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Exploring the interactions between vulnerability, resilience and adaptation to extreme temperatures

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Abstract

Proposed ways of improving adaptation to climate change have most often been supported by narrowly framed and separate analysis. This article investigates how different levels of vulnerability and resilience interplay with adaptation to extreme temperatures, what is the nature of these relationships and whether lower vulnerability and higher resilience contribute to increased adaptation. This article explores the governance implications of a project that, unlike other, brings together vulnerability, resilience and adaptation assessments. The project has made significant advances in addressing the current deficit integrated assessments for shaping governance propositions. Such propositions argue that the diverse levels of vulnerability and resilience convey important bases for (1) targeting at-risk older individuals; (2) developing vulnerability reduction actions; (3) resilience building actions; and (4) understanding 'success cases' and learn from them for developing appropriate policy measures. Taken together, these propositions offer a social, psychological and health framework not simply for governing extreme temperatures but for governing responses to climate change at large.

Keywords Climate change · Extreme events · Extreme temperature events · Extreme heat events · Heat waves · Extreme cold events · Cold waves · Climate change · Assets · Sense of coherence

1 Introduction and literature review

In recent years the impacts of climate and temperature on human health and wellbeing have been receiving increased attention. Both the Intergovernmental Panel for Climate Change (IPCC) and the World Health Organization (WHO) have reaffirmed that weather, climate and climate variability negatively affect human health (IPCC 2018; WHO 2013). Significant human vulnerability to extreme events has resulted in increased impacts on mortality and morbidity (Anderson et al. 2019; Guo et al. 2018). The increased frequency, duration and intensity of extreme temperatures affect how individuals, communities, cities and nations adapt to such events (IPCC 2018). Extreme

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temperature events are more or less prolonged periods of abnormally hot (heat wave) or cold (cold wave) weather (IPCC 2014, 2018). Older people are considered to be particularly vulnerable to extreme temperatures (Tong and Ebi 2019). Within this age group, health status, sex, marital status, living arrangements and social factors are some of the key determinants of risk (Hajat et al. 2007). Despite this, the health impacts of extreme temperatures are preventable and avoidable (Haines and Ebi 2019; Tong et al. 2016; Astrom et al. 2011) and can be mitigated through strategies aiming at reducing vulnerability, increasing resilience and improving adaptation (Bellamy 2019; Keim 2008), but there are still numerous constraints on implementing solutions (Bellamy 2019). To achieve this, some argue that we need to better understand the factors shaping both vulnerability and resilience, as well as the factors underpinning adaptation decisions and actions (Bankoff 2019; Atteridge and Remling 2018; Lei et al. 2014; Curtis and Oven 2012; Cannon and Muller-Mahn 2010).

It has been argued that interdisciplinary research is needed (Tong and Ebi 2019; Tong et al. 2016) and according to Watts and colleagues (2015) and McMichael and colleagues (2006) a more holistic line of research should address the implications of climate change in regard to the determinants of health and reducing health inequalities (Watts et al. 2018; Marmot 2010). Climate change is also as a threat to sustainable development and the achievement of the United Nations 2030 Agenda for Sustainable Development and its sustainable development goals (SDGs) (IPCC 2018). Climate action, for example, is the focus of SDG 13 which aims to take urgent action to combat climate change and its impacts through targets that specifically focus on enhancing resilience and adaptation to climate related hazards and natural disasters, such as extreme temperatures; integrating climate change measures into policies, strategies and planning at different levels, as well as; improving education, literacy and awareness of the risks and impacts of hazards for reduced vulnerability, enhanced resilience and improved adaptation (UN 2015).

Vulnerability, resilience and adaptation mean different things to different people and have been conceptualised in many different ways depending on disciplinary traditions (Lei et al. 2014; Eakin and Luers 2006). Nevertheless, they are intrinsically linked, but despite growing scientific interest and attention, few interdisciplinary scientists have examined how vulnerability, resilience and adaptation interact (Lei et al. 2014). Furthermore, only by integrating them is possible to understand how individuals respond and cope with changes (Lei et al. 2014; Cannon and Muller-Mahn 2010).

This article adopts a case study approach to explore interactions between vulnerability, resilience and adaptation, examining extreme heat and extreme cold temperatures. It aims to understand why individuals respond to extreme temperatures the way they do, allow a clear understanding of what underpins their decisions and focus on what is needed for adaptation actions that minimise impacts. The ultimate goal is to understand how this influences impacts and outcomes, and its potential to change policy and practice. It does this by building on existing knowledge, theories and approaches on the three concepts of vulnerability (Nunes 2019b), resilience (Nunes 2020) and adaptation (Nunes 2018) to build a novel theoretical and analytical multiconceptual approach linking all three concepts. Systematic and broad overviews as well as synthesis of the meaning, use, purpose of assessment, subject of concern and scales of analysis of each concept (Nunes 2020, 2019b, 2018; Eakin and Luers 2006); and the relationship between them can be found elsewhere in the literature (Lei et al. 2014; Cannon and Muller-Mahn 2010) and are brought together here. Previous work has shown the need to clarify uncertainties and increase consistency in relation to both meaning and measurement for improved outcomes (Eakin and Luers 2006), which is presented below.

1.1 Vulnerability

The concept of vulnerability has been widely used across disciplines such as psychology, economics, engineering, sociology, anthropology, disaster management, environment and health (McDowell et al. 2016; Gaillard 2010). Unsurprisingly, there are many ways in which vulnerability is understood and used. This multiplicity of considerations has allowed vulnerability to become a highly contested concept where no single definition exists. Most of the conceptualisations and uses of vulnerability refer to a general, rather than a specified event or situation. As a result, Wisner and colleagues (2004) have expressed apprehension regarding the indiscriminate use of the concept of vulnerability, whilst Moser (2011) and Adger (2006) state that one of the advantages of these numerous conceptualisations is that vulnerability can be used in many different ways, settings and fields.

It has been argued that different and often competing conceptualisations of vulnerability in a diversity of disciplinary fields (e.g. Adger 2006; Eakin and Luers 2006) have in some cases led to an indiscriminate and poorly defined use of the term (e.g. Wisner et al. 2004) in a broad number of settings (e.g. Moser 2011; Gaillard 2010; Hahn et al. 2009; Adger 2006). This has also led to disciplinary divides in vulnerability research despite more authors calling for an interdisciplinary approach for investigating vulnerability (e.g. Alwang et al. 2001; O'Brien et al. 2004; Eakin and Luers 2006). As a result, currently vulnerability can be operationalised in many ways, but there is an increasing interest in the concept of assets and asset approaches as ways of assessing vulnerability (e.g. Birkmann et al. 2010). Assessing vulnerability through assets, as this research does, has allowed different conceptualisations of vulnerability from different disciplines to be brought together aiming at better understanding of how vulnerability is shaped.

The different conceptualisations of vulnerability have led to the development of various methods to measure it (McDowell et al. 2016; Gaillard 2010). Additionally, a further caveat in most vulnerability assessments is the use of secondary data (e.g. Zaidi and Pelling 2013). One of the approaches to quantitatively measure current vulnerability is the development of indices using a composite index approach. In this approach to vulnerability the concept of assets and the five asset model (human, financial, physical, place-based, social assets) play an important role in the process of operationalising human vulnerability. Access to assets can thus be seen as the root causes of vulnerability (Moser 2011), being associated to lack of assets in the sense that the bigger and the more diverse the asset portfolio the less vulnerable individuals are. Despite this, the role of assets in reducing vulnerability still needs to be further understood through exploring the relationships with resilience and adaptation (Ungar 2018; Ebi et al. 2018; Romero-Lankao et al. 2012).

1.2 Resilience

As with vulnerability, the concept of resilience has been widely applied and researched in a range of disciplines (e.g. Gaillard 2010) giving rise to a diversity of definitions and approaches to measure resilience (Leichenko, 2011; Eakin and Luers 2006). In addition, despite being considered crucial in reducing the health impacts of climate change, it is still not clear analytically how human resilience is shaped (e.g. Kjellstrom and McMichael 2013). As a result, the IPCC (2014) has called for more research on human resilience to extreme events, and Curtis and Oven (2012) argue for a better understanding of the social factors and processes involved in shaping human resilience.

The resilience of individuals is modified by events such as extreme temperatures, thus the need for improvements in planning and policy in order to increase resilience in the short, medium and longer terms (IPCC 2018). Ebi and colleagues (2018) and Walker and colleagues (2004) emphasise the importance of access to assets, institutions and governance within the many factors shaping resilience, which can impact on the empowerment and agency of individuals. Resilience has been found to be associated with individuals and the characteristics of the place where they live (Ungar 2018; Brown and Westaway 2011). This includes assets which are considered to influence the impacts of threats and stressors. Curtis and Oven (2012) have called for a better understanding of the factors and processes contributing to human resilience as research has shown that reducing individual vulnerability (e.g. increase access to assets) may increase their resilience. Opportunities to increase resilience have been proposed and include the development and implementation of programmes aiming at reducing vulnerability (Mc Dowell et al. 2016; Keim 2008). Despite this, there is a lack of evidence on human resilience to climate change in general and extreme temperatures in particular (IPCC 2018).

As a result of the diverse disciplinary roots of resilience, many approaches have been taken to measure it (Bankoff 2019; Leichenko 2011; Eakin and Luers 2006). In one of such approaches, Lorenz (2013) makes direct links between the construct of resilience and health by giving special attention to salutogenesis and Sense of Coherence construct (Antonovsky, 1996) as it focuses on the factors (e.g. resources, assets) that make someone resilient (Wilkinson 2005). Almedom (2008) asserts that these changes represent a significant development that allow connections between resilience and the sense of coherence which is the central construct of salutogenesis (Wiesmann et al. 2009). The use of the Sense of Coherence scale to assess human resilience is gaining more interest from researchers and is considered to be an accepted measure of individual resilience (e.g. Kimhi 2014). The Sense of Coherence has links with assets having been used to measure resilience (Glandon et al. 2008; Almedom et al. 2007). As such it has been used to better understand general and specified resilience to different threats (i.e. war, natural disasters) (e.g. Glandon et al. 2008; Almedom et al. 2007).

