9).

LiveWell Greenville ("LiveWell") is a coalition that works to reduce childhood obesity in Greenville County, South Carolina, in addition to supporting healthy eating and active living for all age groups. The coalition has worked with over 250 organizations representing healthcare, schools, governments, parks/recreation, community members, and faith-based and social service organizations. LiveWell staff promote healthy eating and active living by convening partners to impact policy, systems and environmental (PSE) changes throughout Greenville County. Since 2010, LiveWell has actively shaped PSEs where children and their families live, learn, work, pray and play by leading organizations through assessments of current practices and supporting adoption of national best practices. For example, LiveWell worked with Greenville County Schools from 2011–2014 to transform the Greenville County School District's food services' school menus by transitioning from reliance on heavily processed meals to menus featuring scratch-made, nutritious meals that exceeded the national Healthy, Hunger Free Kids Act standards of 2010. The change influenced the food options available at lunch for more than 76,000 students in the district (10). The coalition also led an effort to expand a 22-mile countywide trail system and helped shift policies to promote healthy eating and physical activity opportunities in more than 100 organizations, including churches and private businesses, reaching tens of thousands of Greenville residents from 2011 to 2020 (11).

Despite significant success in engaging local businesses, early childhood centers, schools, afterschool programs, and congregations in organizational PSE change, LiveWell realized the coalition could not directly support all groups in Greenville County that wanted to implement organizational-level change. The staffing that would be required to provide organizational-level technical assistance to implement PSE changes that resulted in population-level impact was not possible or sustainable within the coalition's budget and fundraising capabilities. In 2019, it became apparent that the coalition needed a new approach to create whole-of-community change. The coalition re-tooled its strategy to shape the community-level systems that facilitate or hinder organizational changes, making it easier for organizations to pursue PSE change without direct support from the coalition. In systems thinking terms, LiveWell wanted to create "conditions of systems change" and identify "high-leverage" systems change opportunities (12, 13). Of the six conditions of systems change that include policies, practices, resource flows, relationships and connections, power dynamics, and mental models, LiveWell was already adept at influencing policies, practices, and relationships (8, 9). In their next phase of work, coalition leaders and advisory board members wanted to strengthen their ability to promote resource and information flows, shift power dynamics, and change mental models to normalize decisions and values supporting equity and access to healthy, culturally meaningful foods and physical activity opportunities across the whole community. The coalition believed that doing so could introduce a paradigm shift away from commonly held beliefs placing responsibility for health outcomes on individuals toward ones that posit that interconnected systems (e.g., social, economic, food, healthcare, education) strongly influence health outcomes, and that those systems could be shifted to promote health for everyone in the Greenville community.

To help achieve this shift, LiveWell partnered with ChildObesity180, a research group at Tufts University, and an expert in community-based system dynamics, on the Catalyzing Communities initiative in Greenville. Catalyzing Communities is a whole-of-community approach to decreasing obesity prevalence, improving health, and promoting health equity in communities around the country. Whole-of-community approaches for obesity prevention are multilevel in that they operate within multiple levels of the social ecological model (e.g., intervention targeting environments to effect individual-level behaviors) and multi-component, in that they employ more than one strategy to affect change (14). The Catalyzing Communities project that includes the partnership with LiveWell is guided by a theory called Stakeholder-driven Community Diffusion (SDCD) (15, 16) which focuses on the work of a multi-sector group of stakeholders and integrates systems science methods including community-based system dynamics (CBSD), agent-based modeling, and social network analysis, to guide and evaluate the group's work. This case study focuses on the use of CBSD in Catalyzing Communities; the use of an agent-based model and social network analysis is discussed in other publications (17). The theory hypothesizes that knowledge of and engagement with childhood obesity prevention activities can be increased "upstream" (i.e., within the stakeholder group) and diffused through social network connections to set the conditions for "midstream" PSE change, which ultimately is hypothesized to result in "downstream" outcomes at the individual level, like improved child health (18). The SDCD framework informed a three-phased intervention that has been implemented in three different communities (19, 20).

This case study describes the process of implementing an SDCD-informed intervention with LiveWell, reports how the intervention influenced systems in the county, and compares the SDCD intervention to LiveWell's previous approach to obesity prevention. The study illustrates an approach for working with a coalition to promote whole-of-community change and considers how it could be adapted and replicated in other communities.

Context

Greenville County covers 785 square miles, is one of the fastest growing counties in South Carolina and is the most populous. The county features rural farmland in the south and an urban city center with pockets of wealth and poverty. In 2021 the estimated county population was 523,542 and 22.9% of residents are under 18 years of age; 76.3% are white; 18.4% are African American; 9.5% are Hispanic (21). The median household income for 2015–2019 was $60,351, with 10.7% of the population living below the federal poverty level (22). In 2021, 42,980 individuals from 19,979 households participated in SNAP benefits (23). Out of the 92,584 total Full Benefit Medicaid members for Greenville County in 2019, 65% were children ages 0–18 and 28% adults ages 19–64 (24).

Intervention elements

In the SDCD-informed intervention implemented with LiveWell, two community partners or "changemakers" (SW, MF) worked closely with the research team (LC, KW, JA, TRM, EH, CDE) from ChildObesity180 and an expert in CBSD to co-design intervention activities. The intervention incorporated CBSD, which uses group model building to engage participants in understanding how a system produces trends over time through structured activities and the use of graphs, models, and other visuals (25). The participatory activities use system dynamics conventions to illustrate feedback mechanisms that create system behavior (26, 27). CBSD also emphasizes building capabilities through participation to empower communities to use the approach to understand and change systems (28).

The two LiveWell changemakers attended a CBSD training hosted by the research team in March 2019, then, with assistance from the research team, began identifying multi-sector stakeholders who could participate in the intervention in September 2019. To select participating organizations and sectors, the coalition first identified the sectors within the county that had a significant influence on youth obesity (e.g., school system, health system, local government, philanthropy, community representative). Once the sectors and corresponding influencing organizations were considered, individuals perceived to have a high ability to influence resources and decisions related to child obesity prevention activities within their individual organizations and the county were recruited to participate. Nineteen people from ten sectors (e.g., healthcare, local government, philanthropy) agreed to participate in monthly meetings from October 2019 through January 2020, and then again in June and July 2020. Two individuals declined to participate. They generally held leadership roles in their organizations, with job titles such as executive director, pastor, health director, community member, or program officer. The group of convened stakeholders called themselves the LiveWell Strategic Planning Committee ("the Committee"). The Committee members received a stipend for participating in approximately 30–50 h of intervention activities. The changemakers also receive a stipend for their role in the intervention. The changemakers and research team met weekly to co-design the Committee meetings. After the Committee meetings concluded, the changemakers continued to meet with the research team to advance the priorities identified by the Committee. The research team provided $5,000 to LiveWell as seed funding to kick-start community-level activities that aligned with Committee priorities. The Social, Behavioral and Educational Institutional Review Board at Tufts University approved this study.

Committee meetings

There were six Committee meetings held between October 2019 and July 2020 (four in person and two virtual). The Committee first met in October 2019, where the committee members, changemakers, and the research team introduced themselves. The central question that the Committee was exploring during meetings was "What are the factors that influence youth obesity in your community?" The group used a graph depicting stylized obesity rate trends over time in Greenville to ground the initial discussion and subsequent group model building activities. The group was encouraged to consider policy, systems, and environmental-level influences on youth obesity.

The facilitation team (changemakers and research team) led three group model building activities: "hopes and fears", "graphs over time", and "connection circles". Details about these and other group model building activities, including freely available scripts for planning and facilitating group model building activities, are available elsewhere (29, 30). At the second Committee meeting in November, the group revisited trends over time and started building causal loop diagrams in small groups that showed how variables were connected in a system that influences the central problem trend of interest, childhood obesity rates in Greenville. The group continued working on causal loop diagrams in their third meeting in December. Between the third and fourth meetings, the research team and changemakers refined the diagrams by identifying similarities and differences in key variables and feedback loops across the small groups and integrating them into one causal loop diagram.

During the fourth meeting in January, the research team and changemakers presented the refined causal loop diagram back to the group and facilitated a discussion about system insights emerging from the diagram. Insights included the importance of the built environment for promoting physical activity and shaping food choices, time constraints limiting healthy food consumption, and the long-term health burdens of obesity, perpetuating high healthcare costs and limiting wealth to invest in healthy choices. Then the group discussed their priorities for where they wanted to intervene in the system depicted in the causal loop diagram. At that point the Committee decided to seek input from existing working groups from within LiveWell who were already working in areas that had surfaced during the Committee meetings, to add detail and other perspectives to the causal loop diagram.

The fifth Committee meeting was held virtually in June 2020 because of the COVID-19 pandemic. During that meeting, the Committee reviewed the causal loop diagram by subsystem, the key takeaways in each subsystem, and actions that had been generated by the group in the January meeting and mapped on to the causal loop diagram by the research team. The group then prioritized those areas considering things like scale (i.e., how many children would be reached), impact (whether LiveWell and the Committee could add value in the area), multi-sectoral contribution (whether the strategy aligns with the interests of multiple sectors), and timeline (how long it would take to see impact). Once the systems mapping was complete stakeholders participated in the "Places to Intervene" group model building activity, which uses a series of prompts to brainstorm potential solutions that could be mapped onto the systems map (31, 32). These solutions were then "ranked" by the stakeholders through group discussion and consensus on the dimensions of low to high impact and low to high feasibility, with lowest ranking interventions being those with low feasibility and low potential impact and the highest ranking being those that had high feasibility and high potential impact.

In the sixth and final Committee meeting (July 2020) the changemakers shared input from the working groups, and the research team presented a PowerPoint that highlighted evidence from peer-reviewed publications and consensus reports that aligned with the Committee's ranked priorities. Members of LiveWell's Leadership Team attended in addition to Committee members. The changemakers and research team facilitated the meeting, sharing an overview of the whole SDCD process; briefly summarizing scientific evidence about childhood obesity as a public health problem; highlighting key opportunities for action within the causal loop diagram the

Committee created and associated evidence for why intervening on those opportunities could help improve child health; and then facilitating a discussion with the meeting attendees that resulted in approval of three action areas.

Once the GMB process was completed with the stakeholder group they were invited to join working groups around any of the areas identified as part of the GMB process in both formal (i.e., join workgroup as a formal member) or informally (i.e., provide *ad hoc* feedback and input). While stipends were no longer offered for this work, this was not a barrier to the majority of participants as most participated in the work as part of their formal employment. Beginning in 2021, the coalition instituted a process to provide compensation to community representatives who are not attending meetings as part of their employment in recognition of their time and expertise.

Prioritized action areas

To date, LiveWell adopted three new action areas that helped the coalition move beyond sector and/or organization-specific change toward a larger systemic vision for whole-of-community change. Coalition staff members attributed this shift towards a more systemic vision to the SDCD intervention. The three action areas were: (1) address *food insecurity* through better utilization of federally funded nutrition programs; better coordination among food security partners; creation of the food insecurity index; and ensuring equitable access in neighborhoods experiencing the highest levels of food insecurity, (2) address *community power building* by including more community members in coalition prioritization and decision making; developing a Food Equity Action Board to expand community involvement beyond the Food Security Coalition that already existed within LiveWell; and exploring other opportunities to engage community members in coalition decision making, and (3) engage in more specific and intentional *advocacy* in government, schools, churches, businesses, early childhood and other settings to drive community engagement and build allies in changing local and state policy. Figure 1 depicts a simplified version of the Committee's whole causal loop diagram with colors highlighting areas of the system impacted by prioritized action.

Key insights guiding how LiveWell is addressing prioritized action areas

LiveWell has a long history of translating public health priorities into community-level work. The SDCD theory-informed intervention provided a new approach for considering the systems influencing public health trends and helping guide actions to prioritize in LiveWell's 2021 Five-year Strategic Plan. Complimentary to the three action areas described above, the SDCD theory-informed intervention surfaced four key insights that suggested a need for a new group within LiveWell—the Food Equity Action Board—and new approaches for creating lasting change in the community. The insights aligned with several social determinants of health, including the food environment (i.e., food security, access, and availability), and political and social context (33). The insights highlight opportunities to direct community-based resources towards areas of high need and to engage in whole-of-community change, which has the potential for promoting health equity in Greenville.

Key insight 1: participation gaps in federal nutrition program participation

Federally funded nutrition programs were not being used to their full extent (Figure 1, "Federal Assistance"). For example, there was an observed 65% drop in Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participation among eligible families after a child turns one; the Summer Meals Program was also underutilized, according to conversations with Summer Meals providers. One of the first efforts to increase use of federal nutrition programs was the initiation of a farmers' market in partnership with a local Seventh Day Adventist Church that has a thriving urban garden in a lower resourced community in the City of Greenville. The Food Security Coalition developed marketing materials and assisted in building the infrastructure to accept Supplemental Nutrition Assistance Program (SNAP) benefits and double bucks ("Healthy Bucks") at the market. The Coalition conducted a quality improvement project with participants to estimate demographics of farmers' market shoppers, use of SNAP at the market, and to assess whether items sold at the market met shoppers' needs. The research team provided additional funding beyond the intervention seed funding to support the farmers' market survey, market gift cards as incentives for survey completion, and provided technical assistance to a graduate student who conducted and analyzed the survey.

Key insight 2: opportunity for more coordination among food security efforts

Many of Greenville County's food security efforts were not coordinated efficiently. While the county has many organizations working to address hunger and food insecurity, their efforts were often siloed (e.g., no infrastructure to share excess foods or communicate global community needs) or duplicative (e.g., multiple agencies serving the same food pantries, at times leading to duplicative deliveries and reducing the total number of food pantries receiving donations). Additionally, many of these services are in the city center of Greenville, which is experiencing a high rate of gentrification that is pushing existing residents out of the city center, away from these existing services (Figure 1, "Effects of Moving", and "Transportation"). LiveWell's Food Security Coalition helps coordinate food security services, and the coalition added detail about food insecurity to the causal loop diagram (Figure 1, "Produce Consumption", "Effects of Moving"). LiveWell used insights from the causal loop diagram to propose infrastructure investments (e.g., cold storage) for a portion of the county's CARES Act allocations that aimed to support the County's hunger relief efforts in high need areas. LiveWell was awarded $1.2 million dollars of Greenville County's CARES Act allocations in response to a collaborative, multi-partner application directed toward hunger relief and food system development; the proposal was directly informed by the CLD insights.

Key insight 3: shift towards broad policy and systems change

There was a need to shift away from environmental-level change efforts within individual organizations towards building relationships and advocacy skills to influence broader policies and systems in the community. Examples of broader policy options include tax incentives

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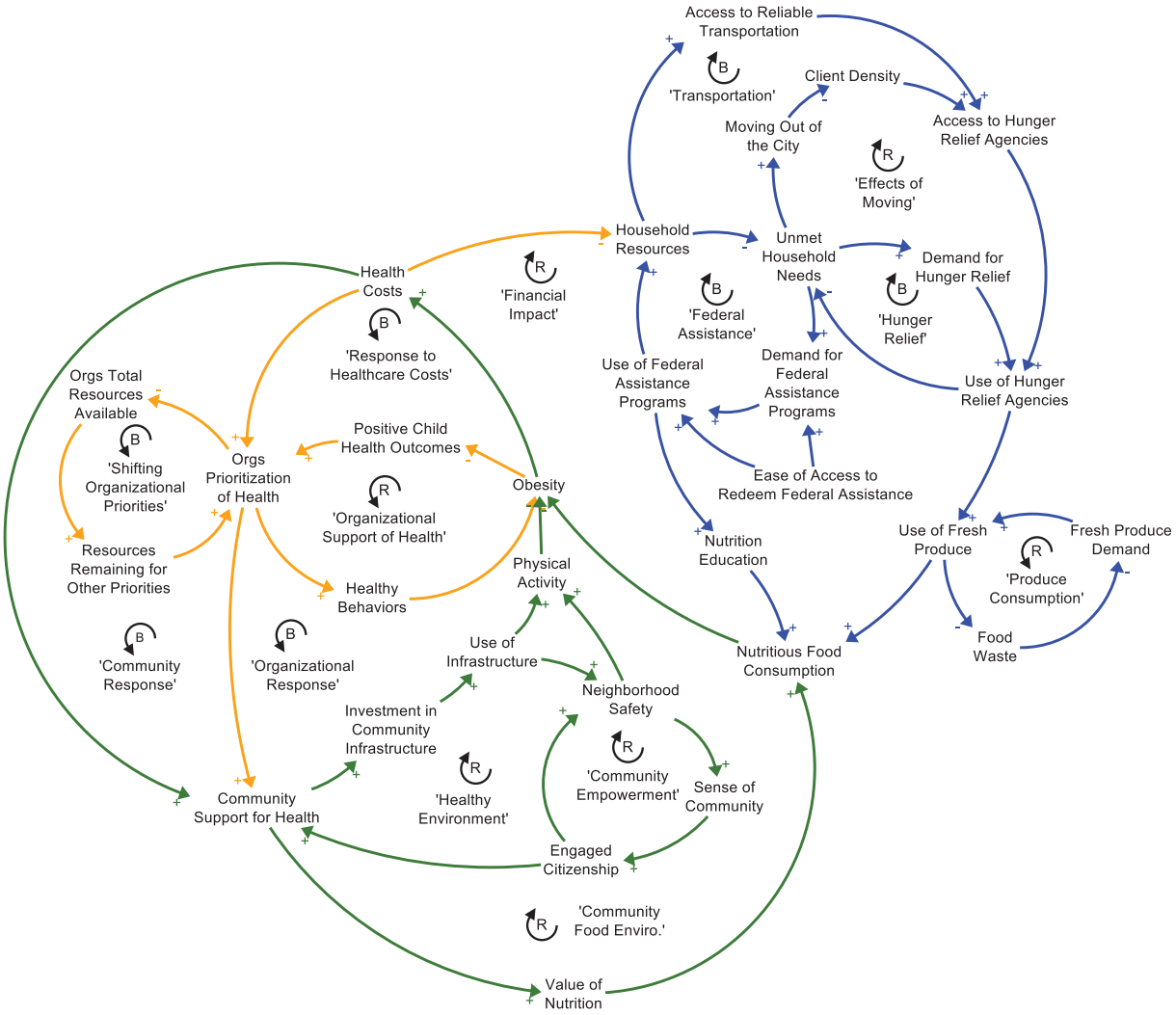

FIGURE 1
How to read a causal loop diagram: Words are variables that can increase or decrease over time. Arrows indicate that a change in the initial variable leads to a change in the variable that the arrow is point to, all else equal. Positive signs indicate that the change happens in the same direction (i.e., an increase leads to an increase, or a decrease leads to a decrease). A negative sign indicates that the change happens in the opposite direction (i.e., an increase leads to a decrease, or a decrease leads to an increase). 'R' represents a reinforcing feedback loop where a change in an initial variable feeds through the loop and amplifies the change in the same direction (i.e., an initial increase leads to more of an increase in the initial variable). 'B' represents a balancing feedback loop where a change in an initial variable feeds through the loop and switches the direction of the change in that initial variable (i.e., an initial increase leads to a decrease in the initial variable).

to develop grocery stores in food insecure neighborhoods, implementing bilingual signage in parks and recreation spaces, and complete streets policies adopted by the county. The Committee agreed that maintaining strong relationships with formal and informal decision-makers and influential people should be a priority to increase community support for healthy eating and active living policy and systems change efforts. In practice, that meant the coalition would work towards building support for health-promoting policies among community members (lay leaders), elected officials, chambers of commerce, and other collaborative efforts rather than focusing on building relationships with individual schools, faith communities, or businesses (Figure 1, "Organizational Response"). Efforts with community members included developing a Food Equity Action Board and a Health Equity Action Leaders Board, composed of community lay community members with lived experience. Both groups met regularly with coalition staff and stakeholders and participated in a cohort-based learning experience about local health issues and how to advocate with their local officials about these issues. Additionally, LiveWell recently hired a Policy and Advocacy Director, with significant state and national legislative experience to work on the coalition's behalf advocating for identified policy and systems changes at the city, county, and state levels.

Key insight 4: citizen engagement for lasting change

A more engaged citizenship is critical to make lasting change in the community (Figure 1, "Healthy Environment"). The coalition has extensive representation from organizations that have a vested interest in changing the youth obesity rates in Greenville County. Over its

history, however, LiveWell has rarely created opportunities for meaningful, long-term engagement and leadership by lay citizens. The Food Security Coalition decided that future efforts should engage community members that have experienced food insecurity, lack of physical activity opportunities, and/or obesity. As a result, the coalition has committed to building infrastructure to shift the coalition from being community-informed, meaning that the opinions of the community members are sought in defining problems and potential solutions, to becoming community-led where community members are at the center of all the work (defining problems, and co-designing solutions, and implementation). The first step of this plan was to identify and meaningfully engage 10–12 community members in a Food Equity Action Board to guide the work of the Food Security Coalition. To date, a Food Security Community Mobilizer has been hired to facilitate and support the Food Equity Action Board, the initial group of board members have been selected, and the group has begun meeting. In addition to seed funding from Catalyzing Communities, LWG leveraged local foundation and federal grant dollars to support the following implementation activities: start the board by hiring a community member to consult on the planning efforts to ensure diversity and cultural appropriateness; provide stipends for Board participants; and implement efforts prioritized by the group.

Building capacity to use community-based system dynamics in Greenville

A core principle of CBSD is to build communities' capacity to use group model building and systems dynamics concepts (24). This principle was realized, as demonstrated by the uptake and use of group model building for understanding systems by other LiveWell-supported initiatives beyond the initial activities in the SDCD intervention. The CBSD approach was adapted to assist in coalition building and planning efforts for several other active workgroups including: LiveWell Early Childhood; LiveWell at Worship's Race Relations Subcommittee; and the Build Trust, Build Health Initiative. For example, LiveWell at Worship's Race Relations Subcommittee used group model building to explore drivers of racial inequities in Greenville, including economic and education inequities. The process helped the multi-racial and multi-ethnic group share their perspectives, and at times deeply personal experiences, promoting a holistic view of many of the drivers and consequences of racial inequities in the community. The Subcommittee is using this understanding to advance racial equity in their community by engaging in advocacy for more transparency in local politics, state level policies to increase access to SNAP, and advocacy for grocery stores with a pharmacy in several neighborhoods. In addition, LiveWell's Executive Director has provided technical assistance to other Greenville County coalitions wishing to employ group model building and CBSD principles in their work. Figure 2 shows the uptake of CBSD-informed projects in LiveWell, starting with the Stakeholder-driven Community Diffusion-informed intervention and spreading beyond the topic of childhood obesity to other important topics. LiveWell has a long history of using extensive community action plans to guide its work; however, the CBSD process brought a new level of sophistication to the plans, resulting in rapid and meaningful changes.

Discussion

Since its inception, LiveWell has focused on PSE change approaches to support healthy eating and active living changes in Greenville County. Historically, much of this work focused on organizational policy change within sectors such as schools, work, out of school time, and faith-based settings. In 2019, LiveWell recognized the need to focus on community-level factors to effectively drive whole-of-community change. CBSD, an established approach employed in the SDCD intervention, provided an avenue to develop a collective and comprehensive understanding of the local contextual factors that were driving community-level obesity prevalence and its associated disparities. The approach also helped LiveWell gain traction to address food insecurity, particularly as the COVID19 pandemic further strengthened the need for better communication and collaboration among food security partners with a sense of urgency that was not felt in the past. This was due in part to the fact that food insecurity emerged as such a central component of the causal loop diagram that they developed together over the course of the intervention. The insights and priorities that surfaced during the intervention provided a strong foundation to seek funding that became available quickly through COVID-related relief funds. LiveWell was awarded $1.2 million in CARES Act funding that was immediately allocated toward priority areas identified during the SDCD intervention, as well as other priority areas identified by the coalition. Moreover, the novel approaches helped LiveWell establish new partnerships and supported multi-sector partners in seeing their role in a complex system that affects health and well-being for all Greenville community members.

CBSD, group model building, and systems thinking have successfully been incorporated into other child obesity prevention interventions. In Australia, the GenR8 Change approach included group model building with over 100 community leaders and members who then committed to join working groups to plan and implement obesity prevention actions such as creating sugar free zones and promoting breastfeeding (34). The SDCD-informed intervention took a somewhat different approach than GenR8 by spending more time with the smaller multi-sector group in Greenville as they developed systems maps and insights. Partnering with a local "backbone" organization was similar in both studies (35). The same research group is conducting a cluster randomized control trial to test whether a participatory systems science intervention can strengthen community action for obesity prevention and whether actions can decrease risk factors for child obesity (36). In the US, the National Academies of Science's Roundtable on Obesity Solutions used group model building to inform a strategic plan that researchers, organizations, and institutions can refer to as they engage in obesity prevention and treatment efforts (37). Another intervention created a systems science curriculum to engage African American youth in exploring environmental factors that influence obesity (38). Study findings suggest the approach may have changed youth's perceptions about important drivers of obesity and lead to an increase in youth's support for policy changes that promote healthier food environments (38). As the field of public health continues to emphasize the need to use systems thinking to address complex challenges, more applications of approaches like those used in the SDCD-informed intervention are likely to emerge (39–41).

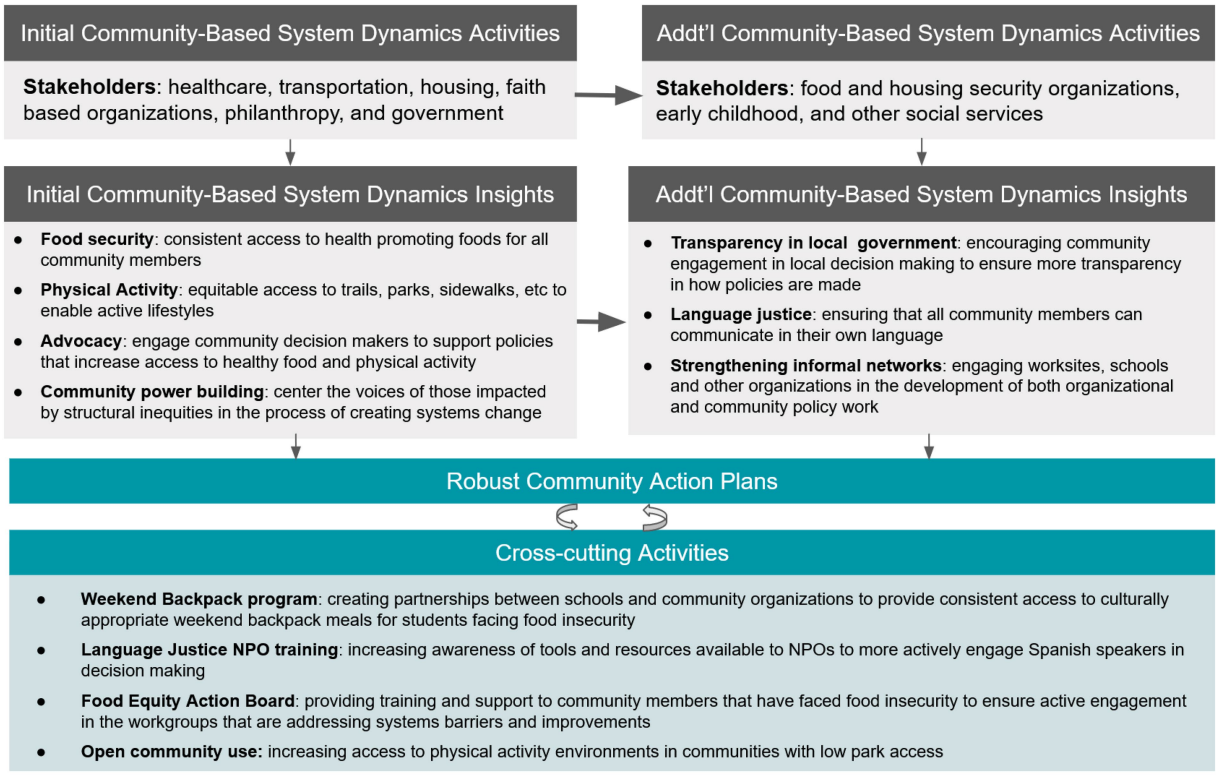

FIGURE 2
Diagram of actions, groups, and use of group model building stemming from a Stakeholder-driven Community Diffusion-informed intervention implemented with LiveWell Greenville (2019 – 2021).

