New Enabling Visions and Tools for End-useRs and stakeholders thanks to a common MOdeling appRoach towards a ClimatE neutral and resilient society

D2.1 Society and climate change links and lifestyle changes measures

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Abbreviations and acronyms

Acronym	Description
ASI	Avoid, Shift, Improve
CRF	Concentration-response function
DLS	Decent Living Standards
ERF	Exposure-response function
GCM	General Circulation Model
HDCC	Human Dimensions of Climate Change
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
LGBTQ	Lesbian, Gay, Bisexual, Transgender, Queer
RCP	Representative Concentration Pathways
SES	Socio-ecological system
SIA	Social Impact Assessment
SLR	Systematic Literature Review
VSL	Value of a Statistical Life

Table of Contents

List of Figures

List of Tables

Executive summary

This deliverable contains information about climate change and society regarding several aspects. The objective is to set a basis for modelling climate change and society interactions in WP4 and WP6. Section 2 contains a review of how social sciences are embedded in climate change research. Section 3 includes a description of how climate change affects society, including a characterisation of social impacts of climate change and a systematic literature review of the representation of some climate change social impacts in integrated assessment modelling. Section 4 contains a preliminary modelling framework for the representation of behavioural change and lifestyle transformations and a portfolio of measures, drivers and barriers obtained through a cross-disciplinary literature review.

1. Introduction

The need to prepare our societies to face climate change is obvious and urgent. Nevertheless, the existence of different actors with different interests sometimes slows down the entry into action. The Paris Agreement has the objective to *'limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees.'* However, it seems unclear whether the economic and social resources that the countries are dedicating to fight climate change are enough (or enough well managed) to move forward at the pace the problem requires (Nieto et al., 2018).

Up to recently, the natural sciences clearly dominated the social sciences in climate change science. Today, the social sciences are becoming increasingly important in analysing and proposing solutions to this major challenge that jeopardizes human societies. Their role is also essential to understand how society relates to the fight against climate change, as the change needed is not only technical but also social.

This deliverable uses social science knowledge and methodologies to make proposals integrable in the NEVERMORE models and tools regarding the representation of climate change impacts on society and the behavioural change and lifestyle transformations that can help mitigate and adapt to climate change.

2. Social sciences and climate change research

Although it is true that climate change science was pioneered by natural science and until recently has been traditionally dominated by it, social sciences are nowadays gaining ground in analysing and proposing solutions to this great challenge that threatens our planet. This is due to the acknowledgement that the analysis of the interrelationships between climate change and human actions is as important as understanding its biophysical effects (Castree et al., 2014).

The relationship between climate change and social sciences has deep roots. Social scientists have long been researching environmental issues, climate change being just one of them. According to Castree et al. (2014), environmental social sciences have two aims: i) to look into the norms, presuppositions, perceptions, relations, preferences, regulations and institutions that define how humans' value and use the non-human world and ii) to determine and assess ways of shifting human behaviour to reach a desirable or necessary end. As part of this second objective, many environmental social scientists consider it important to work hand-in-hand with those that have effects on (or that are affected by) environmental change.

Logically, environmental social science is not a homogenous corpus, but a group of very different academic disciplines that span virtually every social science and humanities discipline. There exist, for example, consolidated disciplines on environmental economics, environmental sociology, environmental psychology, environmental politics, environmental law history, environmental education, and environmental anthropology. Additionally, there are other disciplines that feel more comfortable using environmental related prefixes such as 'eco' or 'bio'. For example, ecological economics, bioeconomics or ecolinguistics. Prefixes are usually indicative of the philosophical paradigm behind. For example, thought schools like environmental economics and ecological economics have radically different point of views on fundamental ontological and epistemological assumptions. Once the former is limited to the study of environmental issues from a conventional economic point of view, the second one, much more interdisciplinary in origin, proposes a radical conception of economy that is embedded in the question of biophysical limits to the economic sphere.

Interdisciplinary areas such as human ecology or political ecology also emerge as new disciplines that integrate knowledge, methodologies, and practices from various natural and social science disciplines. There are also disciplines not traditionally embedded into environmental issues that are currently focused on these topics, such as behavioural psychology, which studies how individuals and groups process and respond to climate change awareness campaigns or human geographies (Clayton et al., 2015).

The conjunction of natural and social science of climate change gives rise sustainability science and also vulnerability science and adaptation science, which generally use common concepts and terms that facilitate information exchanges (examples are 'resilience', 'recovery', 'risk', 'feedback' or 'threshold').

The contribution of social science to climate change science is essential since climate change is a complex phenomenon that crosses every disciplinary boundary. However, the reality is that social science is still behind natural science in terms of funding and representativeness in research. It has contributed to climate change integrated knowledge and to the creation of fundamental concepts such as 'social-ecological systems' or 'human dimensions of climate change', but it is still much progress to be made.

In the following subsections, we explore the role of social science in climate change research in different senses. In 2.1, we describe the climate change social science state-of-the-art. In 2.2, we dive into the social scientific methods that can be useful and in 2.3 we synthesise some critical ideas about the role of social science within climate change science.

2.1. The current state of climate change social science

As mentioned above, although climate change science is dominated by natural science, the positioning of social science is improving (Castree et al., 2014). There is much awareness in academia of the need for a better connection of social science and humanities with natural and climate sciences to address the climate crisis. Currently, much effort is being made on creating cross-sector collaborations between different actors such as academia, business companies or public authorities. The objective is an extension of natural scientific reasoning beyond formal institutions to involve other parts of the society that allows us to change the human systems and tackle the climate crisis. In this sense, the co-production of knowledge by scholars and citizens is seen as an essential element and the social sciences are seen as the tool to reach that aim (Skoglund, 2015).

Figure 1 shows the results of a search in the bibliographic database Scopus by introducing the keyword 'climate change' in all the titles, abstracts and keywords, and limiting the search to social sciences categories. The search was conducted on 12th January of 2023. As we can see, there has been an exponential growth in scientific output since 2007. Before this date, the growth was very low. The results coincide with the study made by (Chen & Xie, 2013), who study the situation of social sciences in climate change research in China. The authors even mention Chinese media and intellectuals designated 2007 as the 'climate change year'.