This research uses a salutogenic approach to resilience through the use of the 'Sense of Coherence' (SOC) concept and the SOC scale to assess general and specified (i.e. extreme temperatures) resilience. Despite having been used before to assess resilience (Almedom, 2008; Glandon et al. 2008), the 'Sense of Coherence' concept had not been applied before in the context of climate change and extreme temperatures, which represents another novelty of this research. Furthermore, this research takes an additional novel approach by adapting the SOC scale (quantitative) to qualitatively assess resilience to extreme heat and extreme cold. The use of the 'Sense of Coherence' concept allows the operationalisation of individual resilience, both general and specified, as well as understanding the different dimensions of resilience (comprehensibility, manageability and meaningfulness) and how they are shaped.

1.3 Adaptation

Human adaptation has been taking place ever since individuals evolved to deal with their environments (Atteridge and Remling 2018; Beall et al. 2012). Additionally, climate change is expected to increase the need for individuals to adapt (Haines et al. 2019; Watts et al. 2018). Entangled in the diverse definitions of adaptation in the literature is the fact that it entails several decisions on the actions to implement (Bellamy, 2019; Atteridge and

Remling, 2018; Adger et al. 2005). Research on extreme temperatures has been mostly limited to the impacts on human health through mortality and morbidity studies, resulting in an incomplete understanding of how individuals adapt and the factors influencing adaptation (Anderson et al. 2019; Ebi et al. 2018; Fuller and Bulkeley 2013).

Brown and Westaway (2011) made links between resources or assets and agency, with assets and access to assets as being what determines adaptation (Atteridge and Remling 2018). Such adaptation research often takes into account an assets approach to vulnerability by focusing on the range of strategies individuals and households in the developing world adopt to respond to a threat through the use of assets (Birkmann et al. 2010). Furthermore, Adger (2003) asserts that access to assets determines individuals' ability to adapt.

The way in which people adapt depends on many factors such as social, cultural and financial (Tong and Ebi, 2019; Tod et al. 2012), perceptions of heat and cold (Ebi et al. 2018; Wolf et al. 2010) as well as on past experiences of extreme temperatures (Fuller and Bulkeley 2013) which may create opportunities as well as limits to adaptation. The IPCC (2018) asserts that adaptation assessments are deemed necessary for the identification of adaptation needs and options aimed at the reduction of the negative impacts of climate change to human health.

1.4 Links between vulnerability, resilience and adaptation

This article brings together diverse conceptualisations and focus on the dynamic factors that shape vulnerability, resilience and adaptation by focusing on vulnerability and resilience as baseline characteristics of individuals (general vulnerability and resilience) influenced by external events such as extreme temperatures (specified vulnerability, resilience and adaptation).

The underpinning processes of how individuals adapt are still relatively unclear, and the breadth of work addressing the links between vulnerability, resilience and adaptation reflects a body of complementary research rather than an integrated understanding of how they are connected. Despite a growing need for a collective agenda, consideration needs to be placed on how the three concepts are defined and operationalised in relation to each other (Bulkeley and Tuts 2013).

Brooks (2003) argues that vulnerability is influenced by adaptations that occurred in the past as well as current availability of potential options for adaptation, and relying on assets. Furthermore, Moser (2011) offers an asset-focused framework for understanding climate change rooted in previous work on asset vulnerability and asset adaptation. Resilience thinking can also provide the tools for analysing and improving adaptation (Bankoff 2019; Ungar 2018; Bulkeley and Tuts 2013). Nelson and colleagues (2007) assert that improving adaptation may also include vulnerability reduction and increase resilience. Despite all this, Leichenko and Silva (2014) argue that not enough is known regarding how resilience is shaped and call for more research on the characteristics or factors that allow individuals to adapt.

According to Miller and colleagues (2010), vulnerability and resilience embody allied approaches to understand adaptation, whilst Nelson and colleagues (2007) provide additional insights stressing that improvements in adaptation may be due to vulnerability reduction and increased resilience. Furthermore, an individual can have high resilience and at the same time be considered vulnerable (Miller et al. 2010). That is why some authors argue it is crucial that translation of theory into practice and policy occurs so that research targets those individuals most impacted by threats, as in most cases they are left out (Ebi

et al. 2018; Miller et al. 2010; Vogel et al. 2007). This also calls for the use of mixed approaches in vulnerability and resilience research using both quantitative and qualitative methods, offering a holistic methodological view on both concepts (Miller et al. 2010).

Vulnerability, resilience and adaptation have emerged and evolved from diverse research arenas (Miller et al. 2010; Turner, 2010; Nelson et al. 2007; Vogel et al. 2007). Despite this, it is agreed that theoretical connections exist between vulnerability, resilience and adaptation and that they are related concepts (Miller et al. 2010; Turner, 2010; Nelson et al. 2007; Vogel et al. 2007). As a result, a growing number of studies have explored the theoretical connections between these three concepts (Ebi et al. 2018; Lei et al. 2014; Miller et al. 2010; Cannon and Muller-Mahn 2010; Turner 2010). Nevertheless, studies operationalising this relationship are still few (Lei et al. 2014). This article builds on existing knowledge, theories and approaches to build a novel theoretical and analytical multiconceptual approach.

In summary, assets are used in this project as a basis for defining the scope for assessing general and specified (i.e. extreme temperatures) vulnerability and for opening up avenues for exploring general and specified (i.e. extreme temperatures) resilience and adaptation. Definitions of the four key concepts explored in this article emerged from the literature and are presented in Table 1, aiming at providing a guide in terms of the theoretical and operationalisation of such concepts.

The framework presented here derives from the literature and participants data (See Sect. 3. Results). The approach taken in this articlē aims to deal with the complexity around the conceptual and practical interactions between vulnerability, resilience and adaptation. As a result, the framework proposed in this article can be considered as a response to Eakin and Luers (2006) argument that: *'the lack of a comprehensive, widely applicable theory or framework to guide both analyses and programmatic efforts for vulnerability reduction has become the bane of vulnerability research'*. The proposed framework can also be considered an 'integrating approach' as advocated by Eakin and Luers (2006) as it integrates elements from risk/hazard, entitlement, psychosocial approaches and analyses, and interdisciplinarity into a single process to assess and understand vulnerability, resilience and adaptation that can help individuals, communities, local and national government to address the root causes of vulnerability, resilience and adaptation.

The project has separately reported on the *adaptation* (Nunes 2018), *vulnerability* (Nunes 2019b) and *resilience* (Nunes 2020) strands of the research. This article focuses on examining the broader and unique *implications* of the project as a whole, *analysing* previously unexamined interactions, *synthesising* the complete set of data, *reflecting* on the

Table 1 Definitions of concepts in this project

Concept	Definition in this project
Asset	Human, financial, physical, place-based and social factors or characteristics directly or indirectly available to individuals in anticipating or responding to threats
Vulnerability	The degree of susceptibility to harm determined by the availability of assets
Resilience	The ability or capacity to actively access, mobilise and use the available assets to positively adapt. Is a function of: 1) ability to make sense of threats; 2) assets availability, access and use; 3) the perception of the ability to cope and act
Adaptation	Action, response, strategy, or behaviour individuals implement in pre-emption or response to threats

findings, and for the first time *developing* a framework for linking vulnerability, resilience and adaptation. It begins by giving an overview of vulnerability and resilience and subsequently how these shape adaptation, before then offering and discussing propositions for policy and practice drawn from its findings. The article concludes by summarising its contributions and posing several key recommendations for future research and policy.

2 Methods

The methods used in this project are explained more fully in Nunes (2020, 2019b, 2018), but understanding the context in which the implications of the project will be integrated and discussed demands the provision of an overview here.

2.1 Study site

The city of Lisbon in Portugal is selected to investigate the interactions between general and specified vulnerability, resilience and adaptation to extreme temperatures. Portugal is a country with a mild Mediterranean climate but with significant changes in the frequency of temperature extremes resulting in severe impacts on human health (Rodrigues et al. 2020; Lucio et al. 2010). In Fig. 1 are presented the mean monthly temperatures for Lisbon from the period of 1971 to 2000. In spite of a series of major extreme temperature events and human health impacts in recent years there is a dearth of impact assessments associated with a dearth of mitigation and adaptation strategies at both national and local levels (Rodrigues et al. 2020; Carvalho et al. 2014; Lucio et al. 2010). Lisbon is Portugal's capital and largest city, and has warm temperate climate with dry and hot summers, and mild winters (Kottek et al. 2006). Lisbon is a suitable location for this study due to the high health impacts observed especially on the older population (Rodrigues et al. 2019; Casimiro et al. 2006).

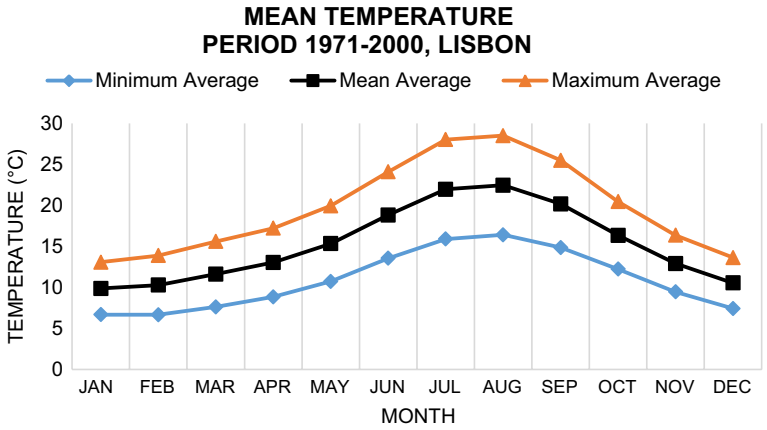

Fig. 1 Mean monthly temperature in Lisbon, Portugal. *Legend*: Data from Portal do Clima (http://portaldoclima.pt/en/#). Climate normal: Modeled historical—1971–2000, Statistic: 30 years average, Global Model: Ensemble, Regional model: Ensemble

2.2 Data collection

A mixed methods research design was used during summer and winter months in three phases. These comprised general quantitative structured interviews (Phase 1), heat-related qualitative semi-structured interviews (Phase 2) and cold-related qualitative semi-structured interviews (Phase 3). Participants were selected using the following inclusion criteria: age 65 years or over; living independently in the city of Lisbon. To allow greater diversity of participants, data from the 2011 Census was used to guide the recruitment of participants. The sampling uses a mix of non-probability sampling techniques and includes a strategy to approach participants with diverse characteristics (e.g. sex, marital status, education level, financial and health status) (Box 1). The sample size was decided after ensuring theoretical saturation (Bryman 2012).