Lessons learned for future applications of stakeholder-driven community diffusion-informed interventions

The insights that came out of the LiveWell—Catalyzing Communities partnership were important both in how they impacted follow-on work with LWG, and in how they helped shape future implementation of the SDCD-intervention in five communities that have since joined the Catalyzing Communities project.

Committee participation

The changemakers and research team learned that while selecting high-level leadership might mean they are powerful within their organization, it also meant that they might be removed from the day-to-day work of the coalition and their partners, and thus were less involved in the implementation of priorities identified through the intervention. If the coalition implemented the process again, it would choose a broader mix of stakeholders, ranging from community members to organizational leaders and decision-makers, that would continue to be engaged in implementing actions prioritized in the SDCD intervention. This shift is reflective of a broader change in implementation of the SDCD intervention in other communities engaged in the Catalyzing Communities project, as a way of bringing together voices that can inform a holistic view of a complex issue, valuing lived experience, empowering participants, and supporting relationship- and network-building across sectors and across the community.

Virtual engagement

COVID-19 made sustaining engagement of the group difficult, and the coalition had to transition to virtual platforms that required intentional planning and creative virtual solutions to facilitate the group model building process (42). The virtual resources developed as part of this process were integral to the group's success and have been employed by the coalition across numerous workgroups to facilitate meaningful dialogue and action planning when in-person meetings were not possible.

Value of systems insights to expand and enhance coalition efforts

One of the challenges in engaging the Committee in developing the causal loop diagram is that some of the issues and root causes associated with obesity in the community were outside LiveWell's scope of expertise and mission. The changemakers and research team learned that in the action planning process they had to balance the Committee's focus on PSE change while also pushing the boundaries of the coalition to adopt health equity and social determinants of health approaches in the coalition's work.

The causal loop diagram helped participants from sectors that were more distal to obesity prevention, like the housing and redevelopment authority and houses of worship, see the important role they played and the expertise they brought to discussions. It also allowed them to see where there was synergy across the partners' work that extended beyond

working with LiveWell. By using systems-thinking, participants realized that they did not have to act on every component of the system to drive significant change in obesity prevention; rather, if they could impact one component of a causal loop it could create a cascade effect that could subsequently impact other aspects of the system. It also allowed the Committee and the coalition to visualize where there was the greatest shared interest and available resources across partner organizations to prioritize action that could result in measurable change. Finally, the portfolio of structured group model building activities facilitated participation and meaningful input across all committee members, which has potential to better balance power dynamics compared to traditional strategic planning approaches if implemented in other places.

Limitations

LiveWell is an established non-profit coalition with 10 years of successes that contribute to its credibility and leadership role in the Greenville community. The coalition currently has seven paid staff who support coalition activities, initiatives, and fund-raising, as well as strong partnerships with Furman University whose faculty, staff, and students provide support for evaluation and community engagement. Given its financial resources and social capital, LiveWell was well positioned to implement and benefit from an SDCD-informed intervention; other coalitions may not be as well-positioned. Another limitation is that this is a case study; we did not rigorously test the effect of the SDCD intervention in a controlled trial with a comparison group. The detail provided in this case study, however, may be useful to groups trying to implement coalition interventions to change systems in their communities.

A large component of the SDCD intervention relies on CBSD principles and group model building skills. Building the pool of individuals with such skills through formal training mechanisms is crucial for scaling up SDCD interventions and similar interventions. The intervention featured in this case study did not employ quantitative simulation modeling that is argued by some in the system dynamics field to be crucial for developing rigorous system insights and determining effective policies (43). Others in the field recognize the utility of informal and qualitative models, like the causal loop diagram developed in this intervention, for helping groups solve learning and coordination problems (44, 45). Quantitative system dynamics simulation models are appropriate when the purpose of the model is for rigorous analysis of objective policies within an existing system and well suited for solving analytical problems when sufficient resources are available to build and test such models. Qualitative models can generate actionable systems insights and, importantly, promote learning and build consensus among participating individuals to initiate and sustain actions (46, 47). Now that the LiveWell coalition has developed some CBSD capabilities and the purpose of modeling necessitates additional insights from simulation, they are working with the research team to explore opportunities to develop quantitative system dynamics models.

Conclusion

This case study describes a theory-informed intervention process to intervene with a group of multi-sector stakeholders to promote whole-of-community change. The process led to three new priority areas for the coalition: (1) addressing food insecurity; (2) a focus on building power within the community; and (3) new advocacy goals to promote systems change beyond the coalition's previous focus on PSE change within individual organizations and sectors. The intervention prompted the application of CBSD to other topics beyond childhood obesity, which could lead to paradigm shifts about how to address complex, entrenched public health issues in the community.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Tufts University IRB. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LC, KW, SW, MF, and JA helped to implement the intervention and contributed to the analysis and manuscript writing. SW is the Executive Director of LiveWell Greenville and MF is the Principal Investigator for LiveWell at Furman University. EH and TM contributed to analysis, interpretation, and manuscript writing. CE conceptualized the study and obtained funding. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Understanding the system dynamics of obesity-related behaviours in 10- to 14-year-old adolescents in Amsterdam from a multi-actor perspective

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Introduction and Methods: To develop an understanding of the dynamics driving obesity-related behaviours in adolescents, we conducted systems-based analysis on a causal loop diagram (CLD) created from a multi-actor perspective, including academic researchers, adolescents and local stakeholders.

Results: The CLD contained 121 factors and 31 feedback loops. We identified six subsystems with their goals: (1) interaction between adolescents and the food environment, with profit maximisation as goal, (2) interaction between adolescents and the physical activity environment, with utility maximisation of outdoor spaces as goal, (3) interaction between adolescents and the online environment, with profit maximisation from technology use as goal, (4) interaction between adolescents, parenting and the wider socioeconomic environment, with a goal focused on individual parental responsibility, (5) interaction between healthcare professionals and families, with the goal resulting in treating obesity as an isolated problem, and (6) transition from childhood to adolescence, with the goal centring around adolescents' susceptibility to an environment that stimulates obesity-related behaviours.

Discussion: Analysis showed that inclusion of the researchers' and stakeholders' perspectives contributed to an understanding of how the system structure of an environment works. Integration of the adolescents' perspective enriched insights on how adolescents interact with that environment. The analysis further showed that the dynamics driving obesity-related behaviours are geared towards further reinforcing such behaviours.

KEYWORDS

overweight and obesity, adolescents, systems thinking, complex systems, causal loop diagram, system dynamics

1. Introduction

Public health problems such as childhood overweight and obesity result from the interaction of multiple factors within a complex adaptive system. A complex adaptive system can be defined as a collection of interconnected factors that is more than the sum of its parts (1). Such factors operate at multiple levels – ranging from individual behaviours like the amount of sedentary time to more upstream factors related to the economic, sociocultural, physical and political environments (2). Identifying such factors and interconnections is considered an important step in gaining an understanding of a complex adaptive system. This understanding can enable action to bring about systems change, and it can serve as a basis to assess changes over time (3, 4).

One way of developing a system understanding is through *system mapping*. A frequently used mapping tool is the *causal loop diagram* (CLD) (5–7). Such diagrams provide visual representations of the complexity of a problem, depicted in the form of factors, causal relationships, polarity and feedback loops (8). A well-known example of a CLD system map is the Foresight map. It identifies a broad range of factors that influence childhood overweight and obesity, thus providing a 'whole' picture of the system (9). At the core of the Foresight map is 'energy balance' around which are over 100 interconnected factors clustered in seven major sub-systems directly or indirectly affecting energy balance. For the first time, this map showed that obesity results from many interconnected policy, environmental, social, economic, cultural, behavioural, and biological causes. While succeeding in effectively illustrating the wide range of causes of obesity, the Foresight map was developed by experts based on empirical research literature, and it thus creates an *academic perspective* on the system in question.

Another potential important perspective to take into account is that of *stakeholders* (6). Friel et al. (10) for example conducted collaborative conceptual modelling workshops with stakeholders from different sectors in Australia including academia, non-governmental health organizations and government to create a system map that illustrated the multiple factors associated with inequities in healthy eating. This system map resulted in the identification of seven sub-systems including (1) food supply and environment; (2) transport, (3) housing and the built environment, (4) employment, (5) social protection, (6) health literacy, and (7) food preferences. One more potential important perspective to consider is that of the *targeted group* itself, often identified through methods such as group model building (GMB) (11–14). Savona et al. (14) conducted for example GMB with adolescents in five European countries in order to map the factors that they considered to be important obesity drivers. In the overall systems map that represented the perspective of more than 200 adolescents, three sub-systems stood out: (1) commercial drivers of adolescents' unhealthy diet, (2) mental health and unhealthy diet, and (3) social media use, body image and motivation to exercise.

A common characteristic of such CLDs is that they provide a single perspective on the system – a perspective of experts based on research literature or a perspective of stakeholders or of the target group. What is still missing, to our knowledge, is a system map or CLD that *integrates* multiple perspectives, including those from experts, various stakeholder groups and the target group itself. Such a *multi-actor perspective* is important because different actors have different perceptions of the causes of a problem, and these influence the ways in which the system can be changed (15–17). Hence, when mapping a system, one should ideally consider the perspectives of the various actors in order to obtain a more complete system understanding (15, 16, 18). Indeed, in their framework for transformative systems change, Foster-Fishman and colleagues have described such a system understanding from a multi-actor perspective as a key step in the process towards effecting systems change, as this accentuates the subjective nature of understanding systems (16).

Another common characteristic of most CLD papers in the literature, including the abovementioned examples, is that these mostly focus on developing and understanding of the system in terms *of system structure*, describing the included factors, connections and feedback loops of a particular problem (5). Foster-Fishman and colleagues further emphasise in their framework that one not only needs an understanding of the *system structure* when trying to understand the targeted system, but an understanding of the *system function* is also required in order to change the status quo of a system. Such a system function understanding includes a more in-depth analysis of the system as a whole, which identifies and understands the deeper system dynamics in terms of structure, goals and paradigm (16, 19, 20).

In this paper, we aim to identify and understand the underlying system dynamics that drive obesity-related behaviours in 10- to 14-year old adolescents in Amsterdam, by conducting systems-based analysis from a multi-actor perspective. We report on how we applied systems dynamics methods to assess the extent to which these methods led to new understandings of the targeted problem in the local context.

2. Methods

2.1. The LIKE programme

The results presented in this study are part of the larger Lifestyle Innovations Based on Youth Knowledge and Experience (LIKE) programme (21), which is part of the Amsterdam Healthy Weight Programme, a local-government-led whole-systems approach (22). The LIKE programme is designed to tackle childhood overweight and obesity in 10- to 14-year-old adolescents in three neighbourhoods with a low socioeconomic status in the Amsterdam East city district in the Netherlands. It combines a system dynamics and participatory action research approach in order to develop, implement and evaluate a dynamic action programme.

To arrive at such dynamic action programme, the first part of LIKE focuses on developing an understanding of the targeted system. In LIKE, we refer to this system understanding as the pre-existing system of obesity-related behaviours in 10- to 14- year-old adolescents in Amsterdam. We allude to 'pre-existing system' because in systems evaluations, there is no control or baseline system, rather, the system continuously changes over time either with or without intentional intervention (3).

Abbreviations: CLD, Causal loop diagram; GMB, Group model building; LIKE, Lifestyle Innovations Based on Youth Knowledge and Experience programme; HCPs, Healthcare professionals.

2.1.1. Procedures

In LIKE, we combine three different perspectives to achieve a system understanding. The academic researchers' perspective provides an external view of the system and was published here (23). In this paper we enriched our system understanding by adding the adolescents' and stakeholders' perspectives to provide an additional internal view of the system. On top of that, we conducted system-based analysis to understand the underlying system dynamics. This was operationalised by following a three-step process. First, data were collected using qualitative methods separately from the different perspectives. The data were then integrated to arrive at an overarching map, or CLD, of the pre-existing system. Finally, the resulting CLD was analysed using system-based methods to qualitatively understand the underlying system dynamics. The exact procedures are detailed below. Ethical approval for the data collections was obtained from the institutional medical ethics committee of Amsterdam UMC, Location VUMC (2018.234).

2.2. Step 1. Data collection from a multi-actor perspective

To operationalise the central aim of identifying and understanding the underlying system dynamics that drive obesity-related behaviours we focused on four behaviours that are particularly significant to childhood overweight and obesity and which are also the focus of the Amsterdam Healthy Weight Programme. These include dietary behaviour, physical activity, sedentary behaviour and sleep. We conducted an in-depth needs assessment in LIKE between 2018 and 2021 to gain insights of the system dynamics that related to these four behaviours. Of note, as our focus was in uncovering the system dynamics, we collected data that accounted for the change over time of factors influencing the four targeted behaviours, rather than a static situation. A central question for the collection of data was therefore: "What factors explain the dynamics in dietary behaviour, physical activity, sleep, and sedentary behaviour, in 10- to 14- year-old adolescents Amsterdam in the past three decades?." During the needs assessment period, various qualitative methods were employed, including the construction of CLDs by academic researchers based on research literature (23); construction of CLDs by adolescents (Emke et al., unpublished data, 2022); GMB with stakeholders, including parents and other actors in the direct environment of adolescents (schoolteachers, sport coaches etc.) (Waterlander et al., unpublished data, 2022); and interviews with healthcare professionals (HCPs) (24), (Van den Eynde et al., 2022).

2.2.1. Researchers' perspective

As mentioned above, the academic researchers' perspective on the pre-existing system had previously been captured in LIKE during 2019–2020 (23). First, factors were retrieved from systematic reviews (*n = 190 factors*). Next, factors were connected by taking into account their causal relationship. A positive polarity marked positive causation meaning that as a cause increases, the effect also increases; or that as a cause decreases, the effect also decreases (more chicken leads to more eggs). A negative polarity marked inverse causation meaning that as a cause increases, the effect decreases; or that as a cause decreases, the effect increases (more foxes leads to less chicken) (23). A total of four CLDs were created around physical activity ($n = 20$ factors), dietary behaviour ($n = 28$ factors), sedentary behaviour ($n = 19$ factors) and sleep ($n = 13$ factors). These CLDs revealed the presence of dynamics including feedback loops, mechanisms and subsystems. Highlighted subsystems included for example home and school environments but also newly identified subsystems such as urban systems, social welfare and macroeconomics. For more details on the construction of these four CLDs and results hereof, we refer to the work of Waterlander and colleagues (23).

2.2.2. Adolescents' perspective

Participatory action groups were conducted between 2018 to 2020 at two primary and two secondary schools located in the LIKE target areas in Amsterdam East. Participatory action groups consisted of four to eight adolescents aged 10 to 14 and an academic facilitator. In these participatory groups, adolescents were first trained in research skills, and they subsequently investigated, among their peers, the factors that influenced their dietary behaviour, physical activity, sedentary behaviour and sleep. Adolescents then analysed the collected data separately for primary and secondary schools and summarised the major factors *(n = 126 factors)* associated with the four targeted behaviours into six CLDs (three constructed by primary school children and three CLDs by secondary school adolescents). From these CLDs, three overarching subsystems were identified: (1) Adolescents live in a physical activity environment with easy access to unhealthy food products, (2) Social norm around unhealthy behaviours are formed by peers, friends and family, and (3) Unhealthy behaviours are interrelated and reinforce each other. Details of the participatory action group process will be published elsewhere (Emke et al., unpublished data, 2022).

2.2.3. Stakeholders' perspective

The stakeholders' perspective was captured through two different methods. First, four GMB workshops were held in 2020–2021 in Amsterdam East. 29 to 31 stakeholders participated in the different rounds and represented the sectors schools, healthcare, local government, the Amsterdam Healthy Weight Programme, sports clubs, and community and youth organisations (including volunteers and parents). During the GMB workshops, participants constructed a CLD around dietary behaviour, physical activity, sedentary behaviour and sleep *(n = 39 factors)*, in adolescents from their perspective as local stakeholders. This CLD revealed the presence of five subsystems: (1) the food environment, (2) the home environment, (3) sleep, (4) physical activity, and (5) transition from 10 to 14 years. The details of the GMB process will be part of a separate paper (Waterlander et al., unpublished data, 2022).

Lastly, interviews with 18 HCPs were conducted in 2019–2020 to gather data about barriers and facilitators that bear upon obesity-related behaviours in adolescents with obesity and their parents. These barriers and facilitators were summarised into seven themes including (1) individual child factors, (2) role of the parents, (3) physical environment, (4) socioeconomic environment, (5) cultural environment, (6) family's experience with healthcare, and (7) family's motivation. For more details on these results we refer to (24). Moreover, the HCPs interviews data were also used to identify barriers and facilitators that influence the professional support and care for adolescents with obesity and their parents. Identified themes included for example conducting a biomedical, psychosocial and lifestyle assessment, tailoring the approach to the adolescent and parents'

needs, and investing in building a relationship. Details will be provided elsewhere (Van den Eynde et al., 2022).

2.3. Step 2. Developing the map of the pre-existing system

On the basis of the data sources outlined above, the next step involved the integration of the data to arrive at a multi-actor perspective CLD of the pre-existing system. The process is outlined below. Maps were first created using STICK-E software (STICK-E version 3, Deakin University) and then imported in KUMU (Relationship mapping software, 2022) for editing purposes. The final representation of the pre-existing map was edited in Adobe Illustrator CS5.

2.3.1. Step 2.1. Merging the researchers' literature-based CLDs

The first step consisted of constructing a 'baseline' CLD system map. As input for this baseline CLD, the four separate CLDs (consisting of factors and their interconnections) – relating to adolescents' dietary behaviour, physical activity, sedentary behaviour and sleep, representing the academic perspective (23) – were merged into an overarching baseline CLD covering all four behaviours. System map development started with the researchers' perspective because those CLDs were already published while the CLDs from the other perspectives were still being developed. Integration of the four separate CLDs was performed by merging the CLDs on the basis of common factors. For example, the sedentary behaviour CLD was linked with the sleep CLD by the factor 'screen use', which was present in both CLDs. Next, the resulting baseline CLD was iteratively refined by removing duplicate variables and by making sure each factor was at the same level of detail and specificity (25). For example, the factors 'screen use for school or work' and 'use of screen-based social media by adults' were incorporated into the 'screen use as social norm' factor. This process resulted in a baseline system map that reflected the researchers' perspective.

2.3.2. Step 2.2. Adding the adolescents' perspective

The next step involved integrating the perspective of adolescents into the baseline map. Factors associated with dietary behaviour, physical activity, sedentary behaviour and sleep that were present in the six CLDs constructed by adolescents (Emke et al., unpublished data, 2022), but still absent in our evolving map, were extracted. Examples include 'gaming', 'nightmares', 'biking', and 'supermarket proximity'. As well single factors as connections between the factors were added to the map. These connections were based upon the causal connections and polarity identified by adolescents in the original six CLDs.

2.3.3. Step 2.3. Adding the stakeholders' perspective

Integration of the stakeholders' perspective into the system map followed a two-step process. First, factors present in the stakeholders' CLD (produced in the GMB workshops) but still absent in our system map were added. Those factors related to issues such as health (e.g., 'listening to your own body', 'health as a priority') and the home environment (e.g., 'parents as role models', 'parents in survival mode'). Connections between the newly added factors were drawn by the present authors reflecting the direction of causality between factors as observed in the original stakeholders' CLD. Second, the interview data from HCPs were incorporated. As previously mentioned, these data were used to identify themes around barriers and facilitators influencing both obesity-related behaviours in adolescents with obesity and their parents (24) as well as around the professional support and care that those adolescents and parents receive (Van den Eynde et al., 2022). Because those data were not in the form of CLDs, we reviewed the identified themes and sub-themes and treated these as factors in order to add these to our system map. Examples of newly added factors include 'parents being supportive and involved' and 'vagueness of the healthcare system' (24). Some factors from the original data were not added, because their level of detail and specificity did not equate with that of the factors already included (overly broad formulations such as 'obesogenic environment' or 'the healthy choice should be the easy choice'). Because the original HCPs data merely noted factors and made no connections between them, we iteratively drew connections and identified directions of causality, based on our interpretations of the data. The researcher that collected the original data (EvdE) closely monitored this process.

2.3.4. Step 2.4. Identification of feedback loops

Lastly, the connections and directions of causality between all factors in the evolving system map were re-assessed to facilitate identification of feedback loops. A feedback loop refers to a sequence of factors and interconnections that creates a closed loop of causal influences (3). Feedback loops can either be reinforcing, which indicates exponential growth or decay, or balancing, indicating stabilisation or tending to equilibrium (26). The identification of reinforcing and balancing feedback loops was performed by ALP and WW, and reviewed by the rest of authors of the present study. Altogether, this process resulted in the creation of a multi-actor map of the pre-existing system of obesity-related behaviours in adolescents.

2.4. Step 3. System-based analysis of the map of the pre-existing system

In the final step, a system-based analysis (22) of the CLD of the pre-existing system was performed to gain an understanding of the dynamics of obesity-related behaviours. This analysis was performed using the Intervention Level Framework developed by Johnston and colleagues and is based on five levels: system paradigm, goals, structure, feedback loops and elements (27). We used the Intervention Level Framework to distinguish the structure and function of the pre-existing system.

To understand the system structure, we analysed the CLD to assess the identified factors (ILF level *elements*) and feedback loops (ILF level *feedback loops*). The clustering of feedback loops revealed the presence of specific themes that helped us identify subsystems and the overall system structure (ILF level *structure*). The identification of the system structure as well as the subsystems was carried out iteratively though group discussions by the authors until consensus was reached. To understand the system function, we subsequently tried to identify subsystem goals (ILF level *goals*) and the overarching system paradigm (ILF level *system paradigm*). This was done by

building on existing expert knowledge on system function, for example as detailed in the report of the Lancet Commission on Obesity (28). Finally, both the map of the pre-existing system and the system-based analysis were reviewed by all authors to make sure all collected data were accurately presented in the CLD and correctly interpreted.

3. Results

In total, we identified 121 unique factors in the final systems map; 50 of these derived from the researchers' perspective, 74 from the adolescents' perspective and 54 from the stakeholders' perspective (Figure 1). Due to overlap between the perspectives, the sum of the factors from all perspectives is greater than the total number of factors in the integrated system map. We also identified a total of 31 reinforcing feedback loops. Six different subsystems emerged (Figure 1). The total numbers of factors within each subsystem from the three perspectives, as well as the numbers of factors that were unique to a single perspective in each subsystem, are shown in Figure 2. Subsystem 6 is not shown in that figure, as the factors in that subsystem were embedded in the other five, as explained below. Identified factors, feedback loops, system structures and system goals will be discussed below separately for each of the six identified subsystems.

3.1. Subsystem 1: interaction between adolescents and the food environment

Figure 3 illustrates the interaction between adolescents and the food environment. Out of a total of 23 factors, 12 were derived from the researchers' perspective, 17 from the adolescents' perspective and 12 from the stakeholders' perspective. A total of 11 factors were unique to a single perspective. Six reinforcing feedback loops were identified as we integrated all perspectives (Figure 3, R1–R6).

The first two reinforcing feedback loops (R1, R2) relate to the relatively low price of unhealthy food, which makes unhealthy food more attractive and easily accessible. This boosts the demand for unhealthy food, which in turn allows food providers to maintain lower prices. The high demand for unhealthy food, in turn, reinforces the availability and accessibility of unhealthy food. The second two reinforcing feedback loops (R3, R4) reveal how this demand and supply chain of unhealthy food leads to high revenues, which can then

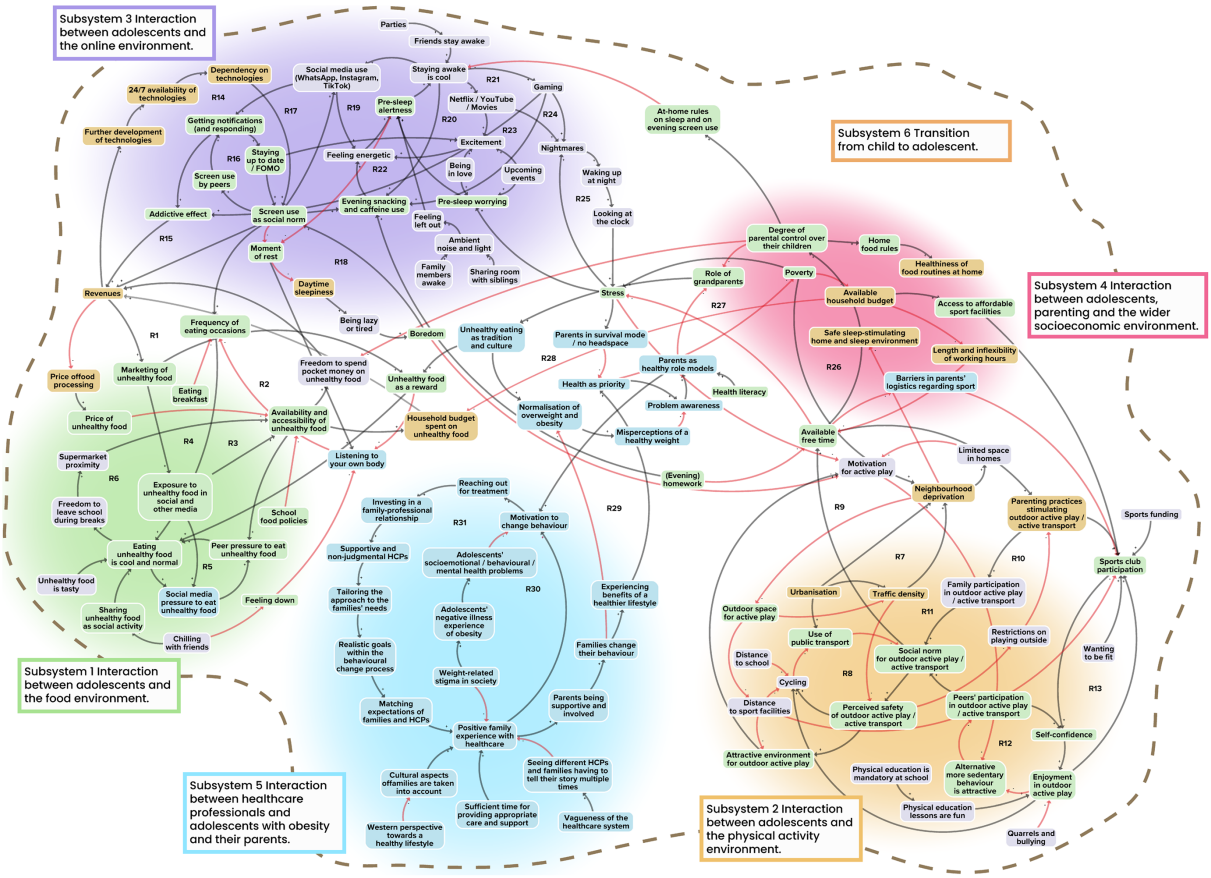

FIGURE 1
Pre-existing system of obesity-related behaviours in an integrated multi-actor perspective with identified subsystems. Factors derived from the researchers' perspective are shown in yellow, those from the adolescents' perspective in purple, and those from the stakeholders' perspective in blue. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

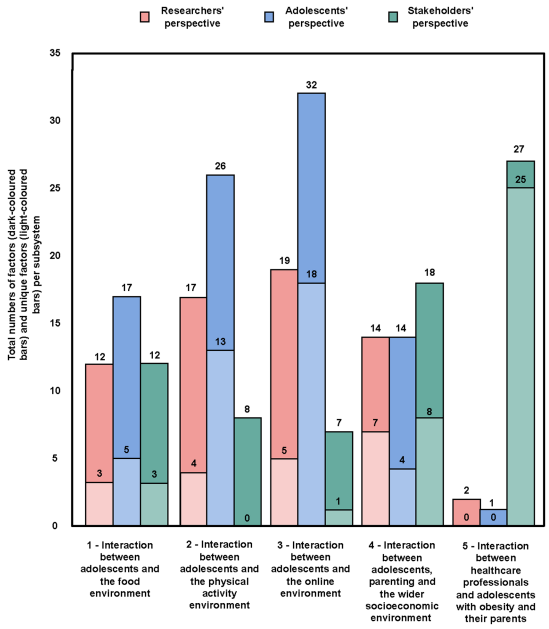

FIGURE 2
Total numbers of factors and unique factors from the perspectives of researchers, adolescents and stakeholders in subsystems 1–5.

be used for the marketing of such foods, thereby further reinforcing the availability and accessibility of unhealthy food.

