

Understanding behavioral and structural determinants shaping older adults' responses in the climate-health-energy nexus: Implications for multi-level support

Keriin Katsaros

keriin.katsaros@hereon.de

Climate Service Center

Jo-Ting Huang-Lachmann

Climate Service Center

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Abstract

Population aging and climate change are two converging challenges having implications for health, energy, and the capacity of older adults to respond to related risks. Understanding how behavioral and structural determinants shape responses is important for developing support that accounts for the interconnected climate-health-energy nexus. This study seeks to understand barriers and enablers influencing climate-friendly, health-promoting, and energy-efficient behaviors and their implications for multi-level support. The Behavioral and Structural Influence Sphere (BSIS), which integrates the Capability, Opportunity, Motivation (COM-B) model into the Social Ecological Model (SEM), was used to analyze qualitative interviews with older adults and stakeholders in Taiwan. Reflexive thematic analysis identified themes representing barriers and enablers, which were mapped according to COM-B components and socio-ecological levels. Barriers were clustered at the individual level and were associated with physical opportunity, while enablers occurred across socio-ecological levels, especially in community and organizational settings. The findings show that older adults' behaviors in this nexus are shaped by interacting individual and structural conditions, highlighting the importance of multi-level approaches that reach beyond individual behavior change. BSIS provides a structured approach for identifying potential entry points and informing the design of multi-level interventions supporting older adults.

1. Introduction

Population aging and climate change are two intersecting global challenges having significant implications for health, care, and well-being. Climate change is a complex global challenge, with the frequency, intensity, and duration of climate change-related events predicted to increase, posing substantial challenges for human populations and socio-ecological systems (IPCC, 2023b). Older adults may particularly be affected due to age-related physiological changes affecting health and how they relate to social, environmental, and economic conditions that can increase vulnerability to climate change-related risks (WHO, 2015). However, their capacity to respond is influenced by the availability of resources, environments, and structural conditions in which they live. Supporting older adults in this context first requires understanding how these factors interact to enable or constrain behavior in response to climate change-related risks.

1.1 The climate-health-energy nexus

Among the frequently cited impacts of climate change is its effect on human health and the subsequent increasing burden placed on global health and care systems. Climate change has been described as the largest global health threat of the 21st century and one that will increase existing inequalities (Daalen et al., 2024). This implies adverse physical and mental health outcomes, increased morbidity, mortality, and incidence of infectious diseases linked to increased need for a large health workforce, emergency services, and long-term care (Martins et al., 2024). Older adults represent a vulnerable group who will be

disproportionately affected by adverse climate change impacts due to decreased adaptation capacities (IPCC, 2023a).

For older adults, climate change poses heightened risks due to decreased thermoregulation capacity, cognitive function, mobility challenges and multimorbidity, which interact with social and structural determinants (Cartagena-Farias et al., 2025; Núñez-Rodríguez et al., 2025; Prina et al., 2024). At the same time, global populations are living longer (WHO, 2025). While this represents a positive advancement for global health, it coincides with increasing climate change impacts. Greater attention should be given to how older adults can adapt and how their environments can support healthy aging. Haq and Gutman advocate for continued climate gerontology research on population aging, extreme weather events and older adults' resilience and quality of life (Haq & Gutman, 2014). Similarly, the World Health Organization (WHO) and the World Meteorological Organization (WMO) call for integrating healthy aging into climate planning through strong collaboration between the health and climate sectors (WHO, 2022; WMO, 2023).

As societies cope with increasing impacts of climate change, increases in overall energy needs are anticipated (Pais-Magalhães, 2022). Energy for healthcare delivery and sustaining thermal comfort is an enabler of health and wellbeing, yet climate change will disrupt energy systems while increasing demands for energy needed to mitigate climate-related risks and to deliver services. Older adults are susceptible to experiencing energy and fuel poverty, described as having insufficient, affordable, and reliable energy for everyday living (González-Eguino, 2015), which is also associated with adverse health outcomes (Bentley et al., 2023).

These interconnections suggest that climate change-related risks and supporting older adults must account for the interactions in this nexus (Katsaros et al., 2024). Health outcomes and the capacity to respond are the result of individual characteristics and how they are shaped by broader conditions such as energy affordability, public infrastructure, housing, financial resources, and available health and care services. The climate-health-energy nexus therefore merits focused attention, and its interconnections can be examined to understand how individual and broader structural conditions shape older adults' responses to climate-related risks and where identify where and how support can be given.

1.2 Behavioral and structural determinants of older adults' responses

A growing body of work supports the view that older adults can exercise greater agency in responding to climate-related challenges. Policies, participatory processes, and community and system-level adaptations have been identified as opportunities for enabling behavior change (WHO, 2022). This view is reinforced by the Sendai Framework for Disaster Risk Reduction, which emphasizes enabling people and their communities to anticipate, prepare for, and reduce risks (UNDRR, 2015). Climate gerontology similarly conceptualizes older adults as active participants in mitigation, possessing valuable knowledge, skills, and social positions that solutions can leverage. The *Green Longevity Framework* likewise emphasizes using existing infrastructure to support equitable, healthy aging (Zhang, 2025).

Although older adults are increasingly recognized as potential agents of change, evidence of their active contribution to climate mitigation, adaptation, and social transformation remains limited. Supporting behavior change requires systems and infrastructure that enable sustainable practices while acknowledging the contextual constraints that shape individual actions (Nielsen et al., 2024; Prina et al., 2024). This shows how broader social, physical, and organizational environments shape opportunities for older adults. This perspective is supported by Katey and Zanu, who found that community contexts leveraging knowledge sharing, participation, and leadership are central to shaping behavioral outcomes (Katey & Zanu, 2024), indicating a strong need for context-specific, tailored, and action-oriented information.

Understanding the behavioral and structural determinants is first necessary for understanding how to effectively support older adults. *Climate services* are a potential approach for applying this understanding into developing practical decision-support, enhancing preparedness, adaptation, and health outcomes. Climate services describe climate-related data, information, and knowledge used to support adaptation, mitigation, and disaster risk management (Hewitt et al., 2012). In operationalizing climate gerontology, green longevity, and global frameworks, climate services can support end users (e.g., older adults, organizations, communities, governments) by providing tailored risk assessments, early warnings, and guidance informing decisions about health services, preparedness, and community resilience, which help reduce vulnerability and strengthen adaptation. In considering the broader structural and environmental conditions in which older adults live, climate services can deliver context-specific information. This responds to the lack of support identified by Prina et al. and the call for actionable solutions by Nielsen et al. by providing decision support tools directly relating to planning and action.

Climate services utilization is characterized by significant gaps. Although the connection between climate change and health is widely acknowledged, climate information is seldom integrated into health sector decision making (WMO, 2023). Where climate services do exist, uptake is limited because of accessibility, data integration, and climate literacy challenges in health sectors. This reflects similar barriers in other fields (Jacob et al., 2025) illustrating the *useability gap*, which describes the disconnect between the production of climate information and its use in decision making (Dilling & Lemos, 2011). For older adults, this may describe whether the opportunities and resources required to act exist in the contexts of the environments in which they live.