Following this assumption, the number of participants was achieved in accordance with logistical and conceptual aspects of the research. Although this approach does not allow a statistically representative sample size, it allowed the researcher to elicit through first person dialogue, in-depth understanding of the research topic. Also for logistical reasons (e.g. use of mixed methods, three research phases, timings and budget) a statistically representative sample was not feasible, but it was possible to mitigate these shortcomings through the implementation of a careful sampling technique. Research participants' mean age was 75.2 years, with a minimum age of participants being 65 years and a maximum age of 95 years, with 67% being female and 33% being male (Census data: 62% female; 38% male; INE 2011). Of all participants in the study, 58% lived alone (Census data: 27% lived alone; INE 2011), 48% were widowed, 29% were married, 8% were divorced and 15% were single (Census data: 32% widowed; 52% married; 7% divorced; 9% single; INE 2011).

Informed consent was obtained for a total of 52 participants that participated in all phases of research, recruited from several organisations through gatekeepers. All interviews were audio-recorded, quantitative data was transferred MS Excel and qualitative transcripts transferred to QSR NVivo software.

Box 1 Types of sampling techniques used

Purposeful sampling strategy was applied to intentionally select individuals that had specific characteristics crucial to the research. A maximum variation approach (selected participants with different characteristics on the criteria thought to be crucial) based on the 2011 Census data was used

Convenience sampling was used to choose accessible and at hand individuals

Quota sample was selected based on age (65 years of age or older) and sex in order to produce a sample reflecting the population characteristics of the research location, in terms of the relative proportions of people in the categories chosen

Snowball sampling was initiated by making an initial contact with individuals relevant to this research topic and receiving recommendations of other local older people (only the case for 2 participants: spouse and husband of participants) to participate in the research

(e.g. Creswell 2014; Bryman 2012; Creswell 2007; Ruane 2005; Seidman 1998)

2.3 Measures included in the study

2.3.1 Vulnerability

Vulnerability is assessed through measuring access to and availability of five different types of assets (human, financial, physical, place-based, social). The quantitative structured interviews (Phase 1) examine participants' asset portfolio for developing the General Vulnerability Index (GVI) using a composite index approach (e.g. Hahn et al. 2009). The GVI varies between 0 (lowest vulnerability) and 1 (highest vulnerability) with a cut-off point of 0.5 ($GVI_i = \frac{w_{HA}HA_i + w_{FA}FA_i + w_{PA}PA_i + w_{PBA}PBA + w_{SA}SA_i}{w_{HA} + w_{FA} + + w_{PA} + w_{PBA} + w_{SA}}$, see Nunes 2019b). Qualitative semi-structured interviews convey a more specific understanding of participants' vulnerability to extreme temperatures (Phases 2 and 3). Thematic analysis (King and Horrocks 2010) was undertaken to assess specified vulnerability to extreme temperatures, i.e. heat- (HRV) and cold-related vulnerability (CRV). HRV and CRV were assessed by defining 'high' assets vulnerability for each of the five types of assets, which determined that participants with at least three 'high' assets vulnerability are considered to have high specified vulnerability (see Nunes 2019b).

2.3.2 Resilience

Resilience is assessed through using the sense of coherence (SOC) approach and the theory of salutogenesis. The Orientation to Life Questionnaire (SOC-13 scale) is used to access general resilience and ultimately for calculating the General Resilience Index (GRI). A novel contribution of this project is the development of the GRI using the SOC-13 scale building on Antonovsky's (1987) work and on resilience composite indices approaches (e.g. Cutter et al. 2008). The SOC-13 scale has been deployed in psychology to capture individual resilience in different settings and threats (Kimhi 2014; Kimhi et al. 2010; Glandon et al. 2008). It has thirteen items that measure three components: comprehensibility (cognitive dimension—sense making), manageability (instrumental or behavioural dimension—perception of availability of assets) and meaningfulness (motivational dimension—aspiration to action) (Antonovsky 1993). The response format was a typical Likert scale 7-point agreement basis. Qualitative semi-structured interviews convey a specific understanding of participants' resilience to extreme temperatures. Specified resilience to extreme temperatures were assessed by coding the data according to the three dimensions of resilience as 'high' or 'low' using thematic analysis (Braun and Clarke 2006) (see Nunes 2020).

2.3.3 Adaptation

The study captured and assessed adaptation to extreme temperatures through response to open-ended questions that explored assets and their role in behaviours and responses to such events. Results were thematically coded (Braun and Clarke 2006) with the identification of themes and sub-themes of dominant groupings of adaptation in relation to assets that included positive and negative valenced responses—*human assets*—independence and control, return to the nest, illiteracy and health illiteracy, chronic illness not frailty; *financial assets*—managing competing expenses and still struggling, savings should be savings,

thrifty and proud; *physical assets*—lack of insulation, lacking cooling and heating devices; *place-based assets*—indoor versus outdoor spaces; work the land, ward level activities, Heatwave/Cold Weather Plan, what Plan?; *social assets*— 'I'm connected … to my family', 'I feel supported but never ask for help', 'I socialise but not as much as I should' (see Nunes 2018).

2.3.4 Relationship between vulnerability, resilience and adaptation

Structured and semi-structured interview data (Phases 1–3) are used as the bases for the combined findings and, vulnerability and resilience matrices. Both quantitative and qualitative vulnerability and resilience findings (Nunes 2020, 2019b) showed a great diversity of vulnerability and resilience amongst participants. The analysis undertaken here is intended to understand how vulnerability and resilience interact with each other by developing 2×2 matrices. Participants are positioned in each matrix taking into account their levels of combined vulnerability and resilience, using both quantitative and qualitative data. The development of the matrices started by defining the variables axis (*y* axis: vulnerability; *x* axis: resilience) and characterising the four quadrants: 1) low vulnerability & low resilience (bottom-left quadrant) representing participants with access to assets but with low ability to act; 2) high vulnerability & low resilience (top-left quadrant) representing the most threatened participants, with lack of assets and low ability to act; 3) high vulnerability & high resilience (top-right quadrant), representing those with lack of assets but with high ability to act; and 4) low vulnerability & high resilience (bottom-right quadrant), with access to assets and high ability to act, representing the strongest participants and the 'success cases' from which to learn for developing appropriate policy measures (Fig. 2).

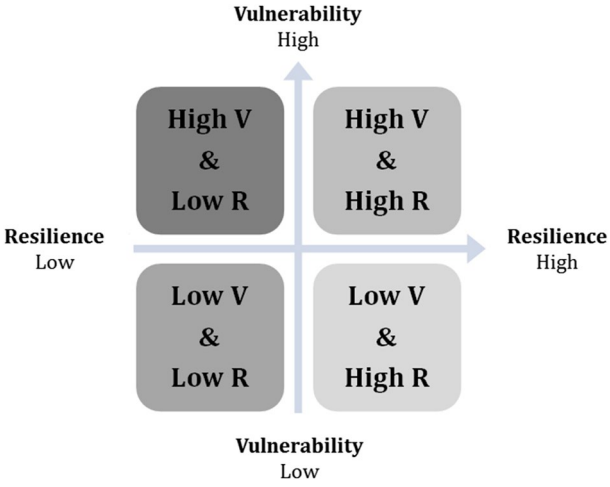

Fig. 2 Representation of the vulnerability–resilience matrix. *Legend*: *V* Vulnerability, *R* Resilience

3 Results

The findings on vulnerability, resilience and adaptation arising from the project are described more fully in Nunes (2020, 2019b, 2018), but it is in this article that their interactions and implications for understanding how they are shaped, and subsequently how this may influence underpinning adaptation decisions are synthesised and discussed. To this end, it will be necessary to briefly elucidate the project's main findings.

3.1 Findings on vulnerability, resilience and adaptation

The analyses carried out in this research demonstrate that general vulnerability is mostly shaped by financial assets, followed by physical assets, social assets, human assets and place-based assets in decreasing order. The majority of participants revealed low general overall vulnerability, with high general financial, human and social assets vulnerability, and low place-based and physical assets vulnerability. Crucially, vulnerability to extreme heat and cold was found to be higher than general vulnerability among participants, with high vulnerability to heat slightly more frequent than high vulnerability to cold. The main assets shaping heat- and cold-related vulnerability included financial assets and physical assets. The majority of participants revealed high heat- and cold-related vulnerability, with high heat- and cold-related asset vulnerability for all types of assets (i.e. human, financial, physical, place-based and social).

These results raise implications for the way in which vulnerability is currently addressed in policy and practice—these focus on vulnerability as a characteristic of older people as a particular group in society. Older people in this research revealed different levels of vulnerability and exposed differences between extreme heat vulnerability and extreme cold vulnerability. The overwhelming importance of these findings suggest the importance of addressing differently the vulnerability to different stresses, shocks and threats, as individuals can be vulnerable to one type of threat and not to other. These findings highlight the need for the development of individualised and tailored actions for reducing vulnerability. Here, the findings also refer to vulnerability as being rooted in the context and characteristics of the society more widely where individuals live their lives. An individual's asset portfolio determines his or hers vulnerability and can be assisted through policies and measures aimed at increasing the assets available to old people. Such findings have deep policy implications that can be supported by low-cost ways in which policy makers could identify these different types and levels of vulnerability, in order to address them differently.

The findings show that general resilience is mostly shaped by high meaningfulness followed by high manageability and comprehensibility in decreasing order. The majority of participants displayed high general resilience with high meaningfulness followed by high comprehensibility and manageability. Additionally, resilience to heat was found to be more frequent than resilience to cold, with participants displaying higher levels of comprehensibility, followed by high levels of meaningfulness and manageability in decreasing order to both heat and cold. The main themes shaping heat-related resilience related to the comprehensibility dimension consisted of feelings of predictability of heat and experiences and memories in dealing with it, as well as understanding the health impacts of heat, perceived ability to acclimatise and ability to respond to it. Regarding the manageability dimension, the main themes were directly associated with individuals moderate availability of assets,

with special emphasis on assets under one's direct control, as well as the threat extreme heat poses to their asset portfolio (e.g. human, physical and financial assets). The main themes within the meaningfulness dimension of resilience were found to be related to the importance heat has in the lives of individuals as it was found to be a common feature in their lives to which they found the need to invest. Despite this, other areas of life requiring investment (e.g. finances, health status) were found to limit the engagement in responding to extreme heat, affecting their perception of ability to act. On the other hand, the main themes shaping cold-related resilience regarding its comprehensibility dimension were found to be linked with the lower predictability of cold (as it was considered to be less frequent reason for individuals to recall extensive personal experiences and memories of extreme cold recently), coupled with lack of awareness of the impacts of cold to health and perceived ability to deal with it (as it is not common and was not perceived as being a threat). Additionally, individuals felt they did not have the assets needed to respond to extreme cold, thus calling for improvements in their asset portfolio (extreme cold was considered to be a threat to physical and financial assets, impacting the manageability dimension of resilience.) Finally, the meaningfulness dimension was found to be related to considering cold as an important event when it happens but with which individuals struggle as other areas in their lives also require investments, resulting in the perception that strategies to deal with cold were lacking.