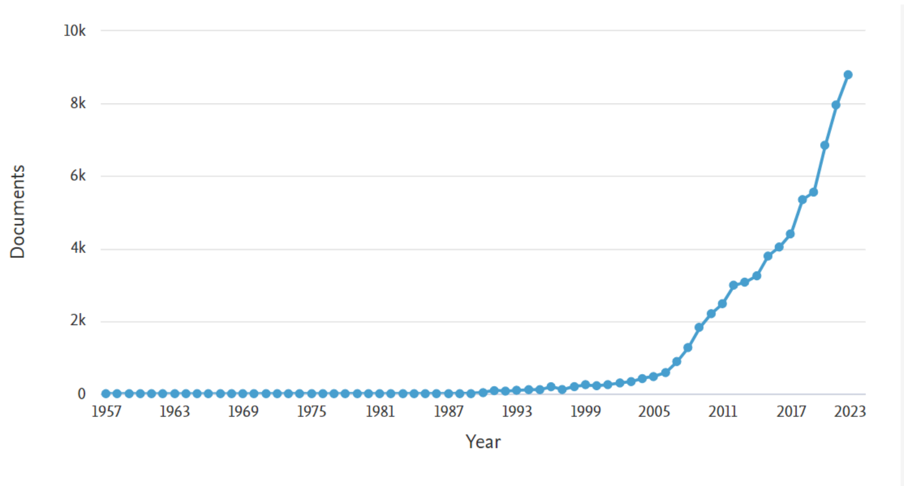

Figure 1. Documents on climate change social science research by year at global level from 1983 to 2022. Source: Scopus

In the search conducted, before limiting it to the social science area, we obtained 396,948 documents from 1983 to 2022. From these documents, 24% fall in the category 'Environmental Science', 15.3% belong to 'Earth and Planetary Sciences', 15% are from the 'Agricultural and Biological Science' category and 9.7% corresponds to social science research (Figure 2).

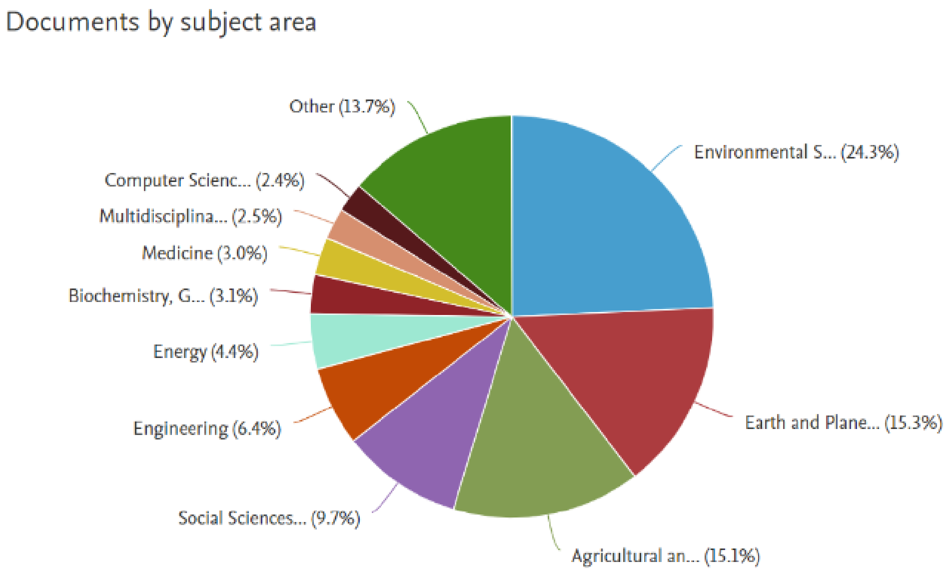

Figure 2. Documents on climate change social science research from 1983 to 2022 by scientific area. Source: Scopus

These results confirm that, although social scientific production on climate change is increasing, there is still a clear dominance of natural science with respect to social science.

The reasons that explain why social science has been delegated to a second role are multiple, ranging from specific elements such as the lack of funding to more complex ones like inertia, power, and domination. In section 2.3, we will go in-depth into the barriers that social science faces within climate change research. Although inequality among scientific areas is undeniable, it is also true that much effort is being done in developing what could be called a 'climate change social science'.

One of the more developed and consolidated climate change social scientific disciplines is climate change economics. The Climate Change Economics academic journal publishes the bulk of the academic research carried out in this area. There is also a consolidated research area on energy and social science, also with a peer-reviewed international journal called 'Energy Research & Social Science', with a very huge part of the research focusing on energy transitions to zero-carbon sources.

In the discipline of sociology, Islam & Kieu (2021) made a review that contains examples of sociological contributions to climate change research on a multitude of topics: anthropogenic forces of climate change, markets and organisations related to climate change, consumption patterns, global inequality and climate justice, the role of civil society and social movements, public opinion on climate change, climate change denial counter-movement and social theories and methodological approaches to climate change.

The climate change social science is not only generated inside specific disciplines but also crosses borders moving towards interdisciplinary. According to Leyshon (2014), social science is producing work along a very wide range of climate change related topics such as 'behaviour, identity, values, economics, policy, governance, regulation, everyday life or co-production'. The research in climate change in social science is actually very diverse. There is a huge variety of interesting research questions, objectives and hypotheses, as well as studies of a very different nature.

Vulnerability is an emerging topic in which social sciences are providing useful information (Debortoli et al., 2018) and in which a huge number of transformative methodological, empirical and theoretical insights are being generated, although it is particularly noteworthy that scientific and technical approaches still dominate in the field (Thomas et al., 2019). For instance, the study of Debortoli et al. (2018) uses network analysis to determine which biophysical but also social variables contribute to climate change vulnerability. In their work, the definition of vulnerability goes beyond a technical one by incorporating the concept of 'contextual vulnerability' which puts the emphasis on feedback loops and cross-sectoral interactions of a social system in which the vulnerable object/subject is placed. Thomas et al. (2019)'s study explains what makes a person more or less vulnerable according to explanations given by cultural anthropology, archaeology, human geography and sociology.