Another feedback loop relates to the social norm that eating unhealthy food is cool and normal. In most larger Dutch towns and cities, a supermarket is found on almost every street corner. Visiting the supermarket with friends during school hours and buying unhealthy food together is seen by many adolescents as normal behaviour and as a fun and attractive social activity. This reinforces the social norm that eating unhealthy food is cool and normal (R6).

In addition to physical exposure, we found a feedback loop involving online exposure to unhealthy food. Adolescents typically spend a large amount of their time in online environments. Especially on social media platforms, peer pressure to buy and eat unhealthy food is commonly prevalent (for example when influencers advertise unhealthy foods) (R5). This further sustains the social norm that eating unhealthy food is cool and normal.

Taking together all 23 factors, their interconnections, and the six reinforcing feedback loops, we see a system structure revolving around the comparatively high availability, accessibility and affordability of unhealthy food. Such food may be preferred by adolescents not only because of the easy access, but also through the prevailing social norm that eating unhealthy food is cool and normal. This is further reinforced by marketing, social media and peer-group influence surrounding unhealthy foods. In terms of system goals, we observe that these factors belong to a larger system that focuses on profit maximisation, which can be achieved by selling as much food as possible – whereby unhealthy foods (heavily processed and with high energy density or high sugar, salt and fat content) are the more profitable option. For example, the stakeholders in our GMB workshops explained that local business owners prefer unhealthy over healthy foods, because the revenues are larger and the losses (as from food waste, logistics and cooling) are much lower.

3.2. Subsystem 2: interaction between adolescents and the physical activity environment

Figure 4 illustrates the interaction between adolescents and the physical activity environment. A total of 31 factors emerged, of which 17 derived from the researchers' perspective, 26 from the adolescents' perspective and 8 from the stakeholders' perspective. In total 17 of the factors were unique to a single perspective. Seven reinforcing feedback loops were identified in integrating the perspectives (Figure 4, R7–R13).

Reinforcing feedback loop R7 illustrates how urbanisation generally increases traffic density and neighbourhood deprivation, resulting in limited outdoor space for active play. The high demand for housing and businesses in cities like Amsterdam has prompted the building of sport facilities on the outskirts of neighbourhoods, thereby increasing the distance to the facilities; as a consequence, adolescents make less use of the facilities. A related factor is greater traffic density, which generally reduces the perceived safety of the physical activity environment. Adolescents then cycle less and make more use of public transport. This hampers sustainment of a healthy social norm of active outdoor play and active transportation (R8). The more the physical activity environment is perceived as unsafe, the more its attractiveness to adolescents declines, leading to lower participation by adolescents and their peers in active play and transport (R9). Also due to the perceived unsafety, parents will be less motivated to encourage habits of active play and transport, further weakening the healthy social norm (R10). In turn, once a social norm of active outdoor play and transport does not prevail, adolescents will be less encouraged to create free time for such activities, thus further reducing their motivation (R11). That may make alternative, more sedentary behaviours, such as screen use, more attractive (R11, R12) (thus linking with subsystem 3 below) and thereby make the physical activity environment all the less enjoyable (R12, R13).

Taking all 31 factors, their interconnections and their seven reinforcing feedback loops together, we see a system structure with dwindling availability of attractive, safe outdoor spaces for physical activity by adolescents. This undermines a healthy social norm of outdoor active play and active transportation. We note that this structure is part of a larger system goal that revolves around maximising utility for limited urban space by prioritising housing, business and motorised transport above outdoor space for active play.

3.3. Subsystem 3: interaction between adolescents and the online environment

Figure 5 illustrates the interaction between adolescents and the online environment. From a total of 38 factors, 19 derived from the researchers' perspective, 32 from the adolescents' perspective and 7 from the stakeholders' perspective. A total 24 of the factors were unique to a single perspective. Twelve reinforcing feedback loops were identified in integrating the perspectives (Figure 5, R14–R25).

The first feedback loop (R14) relates to screen use as part of everyday life. Virtually all ordinary tasks of adolescents, including schoolwork, require using screens. This results in a society that is highly dependent on technology, and where the high demand and supply of new technologies further reinforce that dependency and

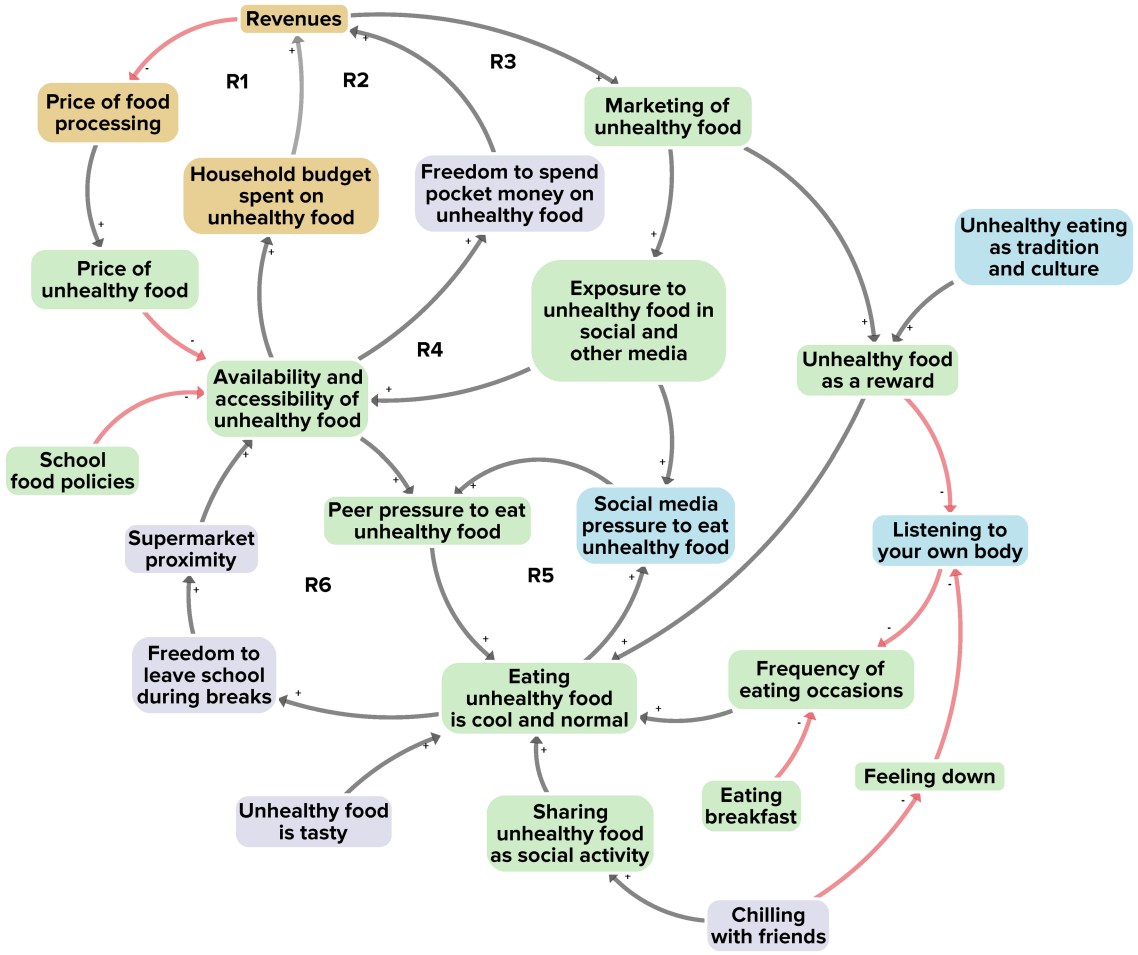

FIGURE 3
Subsystem 1: Interaction between adolescents and the food environment. Factors derived from the researchers' perspective are shown in yellow, those from the adolescents' perspective in purple, and those from the stakeholders' perspective in blue. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

help sustain the social norm of screen use as part of everyday life. The screen use norm is reinforced yet further by a fear among adolescents of missing out (FOMO) on what happens online; this induces an addictive effect of constantly wanting to be online (R15, R16). Social media use by adolescents plays herein an important role. The countless notifications received from WhatsApp, Instagram and TikTok further fuels adolescents' curiosity to stay up to date, not to miss out, and hence to be perpetually online (R17). Adolescents' high levels of screen use are not only common during the daytime; they also use screen devices before bedtime, adversely affecting sleep and reducing restful moments (R18). Social media use, watching Netflix, YouTube and movies, and gaming are activities frequently performed by adolescents in evening and nighttime hours (R19–R21). These reinforce a social norm that it is cool to stay awake (R19–R24). Screen use at night is often accompanied by snacking and caffeine use, giving adolescents an even greater sensation of energy, causing pre-sleep alertness and adversely affecting sleep and dietary behaviour (R21–R22). Furthermore, they often experience nightmares after gaming or watching horror movies, and this also affects sleep (R23–R25).

Taking together all 38 factors, their interconnections and twelve reinforcing feedback loops, we see a system structure revolving around 24/7 availability and accessibility of screens, whereby everyday life tasks are increasingly performed on screens. We observe that this screen use maximisation is part of a larger system whose goal is to maximise the profits obtained from technology use. For example, adolescents who like videogames generally follow their favourite gaming influencers on streaming channels. The more followers those influencers have, the more profits these can make through lucrative deals offered by private sector companies – such as for advertising unhealthy food in their videos – and the more profits those companies eventually make.

3.4. Subsystem 4: interaction between adolescents, parenting and the wider socioeconomic environment

Figure 6 illustrates the interaction between adolescents, parenting and the wider socioeconomic environment. In a total of 31 factors, 14 derived from the researchers' perspective, 14 from the adolescents'

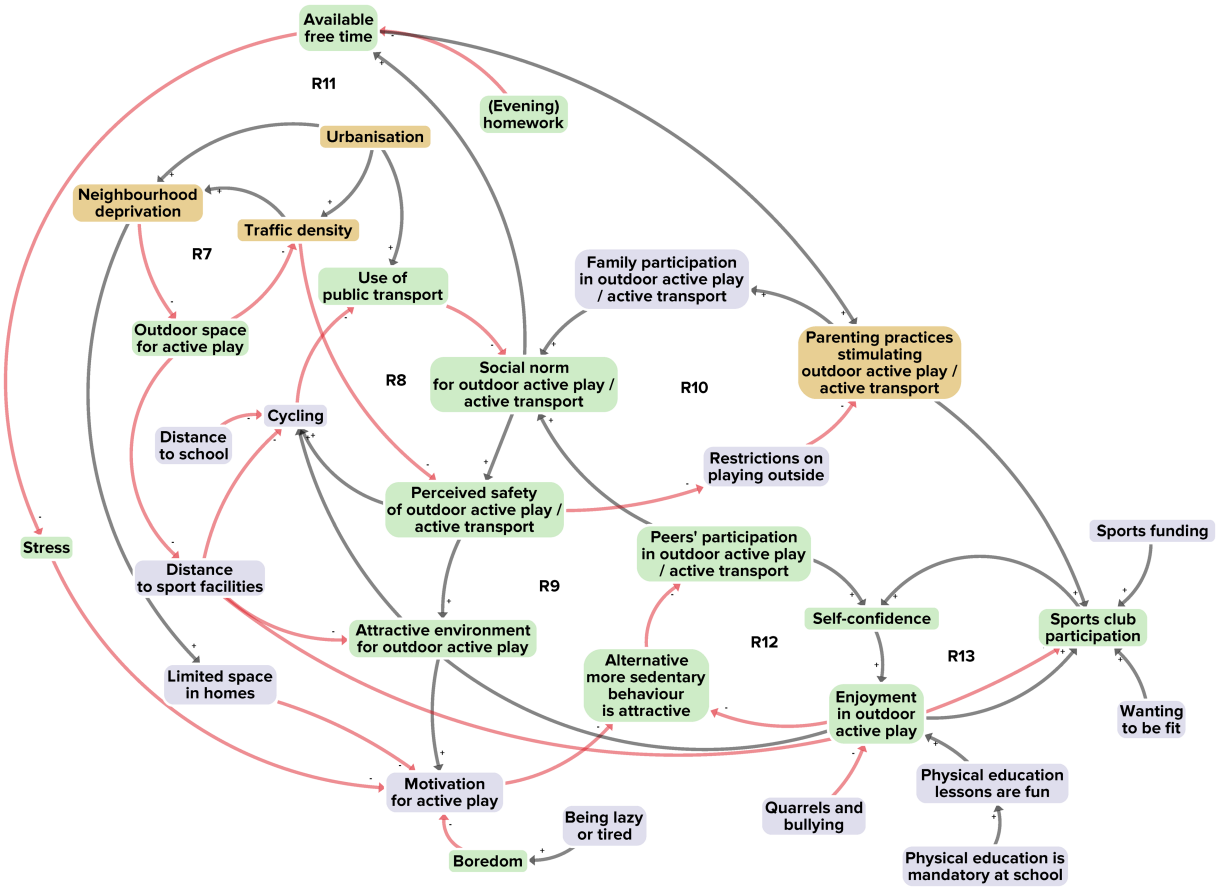

FIGURE 4
Subsystem 2: Interaction between adolescents and the physical activity environment. Factors derived from the researchers' perspective are shown in yellow, and those from the adolescents' perspective in purple. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

perspective and 18 from the stakeholders' perspective. A total of 19 of the factors were unique to a single perspective. Three reinforcing feedback loops were identified in integrating the perspectives (Figure 6, R26–R28).

The first feedback loop (R26) relates to a large number of households in our research community living in relative poverty, where parents typically have long, inflexible working hours and hence limited free time and higher stress levels. This, in turn, may put parents in a 'survival mode', leaving limited headspace for matters such as preparing healthy meals. Parents find themselves in a vicious circle as financial problems accumulate; that triggers even more stress, as they often need to solve such multiple problems in a short time span (R27).

With such financial problems occupying parents' headspace, they often pay less attention to their children's health behaviours. As parents have less time for their children, grandparents may play a greater role in the upbringing of adolescents (R28). In our research community, a large percentage of such grandparents come from cultures where unhealthy eating may be seen as tradition and culture, for example when guests are welcomed with an abundance of food, usually unhealthy.

In combination with the parents' limited headspace, their transition to their new role as coaches or mentors of young adolescents, rather than childrearers of younger children, commonly makes it difficult for them to set, monitor and enforce rules regarding sleep, dietary behaviour, screen behaviour and physical activity.

Taking together all 31 factors, their interconnections and three reinforcing feedback loops, we see a system structure that revolves around parents' limited capabilities to stimulate healthy behaviours, in particular in ethnically diverse groups of lower socioeconomic status. Parents are subject to competing demands and stressors, possibly relating to financial worries, long working hours, general uncertainty, and traditional cultural roles and patterns. We note that this is part of a larger system whose goals prescribe individual responsibility while compelling parents to prioritise household livelihood security at the expense of stimulating healthy behaviours.

3.5. Subsystem 5: interaction between healthcare professionals and adolescents with obesity and their parents

Figure 7 illustrates the interaction between healthcare professionals (HCPs) and adolescents with obesity and their parents. From a total of 27 factors, 2 factors derived from the researchers' perspective, 1 from the adolescents' perspective and 27 from the

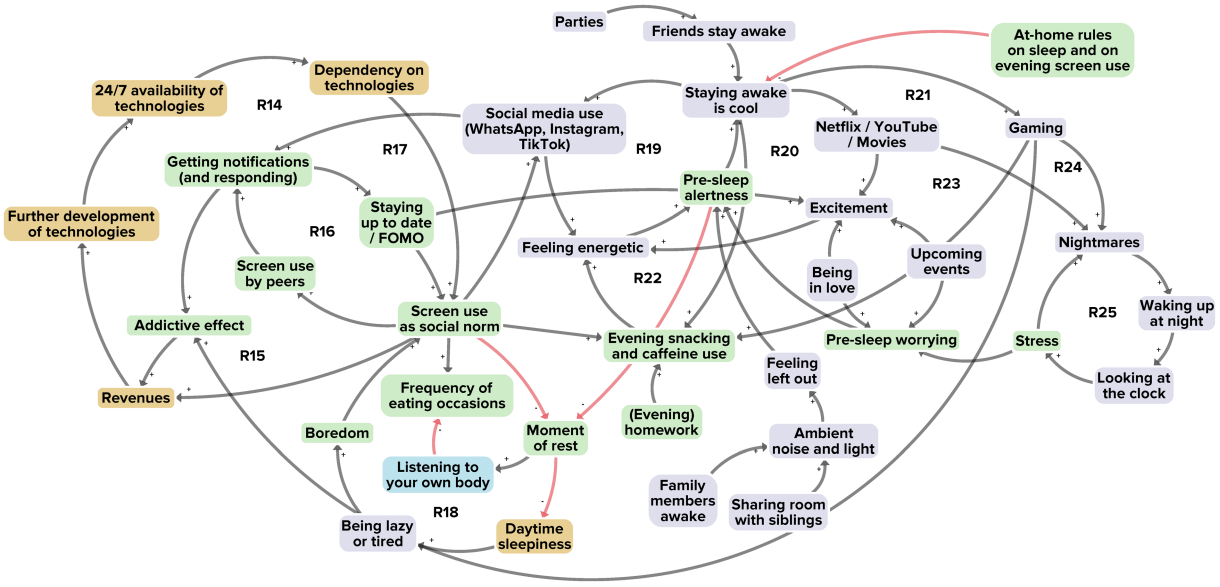

FIGURE 5
Subsystem 3: Interaction between adolescents and the online environment. Factors derived from the researchers' perspective are shown in yellow, those from the adolescents' perspective in purple, and those from the stakeholders' perspective in blue. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

stakeholders' perspective. A total of 25 of these factors were unique to a single perspective, that of the stakeholders. The reason for the comparatively large number of factors in the stakeholder perspective is that 'healthcare' was not included nor discussed as a potential subsystem in the researchers' and adolescents' original data, but only in the stakeholder data. Moreover, in contrast to the other identified subsystems, the healthcare subsystem data relates specifically to adolescents *with obesity* in a healthcare setting or context, rather than to the general population. Three reinforcing feedback loops were identified (R29–R31).

All three of the reinforcing feedback loops were linked to a single feedback loop outlined in subsystem 4 involving the interaction between adolescents, parenting and the wider socioeconomic environment (Figure 6, R26). It showed that poorer families in our research community were often in survival mode, with limited headspace to think about health-related behaviours. This feedback loop feeds into the factors of 'low general priority for health' and 'limited awareness of a health problem' (in this case, overweight) (R29, R30). From the perspective of HCPs, this results in families showing little motivation to change unhealthy behaviours; this could lead to normalisation of overweight and obesity and to misperceptions of what constitutes a healthy weight (R30).

The three reinforcing feedback loops further show that a number of factors are important to ensure that families have a positive healthcare experience. These include investing in a family–professional relationship, offering a treatment approach tailored to a family's needs, and managing treatment expectations between families and HCPs (R31). The interviews with HCPs revealed that achieving these aims is not automatically assured. One challenging situation may arise when HCPs regard a healthy lifestyle from a Western European perspective, hence not sufficiently taking the cultural diversity of families into account. Culture serves here as an example of underlying factors related to obesity that may not be readily observable to HCPs but may nevertheless contribute to the problem.

Taking together all the 27 factors, their interconnections and the three feedback loops, we see a subsystem where many conditions, such as a family–professional relationship and a tailored approach to a family's needs, must be met if adolescents with obesity and their parents are to modify and sustain health behaviours. The interviews with HCPs revealed that these conditions have not yet been fully achieved in the healthcare system, for reasons such as insufficient time for appropriate care and support and insufficient consideration of families' cultural aspects by HCPs. This results in a system that treats obesity mainly as an isolated medical problem, with little attention for the social and cultural contexts that affect problem management by adolescents and parents.

3.6. Subsystem 6: transition from childhood to adolescence

In analysing the sixth subsystem, we took a slightly different approach as compared to previous subsystems. The reason is that the factors relating to the child-to-adolescent transition are embedded within the various other subsystems (Figure 1), rather than forming feedback loops that are unique to this subsystem itself. Subsystem 6 therefore tightly interacts with the five subsystems previously discussed.

We noted that, during this transition period, adolescents are extra susceptible to the influence of the system they are a part of. Such susceptibility may manifest itself in a display of obesity-related behaviours. During the transition, adolescents generally increase their consumption of unhealthy foods (subsystem 1), decrease their levels of physical activity (subsystem 2) and increase their sleep-affecting screen time (subsystem 3). We identified three principal factors that

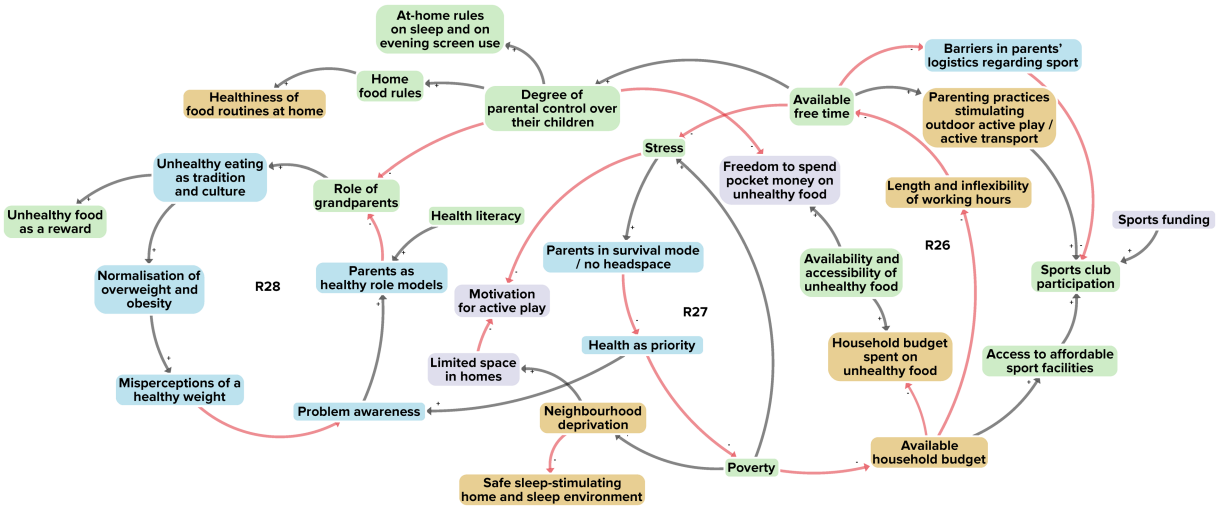

FIGURE 6
Subsystem 4: Interaction between adolescents, parenting and the wider socioeconomic environment. Factors derived from the researchers' perspective are shown in yellow, those from the adolescents' perspective in purple, and those from the stakeholders' perspective in blue. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

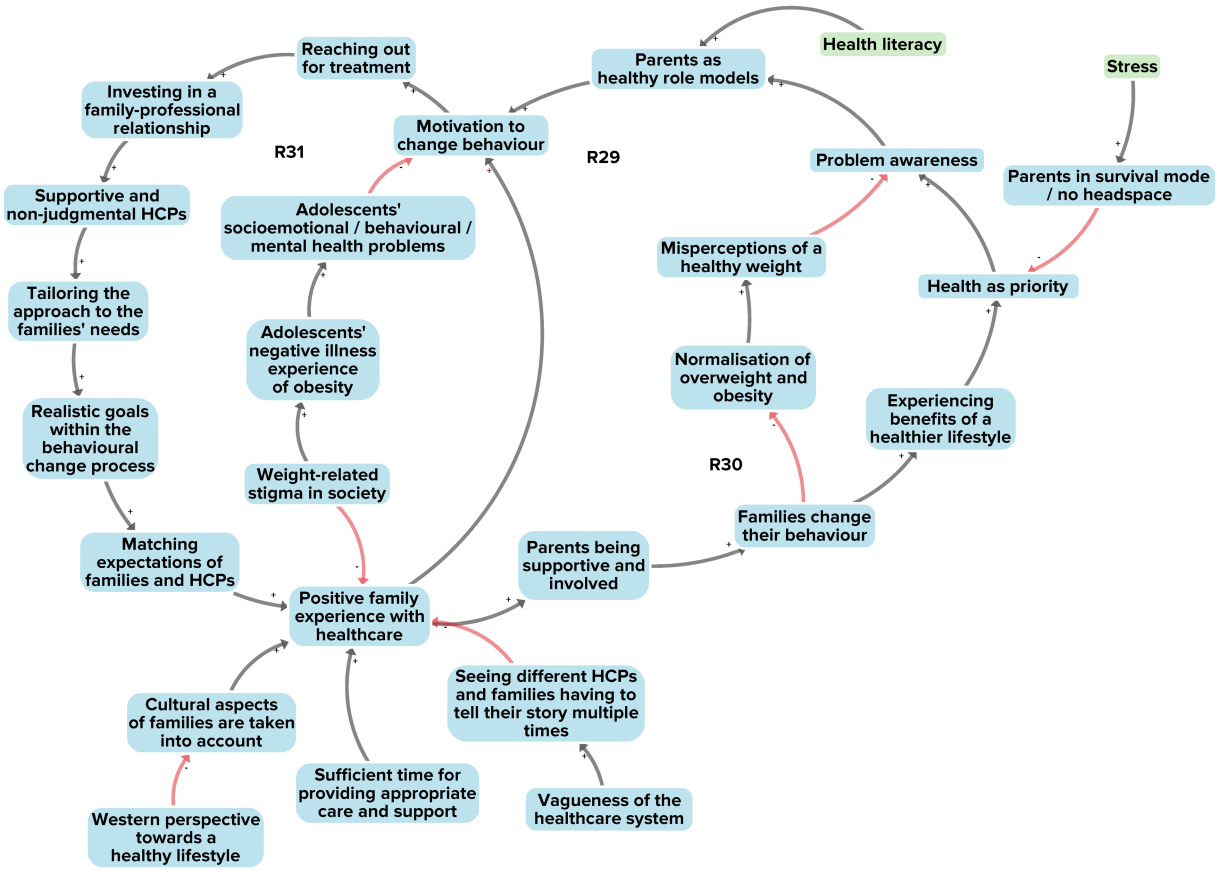

FIGURE 7
Subsystem 5: Interaction between families and healthcare. Factors derived from the stakeholders' perspective are shown in blue. Factors present in at least two of the three perspectives are shown in green. Black arrows indicate positive polarity and red arrows indicate negative polarity in the causal relationship between factors.

foster susceptibility to systemic influence. The first relates to the adolescent urge for freedom. Greater autonomy and independence enables them, for example, to purchase unhealthy food from easy accessible environments (such as supermarkets). The second factor reflects the adolescent desire to be part of and accepted by a group, making them particularly vulnerable to peer pressure and to influences from social media. The third factor involves seeking instant gratification. It is more gratifying for adolescents to spend long hours gaming with their friends and 'enjoying the moment' (subsystem 3) than to force themselves to be physically active because that would be good for their health (subsystem 2). Long-term health benefits are not typically prioritised by adolescents during this transition period; and parents, who could help curb unhealthy habits, may experience diminished influence on their children (subsystems 4 and 5). During the transition from childhood to adolescence, parents shift from a childrearing role to more of a coaching or mentoring role. The new role can make it difficult for parents to set, monitor and enforce rules about healthy behaviours (subsystem 4).