These findings also have implications for addressing the resilience of individuals to different stresses, shocks and threats, as individuals revealed different levels of general and specified resilience. As a result, older people can be resilient to one type of threat and not to another. Portugal's context on dissimilar frequency and intensity of extreme heat (i.e. higher) and extreme cold (i.e. lower) temperatures has implications for the degree to which older people feel able to deal with extreme heat and cold temperatures. Having more experience and memories of extreme heat and having dealt with extreme heat many times allows older people to perceive having higher capacity to face and act upon the challenges it poses. On the other hand, being less experienced and feeling limited in assets to keep warm tends to hinder older people's perception of their own ability to respond to extreme cold. These findings also highlight the necessity of developing individualised and tailored actions for increasing general and specified resilience taking into account Portugal's context.

Assets play a crucial role in shaping adaptation to extreme temperatures in the Portuguese context. This research suggests that adaptation to extreme temperatures is mostly shaped by the context and diversity of assets available and accessible to individuals. As such, adaptations based on assets were found to be predominant. According to the different types of assets within the asset portfolio, adaptations based on *human assets* were mainly influenced by the level of education and health status of individuals, whilst adaptations based on *financial assets* were determined by the available income and costs of using cooling and heating devices, as well as past and current financial situation. On the other hand, this research also found that adaptations based on *physical assets* translated into improvements in housing quality and insulation, but tenure influenced both the capacity and ability to do so. Adaptations based on *place-based assets* were greatly influenced by the availability and willingness to participate in Ward activities, as well as distance to and cost of transport and other public infrastructures (i.e. swimming pool). And, last but not least, adaptations based on *social assets* were surprisingly low mainly due to lack of friends and close neighbours, as well as a lack of a sense of community.

These results highlight the importance of a broad focus on assets which impact on both vulnerability and resilience, and ultimately on adaptation to extreme temperatures.

Older people revealed that the bigger constraint and limit to responding to extreme heat and extreme cold is the lack of assets. Such findings raise questions regarding the access, availability and distribution of assets among individuals, but also about the roles of their neighbourhoods and communities. Other factors impacting on adaptation include educational, cultural, informational and financial aspects. Under the present economic and financial crisis, older people have faced many challenges to manage their pensions. As a result, many of them had to cut costs, which included reducing cooling and warming their homes, as well as nutrition (i.e. food) and healthcare (e.g. medication). The results also suggest that in the context of Portugal and Lisbon in particular, public policies and measures have failed to raise awareness of both Heat and Cold Weather Plans, their respective measures and actions. Furthermore, direct and personalised advice by health professionals on how to better deal with extreme temperatures is welcomed by older people. Additionally, this emphasises the failure of advice and information campaigns directed to the general population on vulnerable groups (older people do not see themselves as vulnerable) and recommendations. As a result, it will be important to review the role of GPs and GP surgeries in the prevention of health impacts from extreme tēmperatures (Nunes 2019a).

3.2 Integrating vulnerability, resilience and adaptation findings

Table 2 presents a summary of the key findings and outlines the combined main findings of this research (Nunes 2020, 2019b, 2018, 2016). Participants in this research showed a variety of levels of both vulnerability and resilience as well as adaptation. Such findings allowed examining the constraints and barriers to adaptation associated with such diversity for understanding the roots and solutions for reducing vulnerability, enhancing resilience and improving adaptation.

3.3 Developing vulnerability and resilience matrices

The matrices explain the links between participants levels of vulnerability and resilience combined. Upon the calculation of both GVI and GRI at the sample and individual levels, matrices were developed to represent the distribution of participants as having ‘high’ or ‘low’ vulnerability and resilience. Matrices of the GVI, its five asset components and GRI were developed. The GRI is presented in the matrix and its dimensions (comprehensibility, manageability and meaningfulness) were not represented as the aim is to understand the relationship between resilience and vulnerability and its components (assets). The decision to represent the findings in the form of matrices resulted from the aim of presenting and summarising the findings in a clearer, more visual and objective way.

3.3.1 General vulnerability and resilience matrices

Each participant was positioned in the vulnerability–resilience matrices according to their individual overall indices values (GVI and GRI) (see Supplementary material A).

The combined GVI and GRI matrices are presented in Fig. 3(a–f). General resilience values are constant and characteristic to each participant throughout, but vulnerability values change. The great majority of participants fall into the two high resilience quadrants (top- and bottom-right quadrants) revealing that most participants despite their levels of vulnerability both low or high showed high levels of resilience. These participants revealed an overall orientation expressing feelings of confidence in their lives. Analysis

Table 2 Summary of research findings and combined main findings

	Vulnerability	Resilience	Adaptation
Research findings	Overall greater general vulnerability derives from lack of financial, followed by physical, social, human and place-based assets Specified vulnerability was found to be much higher than general vulnerability. Heat-related vulnerability was slightly higher than cold-related vulnerability, and both were much higher than general vulnerability. (Nunes 2019b)	Overall high general resilience, greater meaningfulness, followed by manageability and comprehensibility dimensions Overall high heat-related resilience, with higher comprehensibility followed by meaningfulness and manageability. Overall low cold-related resilience with high comprehensibility followed by lower meaningfulness and manageability. (Nunes 2020)	Participants engaged in a variety of adaptation actions. Adaptation is determined by vulnerability and resilience. Engaging in adaptation actions requires adequate information on health risks and impacts of extreme temperatures, in order to identify asset needs and availability for assessing appropriate adaptation options. Adaptation constraints and limits associated with high levels of vulnerability and reduced resilience. Opportunities for enhancing adaptation responses exist and relate to reducing vulnerability and building resilience. (Nunes (2018)
Combined main findings	Diverse combinations of vulnerability–resilience–adaptation actions Numerous barriers to resilience and adaptation were found to be related to individual and place characteristics The levels of vulnerability and resilience convey important arguments for: targeting at-risk older individuals (high vulnerability & low resilience); developing vulnerability reduction actions (high vulnerability & high resilience); resilience building actions (low vulnerability & low resilience), and; understanding 'success cases' (low vulnerability & high resilience), as well as learn from them to develop appropriate policy measures. Generally, planned adaptation options were implemented by low vulnerability & high resilience participants, whilst autonomous adaptation options were more common within other participants Links between vulnerability–resilience–adaptation with social justice, equity and austerity, especially to whether participants or trusted ones have the scope to reduce their vulnerability (assets portfolio) and enhance resilience for adaptation		

of the relative position participants take in the overall matrix (Fig. 3a) shows that the majority of participants are in the 'low vulnerability & high resilience' group (54.9%) and 13.7% fall into the 'high vulnerability & low resilience' group. The matrices also show that around 12% to 14% of all participants are part of the 'high vulnerability & low resilience' group for indicators such as, human assets (13.7%), financial assets (13.7%), social assets (11.8%), (Fig. 3b, c and g), respectively). The percentage of participants falling into the high physical and high place-based assets vulnerability & low resilience is smaller (5.9%; 5.9%, respectively) (Fig. 3d and e), respectively). These findings suggest that the 'high vulnerability & low resilience' group of participants are characterised to a larger extent in terms of human assets, followed by financial assets and social assets vulnerability in their lives in addition to low resilience. Furthermore, in addition to the lack of assets these participants with low resilience struggle to make sense of their lives, and/or perceive they do not have the assets needed and/or lack the motivation to act using the scarce assets available. High resilience participants (bottom- and top-right quadrants), independently of their vulnerability are confident they can confront any threat or stressor and/or perceive they have assets available and/or are motivated to act as best as they can.

This research provided evidence that the great majority of participants fell into the high general resilience group revealing, despite their levels of general vulnerability (low or high), an overall capacity to access the assets available to them, making sense of threats, having feelings of confidence in their lives and ability to act (i.e. high resilience) (Fig. 4). The analysis also showed that participants with 'high vulnerability & low resilience' faced greater restrictions due to lack of human assets, financial assets, social assets, and to a lower extent lack of physical and place-based assets (Fig. 3b–f).

Overall, assets were found to be a key determinant of vulnerability and resilience. Vulnerability was found not to be a key determinant of resilience (Fig. 5), as participants showed diverse combined levels of vulnerability and resilience.

3.3.2 Heat-related vulnerability and resilience matrices

The findings presented here result from the coding and categorisation of heat-related qualitative interviews data. Here, the aim is to bring to life individual participants' characteristics and the factors shaping their vulnerability and resilience to heat, and ultimately, adaptation to heat. Each participant represents a unique combination of vulnerability and resilience that are not fully evident when looking at the whole sample dataset. Supplementary material B presents a summary of participants' heat-related vulnerability and resilience.

A review of all heat-related participants' transcripts was undertaken to characterise their vulnerability and resilience characteristics and map each participant on a vulnerability–resilience matrix. Figure 6 was developed according to individual characteristics and provides a qualitative snapshot of vulnerability and resilience at a defined point in time (i.e. interview). The order of participants within each quadrant does not reflect different levels of vulnerability or resilience.