Tipping points is another field in which climate change natural science has strictly dominated, but in which social science is currently provisioning useful knowledge. The study of H van Ginkel et al. (2020) sets a taxonomy of tipping points that not only include the traditional concept of climate change tipping points (Lenton et al., 2019) but also a concept of 'climate change induced socio-economic tipping points (SETPs)'. Although this seems to be a very promising research field in which social science has a lot to contribute, the review of H van Ginkel et al. (2020) shows that the study on tipping points in the socio-economic domain is virtually non-existent to date.

Regarding *resilience*, it is interesting the work done by Olsson et al. (2015) who explain why social scientists have not contributed that much to the development of this central concept in climate change impacts research. The authors argue that the 'dominant' concept of resilience, that has its roots in ecological and environmental studies, has 'ontological presuppositions' embedded (e.g., ideas related to the equilibria of systems) that are still central debates for social scientists. That is one of the reasons that makes the social scientist stay away from the resilience field, in which key concepts for social science such as agency, conflict, knowledge or power, are completely absent. In line with this work is Plein (2019), who explores what elements provoke sociocultural or socioeconomic inertia that impede effective climate change policy responses. The author argues that ambiguity and fuzziness of concepts such as resilience and adaptation are one of these elements, which make disaster recovery difficult and reinforce non-response, creating this paradoxical but common situation in which although a pro-change social behaviour could be obviously satisfactory, people do not want to shift.

Drivers and *responses* of climate change have also been recently explored in the study of Jorgenson et al. (2019) from the anthropological, archaeological, geographical and sociological points of view. In this last area of responses or *solutions* to climate change, it is important to highlight the work done by Goldberg et al. (2020), who advocates for social science as a tool to generate enduring climate change action. The authors mention 'deep engagement', 'mental models' and 'social norms' as the three categories that can successfully lead to strong motivation to face climate change. Examples of deep engagement could be communication strategies that penetrate further in what climate change dissemination refers to (e.g., using videos instead of text). Mental models are those schemes and narratives that help to frame the problematic aspects of climate change. The author uses the example of United States citizens conceiving climate change as a distant problem (e.g., they visualise a melting ice chunk instead of a tornado destroying their home). This is a mental model that does not lead to climate action and social science should contribute to shifting it by other frameworks based on 'system thinking', which have been found to promote pro-environment attitudes. Finally, social norms are those elements that sustain patterns of behaviour and that can create vicious or virtuous cycles of collective behaviour. Social science can also help to investigate the mechanisms behind social norms (e.g., social pressures, intrinsic values) that conform our imaginary to promote climate change worrying and action. These three broad categories are not mutually exclusive, and they can be combined by generating a multidimensional approach.

There are even social science studies that aim to (re)define the concept of *climate*. For instance, Alexandra (2021) defends that climate is a 'cultural construction' and, thus, it is necessary to throw light on the cultural determinants of our understanding of the world because changing cultural perspectives and values are critical in policy-making.

2.2. Social science methods for climate change research

Social sciences are a catch-all in which many disciplines cohabit. Despite their differences, methodologically, we could say that social science disciplines share common features. Also, climate change social science is not only a group of disciplines but an academic community itself. The review of Sovacool et al. (2018) synthesises what are the appropriate methods to conduct research in energy social science. Even though the study focuses on energy social science, their ideas are applicable to climate change social science in general, since energy systems and transitions are only one of the foci of social science studies working on environmental and climate change issues.

Sovacool et al. (2018) present seven energy social science method categories:

- Experiments and quasi-experiments.
- Literature reviews.
- Surveys and quantitative data collection.
- Data analysis and statistics.
- Quantitative energy modelling (for our purposes, we can call this category 'quantitative climate change modelling' or simply 'quantitative modelling').
- Qualitative research.
- Case studies.

Table 1 includes a description of them and what are the core disciplines that use each method, according to (Sovacool et al., 2018).

Table 1. Dominant research methods in energy social science. Source: Sovacool et al. (2018)

Method	Core disciplines	Description
Experiments and quasi-experiments	Behavioural science, social psychology, behavioural economics	These provide reliable evidence of the causal effect of different mechanisms by explicitly controlling for the effect of different variables

Literature reviews	All disciplines	These scour existing literature with the aim of identifying the current state of knowledge.
Surveys and quantitative data collection	Various, but especially, sociology and marketing	These provide valuable information about a given sample of population or data, allowing the use of descriptive statistics and test of association among variables
Data analysis and statistics	Various, but especially, psychology, economics, and some traditions within political science	These allow exploring quantitative hypotheses, such as comparing means across samples or testing associations of variables. Data can be primary (collected by the researcher) or secondary (already existing).
Quantitative modelling	Economics, engineering, and environmental science	This covers a variety of approaches to analyse the operation and consequences of different mechanisms using simplified mathematical models. These abstract from real-world complexities and focus on key mechanisms, either conceptually or by combining theoretical assumptions with empirical data.
Qualitative research	Anthropology, sociology, history, geography, policy studies, science and technology studies	This includes a variety of techniques for obtaining information regarding understandings, opinions, perceptions and attitudes of different individuals and groups. Some examples are structured interviews, participant observation and focus groups.
Case studies	Various, but similar to qualitative research	These consist of the examination of one or various subjects of study (cases) and associated contextual conditions. Sources used can be several and multiple (qualitative and quantitative).

Most of the methods presented in Table 1 will be used in the NEVERMORE Project. For instance, WP2 is conducting various literature reviews and qualitative research within this deliverable, and also surveys and qualitative data collection within Task 2.2. WP3 is mainly working on data analysis and statistics. WP4 focuses on quantitative modelling, and WP6 is developing a characterization of case studies.

We consider that the Sovacool et al. (2018) classification is interesting as a starting point, but it dedicates relatively little attention to qualitative methods and compounds methods of data collection with methods of analysis. Thus, we suggest a complementary but not complete classification of methods used in climate change social science (Table 2).

Table 2. Alternative classification of social science methods.