We conclude that the wider system goal here is linked to biological and psychosocial mechanisms, which include increased autonomy and independence, susceptibility to peer pressure and social media exposure, and gratification-seeking – factors that make adolescents specifically susceptible to an environment that fosters obesity-related behaviours. Adolescents report, for instance, that they are continuously exposed to a multitude of unhealthy food advertisements and providers in their close surroundings. This may not only trigger a craving for unhealthy food, but it may also constrain them from escaping that environment to seek healthier foods and activities.

4. Discussion

This study sought to identify and understand the underlying system dynamics that drive obesity-related behaviours in adolescents. We developed a CLD with a multi-actor perspective and subsequently performed systems-based analysis to understand the pre-existing system in terms of both system structure and function. The focus was on adolescents aged 10 to 14 in an urban setting. The resulting CLD contains 121 unique factors, 31 feedback loops and 6 subsystems (revealing system structure) with their corresponding system goals (revealing system function).

The first subsystem reveals the interaction between adolescents and the food environment. The system goal is *profit maximisation*, which can be achieved by selling as much food as possible, with the more profitable option being unhealthy foods (heavily processed, high energy density, high in sugar, salt or fat). Subsystem 2 shows the interaction between adolescents and the physical activity environment, whereby the system goal is *utility maximisation* for limited urban space, with housing, business and motorised transport prioritised above outdoor space for active play. Subsystem 3 focuses on the interaction between adolescents and the online environment, with a system goal of *profit maximisation from technology use*. Subsystem 4 shows the interaction between adolescents, parenting and the wider socioeconomic environment; system goals prescribe *individual responsibility*, which may compel parents to prioritise household livelihood security at the expense of stimulating healthy behaviours. Subsystem 5 highlights interaction between healthcare professionals and families, with a system goal under which obesity is *treated as an isolated medical problem*, with insufficient attention to social and cultural contexts that may hinder adolescents and their parents in managing the problem. Subsystem 6 relates to the dynamics of the child-to-adolescent transition, which can also be seen as an element in each of the other five subsystems; here the system goal relates to *biological and psychosocial mechanisms* – increased autonomy and independence, susceptibility to peer pressure and social media exposure, seeking instant gratification – which make adolescents particularly vulnerable to an environment that fosters obesity-related behaviours.

4.1. Findings relating to system structure

The CLD presented in this study shows the combined perspectives of academic researchers, adolescents and stakeholders. Overall, adolescents contributed the most factors to the CLD (74/121), followed by stakeholders (54/121) and researchers (50/121). That finding applied both to unique factors and to factors deriving from multiple perspectives, and it underlines the importance of including multiple perspectives. For example, in subsystem 3 (interaction between adolescents and the online environment), the researcher and stakeholder perspectives highlighted the social norm around screen use as a key mechanism in this subsystem. However, only after we included the adolescents' perspective did it become apparent what this mechanism actually meant to adolescents – that screen use in the form of social media, gaming and movie-watching serves to sustain a social norm that it is cool to stay awake at night.

We further explored that finding by highlighting the factors in the CLD separately for each perspective (Supplementary Figures S1–S3); this reveals that important information on the system structure is lost in each separate CLD. For example, looking at the feedback loops for each single perspective, we found 7 loops for the academic researchers, 12 loops for the adolescents and 5 loops for the stakeholders, whereas integrating the perspectives resulted in 31 reinforcing feedback loops. Generally speaking, the researchers' and stakeholders' perspectives contributed to the exposure of the system structure, of *how a specific environment works*, whereas integration of the adolescents' perspective revealed *the ways in which adolescents interact* with this environment. For example, from the researcher perspective we learned that screen use as a social norm is sustained by an environment that reinforces supply and demand for technological devices. The adolescent perspective then showed how that social norm is *further* sustained in activities like purchasing the latest video gaming devices in the market and using them as instruments of peer interaction in the online world. Previous studies have likewise underlined the importance of including multiple perspectives to obtain a fuller understanding of a system (16). In a study by McGlashan and colleagues (29), factors present in a Foresight map (9) were compared with factors present in a map developed by community stakeholders (11). This showed that the largest proportion of factors in the Foresight map focused on the physiology cluster (23%), whereas social psychology was the largest cluster in the community stakeholders' map (38%), with a mere 2% of factors focused on physiology.

4.2. Findings relating to system function

Whilst analysis of system structure in terms of system factors and feedback loops provides important information about a system, it does not yet provide insights into the deeper system dynamics (system goals). The latter can be referred to as *system function*, and it is crucial for understanding, and subsequently changing, the system as a whole.

First, our analysis of the system as a whole revealed that the system primarily contains reinforcing feedback loops encouraging obesity-related behaviours, without balancing feedback loops discouraging the behaviours. While this finding can partly be explained by the methods we used (with a focus on obesity-related behaviours), it does show a system geared to reinforcing obesity-related behaviours. One subsystem that could potentially serve as a balancing loop is the healthcare system (subsystem 5). In practise, however, the conditions for good obesity care – where social and cultural contexts would form an integral part of the treatment of adolescents with obesity – are not yet being fully satisfied. Moreover, even if such conditions were to be met, healthcare can, at best, provide an answer to only part of the system – by helping those who are already overweight. It cannot prevent obesity-related behaviours from occurring in the first place.

Second, when we examine the functioning of this system in terms of emergent properties at the individual level, we observe a system that gears people towards instant gratification in terms of social media likes, tasty food, belonging to a group and other pleasures. Such gratification is specifically important for young adolescents in the transition from primary to secondary school, in that they are suddenly exposed to greater autonomy, with growing peer-group influence and diminishing parental supervision (30–33). At the same time, parents themselves struggle with this new phase, in particular with regard to a lack of parenting skills surrounding mobile phone and social media use (34–37).

Third, when looking at the emergent properties of the system at a macro level, we see that the system function for multiple, but not all, subsystems revolves around the goal of maximising short- or longer-term economic growth in the paradigm of a market-driven economy. Private-sector companies are known to use strategies that promote specific products and choices that are detrimental to health (38). Specific examples of the conflicting system goals from public health and commercial perspectives can also be found in the growing commercial determinants of health literature. This points up the fundamental conflict between imperative shareholder value maximisation and population health (38). In agreement with previous research, our analysis has shown that young people in the child-to-adolescent transition period are particularly susceptible to the marketing and production strategies of commercial companies. That derives from adolescents' peer influences, their immature cognitive and emotional development, and their high exposure to unhealthy foods in their physical and online environments (39–41).

While it is obviously highly challenging to influence macro system functions, it is important to understand the system in which we are operating, and to be aware that any public health intervention aiming to change the system will have to work within (or probably against) that system. Having such system knowledge will likely result in the development of different types of interventions and programmes (19, 28). For example, the social marketing literature shows us how instruments from traditional marketing (product, price, promotion, place) can be used to 'sell' healthier alternatives. However, even though such a social marketing approach may benefit individuals, groups or societies as a whole (42–44), it still does not address the system goals. Placing cartoon characters on fruit, for example, will not address the marketing mechanisms that make unhealthy food attractive and profitable. The emerging field of systems social marketing indeed emphasises the need to adopt a more holistic or systems mode of operandi (45). A more systemic alternative would include a full understanding and consideration of the adolescents' perspective in efforts to promote a particular health outcome. For example, adolescents indicated to us that they find their physical environment unattractive and boring, as it is designed mainly for young children. If adolescents were to have a voice in the design of outdoor spaces, they might make more use of such spaces and increase their levels of physical activity.

4.3. Strengths and limitations

To the best of our knowledge, this is the first study that combines a multi-actor perspective with a system-based analysis in order to understand the dynamics of obesity-related behaviours. A limitation of our study is that, while we combined different perspectives from the original data sources in our aggregated CLD, the system-based analysis and interpretation was performed only from the academic perspective. Ideally, one would feed the final results back to the adolescents and the stakeholders to make sure our interpretation agrees with their perceptions of the system; or one might even involve adolescents and stakeholders in the analytic process. However, such system analysis without proper guidance might have been challenging for the groups involved here, in particular because not all subsystems identified in our study (such as subsystem 5) were discussed in the original single-perspective data. Nevertheless, authors that were involved in the original data collection on the various perspectives were also involved in the system analysis, and we checked our interpretations against their original data.

Another limitation may be that, although systems are dynamic, the figurations of the system as presented in our study may seem static. Our results should therefore be interpreted as the understanding we developed from snapshots of the pre-existing system, while still bearing in mind that system understanding is a progressive process. The identified subsystems and the concurrent system goals highlighted in our study can serve as a basis for locating points to intervene in the system, also known as leverage points (1). Foster-Fishman and colleagues refer to this step as the final information needed to successfully develop and implement interventions that can alter the status quo of targeted systems (16). In the LIKE programme, we indeed seek to use the insights obtained from the present study as a basis to find leverage points and develop actions to help change the system into a healthier system for adolescents.

Finally, it is important to point out that the uncovered underlying system dynamics described in this study refer to those dynamics found to be relevant to our target group (10- to

14- year-old adolescents) in the context of a Western urban setting. The observed dynamics are a result of our methods which relied on academic experts' perspective and interpretation, and adolescents' and stakeholders' perspectives. For that reason, the resulting pre-existing system CLD of obesity-related behaviours does not present evidence for the exact working of the system dynamics but should rather be interpreted as one piece of a bigger puzzle. Indeed, we did not intend to develop a full conceptual model of childhood overweight and obesity, but one that focused on our target group and setting. However, the types of dynamics (feedback loops, subsystems, and goals) identified in this study are also relevant in other contexts. For example, subsystems that have as goal economic profit.

5. Conclusion

Our paper has confirmed the relevance of combining multiple perspectives in gaining system understanding of obesity-related behaviours. The researchers' and stakeholders' perspectives contributed in particular to an understanding of how the system structure of the obesogenic environment works. Integrating the adolescents' perspective enriched the insights on how adolescents interact with that environment. The system analysis revealed that the system in which adolescents live is composed of multiple subsystems that interact with one another and whose goals serve to reinforce obesity-related behaviours over time. Multiple subsystems operate within a paradigm which, on the individual level, maximises short-term gratification; this is intensified by factors such as the urge for freedom that characterise the transition from childhood to adolescence. On the macro level, the paradigm maximises economic growth. Understanding such types of system drivers is crucial for the development of future interventions.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the institutional medical ethics committee of Amsterdam UMC, Location VUMC (2018.234). Written informed consent to participate in this study was provided by participants or by the participants' legal guardian/next of kin.

Author contributions

ALP, KS, and WW: conception and design of the work and writing original draft. KS and WW: supervision. KS, CD, CR, TA, MC, and SK: funding acquisition. ALP, KS, HE, EvdE, TA, CD, CR, RH, VB, MC, SK, and WW: interpretation and critically reviewing manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1128316/full#supplementary-material

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Participatory systems science for enhancing health and wellbeing in the Indian Ocean territories

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Objectives: Co-creation of diabetes and obesity prevention with remote communities allows local contextual factors to be included in the design, delivery, and evaluation of disease prevention efforts. The Indian Ocean Territories (IOT) comprise the Christmas (CI) and Cocos Keeling Islands (CKI) and are remote Australian external territories located northwest of the mainland. We present results of a co-design process conducted with residents of IOT using realist inquiry and system mapping.

Methods: Interviews with 33 community members (17 CI, 14 CKI, 2 off Islands) on causes and outcomes of diabetes (2020/21) comprising community representatives, health services staff, dietitians, school principals and government administrators. Interviews were used to create causal loop diagrams representing the causes of diabetes in the IOT. These diagrams were used in a participatory process to identify existing actions to address diabetes, identify areas where more effort would be valuable in preventing diabetes, and to described and prioritize actions based on feasibility and likely impact.

Findings: Interviews identified 31 separate variables categorized into four themes (structural, food, knowledge, physical activity). Using causa loop diagrams, community members developed 32 intervention ideas that included strengthening healthy behaviors like physical activity, improving access to healthy and culturally appropriate foods, and overcoming the significant cost and availability limitations imposed by remoteness and freight costs. Interventions included relatively unique Island issues (e.g., freight costs, limited delivery timing), barriers to healthy food (e.g., limited fresh food availability), physical activity (e.g., transient workforce) and knowledge (e.g., multiple cultural backgrounds and language barriers, intergenerational knowledge).

KEYWORDS

diabetes, systems thinking, health and wellbeing, Indian Ocean territories, obesity

1. Introduction and background

Diabetes is a major chronic condition impacting health systems (1). Type 2 diabetes mellitus (T2DM) is the most common type of diabetes, and is associated with multiple risk factors including age, family history, and ethnicity. Other risk factors include modifiable lifestyle characteristics including physical activity, nutrition, smoking, and weight management. People

with diabetes have a higher risk of developing high blood pressure, heart disease, stroke, kidney failure, as well as circulation problems, nerve damage, lower limb amputations and impaired vision (2).

Remote and very remote areas in Australia (3) experience a disproportionately higher rate of diabetes (6%) compared with major cities (4%) (4). Communities in the Indian Ocean Territory, one of Australia's most remote areas, experience even higher rates, at 8 and 11%, respectively, for Christmas Island (CI) and Cocos (Keeling) Island (CKI). The proportion of community members living with overweight and obesity is 84% on CKI and 77% on CI, higher than regional and remote (69%) and mainland Australians (65%) (5). Obesity increases the risk of diabetes (6) and two main factors that contribute to obesity: poor diet and inadequate physical activity, are heightened for the communities in the IOT (5). As one example, the cost of food, and particularly fresh fruits and vegetables, is estimated to be 81.1% (CKI) and 82.1% (CI) higher in the IOT than the nearest major Australian city, Perth (7). The high cost and limited availability of fresh food compared to packaged and processed foods serves as a disincentive for residents to eat healthy food.

Living in a rural and remote setting is a significant factor in disease risk profile and outcomes (8) relating to access to healthy foods (9) and structural elements, e.g., support for active modes of transport. Public health has moved from ignoring remoteness as a cause of disease to making it a key consideration in intervention design (10). Engaging with remote communities has provided unique insight into the drivers of ill health previously not possible in remote communities (11, 12). System science represents a suite of research methods that start with the aim of understanding the complexity of cause and effect in a given problem and using this understanding as the basis of planning a response (13). Approaches, like community-based system dynamics (14), provide methods to actively work with members of a community to build a clear picture of the different relationships of cause and effect creating a problem and understand how these relationships change and interact over time. The subsequent understanding of the system can be more comprehensive than traditional approaches and may include the status of the community, resources, and political acceptability of change, among others (15). Interventions built on these techniques are more suited to place than externally developed and non-consultative intervention strategies. These techniques have been used to support communities responding to climate change (16), COVID (17), GP prescribing behavior (18), and obesity (19, 20).

In this paper we report on a study which set out to:

- create a shared understanding of the drivers of diabetes on CI and CKI
- provide an overview of existing literature to community members and help them understand how interventions may work for people with diabetes in remote and culturally diverse communities
- develop a set of practical ideas to address some of these drivers
- identify policy settings and potential initiatives that would support these changes, and
- identify points in the system where a diabetes intervention could fruitfully be used.

The objective of this study was to co-create, with community members of the Christmas and Cocos Keeling Islands, a set of possible policy initiatives to prevent or manage diabetes in the Indian Ocean Territories.

2. Methods

2.1. Study design

This study is the second half of a two-part research which aimed to identify and develop possible policy initiatives to prevent/manage diabetes in the IOT. The first part was a realist review of the literature (21) which informed this paper including the systems mapping (22) which was further complemented by qualitative interviews with key stakeholders. Realist methods are used when the intent is to understand processes and mechanisms by which observed phenomena come to take their current shape.

Phase one: comprised a realist enquiry (in preparation) to expand relationships between context, mechanism and outcome in the IOT. Initial program theories emerged from interviews with key staff and community members. A literature search for these theories identified >150 studies which confirmed evidence for program theories including subsidizing fresh fruit and vegetables, sustainable farming, and engaging communities to improve health. These were further validated with a second round of interviews. The comprehensive description of this study is the subject of a separate manuscript.

Briefly, for the first set of interviews in the first part of the research, we adopted a constructivist grounded theory analysis approach, which involves a process of iterative data collection and constant comparative analysis of the raw data, the literature, and the research memo to help inform the research; ensuring that the analysis and findings are "grounded" in participants' own words and experiences. The premise behind constructivist grounded theory is that "data do not provide a window on reality. Rather, the 'discovered' reality arises from the interactive process and its temporal, cultural, and structural contexts." This approach is well-suited to investigate dynamic and complex public health challenges composed of distinctive yet interrelated issues that together form a complete picture of systemic issues in a community.

Data saturation was reached in the first phase of the research from interviews with key staff and community members in the Indian Ocean Territories, resulting in initial program theories, that were refined by a realist synthesis and further validated with a second round of interviews. The result of the first part informed this paper, in particular an initial causal loop diagram that was presented to key stakeholder and community members and discussed through a facilitated group model building process using a system mapping approach.

To ensure rigor, transcripts were analyzed by two researchers (SB and LM) with authenticity achieved through verbatim transcription and confirmation of this by listening to recordings. The researchers met daily during the data collection period, and afterwards met weekly to discuss and refine new concepts. Identified patterns were refined as new data was collected. The validity of the findings were enhanced by incorporating findings from debriefings into the subsequent interviews and into the analysis. Feedback from the wider research team was incorporated to establish credibility. Quotes from participants with a range of views further supported accurate interpretation and rigor.

Phase two: This study is the second half of a two-part research which aimed to identify and develop possible policy initiatives to prevent/manage diabetes in the IOT. The first part was a realist review

of the literature which informed the second half of the research including the systems mapping that was further complemented by qualitative interviews with key stakeholders.

Findings from the first phase of the research identified seven theories that influence the success of the target initiatives, across the spectrum of the socioecological model in the IOT: (i) subsidies, (ii) hypothecated taxes, (iii) sustainable farming, (iv) engaging with community organizations and individuals to create a healthier IOT community, (v) engaging with food retailers on the island, (vi) culturally sensitive approach to care, (vii) empowering the community to become actors for change.

These theories were refined by searching the literature for empirical evidence and conducting qualitative interviews with IOT community members. In particular, the community consultations identified a real need for empowerment within the community through meaningful and impactful engagement. The understanding of these mechanisms and interactions translates into useful points for designing and understanding the success of interventions for diabetes especially in complex context as those observed in the IOT.

Interviews during the second phase of the research identified 31 separate variables categorized into four themes (structural, food, knowledge, physical activity). Using causal loop diagrams, community members developed 32 intervention ideas that included strengthening healthy behaviors like physical activity, improving access to healthy and culturally appropriate foods, and overcoming the significant cost and availability limitations imposed by remoteness and freight costs. Interventions included relatively unique Island issues (e.g., freight costs, limited delivery timing), barriers to healthy food (e.g., limited fresh food availability), physical activity (e.g., transient workforce) and knowledge (e.g., multiple cultural backgrounds and language barriers, intergenerational knowledge).

Causal loop diagrams were built to represent the logic of interview data. Community based participatory group model building techniques were used to review the logic model and develop action plans. We worked with residents of the IOT across all phases of the project, this co-production of the research can enhance rigor in qualitative research through the integration of diverse perspectives and interpretations (23). Rigor was further enhanced through using well established scripts for the participatory activities, which provide close detail on running of sessions and allow replicability (14, 22). The session began with the presentation of an evidence brief describing the issue of diabetes and obesity on the IOT, current knowledge about cause and prevention in the research literature. Specifically, participants were presented with the causal loop diagram and a presentation was given on how to understand the conventions of causal loop diagrams describing how the variables were identified as actions leading to, or resulting from, diabetes or obesity in IOT. We described how connections between these variables were identified and the direction of cause and effect captured with an arrow showing the relationship between each variable as either positive (solid line; as one variable changes the other changes in the same direction, or negative; as one variable changes the other changes in an opposite direction). Participants were then provided time to review the model, considering where it made sense, where detail was missing and what they would change or add to improve the model. Participants were then asked to identify and locate where on the map there was existing action, where further action was needed and where the participants felt they had power to act. Participants then developed as many actions as they could think of and prioritized these based on potential impact and feasibility, with emphasis on whether changes were single actions or engaged across several variable or engaged feedback loops (19).

2.2. Setting

The Indian Ocean Territories (IOT), comprising Christmas Island (CI), and the Cocos (Keeling) Islands (CKI), are located northwest of mainland Australia and are categorized as some of the most remote communities in the country (5). The population of the IOT was 2,387 (1,843 on CI and 544 based on CKI) in 2021 with economies centered on phosphate mining, the Immigration Detention Centre (Christmas Island) and tourism. Around one quarter of inhabitants are Caucasian with significant Malay, Chinese and Cocos Malay populations. In CKI, nearly two-thirds (63.6%) of households reported that a non-English language was spoken at home (24).

2.3. Theoretical framework

Phase one: Qualitative stakeholder interviews and synthesis of existing literature following a realist review method (25, 26) was used to build an understanding of the existing health system and constraints relating to the IOT in relation to evidence on diabetes prevention and management. A semi-structured topic guide was developed and informed by the findings from the initial identification of the program theories.

Phase two: Data collection and analysis were informed by community based participatory system dynamics and utilized group model building (15). The intention of these techniques was to surface the mental models of community members regarding the causes of diabetes for the IOT and couple this with the existing evidence base about the causes and prevention of diabetes to develop context specific understanding of potential intervention areas. The underlying theoretical framework posits that change is created where communities engage with and respond to the complexity of cause and effect in community based health problems. Our theory of change, presented in detail elsewhere (15), identifies how community change can engage multiple accumulating factors (known as stocks) changing in relation to balancing and reinforcing feedback loops. This theory of change describes the potential roles for people in leadership positions, their response to a community public health need, community involvement and subsequent quality of action amplified by community buy-in and tailoring of actions to the local context. Higher quality actions and community exposure to actions result in improved community health behaviors.

2.4. Participant recruitment

2.4.1. Phase one

Participants included key stakeholders/policy makers in the IOT and general community members. Purposive sampling was used to recruit participants from IOT health services, education sector, and IOT administrators. Community members were identified through

snowball sampling recommended by key stakeholders. Twenty IOT health service staff and 13 community participants were recruited. The IOTHS staff were phone interviewed by three research team members (SB, LM and EL). For the community member interviews, six face-to-face interviews were conducted by the community researchers (PM and AH) and seven telephone interviews were completed by the research team (LM and SB). Seventy percent of the IOTHS staff and 38% of the community interviewees were female. The IOTHS staff interviewees had been living on the island for 0.25–49 years, while community interviewees for 2–32 years.

2.4.2. Phase two

Participants were recruited through advertisements translated to the local languages and placed at various locations on the islands and in the island-wide newsletter. This was followed up by the community researcher on each island, who assisted with recruitment and allowed for different opportunities for engagement with the community. Participants included stakeholders from council/shire, IOT administrator office, high schools, IOT health services, and representatives of community-based organizations, such as the health services community advisory committee, vocational training association, and community resource center. Purposive sampling was used to recruit 25 community members with understanding of diabetes in the IOT. Participants were 18 years or older and living in the IOT. Additional key informants were identified through snowball sampling.

2.5. Data collection and analysis

Phase one: data from the first set of qualitative interviews combined with a realist synthesis of the literature were used to generate seven initial program theories. These program theories were that obesity and diabetes would be reduced if it were possible to: (1) Improve access to fresh fruit and vegetables (subsidies); (2) Improve access to fresh fruit and veg (tax); (3) Improve access to fresh fruit and veg (sustainable farming); (4) Engaging with community organizations and individuals to create a healthier IOT community; (5) Engage with food retailers on the island; (6) Provide a culturally sensitive approach to care; and (7) Empower the community to co-design a locally relevant diabetes intervention. These initiatives were then confirmed, refined, and refuted through qualitative interviews with community members.

Phase two: the data collected in phase one were used to identify relationships of cause and effect relating to diabetes and obesity on the IOT. These relationships were entered into the *Systems Thinking in Community Knowledge Exchange* (STICKE) software[1] (27) and the links between variables identifying cause and effect were created. These links were then coded to reflect whether a change in the causal variable led to a similar change in the resultant variable (i.e., increasing family activity increased exercise culture) or whether they changed in opposite directions (i.e., an increase in sustaining activity groups decreased sedentary behaviors). These maps were then coded to align with the codes identified in phase one, specifically identifying areas of the map referring to structural, food, knowledge, and physical activity elements. We collected data via qualitative structured group process using video conferencing facilities available through the training center on each island managed by Indian Ocean Group Training Association (IOGTA). The facilities at the training center included Wi-Fi connection, projectors, and a smartboard. They also had a landline access with speaker phones in case of disruption with the Wi-Fi connection. The original plan was to conduct these sessions in person, but travel restrictions due to COVID-19 meant we were unable to conduct these in person. In short, local health team members on each island were recruited and trained to support the delivery of the workshop sessions described below while the team facilitated the sessions remotely. The local facilitators were sent materials ahead of the sessions, notably system maps (A3 size), sticky dots (black and pink) sticky labels (blue and yellow), action ideas recording templates (A5 sheets). One session was conducted on CI and a second on CKI in September 2021 and November 2021. The session format is described in Table 1.

2.6. Ethics

Ethics approval was granted by the Deakin University Human Research Ethics Committee (project no. 2020–080). Written informed consent was obtained from all participants.

2.7. Research team and reflexivity

The research team for this second phase of work which focused on the causal loop exercise comprised three health economists and a population health researcher. The researchers did not have any relationships with participants and the causal loop study was undertaken remotely, via Zoom. No known biases expected.