Figure 6(a–f) presents the combined vulnerability and resilience findings where resilience features of each participant are constant throughout and vulnerability features change. Participants' distribution within the matrix is not uniform and the biggest proportion fall into three of the four quadrants of the matrix. In Fig. 6a of all participants the worse-off (36.5%) fall into the 'high vulnerability & low resilience' quadrant (top-left) and are the most threatened from suffering the impacts of heat as they lack assets, have lower

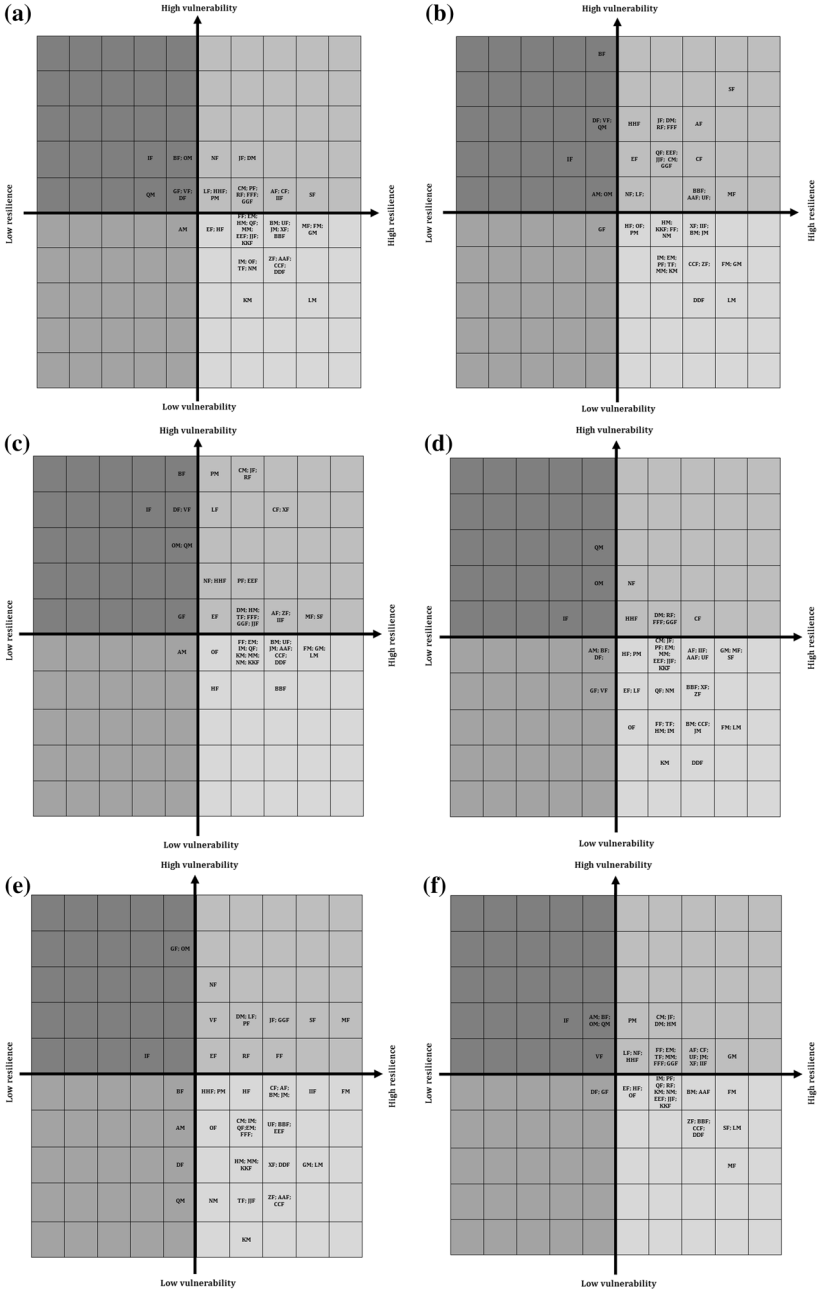

Fig. 3 General vulnerability (GVI) and general resilience (GRI) matrices. *Legend*: **a** GVI & GRI; **b** human capital vulnerability & GRI; **c** financial assets vulnerability & GRI; **d** physical assets vulnerability & GRI; **e** place-based assets vulnerability & GRI; **f** social assets vulnerability & GRI

understanding and/or awareness of what causes the impacts, and/or lack the knowledge of which assets are available and how to use them, and/or lack the motivation to act in order to deal with the threat heat poses to health. 'High vulnerability & high resilience' participants (38.5%) (top-right quadrant) lack assets but manage to make sense of the problem and/or use the assets available to them and/or are motivated to act upon. Better-off participants (23.1%) are situated in the 'low vulnerability & high resilience' quadrant (bottom-right) and overall have the assets and/or the understanding and/or motivation to act in order to reduce the health impacts of heat. Only one participant (1.9%) is located in the 'low vulnerability & low resilience' quadrant (bottom-left) which means that despite having assets needed to respond to heat, this participant lacks the understanding, and/or uses of the assets available to him ineffectively and/or lacks motivation to act. Regarding the asset-related vulnerability–resilience matrices (Fig. 4b–f) participants' positions change to a certain extent. A higher number of participants show high physical assets vulnerability and low resilience (38.5%), and a lower number is included in the high place-based assets and low resilience group (23.1%). Thus, a higher number of participants are most threatened by the combination of having problems with temperature in the home during very hot weather and/or inability to keep the home cool and/or not being able to keep themselves cool in the home during very hot weather and/or not using of cooling devices (high physical assets vulnerability) and low resilience; and a lower number of participants reveal being most threatened by the combination of not being aware of the Heatwave Plan and/or had no interest on it (high place-based vulnerability) and low resilience regarding heat.

3.3.3 Cold-related vulnerability and resilience matrices

The findings presented here result from the analysis of qualitative cold-related vulnerability and resilience interviews (Nunes 2020, 2019b). Supplementary material C presents a summary of participants' cold-related vulnerability and resilience.

The mapping of participants on a vulnerability–resilience matrix was developed following a review of all participants' qualitative interviews and is a qualitative illustration accounting unique individual features in a defined space and time (see Fig. 7(a–f)).

Participants' distribution within the cold-related vulnerability–resilience matrix is not identical and the biggest proportion falls into three of the four quadrants of the matrix. In Fig. 7a) the majority of participants (52.2%) fall into the 'high vulnerability & low resilience' quadrant (top-left) and are the most threatened from suffering the health impacts of cold as they lack the assets, have lower understanding and/or awareness of what causes the impacts, and/or lack the knowledge of which assets and how to use the assets available, and/or lack the motivation to act in order to deal with the threat cold poses to health. 'High vulnerability & high resilience' participants (21.7%) (top-right quadrant) lack assets but manage to make sense of the problem and/or use the assets available to them and/or are motivated to act upon. Better-off participants (26.1%) are situated in the 'low vulnerability & high resilience' quadrant (bottom-right) and overall have the assets and/or the understanding and/or motivation to act in order to reduce the health impacts of cold. No participant is located in the 'low vulnerability & low resilience' quadrant (bottom-left). Regarding the asset-related vulnerability–resilience matrices (Fig. 7(b–f)) participants' positions change to a certain degree. A higher number of participants show high human assets vulnerability and low resilience (46.2%), and a lower number is included in the high place-based assets and low resilience group (34.6%). Thus, a higher number of research participants reveal

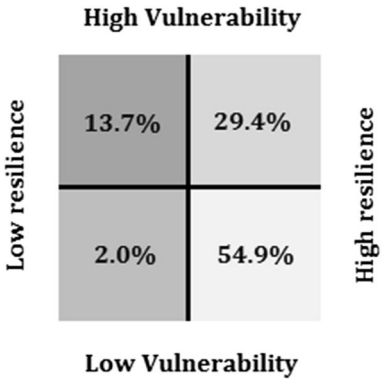

Fig. 4 Percentage of participants in each overall general vulnerability & general resilience quadrant (modified from Fig. 3a))

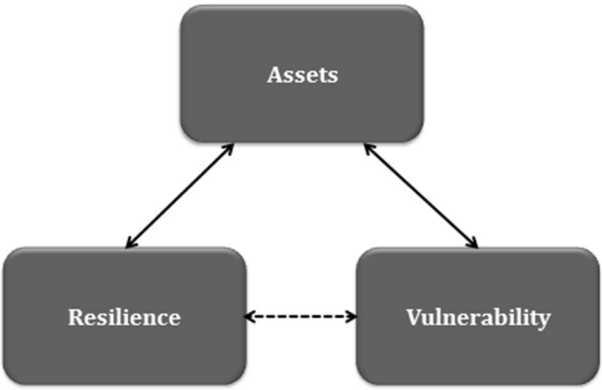

Fig. 5 Relationship between general assets, vulnerability and resilience. *Legend*: full arrows represent key determinant relationships; dotted arrow represents a non-key determinant

being most threatened by the combination of having health problems during very cold weather and/or physical health limitations during very cold weather (high human assets vulnerability) and low resilience, and a lower number of participants reveal being most threatened by the combination of not being aware of the Cold Weather Plan and/or had no interest on it (high place-based vulnerability) and low resilience regarding cold.

In summary, participants' combined vulnerability and resilience to heat and cold reveals that more participants are included in the overall 'high vulnerability & low resilience' quadrant in extreme cold (46.2%) than in extreme heat (36.5%) (Fig. 6a and 7a). These findings unravel higher concerns regarding the ability of these participants to respond to extreme cold. An equal number of participants reveal overall 'low vulnerability & high resilience' (23.1%) to both heat and cold, where all participants kept their position in the matrices, except one participant (BM). This participant saw his vulnerability increase (BM) and his position was occupied by another participant (ZF) who saw her vulnerability decrease (ZF). Most participants kept their positions in the matrices (e.g. BBF, OM) but some saw their vulnerability increase (e.g. BM) and their resilience decrease (e.g. GGF, BM) regarding cold. Despite this, a small number of participants saw their vulnerability decrease (e.g. ZF) and their resilience increase (e.g. KM). Comparatively, regarding the asset-related matrices for both heat and cold