Method	Type	Framework
Experiments and quasi-experiments	Data collection	Quantitative
Surveys and questionnaires	Data collection	Quantitative
Descriptive analysis	Analysis	Quantitative
Statistical data analysis	Analysis	Quantitative
Quantitative modelling	Analysis	Quantitative
Literature reviews	Data collection and analysis	Quantitative (meta-analysis) or qualitative (systematic or narrative reviews)

Observation	Data collection	Quantitative or qualitative
Semi-structured and unstructured interviews	Data collection	Qualitative
Focus groups and group discussions	Data collection	Qualitative
Document analysis	Data collection	Qualitative
Grounded Theory	Data collection and analysis	Qualitative
Thematic analysis	Analysis	Qualitative
Participatory methods	Data collection and analysis	Qualitative
Open-ended surveys	Data collection	Qualitative
Content analysis	Analysis	Qualitative

2.3. Insights of climate change social science and lessons for the near future

As explained above, social sciences have taken a back seat in climate change science, although they have been gaining in importance since some years ago. This has led many social scientists to critically wonder how and in which way social sciences are being involved. The answers to this question are many and varied, and it is worth paying attention to them as we can extract a lot of insights for contextualising the research carried out within the NEVERMORE project.

Until recently, there has been a very clear dominance of the natural sciences over the social sciences in climate change science, which now seems to be waning, which is good news for social scientists. But the way in which social science is beginning to be integrated into climate change research also deserves careful and critical analysis.

Authors such as Castree et al. (2014) have argued that social science research is an essential element for reframing and understanding climate change science, but not all opinions go in that optimistic direction. More recently, Glavovic et al. (2022) argued that the current science-society contract is broken because although climate research and funding grow, climate change-related indicators are worsening. Even though a lot of political scientists, sociologists, economists and human geographers have been conducting very interesting research in the previous decade (see previous section), this has not led to societal transformation so far. Nevertheless, what is valuable according to the authors is that they have contributed to expose some of the power dynamics and vested interests that impede climate action. This article received a reply by (Cologna & Oreskes, 2022) who consider social science research to have a tangible role to change the future. They argue that natural and social scientists have done their job effectively, but that powerful cultural and political forces are constraining the climate change responses. They also argue that more social science and humanities research is needed to keep exposing and addressing these power structures that are blocking the way.

In relation to the role of social sciences and transformative capacity, some authors have also criticised the fact that there is a kind of pressure or preconception that social sciences are expected to trigger social change since their methods very often are aimed at engaging and involving society in knowledge development. But the information to be translated to citizens does not necessarily imply a change. Also, climate change social science has been traditionally relegated to the field of responses to climate change, whereas it has much to contribute to epistemological and ontological definitions of climate change (Skoglund, 2015).

Leyshon (2014) makes a critique on the problematic assumption that social science research *'straightforwardly and unproblematically produces change'.* The author argues that climate change is a 'hybrid ontological object' since it is a product of scientific observations but also of cultural meanings, and simultaneously 'a reality, an agenda, a problem and a context'. However, according to the author, funding and academic publishing regimes do not leave much space to make reflections on this. Alexandra (2021) also argues that 'climate is objective and subjective, scientific and cultural, local and global, and personal and political'. This last author argues that natural science alone is not adequate for facing climate change, since there are a lot of elements such as law, politics, and culture that construct climate change meaning.

There can be cultural barriers determined by social and historical factors that social sciences can help to understand.

Thus, social science is composed of a lot of disciplines with different methodologies and philosophical backgrounds inside social sciences, although it is currently subordinated to dominant ontologies by natural sciences. This opens a new discussion around the idea of *interdisciplinarity*: is interdisciplinarity feasible, and, above all, is it desirable in any case?

There are authors that see interdisciplinarity as an opportunity to allow social sciences to gain importance (Castree et al., 2014; Islam & Kieu, 2021; Meulenberg et al., 2022), whereas others have more moderate and reticent positions (Leyshon, 2014; Olsson et al., 2015). According to Leyshon (2014), the role of social sciences has generally been to support and interpret results of the natural and technology science, which is considered the 'real science', and also to facilitate engagement between academia and others. Although this can be valuable, it should not be the only role of social science. Leyshon (2014, p. 5) also defends that research should avoid 'broad-based, integrated and actionable knowledge that fits any given situation'. Instead, the right way should be to make visible that there are many possible realities that can be studied through different research questions, methods, techniques, and theories. Social science is not a homogeneous body of knowledge, so all the ontologies that these fields can propose are valuable.

There is another concept closely linked to the latter ideas that is worth exploring critically, and that is the idea of *unification*. An interesting question to propose here is: to what extent are we interested in unifying disciplines and at what cost? What are the benefits and what are the losses? Is it feasible and, above all, desirable?

Olsson et al. (2015) explain the difficulties and risks of trying to unify concepts such as resilience or vulnerability across different and disciplines. The authors admit the analytical potential of common and unified concepts to promote integrated approaches across scales, sectors and spaces, but we cannot ignore that there are fundamental differences among social science disciplines and natural science disciplines that can strongly impede this unification. Some examples of difficulties are the definition of the problem or the system boundaries. For instance, the integration of concepts in a quantitative model requires the selection of metaphors and simplifications. Then, some complex societal processes are translated into simplified concepts (e.g., competition, rationality, etc.) and afterwards into mathematical equations. The problem here is that each metaphor selection is grounded in philosophical and political assumptions, and it highlights some aspects while hiding others. According to Olsson et al. (2015), the election of metaphors is not only epistemological, but also ethical and performative, since it results in feedback on society, provoking social consequences in real life and collective imaginaries.

All this is very related to the issue of *political neutrality* in climate change research. Castree et al., (2014) argue that embracing social science is a way to give a political dimension to climate change research, since natural scientists usually and institutions such as the IPCC generally defend a *'policy relevant yet policy neutral model of knowledge provision',* which actually is revealing a political positioning.

At this point, we can ask a fundamental question: what should be the role of social sciences within climate change science? Critical authors have made some interesting proposals.