3. Results

3.1. Phase one

Qualitative interviews in combination with the literature synthesis identified seven possible initiatives to prevent and manage diabetes in the IOT. These initiatives were tax and subsidies to improve access to fresh fruit and vegetables, sustainable local farming, engagement with community organizations and food retailers, culturally sensitive

1 Systems Thinking in Community Knowledge Exchange (STICKE) is a cloud-based software platform that supports a "systems thinking" approach to tackling complex problems. STICKE was developed by researchers at Deakin University in collaboration with Victorian communities. The software guides users through the creation of a system "map" that can then be used to help explore the problem and potential intervention points. STICKE can support communities in mapping a complex problem and its drivers at all levels of policy and decision-making authority and identify appropriate and feasible locally led responses.

TABLE 1 Workshop format and data collection for phase two.

Agenda item	Time (mins)	Description
Welcome	10	The study lead introduced the session and the purpose of the study, welcomed people to the session and outlined the meeting structure and aims.
Evidence Brief	10	Participants were presented with an evidence brief providing the most recent information about the prevalence and disease burden of diabetes and obesity in rural and remote Australia and how this compares to other parts of the country. The evidence brief also presented information on what is known about prevention of diabetes.
Model review introduction	25	The process used to develop the maps in STICKE was described to the participants and the map presented by building the map up theme by theme. The meaning of the variables, direction and style of arrows was described to participants.
Model review	30	Participants were invited to review the A3 maps of the system relating to the causes and effects of diabetes on the IOT and place a black dot where the participant felt there was something important and a pink dot where they felt something was missing. They were offered the opportunity to augment the maps and add things they felt were missing. This provided an updated map that reflected the individual participants understanding of the system and provided data on the maps for future review.
Action review introduction	10	Using their augmented maps participants identified the places on the map where existing action was happening and wrote this on yellow sticky label and placed it on the part of the map the action was affecting, to consider where more action was needed and write this action on a blue sticky note and place this on the map where they felt it would act and to circle the areas of the map where they felt they had power and agency to act to change and reduce the prevalence of diabetes.
Action ideas and prioritize	25	Using the further developed maps, participants were then asked to consider actions that might be taken to reduce the prevalence and burden of diabetes on the IOT. These actions were described on the action ideas template and participants were asked to identify which parts of the map the action would impact.
Prioritize	15	Working in small groups of 2 or 3 people participants were then asked to share their ideas with each other and prioritize these ideas in order from highest to lowest priority. They were asked to prioritize considering both the feasibility of the action and the likely impact of the action.
Group summary to room	20	The small working groups created in the previous step reported their priority actions to the rest of the group and these actions were recorded and displayed at the front of the room.
Next steps and close	5	The next steps in the project were described and the meeting drawn to a close.

approach to care and empowering the community to co-design locally relevant diabetes initiatives.

3.2. Phase two

The causal loop diagram created based on the interviews in phase one included 31 separate variables categorized into four themes (structural, food, knowledge, physical activity) (Figure 1).

Across both sessions participants identified health service programs as being valuable existing resources and price of healthy food, cost of freight, locally grown produce, community awareness of diabetes and family level activity as areas where more work could be done.

Participants across both communities identified 32 separate actions to address diabetes on the IOT (Table 2) including ten with a food focus (3 CI, 7 CKI), seven relating to physical activity (3 CI, 4 CKI), nine regarding knowledge (2 CI, 7 CKI), and six addressing structural issues (1 CI, 5 CKI).

Food related priority actions ranged from increasing the quality and availability of fresh and healthy food to policies impacting portion control and lunch box contents at schools to community wide initiatives like supported community gardens, religious and diet specific cooking education and healthier menu policies in restaurants and schools. Physical activity actions included those to adapt to the local climate: notably heat and humidity and provision of experts in physical activity to provide detailed advice for the diverse members to the community (specific religious groups with clothing constraints, women only activities, older adult, transient workers) and support to overcome barriers imposed by cost of insurance for physical activity programs. Structural changes identified included developing relationships with external providers to improve health of food in schools, subsidizing freight and taxing tobacco and unhealthy foods into the islands to address the cost of healthy fruit and vegetables.

4. Discussion

4.1. Main findings

The community members of the Christmas and Cocos Keeling Islands provided in depth description of the causes of diabetes and obesity and the context specific issues that affect the rates of these diseases and hamper efforts to prevent them. These factors included issues around freight costs and frequency affecting availability and prices of fresh fruits and vegetables, quality of soil and need for facilitation of community gardening, community awareness of diabetes and sustainability of activity groups due to low population size and transient workforce, and an exercise culture. The communities were able to engage with a systems map of these causes and develop evidence informed priorities for action across multiple systems on the islands and at multiple levels of intervention.

There were multiple examples of proposed actions reaching across the themes and no examples that shifted the emphasis on individual decision making, rather placing the emphasis on policy and environment change to make the healthier choice the easy choice. These actions included health classes on cooking, community-based gardening, sporting facilities that suit local conditions such as climate-adapted facilities and ocean pools (Table 2). Similar outcomes have been seen in whole of community efforts to prevent obesity where the levels of engagement and the focus on system rather than individual are considered critical aspects to the approach (19).

The research presented here has enabled the IOT community to respond to several of the directions described for obesity prevention in the wider literature. For example, these findings echo the direction from the Lancet Commission on Obesity to consider the broader environmental system in the development of health-related actions, where IOT have shown clear understanding of the need for change at the intersection of health-related behaviors, outcomes like diabetes and obesity ad climate change (16). Through group model building the community has identified factors like population growth, transport costs, freight impacts and stigma as they relate to healthy food choice and physical activity. These results echo similar findings from studies in mainland Australia (19) where applying methods that empower communities to engage with complexity leads to more nuanced and deep understanding of the intersections between climate, community leadership and health (15).

4.2. Strengths

The shift in the literature from individual victim blaming for poor decision making to acknowledging and trying to address environmental determinants represents one of the commonly acknowledged strengths of the use of group model building techniques (28). This ability to locate initiatives between systemic and systematic efforts also lends itself to policy development (29). A particular strength of the method is the participants are responding to a detailed evidence brief to confirm a model that represents the complexity of the cause and effect of diabetes and obesity. The use of methods from system dynamics results in information on the dynamic nature of these relationships and how each of these key factors interact and change over time to lead to the observed problem. In the current study the identification of taxation of foods creating diabetes and obesity whereby resulting income is directed toward subsidies healthier behaviors provides a salient example.

The use of co-design principles provided new insights and deeper engagement than more traditional approaches to intervention design. The co-design approach is particularly relevant for the Christmas and Cocos (Keeling) Islands because they represent a remote and culturally diverse group of communities. These challenges mean the conditions in which diabetes related behaviors and policy occur are different to those in major cities. Co-design actively works with communities to understand what interventions will be suited to the unique local conditions and how known evidence-based interventions need to be adapted to be effective in unique communities like those represented in this study. These approaches have also shown to be empowering for communities who are not usually actively engaged in developing changes to improve health (e.g., 11, 12) and for remote and rural communities co-design has been seen to positively impact usually intractable problems like child obesity (20). Similarly, the multi-phase approach to the study meant data were able to be considered, synthesized and fed into subsequent steps, demonstrating to the community the respect for which their data was held and the utility it had for supporting their efforts to improve health on the islands.

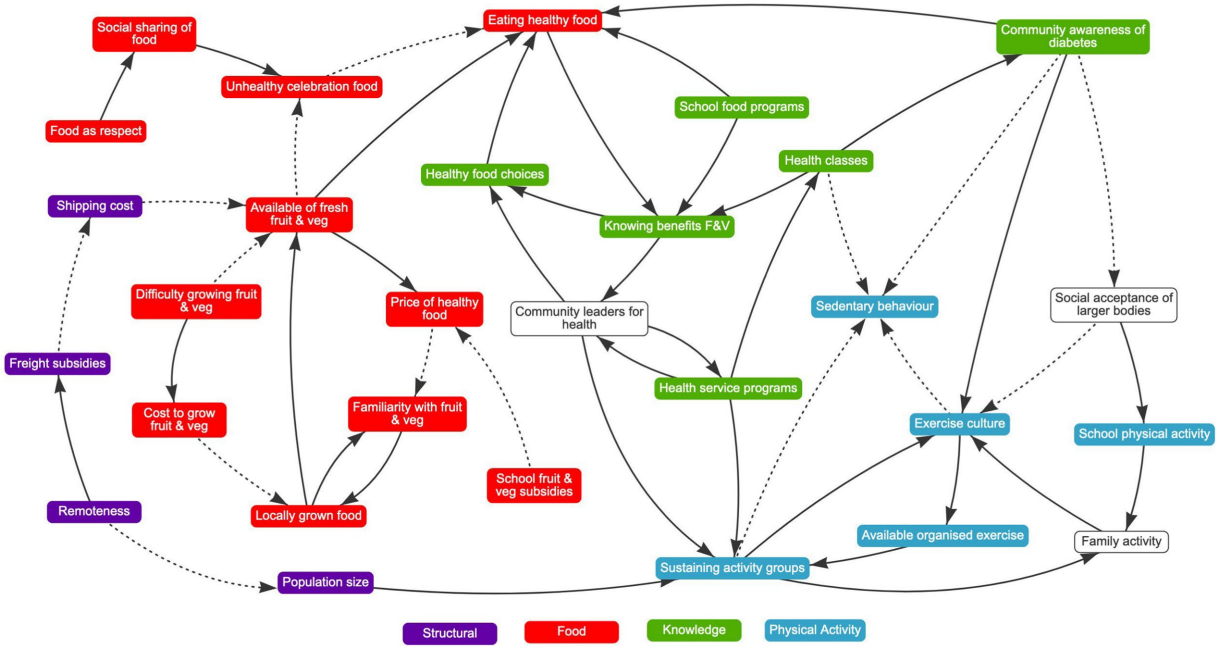

FIGURE 1
Causal loop diagram of the causes of diabetes on the Christmas and Cocos Keeling Islands.

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TABLE 2 Prioritized action ideas by map theme and participating community.

Food	Physical activity	Knowledge	Structural
CI community			
• Increase quality and availability of F&V (ahead of focus on price) • Health classes on cooking • Garden Co-Op – social wellbeing	• Funding to broaden the types of activity available with professional support • Support to overcome insurance limitations • Climate adapted activity	• Community education in diabetes – target community elders because of close contact • Multi-generational education via the school	• Formalized CO-OP to subsidize fresh produce (tax on goods arriving by air)
CKI community			
• Portion control of lunch boxes • Community based garden – accepted and new vegies • Cheaper vegetables • Create food markets and encourage composting (overcome the waste) • Healthy menus and community leader modelling healthy foods for celebrations • Cooking classes tailored to citizens • Advertise healthiness of menus through food outlets	• Connect health school policy – launch and engagement of parents • Provides opportunity for incidental activity • Female friendly exercise area (nicer environment and personalized support) • Ocean pool 24/7 (safe and not tide dependent)	• Community education (results of this study – accessible language) • Continue with community acceptance • Information for parents on food choices (social media sharing) • Engage kids to reach parents • Provides learning environment around F&V • More relevance of fruit and veg • Citizens advice bureau for food and healthy habits	• External providers supporting healthy food provision (in schools) • Bring key stakeholders together to help with materials • Additional freight subsidy for the Islands – more freight opportunities • Increase tobacco and alcohol tax and offset F&V cost • Transparency on the cost of freight – a central issue which is currently less understood by participants – to support decision making

4.3. Limitations

It is widely acknowledged that participatory processes are more powerful when conducted in person and due to COVID and State border closures the research team were unable to physically attend sessions on the islands. The use of videoconferencing is emerging in this type of research and this project represents one of the first to present a hybrid model of activities in place (via Zoom) and data collection and synthesis remotely. Previous research into the effectiveness of participatory methods has emphasized the importance of meeting face to face, and this may be amplified in marginalized populations. Research with Aboriginal populations, for example (12) suggest face to face ensures more collective group work collectively, better sharing and alignment of aims and agendas, and important non-verbal communication. Because of these factors the lack of face-to-face engagement may limit the potential power of, and buy-in to, the solutions generated by the participants and full understanding of the ITO context is less likely. While in this study participants were together in one room, the facilitators dialed in from a remote location suggesting these issues are likely to impact the study outcomes. While not ideal, it may represent an incremental step in making such methods available for remote communities that prior to high quality videoconferencing facilities, was unavailable.

4.4. Implications for practice

It is clear there is desire and will on the islands for change to prevent chronic disease, in this case diabetes and obesity. These efforts also have the potential to positively impact mental health on the islands and the majority of actions are translatable to policy positions, supported by community members suggesting the islands are likely to be receptive to interventions.

The purpose of this research was to develop a map of the causes of obesity and diabetes in the Indian Ocean Territories (IOT), evaluate the effectiveness of a facilitated group model building process and develop a greater understanding of the causes of obesity and diabetes within the IOT.

The facilitated group model building process identified a list of actionable options which serve as a starting point for a community response to the problem. Participants prioritized these action ideas based on potential impact and feasibility, with emphasis on whether changes were single actions or engaged across several variable or engaged feedback loops.

New trials that build on the community engagement and good will generated here would enable insight into whether these actions can be translated into practical policy which have the potential to be implemented on the islands and what effect these may have on diabetes and obesity.

These efforts also have the potential to positively impact mental health on the islands and the majority of actions are translatable to policy positions, supported by community members suggesting the islands are likely to be receptive to interventions.

4.5. Future research

New trials that build on the community engagement and good will generated here would enable insight into whether these actions can be translated into practical policy which have the potential to be implemented on the islands and what effect these may have on diabetes and obesity. Previous examples using these techniques in

community wide intervention design have proven effective and have become embedded as policy positions in multiple jurisdictions (e.g., (30, 31)). Using methods to track and adapt these trials in real time is a further area for advance and emerging techniques provide the utility to achieve these aims (32).

5. Conclusion

Diabetes and obesity are major health concerns for the Christmas and Cocos (Keeling) Islands. These concerns are exacerbated by remoteness of the islands and through co-design new ways to tackle these have been identified which are acceptable and of high priority to the community and which appear to have policy relevance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics approval was granted by the Deakin University Human Research Ethics Committee (project no. 2020–080) and the Aboriginal Health and Medical Research Council Ethics Committee (project no. 1692/20). Written informed consent was obtained from all participants. The patients/participants provided their written informed consent to participate in this study.

Author contributions

SA and EL conceived and developed the initial research idea. SA and SM contributed to the writing of the manuscript and analyzed these interview data. SM, SB, and EL conducted the qualitative interviews. SA, SM, and SB designed and conducted the systems mapping workshops. EL supervised the project. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Epidemiological impact of public health interventions against diabetes in Qatar: mathematical modeling analyses

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Aims: To predict the epidemiological impact of specific, and primarily structural public health interventions that address lifestyle, dietary, and commuting behaviors of Qataris as well as subsidies and legislation to reduce type 2 diabetes mellitus (T2DM) burden among Qataris.

Methods: A deterministic population-based mathematical model was used to investigate the impact of public health interventions on the epidemiology of T2DM among Qataris aged 20–79 years, which is the age range typically used by the International Diabetes Federation for adults. The study evaluated the impact of interventions up to 2050, a three-decade time horizon, to allow for the long-term effects of different types of interventions to materialize. The impact of each intervention was evaluated by comparing the predicted T2DM incidence and prevalence with the intervention to a counterfactual scenario without intervention. The model was parameterized using representative data and stratified by sex, age, T2DM risk factors, T2DM status, and intervention status.

Results: All intervention scenarios had an appreciable impact on reducing T2DM incidence and prevalence. A lifestyle management intervention approach, specifically applied to those who are categorized as obese and ≥35 years old, averted 9.5% of new T2DM cases by 2050. An active commuting intervention approach, specifically increasing cycling and walking, averted 8.5% of new T2DM cases by 2050. Enhancing consumption of healthy diets including fruits and vegetables, specifically a workplace intervention involving dietary modifications and an educational intervention, averted 23.2% of new T2DM cases by 2050. A subsidy and legislative intervention approach, implementing subsidies on fruits and vegetables and taxation on sugar-sweetened beverages, averted 7.4% of new T2DM cases by 2050. A least to most optimistic combination of interventions averted 22.8–46.9% of new T2DM cases by 2050, respectively.

Conclusions: Implementing a combination of individual-level and structural public health interventions is critical to prevent T2DM onset and to slow the growing T2DM epidemic in Qatar.

KEYWORDS

epidemiology, non-communicable disease, risk factors, mathematical modeling, lifestyle management, consumption, legislation, interventions

1. Introduction

Diabetes mellitus (DM), of which 90% of cases are type 2 diabetes mellitus (T2DM), is one of the most rapidly growing global health challenges (1). Globally, in 2021, 537 million (1 in 10) adults were estimated to be living with DM, and by 2045, this number is projected to increase by 46% to 783 million (1). In 2021, 6.7 million deaths and 966 billion USD in health expenditure were due to DM (1). The Middle East and North Africa (MENA) region has the highest prevalence of DM worldwide at 16.2%, where 73 million adults are living with DM, and by 2045, this number is projected to increase by 87% to 136 million (1).

Qatar, one of MENA countries, has a high prevalence of DM and its key modifiable risk factors, where in 2023, Qataris aged 20–79 years had an estimated prevalence of DM, obesity, physical inactivity, and smoking of 17.8, 53.1, 46.5, and 20.7%, respectively. Approximately 80% of Qataris have at least 2 risk factors for DM (2). Recent epidemiological studies investigating T2DM among Qataris forecasted that the prevalence of T2DM will significantly increase over the next three decades, and that obesity will continue to be the main driver of the T2DM epidemic (3–5).

Such high T2DM burden results in economic and social costs, where national T2DM health expenditure is estimated to account for up to 32% of Qatar's total health expenditure by 2050 (3). With such a pervasive public health challenge, individuals, families, and the wider society experience reduced quality of life, premature loss of workforce, and early mortality due to DM (3).

Tackling DM is a critical priority for policymakers in Qatar, as it is outlined in the National Health Vision 2030 (6). The current public health response has primarily focused on providing quality case management and treatment, as well as raising awareness and promoting behavioral interventions through educational campaigns emphasizing individuals' responsibility to address their risk of developing DM. However, this has been insufficient at reducing the growing burden of T2DM. One of the main challenges of the DM response has been the lack of a comprehensive understanding of DM epidemiology, its incidence, drivers, and potential interventions to tackle this epidemic. Therefore, this study used mathematical modeling to investigate the epidemiological impact of specific, primarily structural public health interventions on T2DM epidemiology among Qataris over three decades. The study was informed by previous research on the impact of generic "what-if" interventions on key T2DM-related modifiable risk factors in Qatar (4). The study found that significant reductions in T2DM incidence could be achieved by reducing obesity, while comparatively modest reductions were observed by reducing physical inactivity and smoking, or by increasing physical activity (4).

This study aimed to investigate the impact of five interventions and their specific scenarios on T2DM prevalence and incidence. The interventions were chosen based on evidence from experimental designs or observational studies in the global literature indicating their potential efficacy/effectiveness in reducing T2DM and on their feasibility and relevance for Qatar's cultural and socio-economic context, which were determined through stakeholder engagement during the early phases of the study. The study adopted a public health approach, focusing on the implementation of select and relevant prevention interventions that target the drivers of T2DM incidence, which have the potential to effectively reduce T2DM incidence and control further epidemic growth in Qatar.

The first intervention investigated a lifestyle management intervention applied to populations at high-risk of T2DM and included three specific scenarios. The second intervention investigated increased use of different modes of active commuting and included two specific scenarios. The third intervention investigated increased consumption of healthy diets, including fruits and vegetables, and included four specific scenarios. The fourth intervention investigated the implementation of a subsidy and legislation intervention and included three specific scenarios. The fifth intervention investigated the impact of implementing the most and least optimistic package of the above four interventions.

2. Methods

In this study, we extended a model developed by Awad et al. to predict the impact of public health interventions on T2DM epidemiology among Qataris aged 20–79 years. This age range follows the convention typically used by the International Diabetes Federation for adults (1). The model structure, assumptions, and parametrization of T2DM natural history, risk factors, and demographics of Qataris are summarized in Supplementary Table 1 and Figure 1. Previous publications provided detailed description of the model, its calibration, results, and figures of the calibration as well as several applications of the model (3, 4, 7–10).

Briefly, this study utilized a deterministic compartmental model expressed in terms of a set of differential equations to predict the impact of specific public health interventions on T2DM epidemiology among Qataris aged 20–79 years. The model stratifies the population by sex, age group (20 age bands), T2DM status, and the presence or absence of three major T2DM-related risk factors and their overlap: obesity, physical inactivity, and smoking. Input parameters and data for the model were obtained from available population-level data and T2DM natural history data. Other parameters were derived through fitting the model to existing epidemiological data on T2DM, T2DM-related risk factors, and demographics of the Qatari population using a nonlinear least-square fitting method (11). This approach allowed for the best fit of the sex- and age-specific epidemiological measures to determine T2DM incidence rate, and transition rates between healthy, obese, smoker, and physically inactive states (Figure 1).

Sex- and age-specific T2DM prevalence and incidence were forecasted using this model for the period from 2021 to 2050. MATLAB 2019a was used to implement the mathematical model and to conduct all analyses. The model was validated by ensuring that it fitted all empirical data related to T2DM in Qatar and that it provided a consistent and coherent picture of T2DM epidemiology in Qatar. Sensitivity and uncertainty analyses were conducted in previous applications of this model, which affirmed its validity and reliability to forecasting Qatar's T2DM epidemic (3–5, 7–10). In this study, we investigated different scenarios for each intervention strategy. These scenarios can be considered as sensitivity analyses

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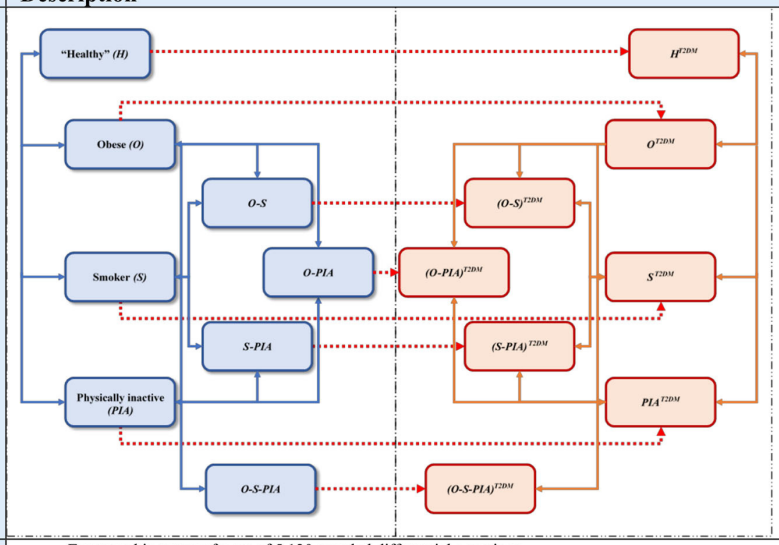
Methodology		Description
Conceptual framework		
T2DM model structure		○ Expressed in terms of a set of 5,120 coupled differential equations. ○ Disaggregated the population into: ○ Sex (male and female) ○ Twenty 5-year age bands (0–4, 5–9… 95–99 years old) ○ Four main susceptible classes: "healthy" (i.e., non-obese, non-smoker, non-physically inactive, and non-diabetic), obese, smoker, and physically inactive ○ Four susceptible classes with overlapping risk factors ○ Eight T2DM classes based on the risk-factor status
Data Sources	Natural history and mortality data	○ Sex- and age-specific relative risks of developing T2DM for the risk factors were obtained from systematic reviews and meta-analyses of prospective cohort studies:[31-33] ○ Relative risk of developing T2DM if obese[33] ○ Relative risk of developing T2DM if current smoker[32] ○ Relative risk of developing T2DM if physically inactive[31] ○ Relative risk of developing T2DM if the individual has more than one risk factor was assumed to be the product of the individual risks. ○ Relative risk of mortality in T2DM as compared to the general population was obtained from the DECODA study.[40]
	Prevalence data	○ Epidemiological data for Qataris were obtained from 2012 Qatar STEPwise Survey.[3, 41] Data included sex- and age-specific (by 5-year age band) prevalence for: ○ T2DM ○ Obesity ○ Smoking ○ Physical inactivity
	Demographic data	○ Age-specific population size and/or distribution by age group were obtained from Qatar's Planning and Statistics Authority.[8, 42, 43]
Fitting method		○ The model was fitted to all available Qatar-specific data using a nonlinear least-square fitting method.[44] ○ Parameters quantified through best fit included sex- and age-specific: ○ T2DM baseline incidence rate (i.e., incidence rate from "healthy" to T2DM) ○ Transition rate from healthy to obese ○ Transition rate from obese to healthy ○ Transition rate from healthy to smoker ○ Transition rate from smoker to healthy ○ Transition rate from healthy to physically inactive ○ Transition rate from physically inactive to healthy

FIGURE 1
Summary description of the mathematical modeling methodology applied in this study. Further details have been published previously in several applications of this model (3, 4, 7, 8, 10).

of how T2DM epidemiology would change at different levels of the intervention.

2.1. Plan of analysis

Five intervention approaches were modeled and investigated among Qataris. Interventions, and their specific scenarios, were selected based on their relevance to Qatar's cultural and socio-economic context, that is those that seemed feasible and relevant in discussion with local diabetes stakeholders including policy makers and public health specialists. The effectiveness of the interventions was parameterized by literature reviews applying evidence from systematic reviews and meta-analyses or high quality randomized controlled trials (12–23). The uptake and adherence levels to the interventions were set at assumed reasonable and realistic values for the Qatari population affected by the intervention.

In the model, the impact of an intervention was assessed by comparing the predicted T2DM prevalence and incidence in the presence of the intervention to a counterfactual scenario with the absence of the intervention. Each intervention was assumed to be initiated in 2021, scaled up to a certain year that varied for each intervention, and then maintained up to 2050. The start year was set at 2021 to provide a prediction time horizon for the simulations of three decades ending in 2050. This allows for the long-term effects

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TABLE 1 Summary of the investigated interventions and their scenarios.