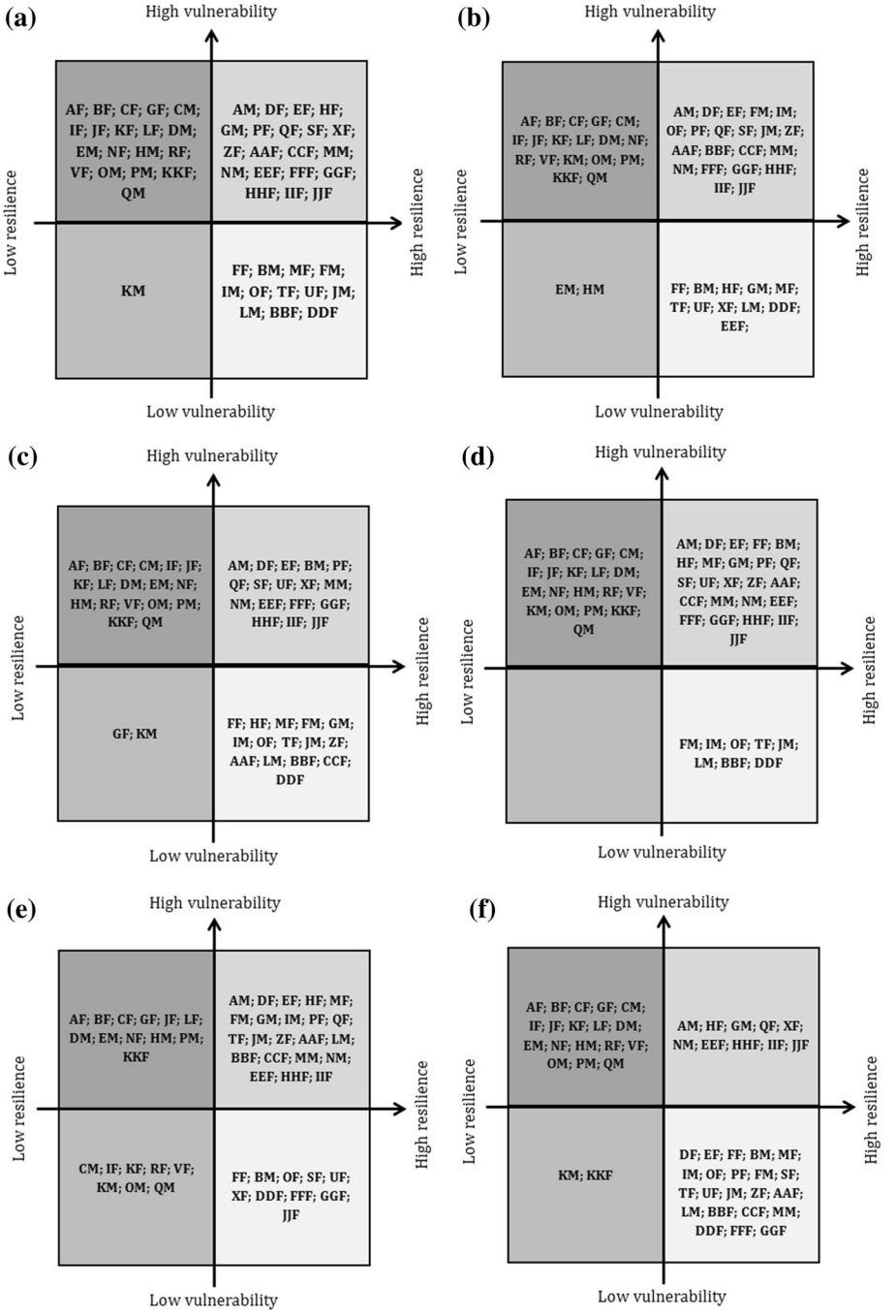

Fig. 6 Heat-related vulnerability- resilience matrices. Legend: **a** Overall vulnerability & overall resilience; **b** human capital vulnerability & overall resilience; **c** financial assets vulnerability & overall resilience; **d** physical assets vulnerability & overall resilience; **e** place-based assets vulnerability & overall resilience; **f** social assets vulnerability & overall resilience. *Note*: Participants' position inside each vulnerability–resilience quadrant of the matrix does not reflect different levels of combined vulnerability and resilience

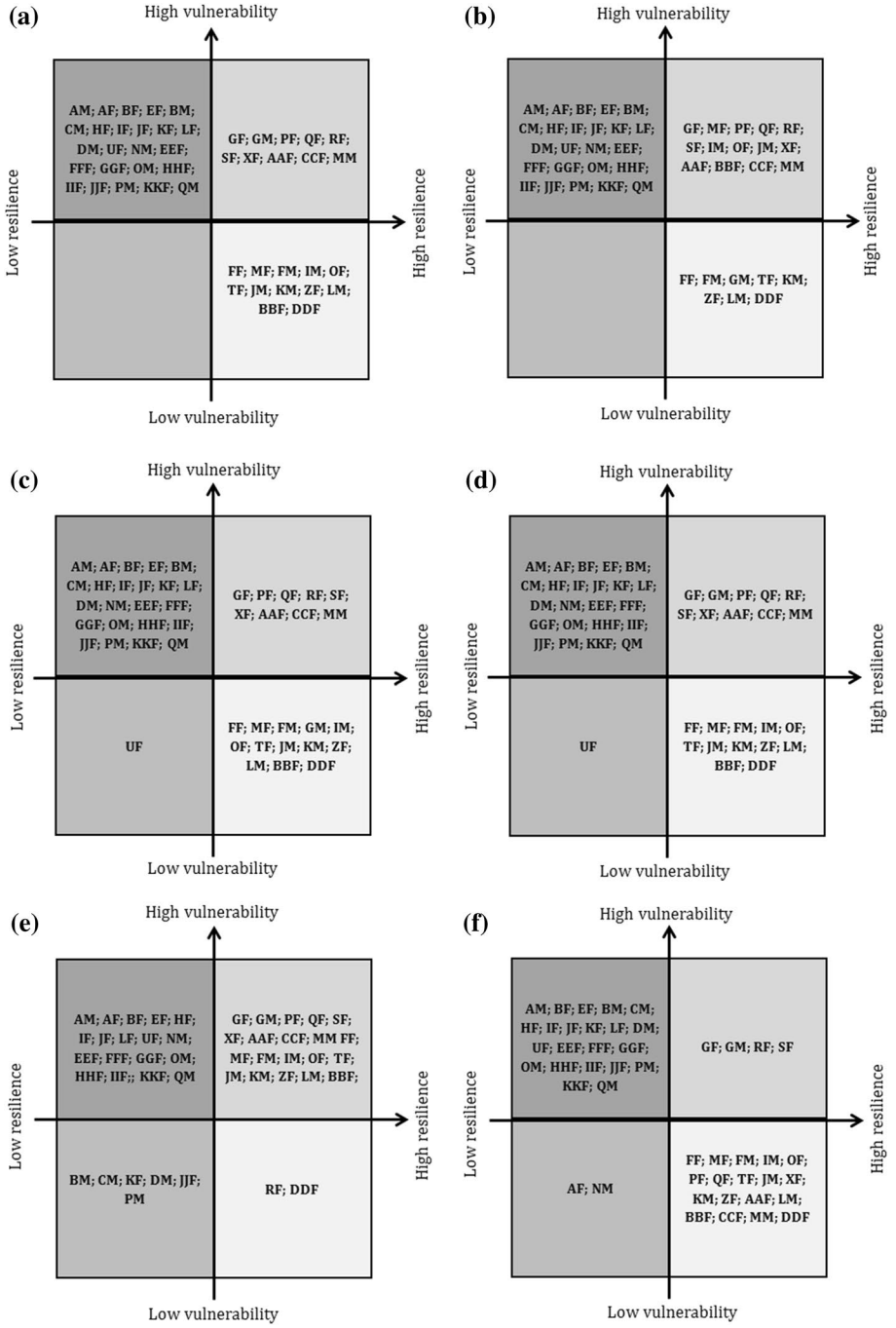

Fig. 7 Cold-related vulnerability- resilience matrices. *Legend*: **a** Overall vulnerability & overall resilience; **b** human capital vulnerability & overall resilience; **c** financial assets vulnerability & overall resilience; **d** physical assets vulnerability & overall resilience; **e** place-based assets vulnerability & overall resilience; **f** social assets vulnerability & overall resilience. Note: Participants position inside each vulnerability–resilience quadrant of the matrix does not reflect different levels of combined vulnerability and resilience

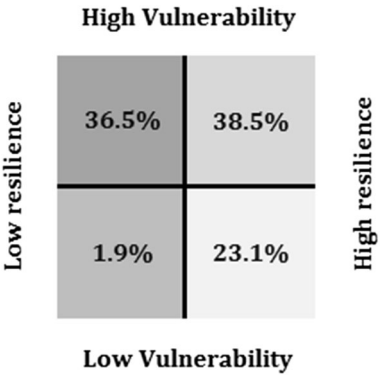

Fig. 8 Percentage of participants in each heat-related vulnerability & resilience quadrant (modified from Fig. 6a))

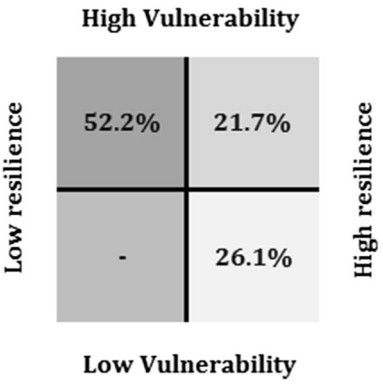

Fig. 9 Percentage of participants in each cold-related vulnerability & resilience quadrant (modified from Fig. 7a))

(Figs. 6 and 7(b–f)), there is a consistent higher proportion of participants falling into the 'high vulnerability & low resilience' quadrant regarding cold in all types of assets.

3.3.4 Integrating vulnerability, resilience and adaptation to extreme temperatures

Having developed the vulnerability and resilience matrices presented above, this section integrates these findings with adaptation. Participants' adaptation to extreme temperatures is varied and intricate with many diverse features, however, recognisable differences in participants' adaptation can be drawn from participants' location within the vulnerability–resilience matrices.

The findings on vulnerability to extreme temperatures showed it was primarily shaped by individual characteristics and the places where participants lived (e.g. housing, neighbourhood) (i.e. assets). In addition, an array of adaptation strategies to deal with extreme temperatures were used by research participants. Despite this, they found constraints and limits to adaptation mainly resulting from their high vulnerability and low resilience (Table 2). Furthermore, participants also found opportunities to improve their responses to extreme temperatures which implied increasing their asset portfolio for reducing their vulnerability and increasing their resilience.

This research found that the distribution of participants within the extreme heat vulnerability–resilience matrix is not uniform: a high percentage of participants had overall heat-related 'high vulnerability & low resilience' (Fig. 8 modified from Fig. 6a); these are considered to be the most threatened by extreme heat as: a) they lack assets (high vulnerability) and; b) they have limited understanding and/or; c) feel they are limited in the assets needed to respond and/or; d) they lack the motivation to act (low resilience).

The biggest proportion of participants were characterised by 'high vulnerability & low resilience' (52.2%) to extreme cold (Fig. 9 modified from Fig. 7a); these are at high risk from extreme cold as they lack assets, have limited understanding and/or perceive they lack assets to adequately respond and/or lack the motivation to act.

This research demonstrates that assets play a crucial role in understanding this relationship, as they are determinant in shaping general and specified (i.e. heat- and cold-related) vulnerability and resilience, and adaptation to extreme temperatures. The research also demonstrates that the relationship between vulnerability and resilience is not straightforward, as the findings show that individuals can display high vulnerability and high resilience, as well as display low vulnerability and low resilience. Vulnerability was also found to be determinant in shaping adaptation, mainly through past experiences, perceptions of warming and cooling weather, perceptions of own and universal vulnerability, and perceptions of health impacts and everyday life disruptions. The findings from the influence of resilience in adaptation to extreme temperatures suggests that resilience plays a determinant role in shaping adaptation, as the ability of individuals to understand the challenges posed by extreme temperatures (*comprehensibility*), feeling one has access and available assets to respond (*manageability*) and feeling motivated to take action (*meaningfulness*) were found to be crucial in implementing adaptation strategies and behaviours to deal with extreme heat and cold (Table 2 and see Nunes, 2018).