In contrast to the idea of unification, Olsson et al (2015) claim for pluralism, which, instead, does not necessarily have the goal of establishing a single theory or approach. Pluralisms assume that a phenomenon can be explained by multiple theories. Thus, rather than falling into a 'false unificationism' (which is actually the domination of one ontological and epistemological framework over the other) that can lead to reductive conclusions, we would exploit and make the most of all disciplines' values. The authors also note that not all kinds of unifications are necessarily bad or 'imperialistic', but their point is interesting since it points out the importance of being careful in interdisciplinary processes.

It is also interesting to consider the point elaborated by Goldman et al. (2018), specifically in relation to co-production and engagement approaches of knowledge. According to the opinion of the authors, currently there is a 'synthesis' work in climate change research where only one climate change definition is recognized. It is the same with related concepts such as resilience or vulnerability. This insinuates that we might be missing a lot of information from groups involved in co-production processes that have radically different understandings and that can hardly find meaning in general or unique concepts. The authors propose to rely on critical political ecology to 'radically rethink' co-production processes and open doors to new ways of engagement.

Alexandra (2021) claims for critical realism as a useful philosophy of science to integrate natural and social science in understanding society and approach climate change research. Critical realism, as a philosophy of science, recognises that there is a material reality based on physical relationships, but proposes that this can only be partially understood and the way we approach it is embedded in cultural prisms within specific historical contexts. Thus, critical realism draws from positivist, relativist, and constructivist perspectives.

Also, Skoglund (2015) argues for a concept called 'blue-skies' social science, which proposes a 'constructive rupture' and curiosity-driven social science agenda for climate change. Starting from the idea that we do not know enough about everything, we have to conduct basic social science research aimed at answering fundamental research questions. Instead of interdisciplinarity, the author advocates *post-disciplinarity*. The author argues that climate social science can provide an alternative to strictly natural science-led studies, which does not mean to disagree with scientific findings nor to devalue cross-disciplinary collaboration, but to try to open a room for other social science basic research.

We consider that all these insights are extremely valuable to define the research pathway we want to explore in NEVERMORE and probably in other future research projects that integrate many different disciplines. We consider that the NEVERMORE project makes a tremendous effort to include social science research in climate change research, although we still have much to advance since the main role still is to support the modelling approach, which is considered the central part of the project. In this regard, we believe that it is also important that projects (and as far as possible, this project) also give social sciences a value of their own, and not only as supporters of modelling. In this sense, the lessons, and insights from critical studies on climate change research will be considered along the project when carrying out social science research both in climate change impacts and responses and also in co-production with stakeholders.

2.4. Theoretical frameworks to analyse climate change and society interactions

Some of the interactions between the natural and social sciences have resulted in the development of theoretical frameworks that are useful for analysing interactions between natural phenomena, such as climate change, and society. Hereafter, we show some of which can be used as a basis for analysing climate change and societal interactions.

The socio-ecological systems (SESs) framework was initially proposed by Ostrom (1990). The underlying idea is that humans are part of nature, so the delineation made to differentiate social systems and natural systems is artificial and arbitrary. The definition given by Redman et al. (2004) says that a SES is 'a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner'. According to these authors, it does not make sense to analyse social and ecological systems separately. Nevertheless, they also recognize that social systems have internal and complex dynamics on their own due to the interrelationships of social institutions, social cycles and orders, that are worth acknowledging. In line with some of the arguments made in the previous section on the risks of interdisciplinarity, some authors such as Fabinyi et al. (2014) have criticised the SES framework by arguing that a comprehensive perspective on human-ecological relationships may underestimate the importance of power mechanisms, social institutions roles and other social values and motivations. Apart from the critiques and suggestions for improvements, the SESs framework has proved to be useful for studying sustainability issues in which there are complex and systemic interactions between humans and nature, and on its basis other frameworks have been developed (Chifari et al., 2018).

The ecosystem services concept was also developed to draw attention to social and ecosystem interaction, with an emphasis on the benefits that ecosystems provide to society and also for raising awareness for ecosystem conservation Millennium Ecosystem Assessment (Program) (2005). Figure 3 shows the four categories of ecosystem services connected to five well-being areas proposed by Millennium Ecosystem Assessment (Program) (2005). This report also highlights that there exists a dynamic interaction between people and ecosystems, with human activity driving, both directly and indirectly, changes in ecosystems and thus provoking feedback changes in human well-being.