Finally, older adults are often grouped with other vulnerable populations, despite having distinct considerations and resources (Katsaros et al., 2026). Limited consideration of older adults as a heterogeneous category in research and policy has contributed to a lack of data and consequently limited tailored support services. Evidence suggests that climate service uptake is shaped by social and contextual factors, which are poorly understood and incorporated into development (Reveco-Umaña, 2023). Therefore, to design support for older adults in the climate-health-energy nexus a comprehensive understanding of where the influences lie and how they shape behavior is required, enabling analysis of how structural conditions affect behaviors and the implications for developing support.

1.3 Understanding behavioral and structural determinants

Qualitative methods are well-suited for understanding older adults' unique experiences and how the conditions and environments in which they live shape their behavior. This research was conducted to understand behavioral and structural determinants shaping climate-, health-, and energy- related behavior among older adults and implications for multi-level support. To do this, the Behavioral and Structural Influence Sphere (BSIS), which integrates the Capability Opportunity, Motivation, Behavior, model (COM-B) and the Social-Ecological (SEM) was developed and used in a qualitative case study with older adults and stakeholders in Taiwan. The integrated framework enables the mapping of barriers and enablers of behavior across behavioral components and socio-ecological levels to identify potential effective entry points for supporting older adults in the climate-health-energy nexus.

2. Materials and Methods

2.1 Theoretical approach using behavioral and socio-ecological determinants

Understanding the interactions of behavioral and structural determinants in the climate-health-energy nexus requires investigation into the conditions influencing behavior and the wider context in which those behaviors occur. The Capability Opportunity, Motivation, Behavior, model (COM-B) and the Social-Ecological Model (SEM) were integrated together as a lens to explore this approach.

According to COM-B (Fig. 1), behavior is described by the interaction of three main conditions: capability, opportunity, and motivation (Michie et al., 2011). The model assumes dynamic interactions between three core components which result in specific behavioral outcomes. Examples of each component in context of climate change, health, and energy and subcomponents are likewise depicted.

COM-B has been applied in research with older adults to understand physical activity levels (S. Chen et al., 2025), frailty (Barrado-Martín et al., 2025), and interventions in care settings (McMichael et al., 2023). It has also been applied to understand climate- and energy-related behavior, such as barriers and facilitators to connecting to a low-carbon energy source (Smith & Doughty, 2025) and household energy efficiency and use (Composto & Weber, 2022). These examples show that COM-B is relevant for understanding the conditions that influence climate, health, and energy behaviors.

However, COM-B on its own lacks depth in understanding macro-level influences on behavior, a restraint that can be addressed by applying SEM in parallel. SEM (Fig. 2) frames behavior within larger social, environmental, structural, and contextual conditions unique to older adults (e.g., housing conditions, built infrastructure, social groups, community membership) that shape COM-B components (McLeroy et al., 1988). SEM describes five interconnected and mutually reinforcing levels that influence behavior: individual, interpersonal, community, institutional, and policy. SEM is particularly well-suited for work with aging and older adults because it considers micro-level influences which often contribute to

marginalization, including socioeconomic status and geographic location and how these are connected to broader environmental and structural influence across interconnected socio-ecological layers that shape the capability to respond to risks.

SEM has been applied to research with older adults to understand physical activity levels (Meghani et al., 2023), adoption of online health technologies (Jiang et al., 2025), nutrition-related behaviors (Sadarangani et al., 2020). As climate change has increasingly been recognized as a public health issue, studies have applied SEM in climate-health related research involving heat-related topics (Lai et al., 2025), water and energy conservation behaviors (Kurz et al., 2005), and adaptation to poor air quality (Palinkas et al., 2023). While SEM identifies multi-level influences on behavior, it does not specify behavioral conditions through which behaviors occur, a gap filled by COM-B.

Use of COM-B and SEM together has already demonstrated value in health-related contexts examining physical activity (van Kasteren et al., 2020), vaccine acceptance (Bell et al., 2022), dietary habits (Kitunen et al., 2025), and the adoption of health-promoting lifestyles (Xing et al., 2025). Nguyen-Trung et al. integrate COM-B and SEM into the SeCOM-B model to address wicked problems like climate hazards (Nguyen-Trung et al., 2025). This research builds upon combined COM-B and SEM approaches by integrating COM-B into the socio-ecological levels to examine behavioral and structural determinants shaping older adults' behaviors within the climate-health-energy nexus.

2.2 The Behavioral and Structural Influence Sphere (BSIS)

BSIS emerged through a literature review process identifying a gap in understanding behavioral and structural determinants among aging and older adults within the climate-health-energy nexus. A systematic literature revealed multiple social-ecological influences shaping how older adults can adapt to and mitigate impacts of climate change on health (Katsaros et al., 2026). Yet, no existing framework simultaneously incorporated individual level behavioral change components and external influences in a way where qualitative data could be used to understand how determinants interact across multiple levels of influence and identify potential entry points for supporting older populations.

Comparing two models revealed alignment: COM-B components (capability, opportunity, motivation) are influenced by SEM layers. Based on this overlap, both were integrated by embedding COM-B components within each social-ecological layer. Through an iterative process with a team of researchers, the framework was refined until it was conceptually clear, resulting in the final version (Fig. 3). This was selected for its ability to visualize pathways and complex interconnections. The BSIS framework is intended to be used as a visual tool to map qualitative findings as demonstrated in the following case study. Figure 3 shows how BSIS embeds COM-B within the nested layers of SEM, with behavior situated at the center. The three main COM-B components and their sub-components are distributed across each SEM layer, for a total of 30 dimensions. Layers are organized as nested layers, from individual-level influences closest to behavior, to policy-level influences at the outermost layer.

The framework has several assumptions:

- Overlap of COM-B and SEM concepts may occur within and across several levels of influence.
- Themes mapped onto the framework align with at least one or more COM-B components which are influenced by one or more SEM layers.
- Themes overlapping with several components should be mapped onto all relevant dimensions.
- Behavioral outcomes are the collective outcome of all COM-B components and SEM layers of influence.

In this study, BSIS was applied to map barriers and enablers identified among older adults and stakeholders in Taiwan, enabling joint analysis of behavioral and structural determinants, and the identification of potential entry points for multi-level support.

3. Results

3.1 Case study: Behavioral and structural determinants among older adults in Taiwan

3.1.1. Case study background and methods

Taiwan is experiencing rapid population aging and transitioning into a super-aged society, bringing challenges for health system capacity and energy demand. Population aging is linked to increased healthcare expenditure and overburdened systems (Hsu & Lin, 2024). At the same time, rising temperatures are associated with increased mortality and care costs for older adults, with extreme heat days and heat-related mortality projected to rise (C.-C. Chen et al., 2021; Lung et al., 2024). Access to appliances, energy sources, and the conditions of the environments in which older adults live have been identified as key factors influencing wellbeing (Huang, 2015), highlighting the need for adaptation measures and for individuals to adopt initiative-taking behaviors to mitigate risk and maintain good health. This case study examines behavioral and structural determinants that enable or constrain behaviors that promote environmental sustainability, health, and energy efficiency, using the BSIS framework to identify barriers and enablers. Comparative analysis enables identification of key behavioral and structural influences, entry points for change, potential entry points for support, and priority action areas.