Overall, assets were found to be a key determinant of vulnerability, resilience and adaptation. Vulnerability was found not to be a key determinant of resilience, which is mostly influenced by an understanding of the challenges posed by threats and feeling motivated to act, thus being a key determinant of adaptation (Fig. 10).

Participants who revealed comparatively *lower levels of vulnerability and higher levels of resilience* to extreme temperatures compared to others demonstrated to be able to better respond. Reasons for this comprise having more diverse and greater assets portfolio readily available to use, and being more likely to define extreme temperatures as non-stressors, non-problematic and believing one can adapt to the demands they pose.

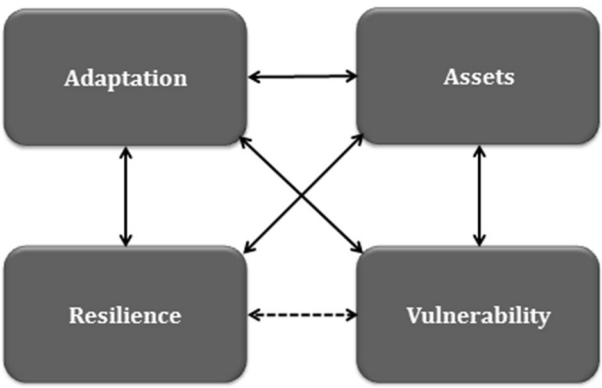

Fig. 10 Relationship between specified assets, vulnerability, resilience and adaptation. *Legend*: straight arrow represents being a key determinant and dotted arrow represents not being a key determinant

Based on the overall sample findings, planned adaptations seem to be a feature more frequently observed in participants with lower vulnerability and greater resilience. Their strategies and responses are based on previous experiences, present impact and envisioning future extreme temperatures stresses and impacts to their health. Their adaptations to both heat and cold were extensive and diverse as they were seen as threats and dependent on their health status.

Participants demonstrating relatively *higher levels of vulnerability and lower levels of resilience* to extreme temperatures compared to others were more likely to reveal narrow and limited strategies and responses. Extreme temperatures were more likely to be seen as universal but not individual threats to health. These participants either did not see themselves needing to engage in planned adaptations as in their view what they already did was deemed enough, or felt they were not able or did not know what and how to engage in additional strategies or responses to be able to deal with the threats these events posed, both now and in the future.

Those participants who revealed somewhat *greater vulnerability and resilience* to extreme temperatures compared to others, felt hope that their responses enabled them to actively deal with the threats these events pose to them. They were not able to engage in planned adaptations due to limits to their asset portfolio but if in provision of enough and the right amount of assets would be likely to initiate planned adaptations as they understood the threat and were motivated to act, and this would be the case for both heat and cold.

Demonstrating relatively *lower vulnerability and resilience* to extreme temperatures was uncommon in the research sample. These participants were more likely to be anxious and at the same time show apathy towards acting in the face of the threats of extreme temperatures, they felt confused and lacking the ability to act. Adapting was found to be focused on emotional features of not being able to manage the anxiety, feeling hopeless, almost as paralysed and overwhelmed to deal with the stress arising from these events. Such participants despite having the assets available to deal with these events see them as stressors, as burdens and assume that they cannot adapt to the demands they pose.

It was found that not only vulnerability influences and impacts on the possibility, willingness and motivation to act (resilience), but that it plays a crucial role in determining how individuals make sense of the threat posed by extreme temperatures, how they perceive the assets available to them to deal with the threat and the motivation to act, and ultimately, adapt. Those participants that revealed greater and extended adaptation relatively to others were those with lower vulnerability and higher resilience. Justifications for this include having more assets available to use, perceiving the threat in an ordered way, feeling that the assets available are adequate and having the motivation to act (bottom-right quadrants). Despite this, other participants with higher vulnerability and higher resilience showed that not having as many assets available did not constrain their orientation to endure; they felt confident that they were able to act and engaged in adaptations with the assets available to them (top-right quadrants). Participants with high vulnerability and low resilience were somewhat most at risk from the impacts of extreme temperatures, as the assets available to them are limited and their confidence and motivation is low making it extremely difficult to them to understand the threat and internally find it worth investing which in practice meant that their adaptations were also restricted (top-left quadrants). Based on the vulnerability–resilience matrices, there were also participants with low vulnerability and low resilience. Their assets availability was high but their orientation and confidence to deal with the threats posed to them, the

perception of assets available and their motivation to act was very low which seemed to compromise their adaptations, meaning that not much strategies were put in action (bottom-left quadrants).

3.3.5 Individual portraits

So far this article has presented individual participants' analysis and positioning in relation to general, heat- and cold-related vulnerability and resilience, as well as providing an approach to integrating adaptation to heat and cold. In this section, more details on the individual characteristics of participants are brought to light by presenting portraits of particular participants as an illustration of their vulnerability and resilience characteristics and adaptation responses to extreme temperatures. The portraits developed aim to illustrate and 'bring to life' certain features of the participants, with the goal of showcasing rich and interesting sketches of how vulnerability, resilience and adaptation to heat and cold materialise revealing different spheres of participants' lives. The six portraits were chosen from all participants taking into account their relative positions in both heat- and cold-related vulnerability–resilience matrices but do not represent fixed typologies of characteristics of participants in the same position of the matrices, thus they are not intended to represent the vulnerability–resilience quadrant they are part of.

Participants' levels of vulnerability and resilience are intrinsically linked to the ways in which they adapt. Less vulnerable participants are in a better position to have high resilience and better adapt to heat. Despite this, some exceptions were found in this research, where low vulnerability does not predict high resilience revealing that not all older individuals with the necessary assets have the willingness and motivation to act/adapt, and due to this face important barriers and limits to adaptation. Similarly, having high vulnerability did not define levels of resilience in this research. A high number of participants were defined as having high vulnerability but with distinguished levels of resilience. Again, not having the necessary assets to deal with heat was not a predictor of the willingness and motivation to act/adapt. A range of diverse factors besides assets are influencing participants' resilience and adaptation behaviours, as discussed above, and can be better understood by looking at six portraits of participants.

The individual portraits of participants (see Supplementary material D) recognise the individuality of participants' circumstances. There is significant individual variability and distinctiveness in vulnerability, resilience and adaptation circumstances between participants which is lost when looking at the whole sample data. The data contains great diversity of vulnerability and resilience combinations, and adaptation strategies which help in the understanding and need for development of person-centred strategies and actions for reducing vulnerability, increasing resilience and improving adaptation to extreme temperatures.

4 Discussion

This research brings together the concepts of vulnerability, resilience and adaptation and investigating the interactions between them in the Portuguese context. It does so, through independently researching general vulnerability and resilience, heat-related

vulnerability, resilience and adaptation and cold-related vulnerability, resilience and adaptation.

The results demonstrate that the levels of combined vulnerability and resilience differ between older individuals. It was found that vulnerability is not a key determinant of resilience, and both vulnerability and resilience were found to be key determinants of adaptation. Altogether these results suggest particular approaches for reducing vulnerability and increasing resilience with implications for improved adaptation.

4.1 General vulnerability and resilience

Relationships between assets and vulnerability have been explored in sociology for four decades (Moser 2011; Chambers 2006; Sen 1981) with an emphasis on the role of inequitable access to assets as sources of vulnerability (Sen 1999, 1981). In the disasters literature, access to assets is seen as an important factor in understanding vulnerability (Bankoff 2019; Birkmann et al. 2010). The health literature has also started to show growing interest in understanding the contributing factors to vulnerability, including assets (Watts et al. 2018; Marmot 2010; Morgan and Ziglio 2007). Despite this, few interdisciplinary studies have been implemented for understanding the role of assets in shaping vulnerability (Ebi et al. 2018; Fussel, 2007). As a result, the work in this article draws from these existing literatures and introduces a novel interdisciplinary and empirical perspective to understanding the role assets play in shaping vulnerability.

The relationship between resilience and assets has been to date less studied; in the disaster and human development literatures, some authors have highlighted the influence between the resilience of individuals and the places where they live (Ungar 2018; Romero-Lankao et al. 2012; Brown and Westaway 2011; Luthar et al. 2000). In examining this relationship, the results of this article show a strong link between access to assets and resilience, which has also been highlighted by the Royal Society (2014). In contrast, however, findings of studies relating vulnerability to resilience have been diverse and less clear cut, with some authors asserting that reducing vulnerability is essential for increasing resilience (Bankoff 2019; Keim 2008). However, this research has found that being more vulnerable does not imply being less resilient. Some aspects of vulnerability do affect one dimension of resilience (manageability) but vulnerability is not a key determinant of resilience. These findings emerge from this research because it has used a different approach focusing on broad aspects of vulnerability and resilience, and used particular metrics to elicit these (i.e. GVI and GRI).

4.2 Vulnerability, resilience and adaptation to extreme temperatures

Few have been the empirical studies investigating the relationships between the concepts of vulnerability, resilience and adaptation to extreme temperatures (Bankoff 2019; Ebi et al. 2018; Deschenes 2013), having mainly focused on one of the concepts in isolation or on combinations of two concepts (i.e. assets and vulnerability, vulnerability and adaptation, resilience and adaptation). A growing number of studies from diverse disciplines have explored the theoretical links between these concepts (Bankoff 2019; Ebi et al. 2018; Miller et al. 2010; Turner 2010; Berkes 2007; Nelson et al. 2007; Vogel et al. 2007). The literature indicates that different types of assets are key determinants of vulnerability to extreme temperatures. As an example, in their work on heatwaves and adaptation, Wolf and colleagues (2010) found that social assets (i.e. social capital) influence older individual's

adaptation and assert that social assets may enhance resilience. Research undertaken by Wilhelmi and Hayden (2010) for example has suggested that adaptation to extreme heat can reduce vulnerability and as a result reduce the health impacts of extreme heat. In addition, the IPCC (2018) has asserted that reductions in vulnerability will result in improved adaptation, as well as increasing resilience, whilst at the same time increasing assets.