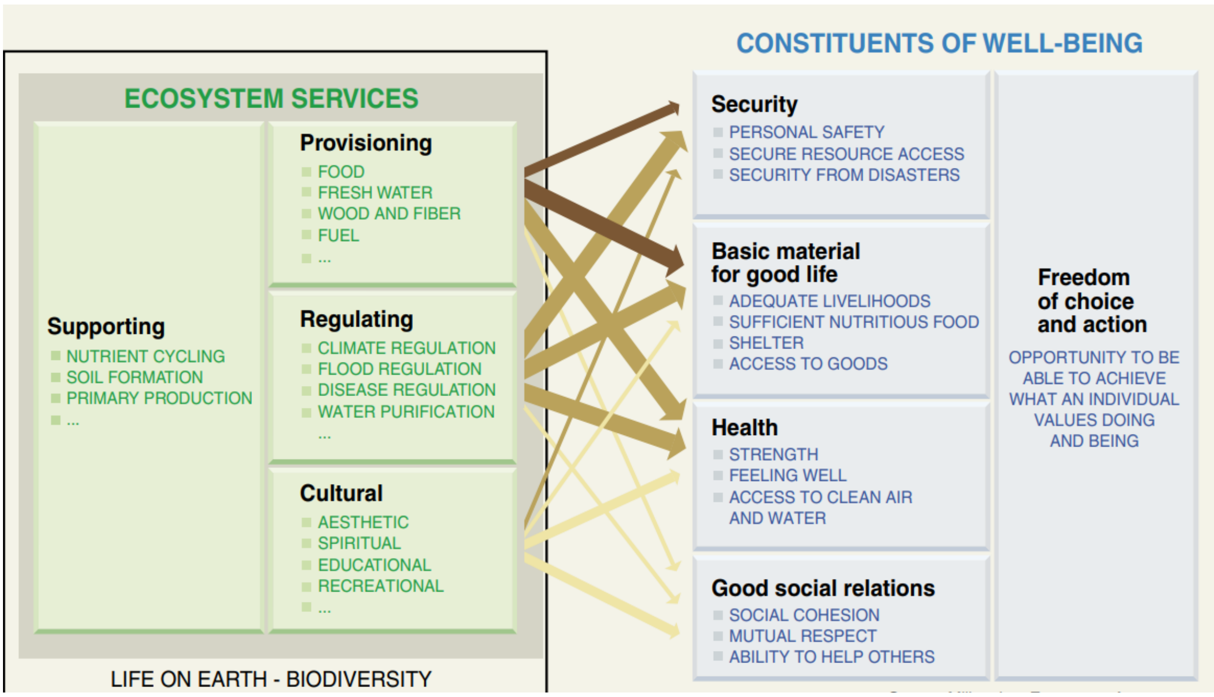

Figure 3. Linkages between ecosystem services and human well-being. Source: Millenium Ecosystem Assessment (Program), (2005)

The ecosystem services framework is interesting to comprehensively connect natural ecosystems resources and processes with human needs, and it can be used for many different purposes and applications. This is also true in the context of climate change impacts and vulnerability (Peng et al., 2023), allowing to explore many indirect impacts of climate change on society taking place through the alteration of some ecosystems' functionalities. Within social sciences, especially in the economics area, hundreds of studies related to ecosystems services valuation and measurement have been conducted. However, monetary valuation of ecosystem services is problematic in some cases. This approach has been criticised by some ecological economists due to the subjectivity and randomness of some of the assumptions behind these methods, and some ethical questions related to whether or not we should monetize certain substantial elements to sustain life (Kallis et al., 2013).

A third concept we propose to analyse climate change and societal interactions is the human dimension of climate change (HDCC). Although this is not a concept that has been systematically defined or on which there exists an agreement about what it is within, it has been used in social science studies to analyse climate change and human interactions with practical application in some case studies (Ford et al., 2012). This concept has been also used as a statement for broadening research on social aspects of climate change, claiming the need of environmental social science and environmental humanities to be more and involved in climate change research with higher quality (Castree, 2016).

According to Goldman et al. (2018), human dimensions of climate change widely refer to *'human capacities, exposure, and response to climate change'*. Some of the terms that dominate the HDCC discourse are vulnerability, resilience, and adaptation. These authors make a critical reflection on the mainstream use of these concepts, which is too technical, limiting the analyses of human response to technical changes. The authors claim that the human dimensions of climate change are a wide topic, and we should be careful with defining and shaping it. Similar to some institutions such as the IPCC have done by generalising and making abstractions on these dimensions, we could exclude the knowledge and experience of many people undergoing climate change in several ways. Unfortunately, we consider that generalisations are sometimes unavoidable, especially when the final aim is modelling so metaphors, simplifications, standardisation and assumptions need to be taken.

What is interesting according to Goldman et al. (2018) is that they claim for new climate change ontologies considering that we should avoid exclusionary discursive politics and we should try to go to co-production practices in which human diversity in experiencing and defining climate change is taken into account.

Another widely used framework for exploring human-ecosystem interactions is the Driver-Pressure-State-Impact-Response (DPSIR) framework, originally developed by the European Environment Agency, EEA (1995). It has been used for many different applications since it was created. Of course, it is not exempt from criticism. For instance, according to Gari et al. (2015), the meaning of each element of the framework is not clear, which has resulted in the same variables placed under different categories in different studies (some authors suggest that a specific variable is a driver whereas others consider it as a pressure). Also, Maxim et al. (2009) argue that the tool is relevant to structure communication between scientists and end-users, but it is not appropriate enough as an analytical tool. These authors propose some interesting modifications to the DPSIR framework by complementing it with the four spheres of sustainability (environmental, economic, social, and political).

An interesting modification of the DPSIR framework is the one proposed by Cooper (2013), who develops the DPSWR framework, substituting 'Impact' by 'Welfare'. According to this alternative methodological point of view, the diffuse boundary between state and ecological impact is eliminated while focusing solely on human welfare in dealing with the impact. Thus, the ecological impact is displaced by the 'State' element, so that the 'Impact' category is focused on socio-economic and health effects.

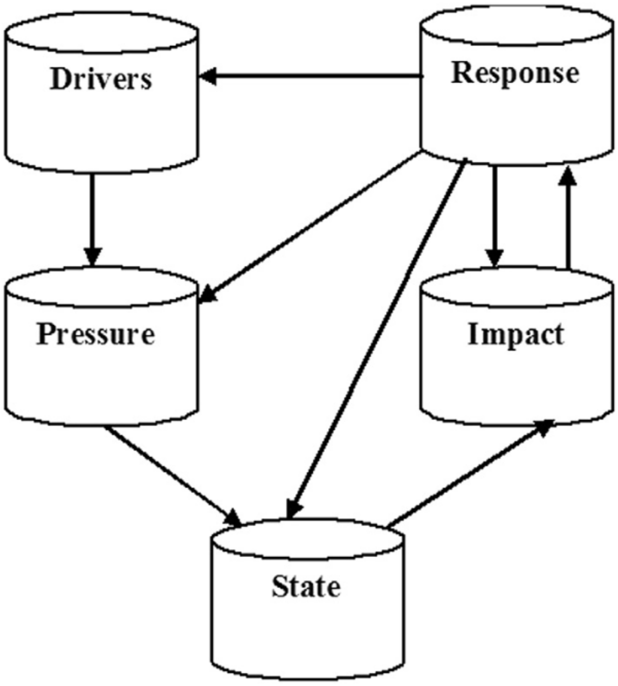

Figure 4. The DPSIR Framework. Source: (Gari et al., 2015)

As DPSIR and DPSWR are useful for structuring and communicating in a simplified way some of the relationships between climate change and society, in Figure 5 we show some of the areas of study of the NEVERMORE Project structured around this framework.