Thematic analysis and framework mapping were employed to analyze semi-structured interviews with older adults aged 50 + and stakeholders in Yilan and Yunlin counties, Taiwan and then analyzed using a hybrid inductive-deductive coding approach and mapped onto the BSIS framework. Interview guides were structured on the COM-B components and SEM layers with four sections: demographic questions, followed by questions on climate change, health and care, and energy-related behaviors informed by capability, opportunity, and motivation. Four guides were tailored to each SEM layer: individual, interpersonal, community/organizational (sharing one guide), and public policy. Two native Chinese speaking team members translated each guide into Mandarin Chinese. Participants were recruited

through professional networks and organizations in Taiwan working with older adults using nonprobability sampling. Following informed consent, two research team members conducted in-person interviews in Mandarin Chinese which were recorded, transcribed, translated into English, and checked for accuracy by the interviewer. Identifying information was removed to uphold anonymity.

Hybrid, reflexive thematic analysis following Braun and Clarke and Fereday and Muir-Cochrane guided the interview analysis. This approach was used because it allows themes to emerge directly from the data while enabling application of the BSIS framework to add structure and utility (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006). MAXQDA 2022 was used for coding and theme development. The first author reviewed interview transcripts and generated initial inductive codes relating to the research questions using a reflective process. As additional interviews were analyzed, codes and themes were systematically refined. Deductive code labels using COM-B components and SEM layers were applied in parallel. Overarching themes, categorized as barriers or enablers, were copied to an Excel table. Within each theme, subthemes defined by assigning SEM levels and coding their function within COM-B domains. These subthemes served as conceptual markers, used to visually map themes onto the framework. Mapping results were reviewed by a second researcher, with inconsistencies discussed within the research team. After mapping was complete, the framework was analyzed. The data analysis process is shown in Table 1.

Table 1
Data analysis process

Step	Process
1	Review data
2	Creation of initial codes (inductive)
3	Application of code labels to relevant text
4	Initial themes created using codes, parallel coding of COM-B and SEM components (deductive)
5	Refinement of themes and identification of framework markers
6	Systematic mapping of subthemes onto two separate frameworks (for barriers and enablers) using alphabetic theme markers
7	Analysis of framework mapping
8	Presentation and interpretation of data

3.1.2 Case study results

15 interviews (Table 2) were conducted from November 2023 to February 2024 in Yilan and Yunlin Counties. Nine themes for barriers and eight for enablers were identified. Supplementary document 1 provides an overview of themes and subthemes, with illustrative excerpts that informed the definition of conceptual markers applied in the framework mapping.

Table 2
Overview of interview participants

Participant ID	Relevant SEM layer(s)	Occupation
T01	interpersonal, organizational	Case worker
T02	community	Manager, community association
T03	organizational	Company owner, energy sector
T04	organizational	Nurse
T05	policy, organizational	Researcher
T06	policy	Researcher
T07	individual	Older adult
T08	organizational	Nurse
T09	policy	Case worker, government- level
T10	community, policy	Therapist
T11	policy, organizational	Case worker
T12	organizational	Home caregiver
T13	individual, community, organizational	Older adult, community volunteer, former nurse
T14	individual, community	Older adult, community volunteer
T15	individual	Older adult

Barriers to climate-, health- and energy-related behaviors

Nine themes with 38 subthemes were identified. Table 3 presents the themes (assigned alphabetic labels A to I), subthemes (outermost to innermost SEM layer), markers, and corresponding COM-B components and SEM levels associated with each subtheme marker.

To visualize themes across behavioral and socio-ecological dimensions, 38 markers in Table 3 are mapped onto the BSIS framework. Markers are mapped at theme level using single alphabetic labels, allowing for a broader analysis of patterns, groupings, and density in dimensions rather than comparison of subthemes. The outcome of the barrier framework mapping is presented in Fig. 4. Descriptive statistics of SEM level and COM-B barrier marker distribution are found in Tables 4 and 5, respectively.

Table 3

Presentation of themes representing barriers to behaviors supporting environmental sustainability, health, and energy efficiency, corresponding to Fig. 4