Scenario description	Uptake of intervention	Adherence to intervention	Scale-up time interval	Maintenance time interval	Intervention assumptions
Intervention 1: lifestyle management intervention applied to populations at high-risk of T2DM					
Scenario 1: lifestyle management programmes applied to those who are categorized as obese	50%	50%	2021–2025	2026–2050	Assumed to reduce the risk of developing T2DM by IRR = 0.70—a reduction of 30% (12, 13). This IRR value is the average of the evidence-based effect sizes of IRR = 0.65 (12) and IRR = 0.74 (13).
Scenario 2: lifestyle management programmes applied to those who are categorized as ≥50 years old	50%	50%	2021–2025	2026–2050	Assumed to reduce the risk of developing T2DM by IRR = 0.70—a reduction of 30% (12, 13). This IRR value is the average of the evidence-based effect sizes of IRR = 0.65 (12) and IRR = 0.74 (13).
Scenario 3: lifestyle management programmes applied to those who are categorized as obese and ≥35 years old	50%	50%	2021–2025	2026–2050	Assumed to reduce the risk of developing T2DM by IRR = 0.70—a reduction of 30% (12, 13). This IRR value is the average of the evidence-based effect sizes of IRR = 0.65 (12) and IRR = 0.74 (13).
Intervention 2: increasing use of different modes of active commuting					
Scenario 1: public transportation use	40%	100%	2021–2030	2031–2050	Assumed to reduce BMI by 0.51 kg/m^2, (15) leading to an obesity prevalence reduction from 53.3 to 50.9% by 2030 (16, 17). The intervention was also assumed to increase the level of physical activity among those physically inactive to reach that of the level of physical activity among the healthy general population (18, 19).
Scenario 2: cycling or walking	20%	100%	2021–2030	2031–2050	Assumed to reduce BMI by 1.68 kg/m^2 (15), leading to an obesity prevalence reduction from 53.3 to 50.4% by 2030 (16, 17). The intervention was also assumed to increase the level of physical activity among individuals under the intervention whereby T2DM risk is reduced by a RR = 0.76—a reduction of 24%.
Intervention 3: increasing consumption of healthy diets including fruits and vegetables					
Scenario 1: consumption of fruits and vegetables	50%	100%	2021–2030	2031–2050	Assumed to reduce the risk of developing T2DM with a RR = 0.93—a reduction of 7% (20).
Scenario 2: consumption of vegetables	50%	100%	2021–2030	2031–2050	Assumed to reduce the risk of developing T2DM with a RR = 0.90—a reduction of 10% (20).
Scenario 3: consumption of green leafy vegetables	50%	100%	2021–2030	2031–2050	Assumed to reduce the risk of developing T2DM with a RR = 0.87—a reduction of 13% (20).
Scenario 4: workplace intervention involving dietary modifications and an educational intervention	50%	100%	2021–2030	2031–2050	Assumed to reduce the risk of developing T2DM with a RR = 0.93—a reduction of 7% (20, 21). Assumed also to reduce BMI by 2.4 kg/m^2 (22, 23), leading to an obesity prevalence reduction from 53.3 to 34.8% by 2030 (16, 17). The target population is the working adult population aged 20–65 years old.*
Intervention 4: implementing a subsidy and legislation intervention					
Scenario 1: subsidies on fruits and vegetables	20%	100%	2021–2030	2031–2050	Assumed to reduce BMI by 0.16 kg/m^2 (22, 23), leading to an obesity prevalence reduction from 53.3 to 52.6% by 2030 (16, 17).
Scenario 2: taxation on SSB	20%	100%	2021–2030	2031–2050	Assumed to reduce BMI by 0.24 kg/m^2 (22, 23), leading to an obesity prevalence reduction from 53.3 to 52.3% by 2030 (16, 17).
Scenario 3: subsidies on fruits and vegetables and taxation on SSB	20%	100%	2021–2030	2031–2050	Assumed to reduce BMI by 0.40 kg/m^2, that is the additive effect of the increments of 0.16 kg/m^2 and 0.24 kg/m^2 (22, 23), leading to an obesity prevalence reduction from 53.3 to 51.6% by 2030 (16, 17).

(Continued)

TABLE 1 (Continued)

Scenario description	Uptake of intervention	Adherence to intervention	Scale-up time interval	Maintenance time interval	Intervention assumptions
Intervention 5: implementing combinations of interventions					
Scenario 1: most optimistic combination package of the above four interventions	Uptake of each included individual scenario is included above	Adherence to each included individual scenario is included above	2021–2030	2031–2050	The package includes the most impactful scenario of each intervention: lifestyle management programmes applied to those who are categorized as obese and ≥35 years old, increased walking and cycling, workplace intervention involving dietary modifications and an educational intervention, and implementing subsidies on fruits and vegetables and taxation on SSB.
Scenario 2: least optimistic combination package of the above four interventions	Uptake of each included individual scenario is included above	Adherence to each included individual scenario is included above	2021–2030	2031–2050	The package includes the least impactful scenario of each intervention: lifestyle management programmes applied to those who are categorized as obese, increased public transportation use, increased consumption of fruits and vegetables, and implementing subsidies on fruits and vegetables.

BMI, Body mass index; IRR, Incidence rate ratio; RR, Relative risk; SSB, Sugar-sweetened beverages; T2DM, Type 2 diabetes mellitus. *The target population for all intervention scenarios is the total adult population aged 20–79 years old. Only intervention 3, scenario 4, targets the working adult population aged 20–65 years old.

of different types of interventions to materialize. Each of these interventions is described in Table 1 and discussed briefly below.

2.1.1. Intervention 1: lifestyle management intervention applied to populations at high-risk of T2DM

The lifestyle management intervention approach, resembling the Finnish Diabetes Prevention Study, reduces the risk of developing T2DM through intensive programmes that support individuals at high risk of developing diabetes (e.g., those with pre-diabetes) to make health promoting changes in dietary habits and exercise, resulting in weight loss. This intervention was assumed to target three high-risk Qatari sub-populations to reduce their risk of developing T2DM: those who are categorized as obese, as ≥50 years old, and as both obese and ≥35 years old (Table 1). Selection of these three target groups was informed by applying the Qatari Diabetes Risk Score, which highlighted a subset of the population at high-risk of developing T2DM (10).

A 50% uptake with 50% adherence to the lifestyle management intervention was assumed among each targeted sub-population. This level of uptake was assumed to be scaled up gradually and to reach its targeted level 5 years after onset of this intervention (2021–2025). The uptake was maintained at this level thereafter until 2050. The intervention reduced the risk of developing T2DM with an incidence rate ratio (IRR) = 0.70, that is, a 30% reduction in risk of T2DM onset (12, 13).

2.1.2. Intervention 2: increasing use of different modes of active commuting

The active commuting intervention approach reduces the risk of developing T2DM by lowering population mean body mass index (BMI) and increasing physical activity levels (Table 1). The modeled uptake of active commuting was scaled up gradually to reach its targeted level after a decade (2021–2030). The uptake was maintained at this level thereafter until 2050. Two scenarios were modeled.

In the first scenario, use (uptake) of public transportation among 40% of Qataris was implemented. This intervention was assumed to reduce BMI among the total population by 0.51 kg/m^2, based on pooled evidence. Applying an established method to transform changes in population mean BMI to changes in obesity prevalence (16, 17), this change in BMI would reduce obesity prevalence among the total population from 53.3 to 50.9% by 2030. The intervention was also assumed to increase the level of physical activity among those physically inactive to reach the level of physical activity among the healthy general population (18, 19).

In the second scenario, cycling or walking by 20% of Qataris was implemented. This intervention was assumed to reduce BMI among the total population by 1.68 kg/m^2, based on pooled evidence. This change in BMI would reduce obesity prevalence among the total population from 53.3 to 50.4% by 2030. The intervention was also assumed to independently increase the level of physical activity among individuals under the intervention whereby T2DM is reduced by a relative risk (RR) = 0.76, that is, a reduction of 24% in risk of T2DM onset, based on pooled evidence. The latter scenario differs from the first in its physical activity assumption as cycling and walking involves more intense physical activity, and therefore, acts as a protective factor against developing T2DM.

2.1.3. Intervention 3: increasing consumption of healthy diets including fruits and vegetables

The dietary intervention approach reduces the risk of developing T2DM by lowering mean BMI through enhanced nutritional education and environmental dietary modifications, such as in workplaces (Table 1). The modeled uptake of increased consumption was assumed to scale up gradually and to reach its targeted level 10 years after initiation (2021–2030). The uptake was maintained at this level thereafter until 2050. Three scenarios were modeled.

In the first scenario, increased consumption of fruits and vegetables among 50% of Qataris was implemented. The

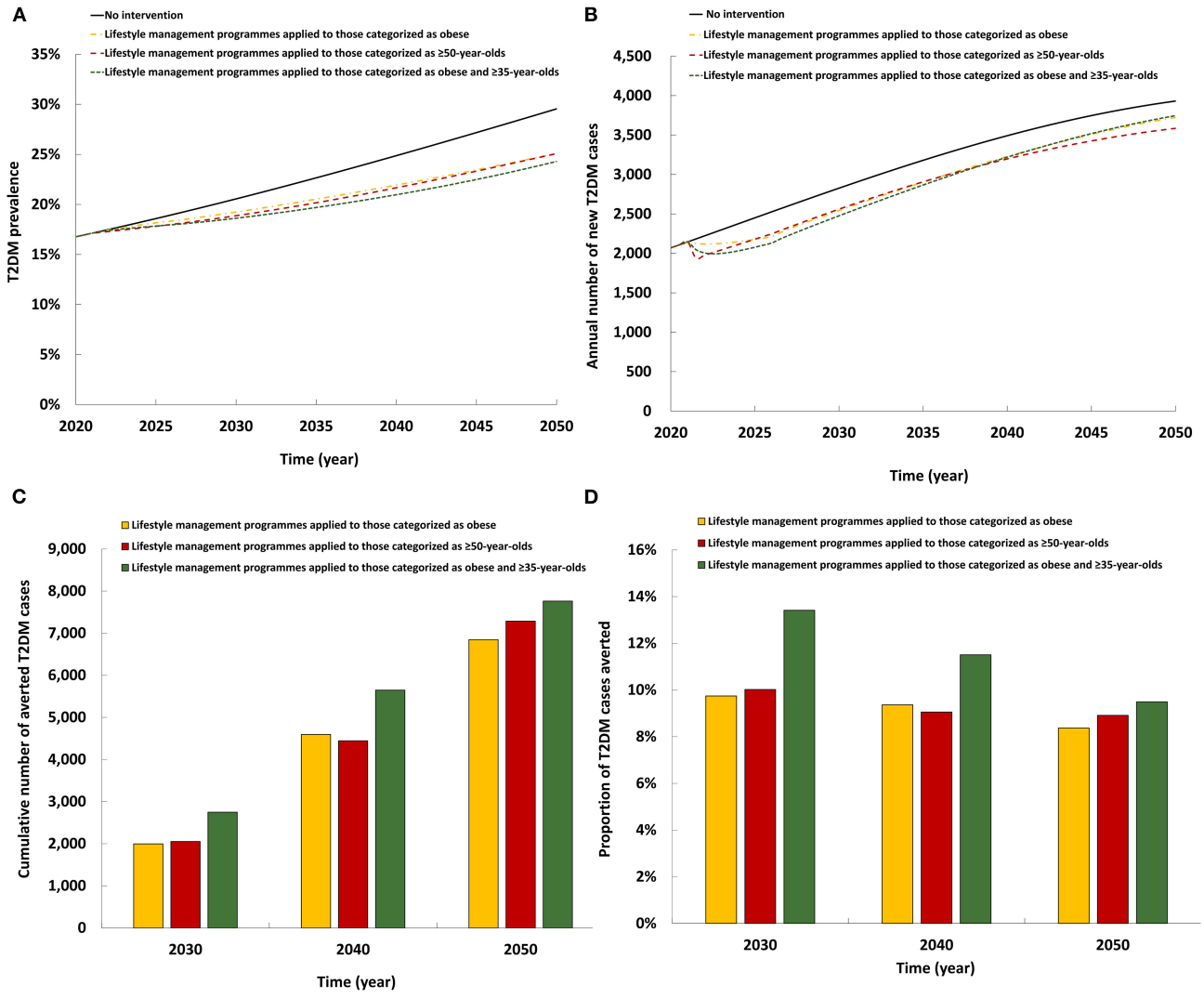

FIGURE 2
Projected impact of the lifestyle management intervention on **(A)** T2DM prevalence, **(B)** annual number of new T2DM cases, **(C)** cumulative number of averted T2DM cases by this intervention, and **(D)** proportion of T2DM cases averted by this intervention.

intervention was assumed to reduce the risk of developing T2DM with a RR = 0.93—a 7% reduction in risk of T2DM onset, based on pooled evidence. In the second scenario, increased consumption of vegetables by 50% of Qataris was implemented. The intervention was assumed to reduce the risk of developing T2DM with a RR = 0.90—a reduction of 10% in risk of T2DM onset, based on pooled evidence. In the third scenario, increased consumption of leafy green vegetables among 50% of Qataris was implemented. The intervention was assumed to reduce the risk of developing T2DM with a RR = 0.87—a reduction of 13% in risk of T2DM onset, based on pooled evidence.

In the fourth scenario, a complex workplace dietary intervention involving workplace environmental dietary modifications and an educational intervention, that also increased fruit and vegetable consumption, was implemented among 50% of Qataris of working age, 20–65 years of age, in whom the risk of onset of T2DM is elevated (24). This intervention was modeled informed by the results of the Food Choice at Work cluster controlled trial (23). The intervention was assumed to reduce the risk of developing T2DM with a RR = 0.93—a reduction of 7% in risk of T2DM onset, based on pooled evidence (20, 21). The intervention was also assumed to reduce BMI among individuals under the intervention by 2.4 kg/m^2, based on factoring the observed change in BMI in the Food Choice at Work trial and extrapolating the effect for a 3-year scale-up (21, 22). This change in BMI would lead to an obesity prevalence reduction strictly among individuals undergoing the intervention from 53.3 to 34.8% by 2030 (16, 17). Admittedly such intervention is somewhat ambitious and aspirational, but it is useful to investigate to provide a context for the size of the impact of such interventions.

2.1.4. Intervention 4: implementing a subsidy and legislation intervention

The subsidy and legislation intervention reduces the risk of developing T2DM indirectly by reducing mean BMI levels through healthier food consumption (Table 1). Informed by the National Institutes of Health's model of weight change, applying legislation

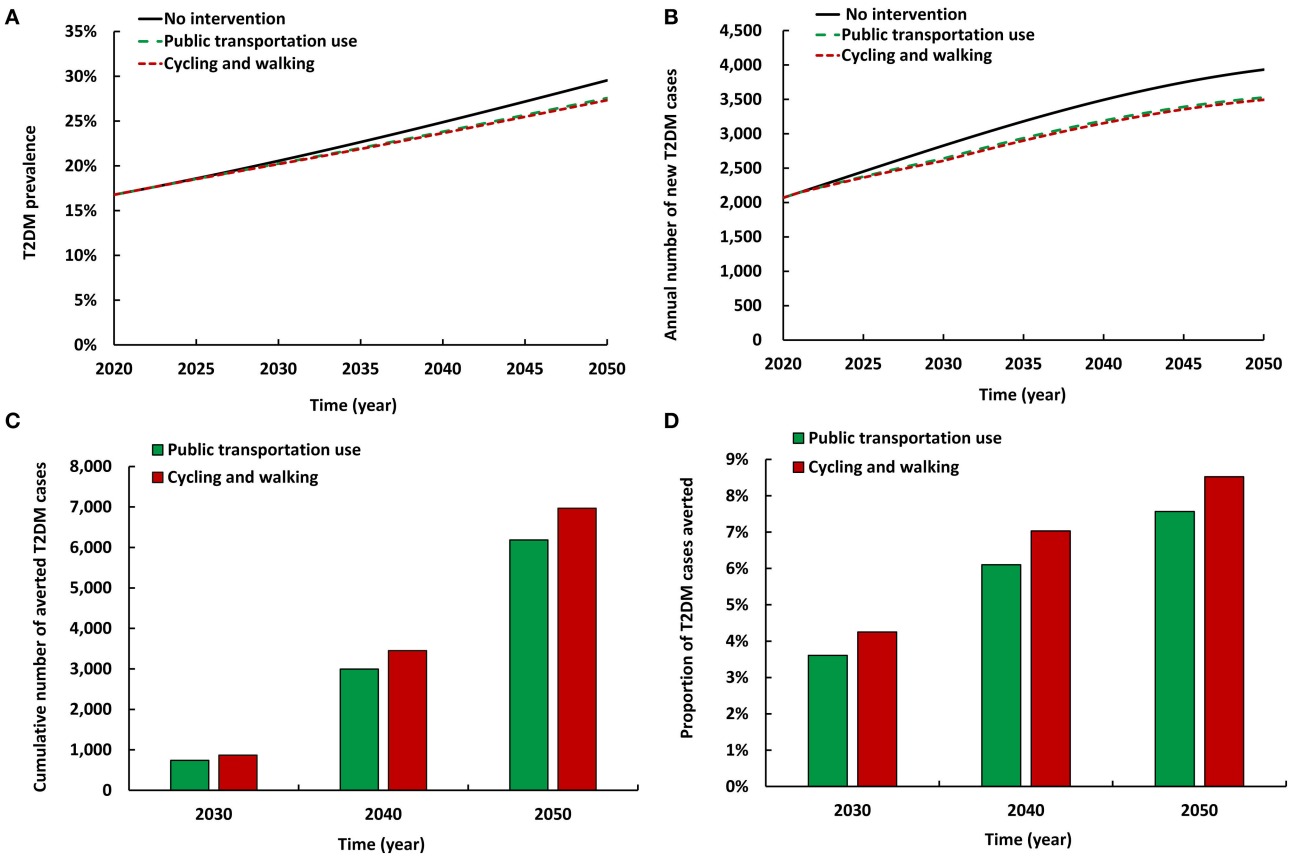

FIGURE 3
Projected impact of increasing use of different modes of active commuting on **(A)** T2DM prevalence, **(B)** annual number of new T2DM cases, **(C)** cumulative number of averted T2DM cases by these interventions, and **(D)** proportion of T2DM cases averted by these interventions.

on food consumption would lower caloric intake, thereby reducing mean BMI levels, such that 50% of the weight decrease should be reached within 1 year of intervention onset, and 100% of the weight change should be reached within 3 years (22, 23). The modeled uptake of this intervention was to be scaled up gradually to reach its targeted level after a decade (2021–2030). The uptake was maintained at this level thereafter until 2050. Three scenarios were modeled.

In the first scenario, an application of subsidies was assumed to lead to an uptake of 20% in the consumption of healthier foods such as fruits and vegetables. This intervention was assumed to reduce BMI among the total population by 0.16 kg/m^2, based on pooled evidence (22, 23). This change in BMI would lead to an obesity prevalence reduction among the total population from 53.3 to 52.6% by 2030 (16, 17).

In the second scenario, an application of taxation on sugar-sweetened beverages (SSB) was assumed to lead to an uptake of 20% in reduced consumption of SSB, that is 20% of the population reduced their consumption. This intervention was assumed to reduce BMI among the total population by 0.24 kg/m^2, based on pooled evidence (22, 23). This change in BMI would lead to an obesity prevalence reduction among the total population from 53.3 to 52.3% by 2030 (16, 17).

In the third scenario, the two scenarios above were applied together assuming their effects are additive. Accordingly, this intervention reduced BMI by 0.40 kg/m^2, that is, the additive effect of the increments of 0.16 and 0.24 kg/m^2. This change in BMI would reduce obesity prevalence among the total population from 53.3 to 51.6% by 2030 (16, 17).

2.1.5. Intervention 5: implementing combinations of interventions

Two combination packages of the above interventions were also modeled (Table 1). The first represented the most optimistic scenario of combining the above four interventions by including the most impactful scenario of each intervention. The second represented the least optimistic scenario of combining the above four interventions, including the least impactful scenario of each. Accordingly, these two packages bracket the utility of combining the above four interventions.

3. Results

3.1. T2DM burden between 2021 and 2050

Calibration of the model to the Qatari population and its epidemiological data has been published previously. T2DM prevalence among 20–79-year-old Qataris, the age group to which the interventions were applied, was projected by the model to increase from 17.1% in 2021 to 29.5% in 2050

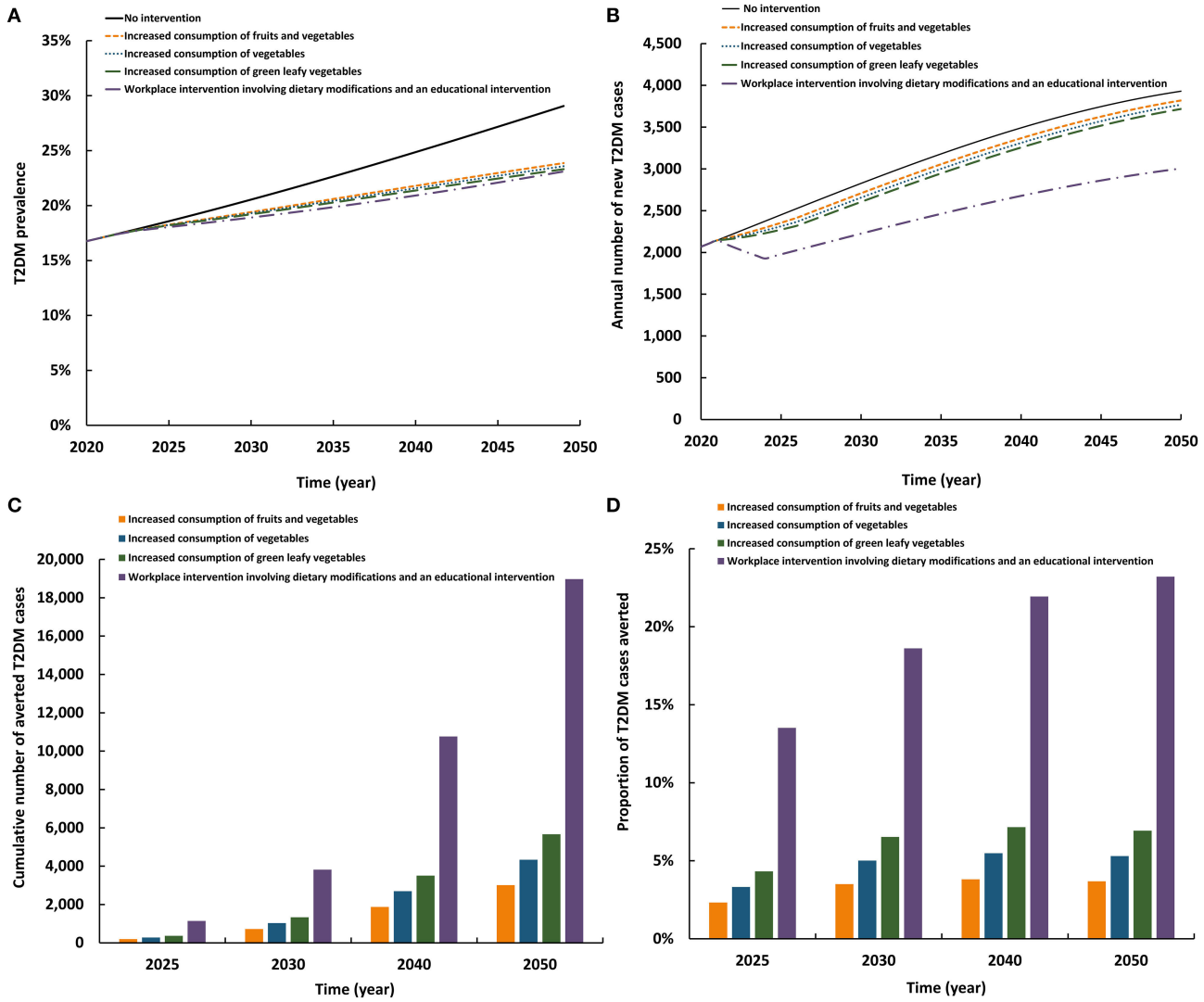

FIGURE 4
Projected impact of increasing consumption of healthy diets including fruits and vegetables on **(A)** T2DM prevalence, **(B)** annual number of new T2DM cases, **(C)** cumulative number of averted T2DM cases by this intervention, and **(D)** proportion of T2DM cases averted by this intervention.

(Supplementary Figure 1). The prevalent number of T2DM cases is expected to increase from 33,821 in 2021 to 84,516 in 2050. The annual number of new (incident) T2DM cases is expected to increase from 2,145 in 2021 to 3,931 in 2050.

3.2. Impact of lifestyle management intervention applied to populations at high-risk of T2DM

The three modeled scenarios of the lifestyle management intervention had roughly comparable impact (Figure 2). All three reduced T2DM prevalence in 2050 by 4.4–5.2 absolute percentage points and reduced the annual number of new T2DM cases by 4.7–8.8%. By 2050, the cumulative number of averted T2DM cases by the intervention ranged between 6,845 and 7,762. Also, by 2050, the proportion of T2DM cases averted by the intervention ranged between 8.4 and 9.5%. Lifestyle management programmes when applied to individuals categorized as both obese and ≥35 years old had a slightly higher impact on T2DM prevalence and incidence than when applied to individuals categorized as obese or as ≥50 years old.

3.3. Impact of increasing use of different modes of active commuting

The two modeled scenarios of active commuting intervention had comparable impact (Figure 3). Both reduced T2DM prevalence in 2050 by 1.9–2.2 absolute percentage points and reduced the annual number of new T2DM cases by 10.3–11.1%. By 2050, the cumulative number of averted T2DM cases by the intervention ranged between 6,187 and 6,970. Also, by 2050, the proportion of T2DM cases averted by the intervention ranged between 7.6 and

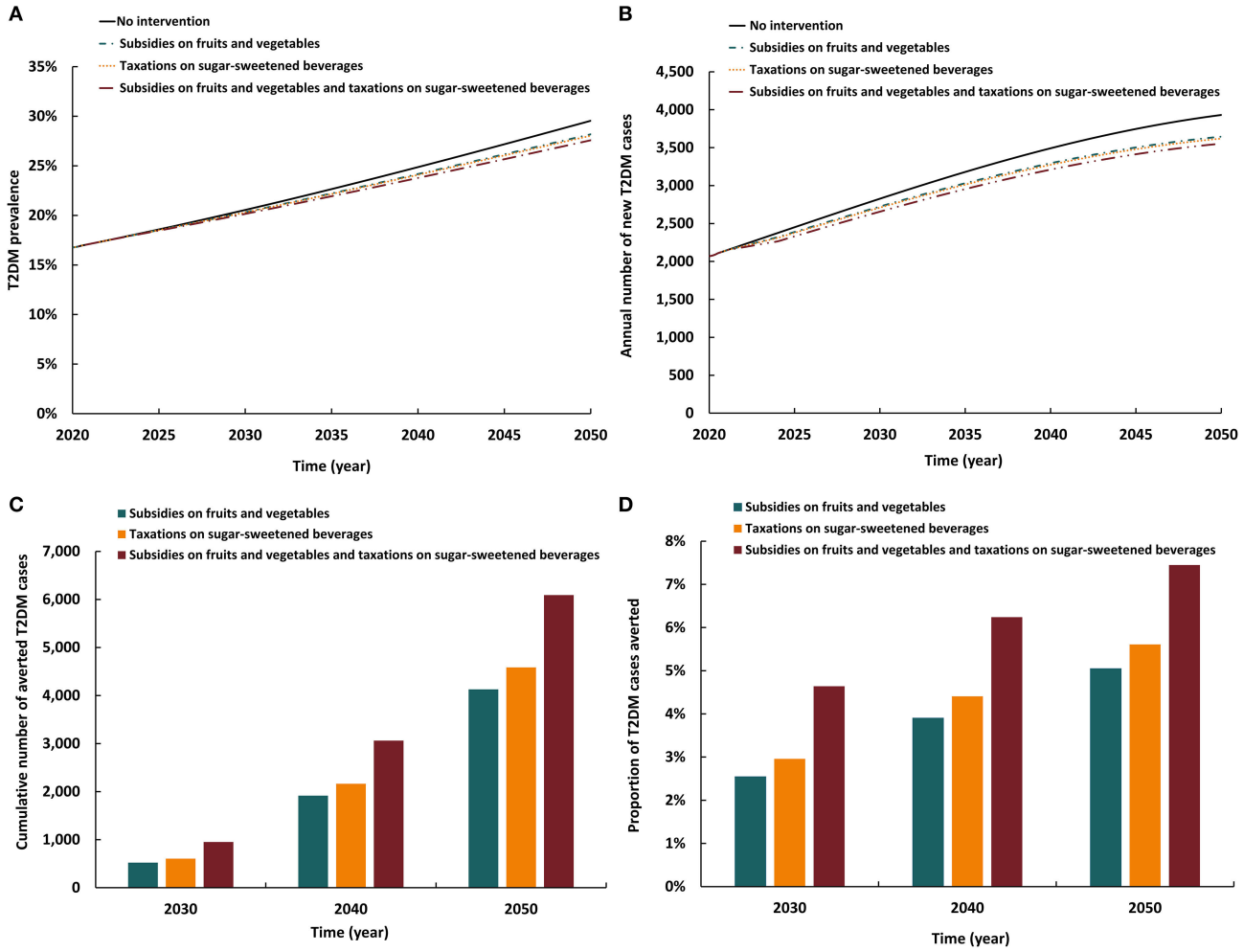

FIGURE 5
Projected impact of implementing a subsidy and legislation intervention on **(A)** T2DM prevalence, **(B)** annual number of new T2DM cases, **(C)** cumulative number of averted T2DM cases by this intervention, and **(D)** proportion of T2DM cases averted by this intervention.