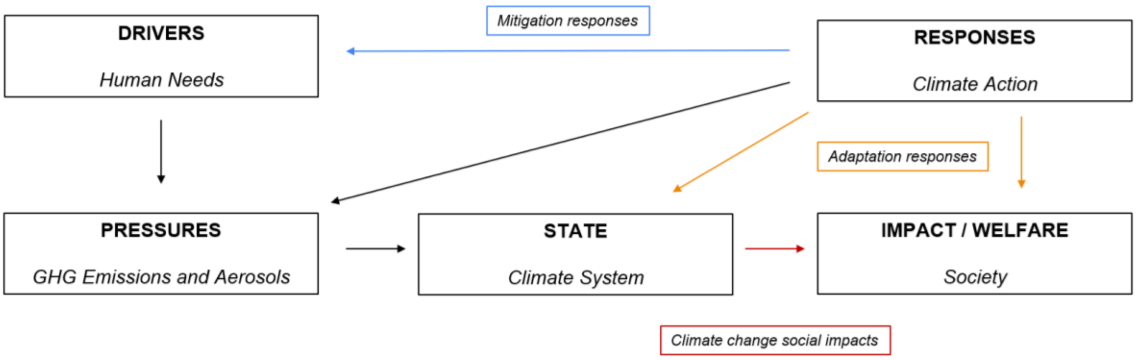

Figure 5. DPSIR Framework adapted to NEVERMORE purposes

According to this structure, the following sections of the deliverable are structured as follows. In section 3 we explore climate change social impacts (the relationship between 'state', which is the climate system, and 'impact / welfare'). In section 4 focus on climate action, specifically on mitigation and adaptation responses in the form of behavioural change and lifestyle transformations since institutional policies are being studied within WP5.

3. Climate change social impacts

One of the objectives of this task is to identify and provide a mapping of main climate change impacts on society in order to set a basis for its future modelling. Thus, this section includes: i) a sub-section

3.1 including a literature review on frameworks and definitions of climate change impacts on society; and ii) a sub-section 3.2 that, on the basis of the previous one, presents a systematic literature review on the representation of social impacts of climate change in integrated assessment modelling.

3.1. Theoretical considerations

In this section, we review theoretical concepts and frameworks that we consider useful in defining what we mean by climate change social impacts. As we mentioned previously, there are authors who argue that there is no single climate change and that the social sciences can contribute to the definition of this phenomenon (Alexandra, 2021; Goldman et al., 2018). However, for the purposes of this task, we are more interested in using social sciences for defining *social impacts* rather than *climate change* as an experience, even though both concepts are not dissociable.

To our knowledge, there does not exist a universal definition of climate change social impacts. The three dimensions (environmental, economic and social) are widely used in climate change impacts and sustainability literature (Keshavarz et al., 2013) and are also used by the NEVERMORE consortium. However, this categorisation presents difficulties to be operationalised and defined in concrete terms.

Figure 6 shows how the environmental, economic, and social dimensions of sustainability can be brought together in various ways. Although the three of them show a certain degree of dependency and interrelation across dimensions, they define very different paradigms leading to very different conceptualisations. The Venn diagram on the left is the most typically used, representing the mainstream and dominant perspective of sustainability, while the other two depictions are alternative representations founded in ecological economics theory (Purvis et al., 2019).

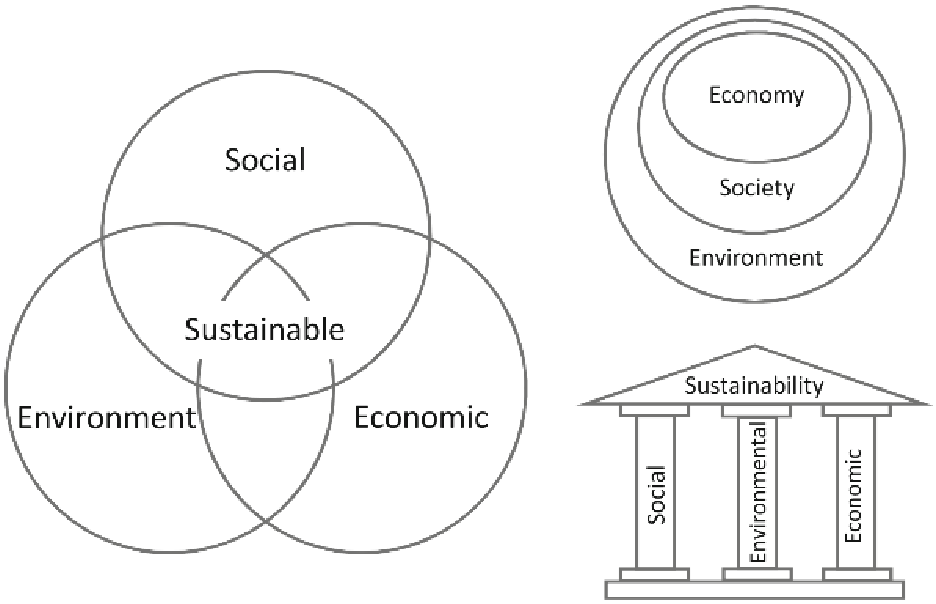

Figure 6. Representations of the dimensions of sustainability. Left, typical representation of sustainability as three intersecting circles. Right, alternative depictions: literal 'pillars' and a concentric circles approach. Source: (Purvis et al., 2019)

As Purvis et al. (2019) argue, there are neither clear origins nor theoretical foundations for the mainstream diagram, yet it is generally used, and has many implications. For example, in defining sustainability, equal importance is given to 'economic sustainability' (generally understood as growth) and environmental sustainability, whilst many authors argue that these two concepts are incompatible (Ayres, 1996; Ekins, 1993; Krysiak, 2006).

We believe it is important to use certain theoretical frameworks to ontologically define the object of study. For instance, considering that 'social' and 'environmental' are separate categories has different implications than considering that the social is embedded into the environmental. The resulting list of impacts will be different in each case.

Even though defining environmental, social and economic impacts can be too general, social might be the most abstract dimension of the three. Indeed, there have been some attempts to measure climate change economic impacts through comprehensive modelling exercises (Auffhammer, 2018; Bosello et al., 2012; Darwin & Tol., 2001; Hsiang et al., 2017), whereas the quantification and measure of social climate change impacts is a very underdeveloped area (Adger et al., 2011, 2022).