Theme	Marker	Sub-theme	SEM component	COM-B component ^a
A: Policy implementation gaps Weaknesses and gaps in existing policy design and implementation reflect a lack of understanding of local conditions and target populations. This includes incomplete policies, limited resources, and capacity to implement policies, and weak cross-sector and system integration.	A1	Poor understanding of the local context and needs of target populations results in inadequate policies and services that are ineffective and inequitable.	policy	C- psychological
	A2	National strategies and laws do not consider the available resources and conditions to implement them on the local level. Complex application and approval processes impede services for older adults.	policy	O-physical
	A3	Superficial actions show limited investment and urgency.	policy	M- reflective
	A4	Weak implementation of policies limit care provision and rely on involvement of the private sector to implement initiatives. Complicated administrative processes limit contributions from the private sector.	organizational	O- physical
	A5	Poor implementation of policy on local levels limits access to services for older adults.	individual	O-physical
B: Infrastructure, built environment, and geographic location inequalities Public infrastructure, changes to the built	B1	Lack of investment in infrastructure and basic public utilities in constrain daily functioning and access to services.	policy	O-physical
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^a
environment, and geographical location affect exposure to climate and weather risks and access to services.	B2	Older adults living in rural areas face transportation barriers because of limited public infrastructure and utilities resulting in reduced access to health and care services.	community	O-physical
	B3	The built and environmental conditions limit mobility, safety, and access to services, leading to increased temperature and reliance on AC.	individual	O- physical
C: Climate and weather-related disruptions to mobility, access, and participation Climate and weather-related conditions interrupt daily routines and functioning of older adults, constraining mobility, limiting access to health and care services, and negatively influencing participation in community and social activities.	C1	Adverse weather disrupts participation in community-based events and courses on sustainability and health.	community	O- physical
	C2	Adverse weather negatively impacts the mobility and safety of older adults in accessing health and care services.	individual	C- physical
	C3	Adverse climate and weather conditions impedes daily care routines, outdoor activities, exercise, and participation.	individual	O- physical
	C4	Adverse weather conditions negatively influence motivation to participate in social and educational activities and to travel to medical appointments.	individual	M- automatic
D: Energy affordability and household energy vulnerability Energy sources and appliance constraints	D1	Inadequate subsidies limit access to energy-efficient appliances and affordable energy use.	policy	O-physical
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^a
influence how older adults use energy, limiting access to safe and efficient options, increasing reliance on unsafe traditional fuel sources and, constraining adoption of energy efficient appliances because of financial, informational, or habitual barriers.	D2	High costs of electricity act as a barrier to maintaining optimal temperature in institutions.	organizational	O-physical
	D3	Cognitive, knowledge, and awareness restraints limit uptake and adoption of energy-efficient appliances and sources.	individual	C-psychological
	D4	Energy poverty and insufficient heating and cooling is driven by energy-dependent medical devices and unstable access to appliances and energy sources.	individual	O-physical
	D5	Habits reinforce the use of unsafe, traditional heating methods.	individual	M- automatic
	D6	Reluctance to invest in or use energy-efficient appliances and subsidies.	individual	M- reflective
E: Gaps in providing care and support Gaps in providing care and support affect older adults due to limited family involvement, insufficient understanding of the caretaking roles, social isolation in rural areas, exclusion of foreign workers in policy frameworks, and unequal access care technologies.	E1	Policy blind spots regarding foreign workers employed by families negatively affect quality of care.	policy	O- physical
	E2	Services, such as in-person visits, are limited and constrained, especially in rural areas.	organizational	O- physical
	E3	Geographic distance from family members and living in rural areas limits availability of caregiving support.	interpersonal	O- social
	E4	Insufficient caretaking capacity due to limited capability and understanding of the	interpersonal	C-psychological
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^a
		role constrains quality of care.		
	E5	Living alone, especially with impaired health or limited digital access, isolates older adults and contributes to communication and care gaps.	individual	O- social
F: Drivers of maladaptive behavior Behavioral influences interfere with the adoption of positive changes, shaped by past life experiences, misperceptions of one's health or risk, preferences and habits, and socially constructed gender role expectations.	F1	Community-level social and gender norms shape perception of appropriate participation in activities.	community	M- reflective
	F2	Underestimating personal needs and low perception of entitlement limit uptake of care and support services.	individual	M- reflective
	F3	Established habits, attitudes, preferences, and emotional responses influence participation and the use of heating and cooling technologies.	individual	M- automatic
G: Economic and financial constraints Financial constraints on the individual, family, and policy levels limit access to services and affect the ability of older adults to mitigate risks.	G1	Insurance limitations, low-income thresholds, and reduced funding limit access to services.	policy	O- physical
	G2	Insufficient financial support or lack of support from family members constrains access to care and resources.	interpersonal	O- social
	G3	Personal economic instability and income limitations limit access to energy and technologies.	individual	O- physical
	G4	Reluctance to spend money on energy,	individual	M- reflective
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^a
		appliances, health, or care.		
H: Knowledge and information gaps Deficits in knowledge and information, including limited digital literacy, unclear or inadequate communication from service providers and media, influences access to services and informed decision-making.	H1	Unreliable and inadequate information complicates planning and decision-making.	policy	O- physical
	H2	Limited literacy and awareness of options negatively influence access, interpretation, and application of information.	individual	C- psychological
	H3	Gap in accessing information and resources due to inability to access digital information services and isolation.	individual	O- physical
	H4	Limited perception of climate risk and low perceived immediacy of impacts reduces uptake of sustainable and health promoting practices.	individual	M- reflective
I: Health-related limitations Physical, mental, and cognitive impairments affect daily functioning and physical capacity and require increased reliance on health and care services.	I1	Decreased mobility leads to reduced contact with others and increased loneliness and isolation.	interpersonal	O-social
	I2	Age-related physical and sensory limitations constrain mobility, communication, and response to weather and climate conditions.	individual	C- physical
	I3	Cognitive decline and dementia limit independence and daily functioning.	individual	C- psychological
	I4	Adverse climate and weather conditions negatively affect mood and emotions.	individual	M- automatic
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Table 4
Barrier marker distribution across SEM levels of influence

Level of influence	n (barrier markers)	% total
Policy	8	21.1
Community	3	7.9
Organizational	3	7.9
Interpersonal	4	10.5
Individual	20	52.6
Total	38	100

Table 5
Barrier marker distribution across COM-B components

COM-B Component	Subcomponent	n (barrier markers)	% total	% within component
Capability	Physical	2	5.3	28.6
	Psychological	5	13.2	71.4
	Total	7	18.4	100
Opportunity	Social	4	10.5	19.0
	Physical	17	44.7	81.0
	Total	21	55.3	100
Motivation	Reflective	6	15.8	60.0
	Automatic	4	10.5	40.0
	Total	10	26.3	100
Overall	--	38	100	--

Barrier markers were unevenly distributed across the BSIS framework. Across levels of influence, most were concentrated at the individual level (52.6%, n = 20), followed by policy (21.1%, n = 8), and interpersonal (10.5%, n = 4) levels, with community and organizational levels least represented (7.9%, n = 3 each). By COM-B component, opportunity accounted for most barriers (55.3%, n = 21), followed by motivation (26.3%, n = 10), and capability (18.4%, n = 7), with physical opportunity comprising 44.7% (n = 17) of all markers. Capability, specifically physical capability, accounted for the fewest barriers (n = 2, 5.3%). The highest concentrations were seen in physical opportunity-individual and physical opportunity-policy dimensions (n = 6 each), followed by individual-reflective and automatic motivation dimensions (n = 4 each).

Overall, barriers to behavior change were influenced by individual-level constraints related to physical opportunity (e.g., infrastructure, built environment, resources, services), with few barriers related to capability or to community and organizational level influences.

Enablers of climate-, health-, and energy-related behaviors

Eight themes with 31 subthemes were identified as enablers. Table 6 presents the themes (alphabetic labels A to H), subthemes (outermost to innermost SEM layer), markers, and corresponding COM-B and SEM components associated with each subtheme marker.