8.5%. Increased cycling and walking had a slightly higher impact on T2DM prevalence and incidence than increased use of public transportation (please note intervention coverage in each scenario is different; Table 1).

3.4. Impact of increasing consumption of healthy diets including fruits and vegetables

The first three scenarios for increasing fruit and vegetable consumption had roughly comparable impact, whereas the fourth scenario had a considerably higher impact (Figure 4). The four scenarios reduced T2DM prevalence in 2050 by 5.4–6.1 absolute percentage points and reduced the annual number of new T2DM cases by 2.8–23.5%. By 2050, the cumulative number of averted T2DM cases by the intervention ranged between 3,009 and 18,975. Also, by 2050, the proportion of T2DM cases averted by the intervention ranged between 3.7 and 23.2%. Implementing a complex workplace dietary and environmental intervention (that includes increased fruit and vegetable consumption) had a substantially higher impact than increased consumption of fruits and vegetables, of vegetables, or of leafy greens on their own.

3.5. Impact of implementing a subsidy and legislation intervention

The three modeled interventions involving subsidy and legislation had similar impacts (Figure 5). The three reduced T2DM prevalence in 2050 by 1.3–1.9 absolute percentage points and the annual number of new T2DM cases by 7.3–9.6%. By 2050, the cumulative number of averted T2DM cases by the intervention ranged between 4,130 and 6,090. Also, by 2050, the proportion of T2DM cases averted by the intervention ranged between 5.1 and 7.4%. The scenario combining subsidies on fruits and vegetables with taxation on SSB had the highest impact on T2DM prevalence and incidence than either intervention scenarios alone.

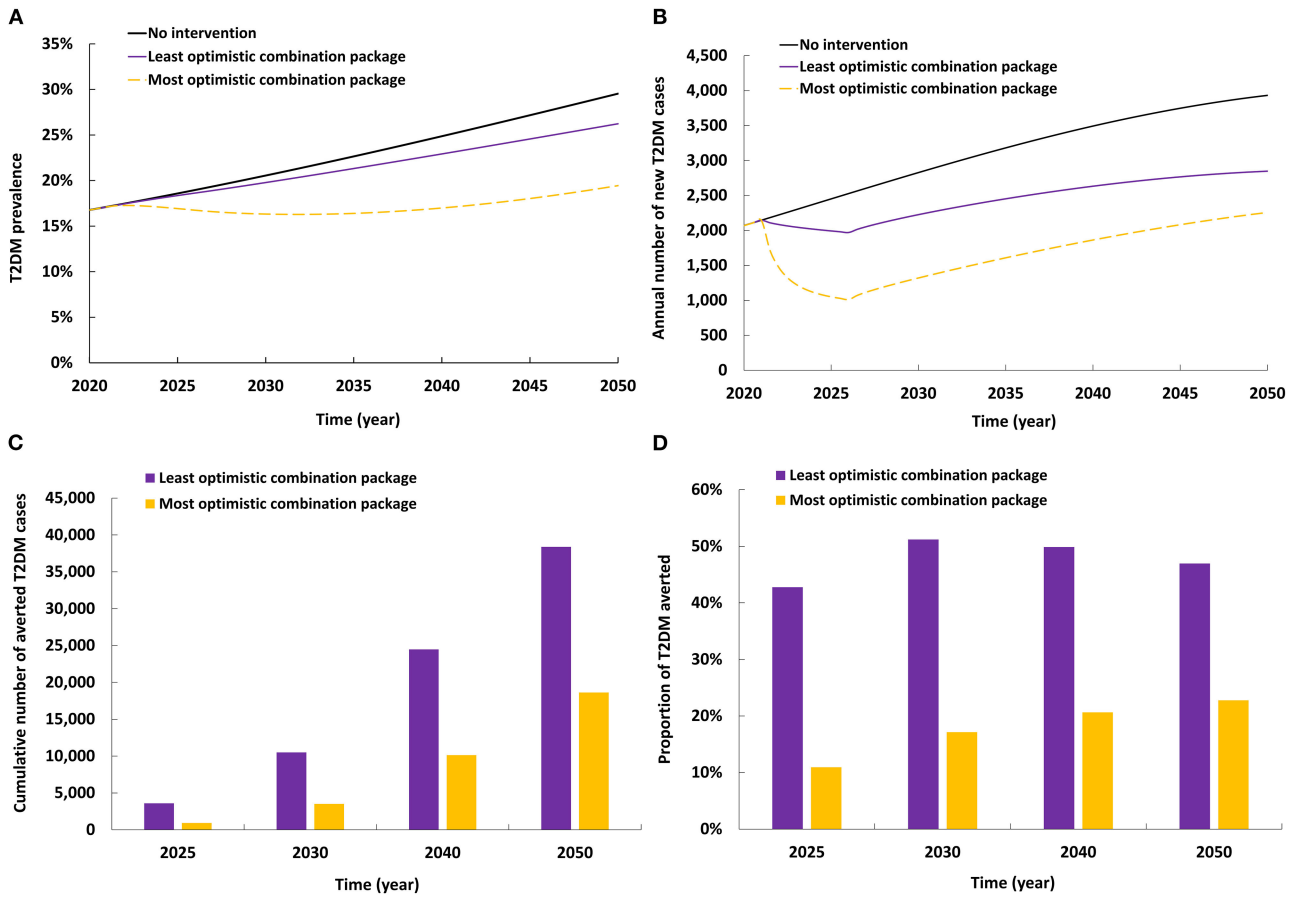

FIGURE 6
Projected impact of implementing combinations of interventions on **(A)** T2DM prevalence, **(B)** annual number of new T2DM cases, **(C)** cumulative number of averted T2DM cases by combinations of interventions, and **(D)** proportion of T2DM cases averted by combinations of interventions.

3.6. Impact of implementing subsidy and legislation intervention

The impact of combining packages of interventions is shown in Figure 6. The least optimistic combination of interventions reduced T2DM prevalence in 2050 by 3.3% and reduced the annual number of new T2DM cases by 27.6%. By 2050, 18,619 new T2DM cases (22.8%) were averted by this package of interventions.

The most optimistic combination of interventions reduced T2DM prevalence in 2050 by 10.1% and reduced the annual number of new T2DM cases by 42.6%. By 2050, 38,379 new T2DM cases (46.9%) were averted by this package of interventions.

4. Discussion

T2DM is the leading public health challenge in Qatar. This study investigated the epidemiological impact of specific, primarily structural public health interventions at reducing T2DM burden. Each intervention approach and its scenarios reduced T2DM incidence appreciably. However, combinations of these interventions were most effective and could potentially avert between 23 and 47% of new T2DM cases. These findings demonstrate the difficulty of controlling the T2DM epidemic using a single approach, as no single public health intervention had a major reduction on the projected T2DM prevalence and incidence throughout the three decades of investigation. Tackling this epidemic will require major investments in specific, large-scale interventions applied together. Although we did not analyze this directly, other evidence suggests such approaches may also be more equitable e.g., by sex and socio-economic status (9).

While all interventions had an impact, there were differences in the immediacy of the impact. Intervention approaches that directly affected onset of T2DM, that is lifestyle management programmes applied to populations at high-risk as well as increasing consumption of fruits and vegetables, had an immediate impact on reducing T2DM incidence during the scale-up time of the intervention, but this reduction saturated by end of scale-up. Interventions that affected onset of T2DM indirectly by affecting obesity and physical inactivity, i.e., increasing active commuting and subsidy and legislative interventions, had limited impact in the short term, but large long-term impact, with benefits increasing over time, even well after end of scale-up.

Interventions that were applied to the age group in which T2DM onset is rising rapidly, those 40–55 years of age (24), averted more T2DM cases, as the intervention directly affected those that

are likely to progress to T2DM within the next few years. This was the case for the scenario implementing a complex workplace dietary intervention that had a substantial reduction in T2DM incidence as it was applied to the age group that experiences the highest rate of T2DM onset (24), thereby delaying onset of T2DM to older age or preventing it altogether.

Impact of the interventions on reducing T2DM incidence was higher than on reducing T2DM prevalence. This outcome is due to the already existing high prevalence of T2DM in Qatar and to the nature of the interventions consisting of public health strategies that aim specifically to prevent onset of T2DM. Some scenarios did not have a large impact on T2DM burden, which was partly due to the limited intervention adoption/coverage assumed. For some scenarios, we assumed a realistic adoption of only 20% if the strategy were implemented in Qatar. A higher impact would be observed had we assumed a larger uptake.

Although the response to T2DM in Qatar is evolving, it lags behind the growing epidemic and most prevention and health promotion efforts remain small-scale, generic, and didactic (25). Current public health response focuses on behavioral and lifestyle interventions through education and awareness campaigns. There remains a perception, among policy makers worldwide, that it is an individual responsibility to address the risk of developing T2DM. Resources have been allocated and spent to raise awareness about T2DM, the importance of T2DM screening, and treatment options. Although such T2DM response has had an impact on controlling glucose levels in the population and on averting T2DM complications, i.e., tertiary prevention, such efforts are insufficient in creating a major impact on T2DM epidemiology and controlling T2DM incidence. In line with Qatar's National Diabetes Strategy (2016–2022), structural and more upstream population-level interventions are needed, i.e., primary prevention.

While structural population-based strategies have the potential to be effective in reducing the burden of T2DM (26–28), their implementation is often hindered by various barriers and challenges, such as political, policy, and social constraints (29). These interventions are more difficult to measure and assess their tangible outcomes in both the short- and long-term, particularly in experimental designs with population-level randomization (29). However, this study provides quantitative evidence advocating for the implementation of such interventions by demonstrating their potential epidemiological impact over the next three decades.

The uptake and adherence levels assumed in this study's scenarios remains to be validated in actual application, given Qatar's unique socio-cultural and socio-economic context, which is rapidly evolving. To address this challenge, pilot interventions should be conducted to test the feasibility of the proposed interventions and adjust uptake levels accordingly. This study emphasizes the importance of adopting a public health approach that intervenes on whole populations, as it can effectively tackle the burden of T2DM by addressing the fundamental drivers of DM incidence and by being more cost-effective in the long run (26–28). Policy-makers and public health specialists should prioritize resource allocation to structural population-based strategies to reduce the burden of T2DM and other chronic diseases.

The present study is grounded on the conceptual framing of taking a public health approach to tackle the growing T2DM epidemic with the aim of improving quality, effectiveness, and cost-effectiveness of health interventions. This approach considers T2DM epidemiology as reflecting a "sick population" rather than "sick individuals." The current public health approach focused on "sick individuals" will have limited success in stemming the rising tide of T2DM incidence and prevalence, as it does not address the drivers of T2DM incidence. Meanwhile, an approach focused on a "sick population" seeks to shift the distribution of T2DM drivers and underlying risk factors (i.e., obesity) so that disease onset is prevented in the first place. Our findings advocate for the relevance and effectiveness of this approach.

The evidence presented here demonstrates that policy level facilitation is necessary to create an environment that makes the "healthier choice the easier choice." Structural public health interventions have the greatest potential to substantially impact the T2DM epidemic. Such structural interventions are fiscal, legislative, or environmental in nature, and outside an individual's control. They include policies to reduce consumption of unhealthy foods through fiscal policies, e.g., increasing taxation on sugar-sweetened beverages, or providing subsidies for healthier foods, and increasing consumption of fruits and vegetables. Other interventions include changes to food environments, e.g., altering the types of foods in vending machines located in schools, workplaces, or other community settings. Increases in active commuting could be achieved through increased taxation on roads, cars, fuel, or car parking charges, alongside improved cycling and walking routes and infrastructure. These contrast with, but complement, behavioral interventions applied to individuals at risk for T2DM with the aim of changing their diets and/or increasing their physical activity levels.

This study has limitations. The model was parameterized using global data for effect sizes of interventions, effects of risk factors on T2DM, and effects of T2DM on mortality, but the representativeness of these effect sizes for the Qatari population remains unknown. However, these effect sizes are based on pooled estimates from multiple settings worldwide (12, 13, 15–23, 30–32), thereby perhaps accounting for some variability in the global population. Effect sizes should also represent biological mechanisms that may tend to be universal in their effect.

Data used to parameterize the model for physical inactivity levels were self-reported and potentially inflated relative to physical inactivity levels assessed using objective biomarkers. In analyses that included increasing physical activity levels, we only factored the direct effect of physical activity on T2DM incidence, which may underestimate its impact, given that physical activity may also indirectly impact T2DM incidence by reducing obesity. However, most studies have identified only small effects of physical activity on weight change. We strictly focused on reducing obesity in the population, but this may underestimate the impact of incremental reductions in BMI on T2DM incidence, i.e., BMI reductions that do not cross the obesity threshold, but can still reduce T2DM incidence (14, 33, 34). BMI $\geq$30 kg/m^2 was used to define obesity as it is a pragmatic measure often used in surveys (35); however, this may not be the best measure to capture the impact of obesity on T2DM incidence (as opposed to say abdominal obesity) (35).

Albeit we used current and relevant epidemiological data to parameterize our model, the availability of more nationally representative surveys with T2DM data could have improved its accuracy in long-term predictions. Nonetheless, previous applications of the model included sensitivity and multivariate uncertainty analyses, which confirmed its validity and reliability in making predictions (3, 4, 7–10). The sensitivity analyses showed that the model's outcomes were highly dependent on the RR of developing T2DM when obese, as expected since obesity is the leading cause of T2DM in Qatar. Additionally, the results indicated that the self-reported rates of physical inactivity impacted (to a modest extent) the model's accuracy, suggesting the need for objective biomarkers in physical activity surveys. The multivariate uncertainty analyses indicated narrow uncertainty intervals around the point estimates of the model output, after factoring the uncertainty in input parameters.

Although we focused on the Qatari population due to the availability of nationally representative data, the health benefits of the interventions investigated in this study extend to the expatriate population living in Qatar. Once representative data for the expatriate population become available, the benefits of the interventions should be quantified. Although this study focused on T2DM, the intervention approaches investigated could simultaneously lower the incidence of other serious morbidities such as cardiovascular diseases and cancer. Therefore, the impact estimates should be considered as conservative estimates of the broader health benefits of these public health interventions. The innovative modeling methodology used in this study can be extended beyond Qatar to other countries in the MENA region and elsewhere, particularly those affected by a similar T2DM epidemiology. The findings, indicating the effectiveness of implementing combinations of individual-level and structural interventions, can inform DM response in various countries and could be applicable, to a certain extent, to other countries.

4.1. Conclusion

The study findings highlight the critical need to implement a combination of individual-level and structural public health interventions to prevent T2DM onset and slow the growing T2DM epidemic in Qatar. The evidence presented demonstrates that policy level facilitation is necessary to create an environment that makes the "healthier choice the easier choice," and consequently, to reduce T2DM risk by reducing its key risk factors. Structural public health interventions targeting T2DM and its risk factors have the greatest potential to affect diabetes epidemiology and to slow the epidemic; individually focused interventions targeting those at higher risk cannot have a major impact alone. These structural interventions complement behavioral interventions that are applied to individuals at risk of T2DM with the aim of changing their diets and/or increasing their physical activity.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LA-R conceived the study. SFA, JC, and LA-R designed the model and intervention scenarios. SFA and AA conducted the analyses. AA, SFA, and LA-R analyzed and interpreted the results. AA with LA-R wrote the first draft of the manuscript. All authors contributed significantly to this study, interpretation of the results, writing of the manuscript, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1167807/full#supplementary-material

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Comprehensive application of a systems approach to obesity prevention: a scoping review of empirical evidence

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A systems approach to obesity prevention is increasingly urged. However, confusion exists on what a systems approach entails in practice, and the empirical evidence on this new approach is unclear. This scoping review aimed to identify and synthesise studies/programmes that have comprehensively applied a systems approach to obesity prevention in intervention development, delivery/implementation, and evaluation. By searching international databases and grey literature, only three studies (10 publications) met inclusion criteria, which might be explained partially by suboptimal reporting. No conclusion on the effectiveness of this approach can be drawn yet due to the limited evidence base. We identified common features shared by the included studies, such as measuring ongoing changes, in addition to endpoint outcomes, and supporting capacity building. Some facilitators and barriers to applying a comprehensive systems approach in practice were identified. More well-designed and reported studies are needed, especially from low- and middle-income countries.

KEYWORDS

systems approach, systems thinking, obesity prevention, group model building, system dynamics, intervention development, intervention implementation, intervention evaluation

1. Introduction

Obesity is driven by interactions of complex factors, including environmental, social/cultural, political, economic, and behavioural dimensions, making obesity prevention challenging (1). Techniques from systems science have been advocated as potential tools to address this complexity (2). These tools can help identify the relationships amongst factors involved in a complex obesogenic environment/system and understand how these change over time. The use of a Causal Loop Diagram (CLD), for example, as one of the many tools, helps investigate and visualise the causal structure of a complex system, and identify feedback mechanisms and the 'leverage points' that produce the desired outcome(s). Previously used approaches in obesity prevention were limited in their usefulness in understanding the dynamic relationships amongst the factors that contribute to obesity. Acquiring a deeper understanding and thinking in terms of these mechanisms (feedbacks and delays), aligned with the structure

and dynamics of the community, may also help design more effective and sustainable interventions to prevent obesity (3).

Multiple approaches exist to understand and address complexity within traditions of systems thinking. This means that a systems approach to tackling obesity could take different forms (4). Systems thinking approaches generally conform to 'hard,' 'soft,' or 'critical' traditions. Each has a particular focus within systems thinking, and has its own unique set of methods. Hard system approaches express systems in quantitative terms, and typically involve the use of mathematical modelling to predict or explain the system's behaviour. Soft systems approaches consider the system to be an epistemological construct instead of a real-world entity. This approach involves the use of qualitative methods, and incorporates a variety of perspectives from stakeholders within the system to understand the problem (4). The critical systems tradition has its roots in the soft systems tradition though emphasises the influence and perceptions of power relations on the problem. This is perceived to be inadequately addressed in the other systems traditions (4). Despite the clear differences between the traditions, in practice these often overlap and/or work synergistically (4).

Common approaches stem from system dynamics that seek to surface and use mental models of cause and effect within specific problems and identify relationships of feedback and the impacts of change over time within a system. Any adoption of a systems approach to obesity intervention should be informed by a clearly defined branch of systems sciences. Approaches should recognise nonlinear and dynamic interactions between variables operating across different levels or subsystems within the environment where a target population lives. Intervention development, implementation and evaluation must actively engage with this complexity both across and within intervention components/settings. This means that an intervention which solely comprises multiple components and/or operating at multiple settings is not necessarily an intervention taking a systems approach (5–7).

Applying a systems approach involves utilising mental/computational models, feedback loops and structures within a system; and this may re-orient the goals, structures, and resources of the system (5, 7). Models are formed based on the scientific and/or practical knowledge of the people who have built them. They provide a visual presentation of the system or problem being investigated. Feedback loops which can be reinforcing and balancing, describe cause and effect relationships.

Despite the concepts and terminology of systems approaches existing for several decades (8, 9), empirical knowledge about their application and effectiveness for obesity prevention is limited. More clarity is required regarding what systems-based obesity prevention interventions look like in practice.

Several reviews have used the term 'whole system approach' (WSA) to identify obesity prevention programmes. In 2010–2011, three reviews were conducted by the National Institute for Health and Care Excellence (NICE) to identify the key elements (6), effectiveness (10) and barriers/facilitators (11) of WSA to obesity prevention. However, due to lack of studies, these NICE reviews widened the definition of WSA to include multi-level/multi-setting programmes and proposed a list of 10 features of a WSA to tackle obesity based on their wider definition. A later systematic review aimed to synthesise available evidence on WSA targeting obesity and other public health areas based on the NICE 10 proposed WSA features (12). However, since these features were developed based on studies that did not show all characteristics of a systems approach, this later review included multi-level/multi-setting interventions. The authors of this review recognised the need to re-define WSA. The 2019 Public Health England guide to support local approaches to promoting a healthy weight using a WSA offered a better description of WSA (13). Although some of the case studies included in this guidance might not show evidence of taking a systems approach in all intervention stages, the definition and guidance offered in this document recognise essential features of systems thinking. Thus, they are helpful for the academic community, public health practitioners and policy makers in a practical sense. More recently, a systematic review identified different systems methods used to evaluate public health interventions.

To date, no systematic reviews have been specifically designed to identify programmes or studies that applied systems thinking across all stages of an intervention's life cycle.

Therefore, we conducted a systematic scoping review to identify and synthesise programmes/studies that have comprehensively used a systems approach to address obesity. A 'comprehensive' application of a systems approach should demonstrate systems thinking in all key stages of an intervention's life cycle, not just at the development stage. As a result, we excluded some studies that applied a systems approach at the intervention development stage but did not clearly report how they implemented or evaluated the developed interventions in a way that demonstrated systems thinking. It is important to note that the purpose of our review was not to identify or define authentic applications of a systems approach to obesity interventions.

1. Our specific research questions were: How many studies or intervention programmes have made a comprehensive application of a systems approach to obesity prevention? (see Methods for our inclusion criteria)?
2. What is the available empirical evidence on the effectiveness of included programmes/studies that demonstrated systems thinking in all stages of the intervention's life cycle?
3. Were there any adaptations incorporated into the systems approach to obesity prevention to suit different settings?
4. What were the main features shared by studies/programmes that made a comprehensive application of a systems approach to obesity prevention?
5. What are the reported barriers and facilitators to applying this systems approach to obesity prevention?

2. Methods

Our review adopted the five stages framework provided by Arksey and O'Malley (14) and Levac et al. (15) and used the reporting criteria of The PRISMA Extension for Scoping Reviews (PRISMA-ScR) (16). For research question 2, studies should have reported at least behavioural or anthropometric outcomes. In addition, we included other outcomes, such as intervention implementation, cost-effectiveness, and psychosocial impact. Any peer-reviewed research or grey literature was considered. We excluded theoretical literature, editorials, opinion pieces/commentaries and conference abstracts. We also excluded studies that used systems science to understand the mechanisms of obesity unless these aimed to inform the development of a systems-based intervention and the intervention has been implemented/evaluated. To be considered a **comprehensive application of a systems approach**, studies/

TABLE 1 Foster-Fishman framework (16).

Bounding the system	Understanding system parts as root causes	Assessing system interactions	Identifying levers for change
• Problem definition • Identification of the levels, niches, organisations, and actors relevant to the problem	• System norms, resources, regulations, operations.	• Reinforcing and balancing interdependencies • System feedback and self-regulation • Interaction delays	**Identifying parts to leverage for change:** • Exerts or could exert cross-level influences • Directs system behaviour • Feasible to change **Identifying interactions and patterns to leverage for change:** • System differences that create niches compatible with systems change goals • Long-standing patterns that support or hinder change goals • Gaps in system feedback mechanisms • Cross-level/sector connections that are needed.

programmes had to meet all the following criteria associated with the development, delivery/implementation, and monitoring/evaluation stages of an intervention's life cycle:

a. The process to develop the intervention featured all the principle steps for transformative systems change provided by the Foster-Fishman's framework (17) (Table 1).
b. The chosen approach to deliver (for experimental purpose) or implement (as a public health initiative) the intervention showed evidence of recognising the dynamic and complex nature of the intervention and the system for which the intervention was developed.
c. The chosen approach to monitor/evaluate the developed intervention also showed evidence of recognising the dynamic and complex nature of the intervention and the system for which the intervention was developed.

The Foster-Fishman's framework was selected as a part of our criteria during the study selection process. The framework provides some clarity about what a systems approach to intervention development might entail. It describes systems approaches as comprising 'bounding the system,' 'understanding system parts as root causes,' 'assessing system interactions,' and 'identifying levers for change' (17).

Several questions were used to determine study eligibility against each intervention stage. For example, for the development stage, we considered 'have the authors specified the theoretical underpinning of the systems approach applied to develop the intervention and justified their choice?'; and 'have the authors described clearly the methods applied to develop the intervention and justified their choice?'

For the implantation stage, example questions were: 'have the authors specified the responsibilities of all individuals and organisations involved in the delivery of jointly identified and prioritised intervention actions?'; and 'have the authors described in sufficient detail what were delivered/implemented, including the initial plan and subsequent changes to the initial plan?.' For the evaluation stage, we asked, for example, 'have any evaluation outcomes been used to review and update stakeholders' understanding of the system gained collectively prior to intervention delivery?'

We did not apply any restrictions on research/community settings or participants characteristics. We searched the following databases from inception to February 2021: Web of Science, PubMed, and MEDLINE. Moreover, grey literature was searched with particular attention to significant bodies, and hand searches were also used. Search terms are provided in Supplementary material 1.

We imported all references and removed duplicates in Covidence online software (18). Two reviewers independently conducted the titles and abstracts screening and selected articles based on the predetermined inclusion and exclusion criteria. Then, we extracted and recorded relevant data using a customised form. We extracted data on the author(s), year and type of publication, location/setting, targeted participants or population group, study aims, systems methods/tools, intervention details, study design, outcome measures, and key findings from each programme/study. The Consolidated Standards of Reporting Trials (CONSORT) extension abstracts (SW-CRT) (19) and the standard Critical Appraisal Skills Programme and EPPI-Centre tools (20) were used to assess the included studies.

3. Results

3.1. Articles retrieved

We identified 2,396 articles. After removing duplicates, 1,804 records underwent title and abstract screening, and 209 underwent full-text review (Figure 1). Of these, 10 articles met the inclusion criteria.

Ten articles from two countries were published between 2016 and 2022. Three articles describe the design and methods of three programmes for preventing childhood obesity (21–23). The remaining seven articles report on a process evaluation and the key findings of the included intervention programmes (24–30).

3.2. How many studies or intervention programmes have made a comprehensive application of a systems approach to obesity prevention according to the definition used in this review?

Three obesity prevention interventions meet our inclusion criteria to apply a systems approach to obesity prevention (Table 2) comprehensively. All excluded studies/programmes and reasons for exclusion are provided in Supplementary material 2. We describe the three included programmes below.

3.2.1. The whole of systems trial of prevention strategies for childhood obesity and the reflexive evidence and systems interventions to prevent obesity and non-communicable disease study

These two studies were conducted in Victoria, Australia, using a similar methodological approach (systems dynamic) to intervention development, implementation, and evaluation (21). The whole of systems trial of prevention strategies for childhood obesity (WHOSTOPS) study (Western Victoria) predated reflexive evidence and systems interventions to prevent obesity and non-communicable disease (RESPOND; Northern Victoria), the latter extended the approach pioneered in the earlier trial (23).