This research agrees with the literature, on the role access and availability of assets play in adaptation to extreme temperatures. However, this research has found that vulnerability is not a key determinant of resilience. This is based on the finding that assets have an important role in one of resilience dimensions (manageability) but not in the other two dimensions (comprehensibility and meaningfulness); and in fact participants revealed diverse levels of combined vulnerability–resilience. Furthermore, the work in this article is in agreement with the literature asserting that older individual's resilience is an enabler for adaptation (Ebi et al. 2018; Ungar 2018; Conlon et al. 2011; Hansen et al. 2011).

Thus, this research contributes to a better understanding of human general and specified vulnerability and resilience, as well as adaptation to extreme temperatures by building an integrated framework. This research has highlighted the role assets play in shaping human vulnerability, resilience and adaptation. Access to and availability of assets determine the vulnerability, resilience and adaptation of older individuals. This research also found that vulnerability is not a determinant of resilience, as older individuals showed great diversity of combined vulnerability and resilience. Whilst vulnerability is determined directly by access to and availability of assets, resilience is determined by the ability to make sense of the threat extreme heat and cold pose (comprehensibility dimension), the motivation to act and respond (meaningfulness dimension) and the perception that assets are available for one to use to respond to the threat extreme heat and cold pose (manageability dimension). As a result, individuals may be vulnerable and at the same time resilient to extreme temperatures. However, adaptation is determined by both vulnerability and resilience. This article challenges previous theoretical perspectives, suggesting that increasing assets is essential to reduce vulnerability, increase resilience and improve adaptation.

The work in this article also highlights the importance of undertaking more integrated studies and assessments of vulnerability, resilience and adaptation, which build upon the more singularly focussed analyses of vulnerability, resilience and adaptation found in most research to date.

An important contribution of this article is also in the similarities of the relationships between assets, vulnerability, resilience and adaptation to extreme heat and extreme cold found in this empirical research; these suggest some common lessons regarding these two expressions of extreme temperatures can be derived from this work. Furthermore, similarities and alignments can also be found with other agendas such as, sustainable development, as there is wide agreement that climate change denotes a threat to sustainable development (IPCC, 2014).

4.3 Alignment with the UN 2030 agenda for sustainable development

Achieving reduced vulnerability, strengthened resilience and enhanced adaptation is coherent and agrees with the need to achieve sustainable development (IPCC 2018, 2014). The identification of synergies between these agendas can be increased if there is an intentional strategy and process in place that focus on coherence, efficiency and effectiveness of actions that simultaneously address all the above to improve collective outcomes and avoid trade-offs. Nevertheless, this can only be achieved if certain conditions are met in terms of

governmental and institutional as well as key stakeholder buy-in, engagement and collaboration, and subsequent coordinated development, implementation and sharing of information and knowledge between all those involved. Aligning the vulnerability, resilience and adaptation agendas with the sustainable development agenda can be extremely beneficial for reducing the impacts of extreme temperatures. Concerted efforts and opportunities can be capitalised to reduce vulnerability, strengthen resilience and enhance adaptation, and at the same time achieve sustainable development (IPCC 2018).

The findings on vulnerability, resilience and adaptation, suggest the need to prioritise and strengthen the alignment between these three agendas and sustainable development efforts (UN, 2015), as they have common themes, scopes and objectives (IPCC 2018). Prioritising vulnerability reduction, resilience strengthening and adaptation enhancement is consistent with efforts to achieve SDG1 (no poverty), SDG2 (zero hunger), SDG3 (good health and well-being), SDG7 (affordable and clean energy), SDG10 (reduced inequalities), SDG11 (sustainable cities and communities) and SDG13 (climate action).

As a result, implementing nationally and locally informed social protection strategies (Target 1.3), ensuring access to financial, human, physical and place-based assets (Target 1.4; 2.1; 3.d; 7.1; 10.4; 11.1; 11.7) are convergent with the findings of this study (Table 2) and the need to reduce vulnerability, build resilience and improve adaptation. Building the resilience, reducing the vulnerability and improving the adaptation efforts of individuals (e.g. older people) to hazards (e.g. extreme temperatures) (Target 1.5) and at the same time creating opportunities, developing and implementing policies and plans for cities (e.g. Lisbon) and countries to become less vulnerable, more resilient and better able to adapt to the challenges of hazards (e.g. extreme temperatures) (Target 11.b; 13.1; 13.2) also overlap with the findings presented here and the interconnections between vulnerability, resilience and adaptation (Fig. 10).

4.4 Implications for policy and practice

Responding to extreme temperatures requires adequate information on risk and impacts of heat and cold, in order to identify assets needs and availability to access appropriate and available adaptation options. Adaptation constraints and limits were shaped by participants' high vulnerability and low resilience. Despite this, research participants revealed that there are a range of opportunities for enhancing their adaptation strategies drawing on assets that they would welcome. The lack of understanding of how individuals will adapt successfully taking into account the accessibility and availability of incentives, resources, knowledge and skills (Fankhauser et al. 1999) have led some authors to argue that it is the access to assets that determines the capacity of individuals to adapt (e.g. Grothmann and Patt 2005; Adger 2003). The research undertaken for this article supports the call for more work on the breadth of adaptation strategies used by older people and the influence of assets (e.g. White-Newsome et al. 2011), coupled with the need to assess what, how and to what level human adaptation is occurring and can be enhanced in the future (Deschenes 2013).

The findings of this research provide a range of contributions to policy and practice for reducing the human health impacts of extreme temperatures. This study indicates these can be achieved through the planning, development and implementation of policies and actions aiming at: a) reducing vulnerability; b) increasing resilience and; c) improving adaptation. In order to accomplish this, a core focus on increasing assets, both access and availability, as well as quality and quantity of each type of assets and overall asset portfolio is key. An

important element is that by increasing assets a simultaneous improvement could be felt in all areas (vulnerability, resilience and adaptation) indicating that these policies and actions can be overlapping and pursued simultaneously.

The starting point to ensure the robustness of decisions regarding both policies and actions aiming at achieving reductions in the health impacts of extreme temperatures is first of all to understand that '''robust decisions'' are defined as decisions that work well (that achieve their goals) even with the inclusion of various uncertainties. In other words, ''robust decisions'' are decisions that are insensitive to uncertainties known at the time.' (Dessai and Hulme 2007: 60). As a result, the criteria used in this research to assess robustness of decisions should consider include: the main themes shaping vulnerability; the themes related to resilience according to the manageability dimension of resilience, and; the opportunities for improving adaptation based on older people's own views (Sect. 3.1.; Table 2). This research highlights that in order to make robust decisions one needs to take into account all types of assets. These would be more robust because by focusing on all types of assets decisions would not ignore other important characteristics of a specific type of assets and would increase opportunities to make good use of assets. As such, robust decisions made for planning, developing and implementing policies and actions that focus on increasing assets are thought to be possible and deemed necessary.

5 Conclusions

This article has integrated and discussed the results of combined general and specified vulnerability, resilience and adaptation to extreme temperatures. The approach taken in presenting a combined analysis is novel and a contribution to knowledge in the sense that it allows an integrated discussion of the roots and drivers of vulnerability and resilience for understanding adaptation to heat and cold. The findings of this research demonstrate how vulnerability, resilience and adaptation are contingent on human, financial, physical, place-based and social assets, as well as on the comprehensibility (i.e. cognitive), manageability (i.e. behavioural/instrumental) and meaningfulness (i.e. motivational) dimensions of resilience. In addition, wider aspects of the Portuguese context, including welfare provision, the role of family relationships and the role of community, including the residential building stock, services and facilities, traditions which encourage a strong sense of personal independence and also fatalism and resignation to divine will. At the individual level, participants' general and specified (i.e. extreme heat and extreme cold) vulnerability, resilience and adaptation are quite variable and those who are less vulnerable, more resilient and those that most successfully adapt to normally prevailing conditions (i.e. general) are not always those best able to adapt to specified threats such as extreme temperatures.

Participants revealed diverse combinations of vulnerability–resilience and adaptation actions. First, participants revealing comparatively lower levels of vulnerability and higher levels of resilience presented better ways of responding to both heat and cold. Second, participants comparatively demonstrating relatively higher levels of vulnerability and lower levels of resilience were more likely to reveal narrow and limited strategies and responses to both heat and cold. Third, participants revealing somewhat higher vulnerability and resilience felt hope that they would be able to actively respond to heat and cold, despite not having all the assets needed to do that. Fourth, participants demonstrating relatively low vulnerability and resilience were uncommon in this study, and were more likely to be anxious and at the same time show apathy towards acting.

The levels of vulnerability and resilience convey important bases for: targeting at-risk older individuals (high vulnerability & low resilience); developing vulnerability reduction actions (high vulnerability & high resilience); resilience building actions (low vulnerability & low resilience), and; understanding 'success cases' (low vulnerability & high resilience) and learn from them for developing appropriate policy measures. Generally, planned adaptation options were implemented by low vulnerability & high resilience participants, whilst autonomous adaptation options were more common within other participants. Participants also commented on the links between vulnerability, resilience and adaptation with social justice, equity and austerity, especially to whether participants or trusted ones have the scope to reduce their vulnerability (assets portfolio), enhance resilience (comprehensibility, manageability and meaningfulness) and improve adaptation.

The conceptual and analytical framework, as well as a methodological approach presented in this article can be replicated at the national, regional and local levels, by local authorities, NGOs, Health Trusts, among others to better understand the needs, constraints, limits and opportunities for better understand the relationship between assets, vulnerability, resilience and adaptation for reducing vulnerability, enhancing resilience and improving adaptation to extreme temperatures in particular, and important insights for other threats, shocks and stresses in general. Assets are at the core for understanding vulnerability, resilience and adaptation; they are the root causes of human vulnerability, they impact on the resilience of individuals through their links to all three dimensions of resilience (comprehensibility, manageability and meaningfulness) and determine the strategies and behaviours available to individuals for responding to extreme temperatures in particular (adaptation), and other threats, shocks and stresses in general.

The findings of this study align with the United Nations 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). Direct links exist between reducing vulnerability and enhancing resilience and improving adaptation to extreme temperatures through SDG 3 on good health and well-being (Nunes 2020; IPCC 2018; Nunes et al. 2016).

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Data availability Further data available as Electronic Supplementary Material.

Declarations

Conflicts of interest The author declares no conflict of interest.

Ethical approval Ethical approval was obtained was obtained from the University of East Anglia, Faculty of Medicine and Health Sciences Research Ethics Committee (Reference 2011/2012–30) and from Universidade de Lisboa, Instituto de Ciências Sociais Ethical Committee.

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Consent for publication Author consents publication.

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