Table 6
Presentation of themes representing enablers, corresponding to Fig. 5

Theme	Marker	Sub-theme	SEM component	COM-B component ^b
A: Economic and policy support for older adults Economic and policy support like subsidies, private sector assistance, and community associations enable older adults to access services and resources.	A1	Effective public policy increases access to subsidies for long-term care, transportation, training, agricultural support, and initiatives that promote energy-efficiency, along with insurance schemes for health and care services.	political	O- physical
	A2	Private sector organizations fill gaps in government funding to provide technology, sustainability initiatives, and expand insurance coverage.	organizational	O- physical
	A3	Community associations support older adults and fill gaps left by government funding.	community	O- physical
	A4	Family financial capacity to enable access to caregiving support.	interpersonal	O- physical
B: Enabling infrastructure and built environment Enabling infrastructure, architectural design, and built environments to facilitate older adults in mobility, social engagement, and safe, sustainable, living conditions.	B1	Transportation and mobility services facilitate access to social participation in events and medical care.	policy	O-physical
	B2	Accessible community spaces and community-owned resources enable mobility, physical activity, and social engagement.	community	O- physical
	B3	Green building principles, climate resilient building design, and energy efficient construction help buildings stay at safe temperatures.	organizational	O-physical
C: Responsive health and care systems Responsive health and care systems meet the needs of older adults by overcoming mobility	C1	Health system infrastructure has structures that enable responsive care processes.	policy	O-physical
^a C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^b
barriers and providing need-based services.	C2	Community-based dementia prevention programs support delaying functional decline.	community	C- psychological
	C3	Community-based programs and targeted support services facilitate access to long-term care and meal services.	community	O-physical
	C4	Structured assessment and home-based services reduce mobility barriers and provide access to tailored health and care.	organizational	O- physical
D: Access to and utilization of energy efficient devices and supportive technologies	D1	Subsidies enable acquiring energy efficient and remote care technologies supporting health and thermal regulation.	policy	O-physical
Supporting the use of devices and technologies enables efficient, safe, and effective care for older adults.	D2	Remote monitoring and communication technologies support safe and efficient caregiving for families.	interpersonal	O- physical
	D3	Smart automated features support individual capacities for safe and energy efficient use of technologies.	individual	C- psychological
	D4	Perceived cost saving and efficiency of technology influences decisions on technology uptake.	individual	M- reflective
E: Supportive social and community environment	E1	Community engagement encourages supportive behaviors through social practices, culture, and collective expectations.	community	O- social
Supportive social and community environments facilitate access to services, quality care, engagement, and resources.	E2	Community-based services enable outreach and access.	community	O-physical
	E3	Structured community learning enables knowledge	organizational	C- psychological
^b C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^b
		uptake and access to information.		
	E4	Infrastructure, services, and programs support sustainable and supportive community environments.	organizational	O-physical
	E5	Enabling caregiving support allows continuous, at-home care.	interpersonal	O- physical
F: Access to knowledge and information Diverse information channels enable dissemination of knowledge and information	F1	Dissemination of institutionalized information through media and organized structures.	policy	O-physical
	F2	Community-based social contacts support information dissemination.	community	O- social
	F3	Structured community courses provide organized information pathways.	community	O-physical
	F4	Contact with organizations provide organized information pathways.	organizational	O-physical
	F5	Personal networks serve as key channels for the transmission of information and knowledge.	interpersonal	O- social
G: Adoption of adaptive habits Adaptive habits like daily practices and deliberate actions promote energy efficiency, health, and environmental sustainability	G1	Conservation practices in shared community environments.	community	M- reflective
	G2	Resource conserving practices are shaped by lived experience and cultural norms.	individual	M- automatic
	G3	Deliberate practices and actions to conserve resources and promote health.	individual	M- reflective
H: Individual capacities and dispositions shape behavior and lifestyles	H1	Cognitive capacity facilitates independent knowledge acquisition and use.	individual	C- psychological
^b C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

Theme	Marker	Sub-theme	SEM component	COM-B component ^b
Individual cognitive abilities and motivation shape uptake of practices, enable decision-making, and engagement in activities.	H2	Proactive engagement in meaningful activities and lifestyles.	individual	M- reflective
	H3	Past experiences and lifelong habits support positive outcomes.	individual	M- automatic
^b C denotes capability, O denotes opportunity, and M denotes motivation in the COM-B model				

The 31 markers in Table 6 are mapped onto the BSIS framework to visualize themes across behavioral and socio-ecological dimensions, with each theme labeled using a single letter. The mapping outcome for enabler markers is presented in Fig. 5. Descriptive statistics of SEM level and COM-B enabler marker distribution are found in Tables 7 and 8, respectively.

Table 7
Enabler marker distribution across SEM levels of influence

Level of influence	Enabler markers (n=)	% total
Policy	5	16.1%
Community	9	29.0%
Organizational	6	19.4%
Interpersonal	4	12.9%
Individual	7	22.6%
Total	31	100,0%

Table 8
Enabler marker distribution across COM-B components

COM-B Component	Subcomponent	n (enabler markers)	% total	% within component
Capability	Physical	0	0	0
	Psychological	4	12.9	100
	Total	4	12.9	100
Opportunity	Social	3	9.7	14.3
	Physical	18	58.1	85.7
	Total	21	67.8	100
Motivation	Reflective	4	12.9	66.7
	Automatic	2	6.5	33.3
	Total	6	19.35	100
Overall	--	31	100	--

Enabler mapping presented a more distributed pattern across levels of influence, with the highest concentration on the community level (29.0%, n = 9), followed by individual (22.6%, n = 7) and organizational (19.4%, n = 6) levels. Policy (16.1%, n = 5) and interpersonal (12.9%, n = 4) levels were least represented. Across the COM-B components, enablers were most strongly associated with opportunity (67.8%), particularly physical opportunity (58.1%, n = 18). Within motivation (19.35%), reflective motivation (12.9%) was more prominent than automatic (6.5%), while capability (12.9%) was represented exclusively by psychological capability (12.9%). No physical capability markers were present.

The results suggest that enablers are mostly driven by conditions formed by higher- level structural and contextual determinants, especially related to environmental and material influences on behavior (e.g., resource availability, policy, services) alongside the importance of cognitive and mental abilities and motivation.

Comparative analysis of behavioral and structural influences and implications for multi-level support

Mapping barriers and enablers onto separate BSIS frameworks enabled a comparative analysis. Barriers were clustered on the individual level, while enablers were more distributed across policy, community, and organizational levels. This distribution shows that barriers were mostly identified at the individual level, while enablers appeared more frequently at higher structural levels, especially within community and organizational settings. The high concentration of enablers at the community level in comparison with relatively few barriers, similarly, points to the community level as a promising potential entry point for supporting older adults.

Across both the barriers and enablers mapping, physical opportunity was the most dominant component, indicating a significant role of social and environmental conditions in shaping behavior and identifying physical opportunity as a priority action area. Capability, especially physical capability, was least represented, suggesting that physical and psychological limitations may be partially mitigated through appropriate support when resources and services like enabling infrastructure and responsive health and care systems are available. Overall, reflective motivation was more prominent than automatic motivation, suggesting deliberate decision making has a larger impact on behavior than habit. This points to the potential for decision support to influence individual-level behavior. Findings of the comparative analysis show that behavior depends on enabling conditions within a person's environment, which are shaped by larger policy, community, and organizational structures.

4. Discussion

This study investigated behavioral and structural determinants shaping climate-, health-, and energy-related behaviors among older adults and the implications they have for multi-level support. Findings show that behaviors are influenced by interconnected individual and structural contexts. Barriers were concentrated on the individual levels while enablers were more distributed across broader social-ecological levels, especially in community and organizational settings. Across barriers and enables, the most prominent behavioral component was physical opportunity, emphasizing the importance of environments, resources, and services in influencing older adults' capacity to act. By examining how behavior is shaped by broader structural and environmental influences, BSIS enabled a more comprehensive understanding of where and on what socio-ecological levels determinants originate and how they influence behavior.

These findings contribute to the growing fields of climate gerontology and green longevity by showing how older adults' responses within the climate-health-energy nexus must account for more than just individual behavior alone. The capacity to act is mediated by broader conditions. The methodological approach used in this paper is relevant to environmental gerontology because it helps to identify how individual barriers experienced by older adults result from and are reinforced by structural and environmental conditions.