3.2.1.1. Intervention development

Both studies (21, 23, 28–30) facilitated a deeper and shared understanding of system components such as systems norms, human resources, social resources, economic resources, operations, and regulations. This included assessing alignment of current system with values and assumptions of targeted outcome or change and assessing degree to which current system has in place or is building the infrastructure to support goals or targeted outcome.

In the next step, both studies started to explore the interactions and interdependencies amongst system subsystems or components and how the system self-regulates using Group Model Building (GMB) workshops and co-produced CLD. GMB is a system dynamics method that provides a workshop structure to engage diverse stakeholders in collective activities to create a dynamic system model known as a CLD. These visualised the nonlinear and dynamic interactions between variables operating across different levels or subsystems within the environment. The CLD was used as a representation of the system at the third workshop with a broad group

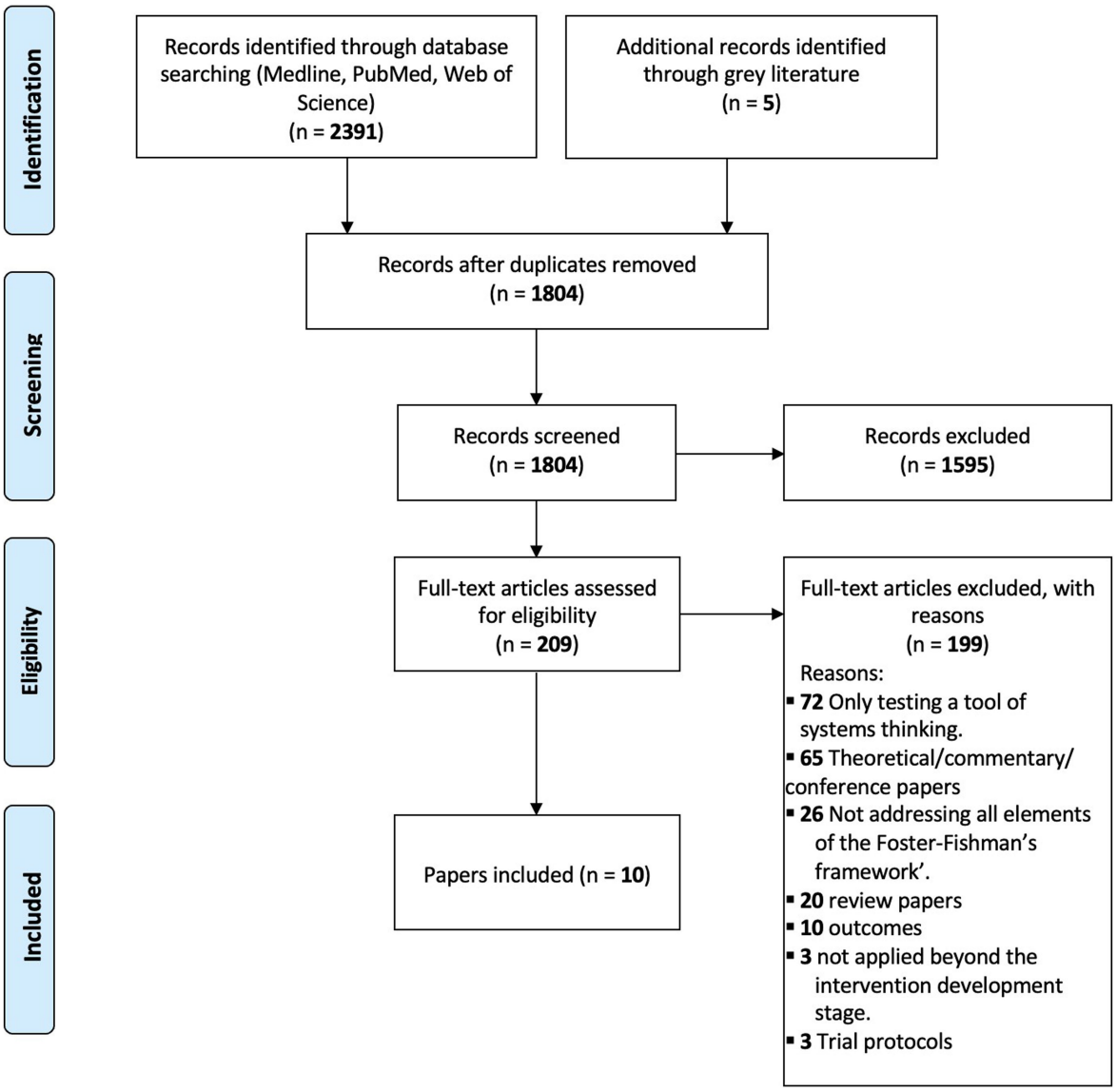

FIGURE 1
Flow diagram of scoping review study identification.

TABLE 2 A summary of studies that made a comprehensive application of a systems approach to developing, delivering and evaluating childhood obesity prevention according to the criteria used in this review.

Study title and years	Country	Target Population	Programme/Intervention characteristics[a]	Evaluation approach	Outcomes	Systems method and Theoretical basis	Trial findings/ status	Comprehensiveness as defined in this review
WHO STOPS Childhood Obesity (20, 24) 2016–2021	Australia	Children (grade 2, 4, 6; ages 7–12 years)	- Assessing alignment of current system with values and assumptions of the targeted outcome. - Exploring the interactions and interdependencies amongst system subsystems or components - Using the established systems map to identify intervention opportunities and convert these to community-built and systems-oriented action plans.	A stepped-wedged cluster randomised controlled trial	• Anthropometry (BMIz[b], overweight/ obesity prevalence) • Physical activity and sedentary behaviour • Diet type, frequency • Quality of life • Environments • Social networks (ecological data) • Process/ implementation indicators	Group Model Building (GMB), Systems dynamics	Trial findings have been published. **Main Result:** *WHOSTOPS* had a positive impact on takeaway food intake and health-related quality of life. A full summary was included in section 3.4.	A systems approach was used in all stages of the intervention's life cycle (intervention development, delivery and evaluation)
RESPOND (22) 2018–2023	Australia	birth to 12 years	**Five components:** 1. Systems approach capacity building for each participating community: a. *Face-to-face GMB training to develop local interventions* b. *Online support* 2. Community-led intervention activity. 3. School Monitoring System and analysis of weight status of infants and young children aged 2 and 3.5 years (via de-identified Maternal and Child Health Data) 4. Knowledge, engagement and social network analyses (using surveys to collect data on changes over time relevant to obesity amongst children) 5. Collaborative Governance and Implementation Structure (Collective Impact).	A stepped-wedged cluster randomised controlled trial	• BMIz[b] • Overweight/ obesity prevalence • Typical/usual serves of non-core (discretionary) foods consumed daily	Group Model Building (GMB), Systems dynamics	Data from the baseline measurement has been presented. The study has entered step two of the stepped wedge trial design	A systems approach was used in all stages of the intervention's life cycle (development, delivery, and evaluation)

(Continued)

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TABLE 2 (Continued)

Study title and years	Country	Target Population	Programme/Intervention characteristics[a]	Evaluation approach	Outcomes	Systems method and Theoretical basis	Trial findings/ status	Comprehensiveness as defined in this review
The LIKE (21) 2018–2022	Netherlands	10–14 years	- Understanding the pre-existing systems about dietary, physical activity, sleep, and screen-based sedentary behaviours. - Summarising findings in a systems map and using Social Network Analysis (SNA) to identify the influential actors (societal stakeholders/policymakers) to develop actions using GMB workshops. - Use the understanding gleaned in the systems maps to support adaptation, ongoing programme development, and feedback on broad systems change as the intervention programme was implemented.	Developmental systems evaluation, supplemented with routinely collected data	• BMIz[b] Behavioural (diet, physical activity, screen use and sleep)	Group Model Building (GMB), social network analysis (SNA), Systems dynamics	The study has been running since 2017 and will be completed (including a dynamic evaluation) in July 2023	A systems approach was used in all stages of the intervention's life cycle (intervention development, delivery and evaluation)

[a]Unlike traditional interventions studies where interventions components are clearly defined and adherent to protocol, the interventions implemented or delivered in the three included studies involved GMB and capacity building work in participating communities. The intervention actions varied between communities and evolved (were modified) in response to ongoing evaluation results. This is an important sign of the comprehensive application of systems approach to obesity prevention.
[b]Body mass index z score (standard deviation score).

of community members to identify and prioritise levers that can be used to change the system (21, 23, 28–30).

3.2.1.2. Intervention implementation

Each intervention was oriented around strengthening leadership, workforce development, resources, partners, networks and intelligence through intensive training and support for each intervention community. The system intervention was carried out with community stakeholders who had authority or control over the environments in which children were exposed to the identified system drivers risk factors. For WHSTOPS, the research team delivered the GMB workshops and were actively involved in planning implementation. In contrast, for RESPOND, the research team trained local community and health staff to deliver this process, plus a new and existing coalition of community leaders was convened to lead community-wide structural change (21, 23, 28–30). Both studies formed a steering group to prioritise changing systems to support physical activity, healthier food choices and childhood obesity prevention across the intervention design process.

3.2.1.3. Intervention evaluation

Both studies used a stepped-wedged randomised control trial design (SW RCT) to minimise practical and ethical issues associated with complex, population-level interventions (25, 28–30). Stepped-wedged randomised control trial is one of the recommended study designs for evaluating complex interventions that involve whole-community policy/service changes that require political, logistic, and ethical consideration (31). Moreover, the WHOSTOPS evaluation approach included continuous outcome measurement (vs. measuring outcomes at certain endpoints). This showed recognition of the dynamic nature of implemented interventions, and continuous data collection made investigation of how system changes occurred possible.

3.2.2. Lifestyle innovations based youth's knowledge and experience (the LIKE programme)

LIKE was a 5-year study set in three districts in Amsterdam, with an intended overrepresentation of lower socio-economic and ethnic minority groups (22). It aimed to build a dynamic action programme based on the current system. It evaluated (1) how the system evolved in response to the developed programme and (2) how it contributed to improvements in health-related behaviours and prevalence of overweight and obesity amongst children aged 10 to 14 years old.

3.2.2.1. Intervention development

The LIKE programme was started by understanding the pre-existing systems that contribute to determinants of dietary, physical activity, sleep, and screen-based sedentary behaviours in the target population (22, 26, 27). Findings related to these determinants were summarised in a systems map built using GMB. This map was used as a reference for developing actions and as a basis for evaluation. They used Social Network Analysis (SNA) to identify the influential actors who hold a central position within the local governance and/or at community level and invited them to develop actions through the use of GMB workshops (22, 26, 27).

3.2.2.2. Intervention delivery and evaluation

The evaluation used developmental systems approaches, supplemented with routinely collected data on weight status and key

health behavioural indicators (22, 26, 27). A key stated aspect of this approach was using the understanding gleaned in the systems maps to support adaptation, ongoing programme development, and feedback on broad systems change as the intervention programme was implemented. In other words, the intervention was being developed, implemented, monitored and re-developed in a continuous, adaptive process (22, 26, 27).

3.3. What is the available empirical evidence on the effectiveness of this intervention approach?

Only WHOSTOPS paper (25) reported the effectiveness of using a comprehensive systems approach to obesity prevention. No effectiveness findings had been reported for other included interventions at the time of writing.

WHOSTOPS was evaluated using a SW-RCT design over 4 years and reported a significant decline in mean BMI z score in the intervention group within the first 2 years followed by an increase. The mean BMI z score amongst the control group remained unchanged throughout the study period (25). A similar 'U shape' pattern of change was observed for the percentage of overweight/obesity in the intervention group, whilst the corresponding figure for the control group remained stable. There was an intervention by time interaction in BMI z scores ($p = 0{\cdot}031$). The authors suggested several contextual explanations for such findings. First, as planned, the research team reduced their implementation support to step-one communities in the second year to focus more on recruiting communities for step two. Due to bushfires and other natural disasters, control communities had to delay intervention uptake for 2 years. The resources allocated to the first set of intervention communities was reduced by at least half of what was planned for the last 2 years of the study. Second, there might be an unintended consequence (e.g., complacency, a feeling of the job being done and shifting priorities) of seeing early signs of a positive outcome in the intervention communities. The study did not achieve the desired sample size of 1,500 in each trial arm and was underpowered to detect hypothesised BMI z score change (25).

3.4. Were there any adaptations incorporated into the systems approach to suit different research settings?

No adaptions were reported for the included programmes. The WHOSTOPS, RESPOND and LIKE (21–23) were each developed using GMB. In each case, these methods were underpinned by previously developed scripts to design and run these sessions. The scripts themselves provide scope for the design team to adapt the framing of the question, the scale of the target area and the systems requiring attention.

3.5. What were the main features shared by studies that have made a comprehensive application of a systems approach to obesity prevention?

The main features shared by all three included studies (21–23) are described below.

3.5.1. Mapping the systems of obesity drivers and embedding actions within the systems

The WHOSTOPS, RESPOND and LIKE (21–23) used a systems lens to understand the various system levels and interventions required for sustainable, large-scale changes. GMB workshops as a systems dynamic tool were used in all studies to create a system map that recognises nonlinear and dynamic interactions between variables operating across different levels or subsystems within the target population's environment. All programmes (1) started with understanding current systems and contexts within the communities; (2) identified, prioritised, and acted on systemic drivers of obesity; and (3) identified ways in which current systems and resources can be re-oriented or used for better health outcomes. All three studies used the *Systems Thinking for Community Knowledge Exchange* (STICKE) software to support the process. STICKE was initially developed to support WHOSTOPS (32) and subsequently is continually adapted to meet the needs of the communities in terms of increasing understanding and aligning with their existing planning and reporting requirements (33).

3.5.2. Measuring ongoing changes not just the endpoint outcomes

All studies (21–23) demonstrated systems thinking throughout the development, implementation, and evaluation stages of their intervention's life cycle. Most notably, at the evaluation stage, all studies included evaluation and tracking of changes in the systems (34). Such an evaluation and monitoring approach is necessary given the dynamic and adaptive nature of any system. For example, within the WHOSTOPS study (21), ongoing data collection and updates of the systems map helped to optimise implementation and facilitate diffusion of the selected actions; new ideas were stimulated in an adaptive, constructive, capacity-building cycle. In depth interviews with community practitioners demonstrated how data helped frame the priorities of community prevention efforts to child health behaviours and the continual mapping process helped leaders to identify and track junk food, physical inactivity and moves from programmatic approaches as key areas of focus (28).

3.5.3. Measuring intervention processes

All studies undertook a process evaluation to understand how successfully the systems approach created a sustainable programme and how communities responded to systems interventions. Just as with ongoing outcome measurements, process evaluation can also inform adaptive/new actions to optimise intervention outcomes. Both the knowledge about and interventions on the systems are advanced continuously. However, no authors reported whether or how process evaluation contributed to learning how the systems worked.

3.5.4. Local decision-makers and influential actors lead and own intervention development and implementation

A common feature across studies (21–23) was that researchers in these studies supported local decision-makers and influential actors to develop and implement systemic interventions for transformative systems change through a co-creation, participatory approach. Those individuals were leaders from local government and other key sectors/subsystems of the communities (21–23). They have the authority, power, and/or resources to approve and/or implement prioritised interventions. In the WHOSTOPS and RESPOND studies, community leaders who directly affected pre-adolescent environments were invited to develop and implement interventions (21, 23). Social

Network Analysis was used in LIKE to identify influential actors who were then invited to participate in all parts of the project (22).

3.5.5. Supporting capacity building as an essential goal alongside achieving clinical effectiveness

All included studies have explicitly spent effort to strengthen the World Health Organisation (WHO) system building blocks (35, 37), including leadership, resources, partnership and intelligence in community settings. For example, the WHOSTOPS study convened a new and existing coalition of community leaders who have the capacity and network to lead systems change across the community. The strength and structure of this network and influence on action is reported in relation to the initial system map developed by the community (29). Moreover, the RESPOND study trained local community leaders to run GMB workshops. One result of this capacity building is the use of techniques in these communities for problems outside the initial intent to address to childhood obesity (21, 23). For example, several RESPOND communities used GMB and systems methods to understand and plan responses to food insecurity arising from the COVID-19 pandemic (30). Furthermore, the LIKE study invited adolescents to a capacity building workshop to teach them how to conduct research amongst their peers about healthy behaviours and potential actions towards stimulating healthy behaviours.

3.6. What are the reported facilitators and barriers to applying a systems approach to obesity prevention identified by the included studies?

Only one article (24) reported barriers and enablers. This article is a process evaluation of a pilot community that participated in the WHOSTOPS (21) programme in Victoria, Australia's Great South Coast region.

The GMB workshops and 'the organic evolution' of the programme in all areas and levels of the system were reported by the steering and community task team members to be helpful. This approach established community ownership of the system by engaging a diverse range of community members who collectively unpacked the complexity of obesity and its main influences (24). Furthermore, co-creation teamwork, including sharing information within the steering group, engaging local agencies, and commitment of authorities to integrated working, has been identified to positively impact the programme's feeling of ownership, development, and progression (24).

Focusing on community assets rather than needs or lacks was helpful in information sharing between members, engaging relevant organisations, forming a relationship with a topic expert, and attaining the commitment of many local authorities to participate in the collaboration (24). This can be accomplished by shifting mindsets from deficits to capabilities, highlighting and connecting a varied range of community assets and mobilising the connected assets for action (38).

Triggers to personal involvement in the programme and perceived prompts for others to participate have been identified as important facilitators of engagement in the process. For instance, the use of GMB has been found as a powerful tool to promote a shared understanding of the complexities of obesity in the local context and the need for collective actions (24).

Some of the identified barriers are miscommunication and confusion observed within the steering group organisation regarding individual responsibilities and roles. As a result, thought processes amongst members of the steering groups were not always aligned. Furthermore, a lack of support to those working at a lower level was identified within the steering group (24). Another barrier is related to the lack of application of the asset-based community development (ABCD) approach that promotes ownership and sustainability and could have been more effective if it occurred in conjunction with the GMB workshop (24).

The standard processes of GMB workshops were not adapted to support community members who had low health literacy, and no additional efforts were undertaken (24). This may negatively affect the efficiency of the task teams. Another identified barrier is related to unforeseen social and economic shocks. For WHOSTOPS, the bushfire impacted the subsequent delivery of intervention (25), which will be even more marked when we understand the impact of COVID.

3.7. Quality assessment

The quality of two papers (24, 25) was assessed by an appropriate tool based on their study designs. We only assessed these two papers since these reported interventions outcomes. The WHOSTOPS met 14 of 17 of the reporting quality items of the Consolidated Standards of Reporting Trials (CONSORT) extension for the stepped wedge cluster randomised trial (SW-CRT; see in Supplementary material 3). The process evaluation study (24) was assessed using the SCAS-EPPI (20). The reliability of the included process evaluation findings was rated as a medium, whilst the usefulness of the findings was rated as high (see in Supplementary material 4).

4. Discussion

This review included 10 publications (21–30) reporting on three eligible studies (21–23). This number suggests that comprehensive application of a systems approach to obesity prevention is limited. Although there is positive evidence, more empirical evidence is needed to understand the application and effectiveness of this approach. Furthermore, no empirical evidence is available from non-western, developing settings.

The scarcity of studies using a comprehensive systems approach may partly be due to the uncertainty around the exact meaning of 'a systems approach'. Some programmes appeared to implement multi-level, multi-component interventions, or did not meet our inclusion criteria for intervention development (Supplementary material 2). Moreover, sub-optimal reporting might have also explained the small number of studies meeting our inclusion criteria. The 2019 systematic review also found that the reporting of most included studies lacked sufficient detail (12). Similarly, authors of the recent review on different methods used to evaluate various public health interventions also suggested that more consideration could be given on how to present findings from complex systems evaluation (36). Therefore, robust and well-reported evidence is needed to improve our understanding of how a systems approach can be applied practically. To address this issue, we developed a practical guidance for reporting health interventions underpinned by a systems approach (39). This

guidance is presented in a format of practical questions to assist academic authors, journal editors and other interested stakeholders to design, report or review future interventions that apply a systems approach to tackle obesity or other public health challenges. These questions were developed based on our empirical experience of applying a systems approach to health promotion across 16 countries, and comparative reflections on what were reported by studies included in this review and what were not reported by excluded but potentially eligible studies (those that were excluded due to insufficient reporting). The guiding questions are organised by the three interrelated stages of an intervention's life cycle: 'development' (10 guiding questions), 'implementation/delivery' (10 guiding questions) and 'evaluation/monitoring' (12 guiding questions).

Our review only found one article that reported on the effectiveness of the WHOSTOPS programme. Therefore, published evidence on the impact of taking a comprehensive approach to obesity prevention is still limited. However, we are aware of several ongoing studies that will publish their evaluation outcomes within the next few years. Overall, WHOSTOPS was found to positively impact health-related quality of life, take-away consumption and water consumption amongst girls, and packaged snacks amongst boys (25). However, a 'U shaped' pattern was observed for changes in mean BMI z-scores and overweight/obesity percentages amongst the intervention communities, whilst these two outcomes remained largely unchanged amongst the comparison communities throughout the study period. A valuable finding from this study was the suggested explanation (explained in section 3.4) for such findings by the programme's/study's researchers. Furthermore, the length of an intervention might be critical in determining measured intervention outcomes. A systematic review of 26 obesity prevention studies focused on the same age group (7–12 years) as WHOSTOPS found that interventions lasting 12 months or less were most effective in preventing obesity (40). Future research should pay attention to potential interactions between intervention length and impact.

Our review did not limit searches to English-language publications only but all included studies (21–23) were based in western, high-income countries (Australia and the Netherlands). Although it is possible that eligible research that is not archived by international databases might have been missed, we believe this is unlikely given the origin and early stage of applying systems approaches to obesity interventions. This finding raises an important question about the feasibility of applying a systems approach in non-western and/or developing countries. One challenge might be realising cross-boundary collaboration amongst authorities and organisations to tackle health issues. For example, a study conducted in a Middle East country found that collaboration amongst diverse stakeholders is limited due to cultural and gender barriers (41). Moreover, many non-western countries adopted a highly centralised governing model in which the central authority has more strict control over local authorities. This could be a particular challenge when implementing a systems approach to public health intervention development and implementation as this approach is bottom-up and collaborative. Moreover, a centralised government can disempower local councils and not view health promotion or disease prevention activities as politically favourable (42, 43). These challenges imply that the feasibility of using the systems approach in non-western countries should be a focus of future research.

Our review identified common features shared by studies that were considered to have comprehensively applied a systems approach to obesity prevention. Similarly, the 2019 review (12) and the NICE review (8) found that building relationships and community capacity was required to create successful outcomes.

Our review identified only one process evaluation (24) of an included intervention. This makes it challenging to provide a comprehensive summary of reported barriers and facilitators to applying a systems approach to obesity prevention. However, the identified barriers and facilitators can improve the design and delivery of future obesity interventions that take a comprehensive systems approach. For example, focusing on community assets will create a complete picture of shared motivations for change. This increases the possibility that change efforts will receive widespread support and success (38). Moreover, a strong reciprocal relationship was identified between systems thinking, collective impact and asset-based community development. Using these concepts seems to prevent an intervention programme (at least in the short term) from reverting back to business as usual (24, 44–46).

This is the first review to identify and assess published evidence of a systems approach to obesity prevention using strict inclusion criteria to encompass all stages of an intervention's life cycle. This is the main strength of our review since previous reviews applied broader inclusion criteria. A wide range of data sources, outcomes and process evaluation were included to capture all available evidence. Moreover, common features of comprehensive use of a systems approach to obesity prevention and application facilitators and barriers were identified.

The review also has limitations. First, there are two sides to applying strict inclusion criteria in this review. Although strict inclusion criteria allowed us to identify and synthesise evidence from studies that applied a systems approach at all stages of the intervention life cycle, some valuable knowledge generated by studies that only met our inclusion criteria partially was not captured by this review. Second, our definition of comprehensive use of a systems approach to obesity prevention was determined based on the current academic knowledge and our empirical experience. Our definition and review may be updated accordingly as the practical application of a systems approach to obesity prevention, and other public health challenges are advanced. Moreover, it is possible that some studies/programmes might have made comprehensive use of a systems approach but were excluded from this review for lacking methodological and process details in associated publications. This might mean that findings on other eligible studies/programmes were not considered in this review. There is an urgent need to develop practical guidance for reporting public health interventions underpinned by a systems approach to advance evidence synthesis and methodological development. Furthermore, we identified evidence for the effectiveness of this approach on behavioural outcomes and quality of life. However, this was based on one included study. More research is needed to understand better the impact of adopting a comprehensive systems approach to obesity prevention. Researchers and authors should also report major changes in the intervention environment and reflect on how such changes might have influenced intervention outcomes at different times. Non-western researchers are encouraged to test the approach in their settings and report any

culturally relevant adaptations made to existing processes and tools.

5. Conclusion

Our review identified only three studies considered to have made a comprehensive application of a systems approach to obesity prevention intervention. This might be due to a misunderstanding of this approach or insufficient reporting of key processes and methods. Currently, no published empirical evidence is available from outside western, high-income settings. The evidence for the effectiveness of this approach on behavioural outcomes and quality of life was identified based on one included study. However, given this extremely limited evidence base, no conclusion on the effectiveness of this approach can be drawn yet. This review also identified common features shared by included studies, which may help clarify existing confusions around the meaning and practical application of a systems approach to obesity prevention. Finally, some barriers and facilitators to applying a comprehensive systems approach in practice were identified, and they would help improve the design and implementation of future work.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

BL conceived the study idea and led the development of the study design. CF provided methodological advice and supervised the study with BL. MA conducted the literature search, screening/selection of papers, and data extraction and analysis. SA provided training and theoretical and methodological advice. BS provided theoretical expertise. RP worked as a second reviewer during the screening and selection of papers. Any disagreements between MA and RP over the eligibility of specific studies, the data extraction process and the quality assessment process were resolved by discussion with BL. BL, MA, SA, BS, RP, and CF contributed to the interpretation of the review findings. MA drafted the manuscript, which was revised substantially by BL, CF, and SA. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1015492/full#supplementary-material

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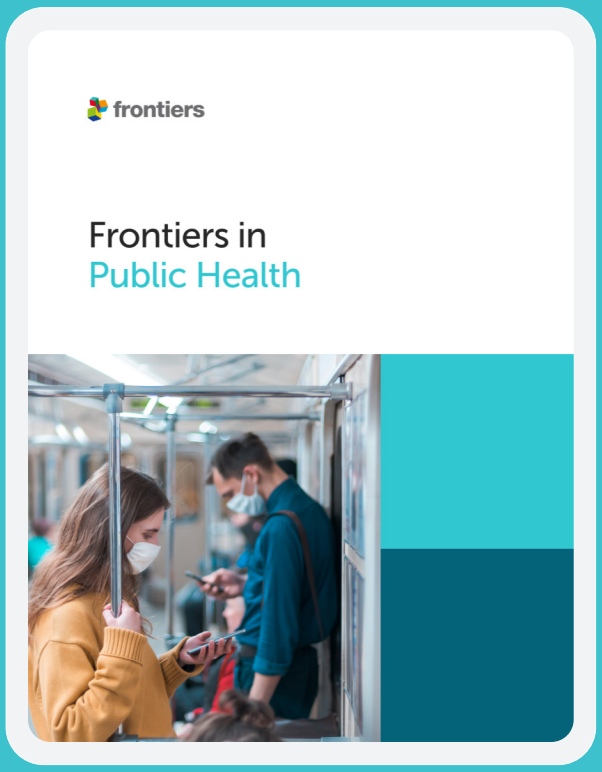

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