The findings align with existing work relating to behavior and support in nexus contexts. Cremades et al. state that decision making within complex triple nexus problems is dependent on long-term, cross sector structures, with opportunities created by organizations, communities, and policies (Cremades et al., 2019). Similarly, Katey and Zanu identify the community level as a leverage point for strengthening older adults' climate resilience, while highlighting that constraints at this level are formed by the context and systems in which people live (Katey & Zanu, 2024). The mapping analysis had similar results, with enablers at outer levels largely shaped physical opportunity at the individual level, forming the conditions by which a person can act. Examples of enabling conditions included shared community spaces and accessible health and care services, showing how older adults' environments shape their capacity to act. Key pathways emerged across community, organizational and interpersonal levels, each with trusted

actors like social workers, friends, family, and village heads who can be used to reinforce and transmit information. This aligns with MacInnes et al. who found that individuals place greater trust in community and interpersonal networks than policy-level sources (MacInnes et al., 2026). This reinforces the community level as a critical leverage point, suggesting a multi-level approach supporting older adults in responding to climate-, health- and energy-related challenges. The findings also support research suggesting response to climate change-related risks are embedded into broader social contexts such as policy conditions.

4.1 Implications for multi-level support

The findings identify opportunities for multi-level support across policy, community, organizational, interpersonal, and individual levels. Climate services are one mechanism through which support can be operationalized, translating climate information into context-specific information for older adults and stakeholders supporting them. At the policy level, climate services can function as decision support and information tools, informing investment in energy efficient and climate resilient infrastructure and public spaces, guiding development of context-specific heat action plans, and informing financial support mechanisms like subsidies or incentives for energy-efficient and health supportive technologies.

At the community level, climate services can support education and outreach by providing relevant community-level information that enables local adaptation to mitigate climate and health risks for older community members. Frequently visited community spaces and trusted actors can be utilized to influence community norms and collective practices like recycling, volunteering, physical activity, and community cohesiveness.

Organizational settings with frequent contact with older adults, such as senior centers and medical institutions, can embed climate services into routine service delivery, which improves accessibility by reaching older adults in familiar settings they already engage with. Additionally, user-friendly climate services can support organizations to remain responsive to the changing needs of older adults during extreme weather events or when faced with mobility constraints. These efforts can be reinforced by trusted interpersonal contacts such as village heads, social workers, and family members. At the individual level, climate services should provide tailored, context-specific information including relevant examples of climate, health, and energy behaviors, and action-oriented support tools in accessible formats.

4.2 Contributions and limitations

Applying BSIS to a qualitative case study revealed patterns, clusters, and relationships across behavioral determinants and levels of influence that may not have been captured solely through thematic analysis. In comparison with existing approaches (e.g., SeCOM-B), BSIS uses a systematic mapping process according to a behavioral (COM-B) condition and socio-ecological (SEM) level to visualize relationships, identify entry points, and priority action areas. This study demonstrates how applying an integrated COM-B/SEM framework consistently across all research stages provides a clear visualization of how

multiple levels and fields of influence shape individual behavior and how conditions can enable or constrain action among older adults.

Some limitations should be noted. BSIS has not been validated on a larger scale, thus findings should be interpreted with caution concerning generalizability beyond the present study context. The case study was conducted with a small number of participants to explore behavioral and structural determinants in this specific context. Thus, barriers and enablers may not be representative of older adults in other settings. Future research should aim to validate the framework across different contexts with a larger sample size. A survey based on BSIS would further strengthen rigor through data triangulation with quantitative data.

5. Conclusion

This study provides evidence that older adults' behaviors within the climate-health-energy nexus are shaped by interacting behavioral and structural determinants across several levels of influence. Using a case study from Taiwan, BSIS was used to map barriers and enablers of behavior, revealing several social, structural, and environmental influences shaping behavior. The mapping further allowed for the identification of potential pathways, entry points, and priority areas for multi-level support. The findings show how conditions surrounding older adults, including community settings, infrastructure, health and care services, and access to resources and support, can constrain or enable behaviors. The prevalence of physical opportunity markers and distribution of enabler markers across broader socio-ecological emphasizes the importance of expanding support for older adults beyond behavior change initiatives on the individual level.

These insights can inform multi-level strategies that address both the individual and structural contexts that shape older adults' responses to climate friendly, health-promoting, and energy-efficient behaviors. Climate services are one mechanism to operationalize support by providing climate information into context-specific and practical decision support tools. Key strengths of BSIS are its ability to integrate barriers and enablers into a single conceptual framework and visual framework. Future research can address limitations in generalizability by validating the framework in diverse environments and settings. As climate change-related events intensify alongside population aging, understanding and addressing multi-level conditions influencing behavior will become even more important to support health and resilience.

Declarations

Author Contribution

KK: conceptualization, methodology, formal analysis, visualization, investigation, writing- original draft. J-T H-L: supervision, writing- review and editing, funding acquisition.

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Data Availability

All relevant data are reported in this manuscript or supplementary materials. Original interview data are not publicly available to protect participant privacy considerations and comply with ethical requirements.

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Figures

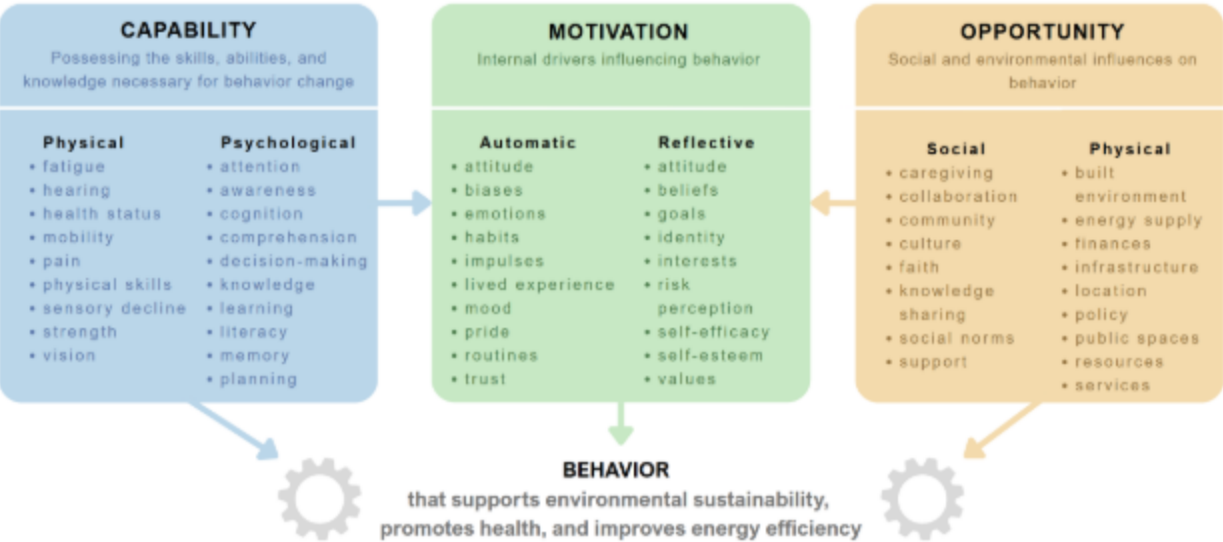


Figure 1

COM-B components influencing behavior change in older adults within the climate- health-energy nexus (adapted from Mitchie et al., 2011)

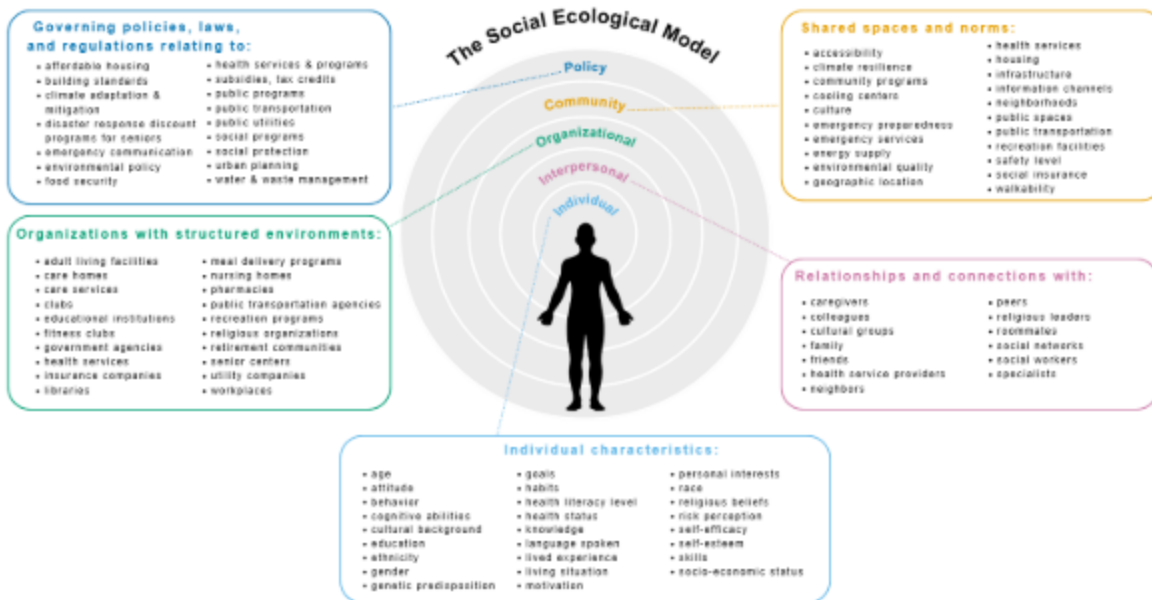


Figure 2

The Social Ecological Model with examples of factors influencing behavior change in older adults within the context of climate change, health, and energy (adapted from McLeroy et al., 1988)

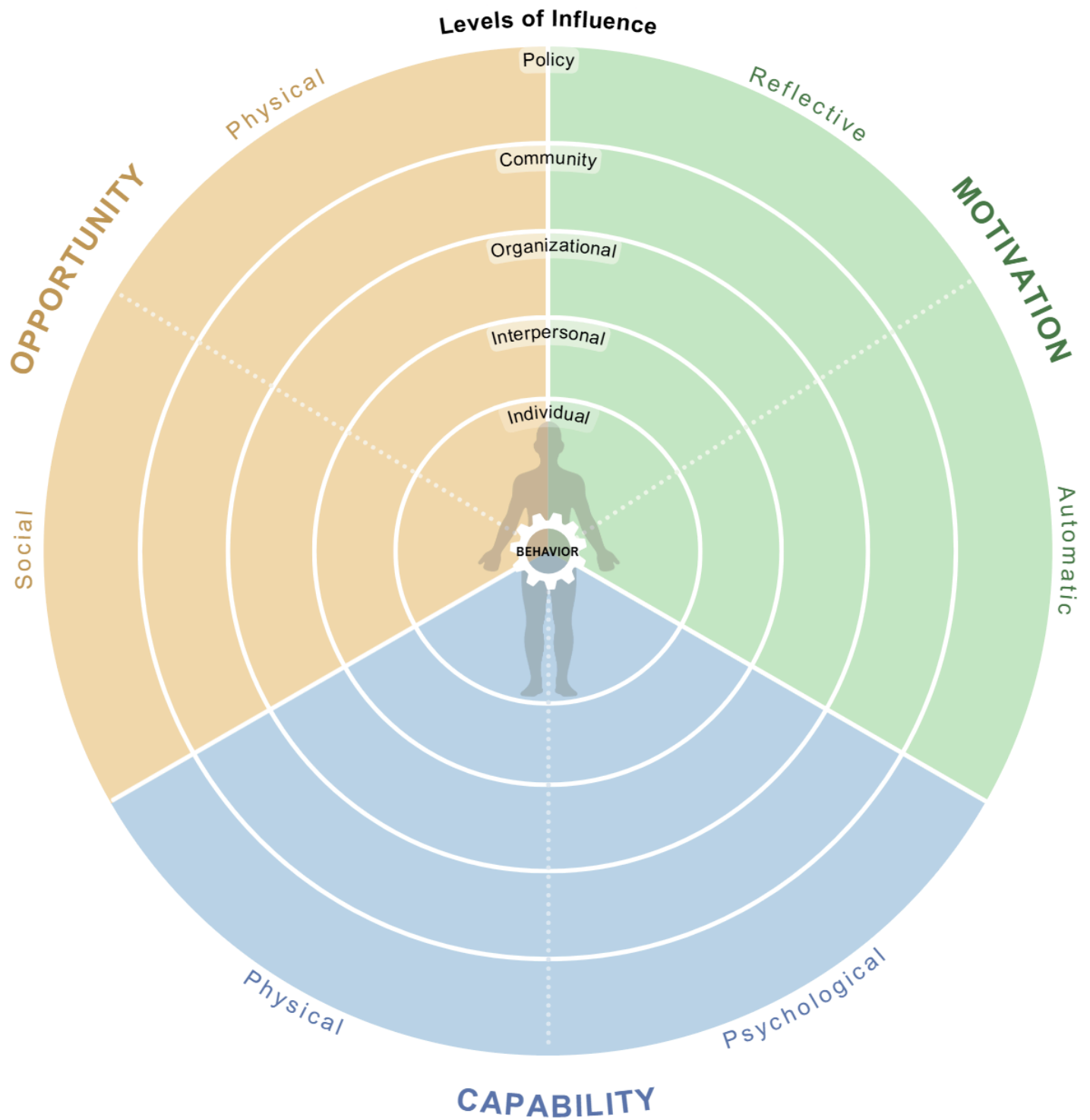


Figure 3

Behavioral and Structural Influence Sphere (BSIS)

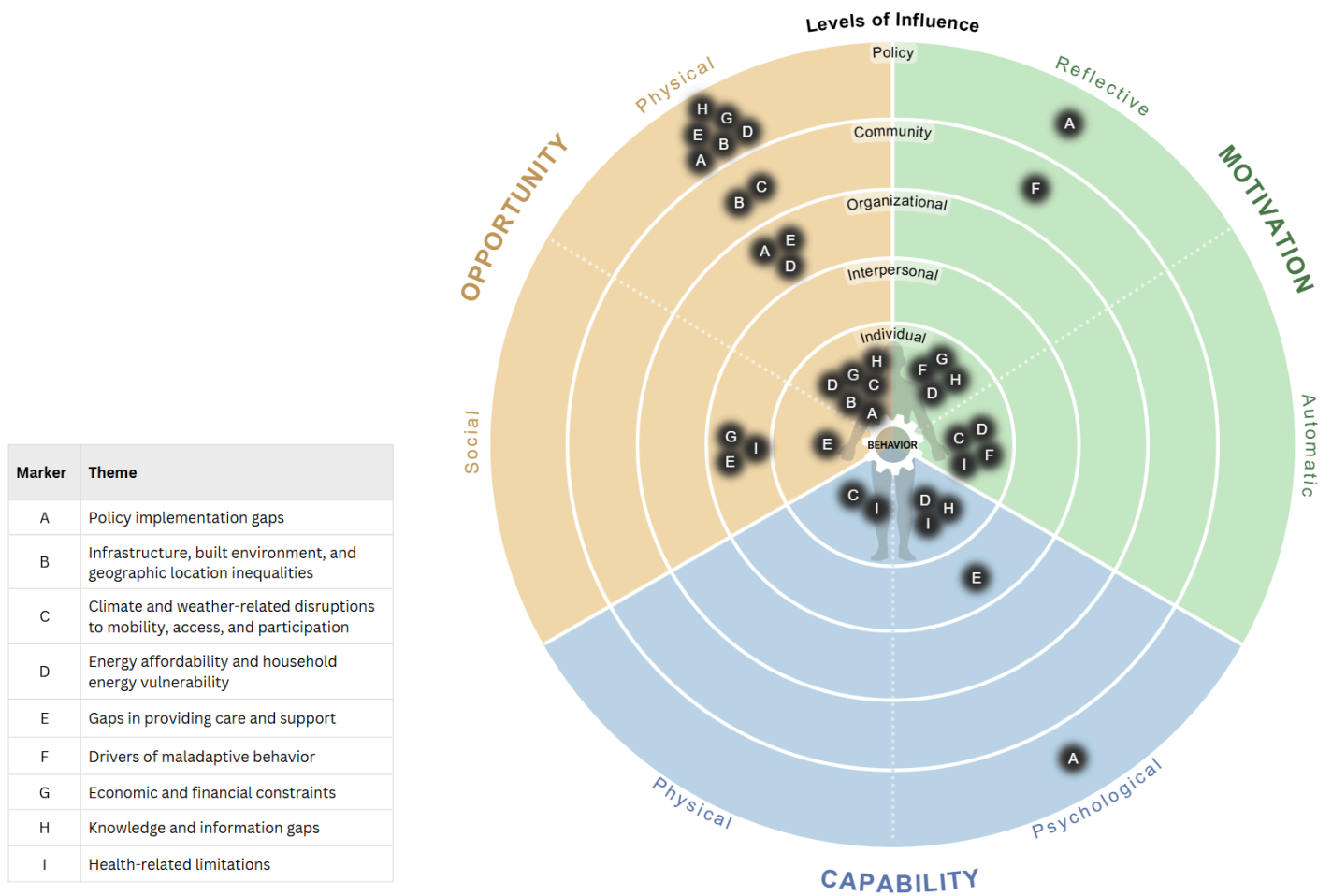


Figure 4

Themes representing barriers to behavior promoting environmental sustainability, health, and energy efficiency mapped onto BSIS

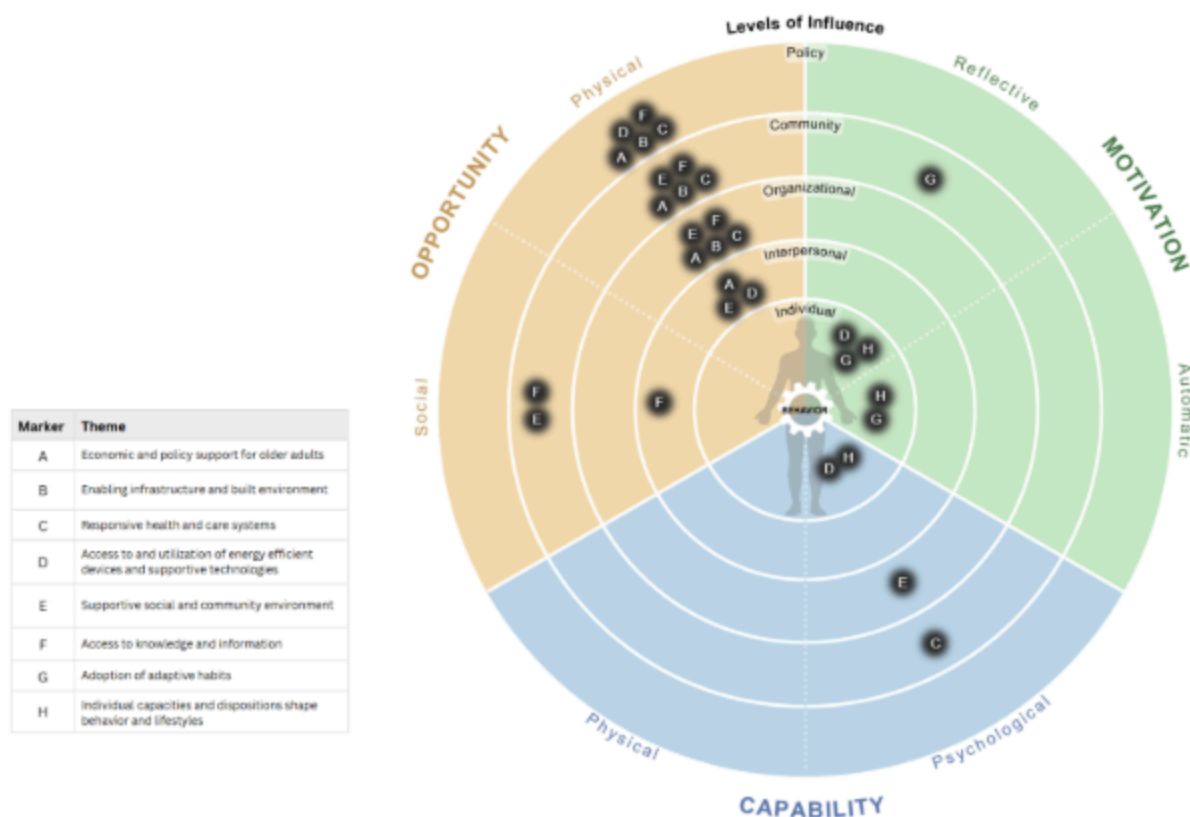


Figure 5

Themes representing enablers to behavior promoting environmental sustainability, health, and energy efficiency mapped onto BSIS

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementarydocument1Illustrativeexamplesofmarkerpoints.pdf](#)