According to Adger et al. (2011), the idea that explains why there are so many attempts to monetarily quantify the economic impacts of climate change is that climate change only becomes important when it affects material aspects of wellbeing. Thus, other intangible aspects of wellbeing are neglected. From a utilitarian point of view, wellbeing can be given a price and then measured and summarised in economic costs. To the idea of Adger et al., 2011, we add that the measurement of wellbeing in economic terms is very problematic even for physical or material well-being, since the selected prices can hide many subjective assumptions and premises (Wegner & Pascual, 2011).

It is also worth to pay attention to the terms 'market impacts' and 'non-market impacts', which are widely used in the climate change impacts related literature. Most of the economic analysis of climate change impacts focuses on market-impacts recognizing that the inclusion of non-market impacts would greatly increase the quantification of damages (Bosello et al., 2012; Rothman et al., 2003).

Although one could conclude that market impacts are synonymous with economic impacts and non-market impacts with social impacts, this reasoning is rather problematic for several reasons. As ecological economics and other heterodox schools of thought have demonstrated, economics is not only about monetary valuation. In fact, some of these schools even reject this method of valuation or are very critical of its widespread use (Wegner & Pascual, 2011). Therefore, economic analysis, understood as monetary, of market and non-market, social and economic aspects, may be of limited use and should be complemented through other valuation methods.

There exist alternative notions of value that can lead to alternative accounting and valuation methods (see Figure 7), as explained by Rothman et al. (2003).

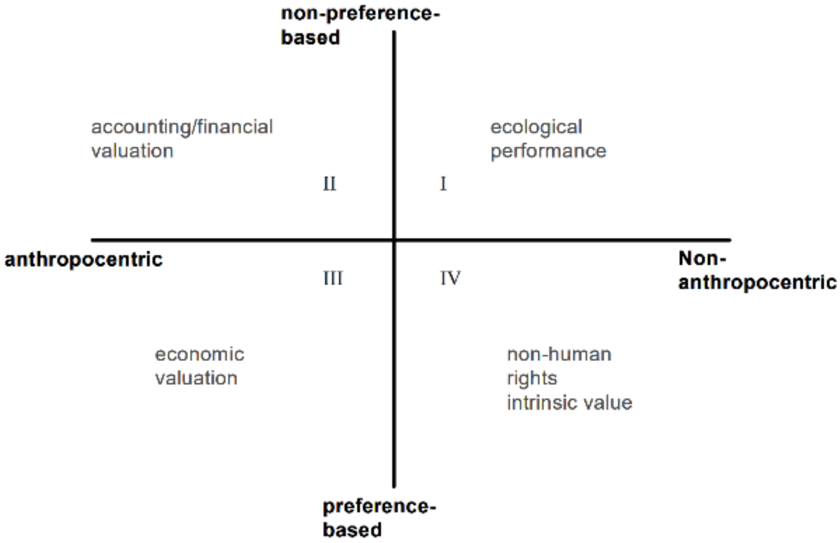

Figure 7. Classification of accounting valuation methods. Source: Rothman et al (2003)

Rothman et al. (2003) also make a critique about climate change impacts categorisations, arguing that these have been *'somewhat haphazard groupings*.' This can hinder a comprehensive analysis and lead to double counting since interrelationships across categories are usually not clearly defined. Rothman et al. (2003) puts as an example the sectors used to analyse climate change impacts in the IPCC's Second Assessment Report. These were 'Agriculture, Forest, Sea level, Energy, Water, Human life, Migration, Extreme events, Recreation, Species loss, Urban Air pollution'. A critique is made saying they are mixing elements from very different nature.

Rothman et al. (2003) propose alternative classification approaches that do not follow the 'environmental, economic and social' dimensions. These are synthesised in Table 3. A social dimension can be found in all the approaches.

Table 3. Climate change impacts categorisation by Rothman et al. (2003)

Approach to categorise climate change impacts	Description
5 Major Systems approach	Impacts on atmospheric systems, aquatic systems, geologic systems (especially soils), biological systems (including humans) and built environment (including buildings, machinery, infrastructure, etc).
Types of capital approach	Impacts on Manufactured Capital (buildings, roads, factories), Human Capital (knowledge and skills), Social Capital (Institutions and Relationships), Natural Capital (living and non-living resources). This is a stock-based approach.
Goods and services approach	Focusing on the impacts on the goods and services that each type of capital provides. For instance, goods and services provided by Natural Capital are the ecosystem services. This is a flow-based approach.
Human well-being approach	The necessary material minimum for a good life; health and bodily well-being; good social relations; security; freedom and choice; and peace of mind and spiritual experience.

In order to check if the IPCC's classification of sectors and social impacts have improved since IPCC AR2, we have made a review of the Working Group II (WGII) contribution to the IPCC's Sixth Assessment Report (AR6) (IPCC, 2022). Here, the term 'sector' is used numerous times with several purposes. Although the report does not offer a clear and comprehensive list of sectors, the chapters 2 to 8 in the WGII Report are considered the 'sectoral chapters'. The respective sectors are:

- *Chapter 2: Terrestrial and freshwater ecosystems and their services.*
- *Chapter 3: Ocean and coastal ecosystems and their services.*
- *Chapter 4: Water.*
- *Chapter 5: Food, fibre, and other ecosystem products.*
- *Chapter 6: Cities, settlements and key infrastructure.*
- *Chapter 7 Health, wellbeing and the changing structure of communities.*
- *Chapter 8: Poverty, livelihoods and sustainable development.*

In each chapter, more specific categories and sectors are considered. But classifying these chapters and the sectors within them into environmental, economic and social dimensions is not straightforward. One could think, for instance, that Chapters 7 & 8 are the ones referring to social impacts. But this is too simplistic, as one can also make a social analysis on access to water, food or how cities are organised.

The term ‘social impacts’ is used several times in the IPCC WGII AR6, although they are not specifically defined throughout the whole document. We only found the following in Figure 8 where there is a proposal for ‘Other societal impacts’, whilst ‘main’ social impacts are not defined but apparently distributed across the other sectors.

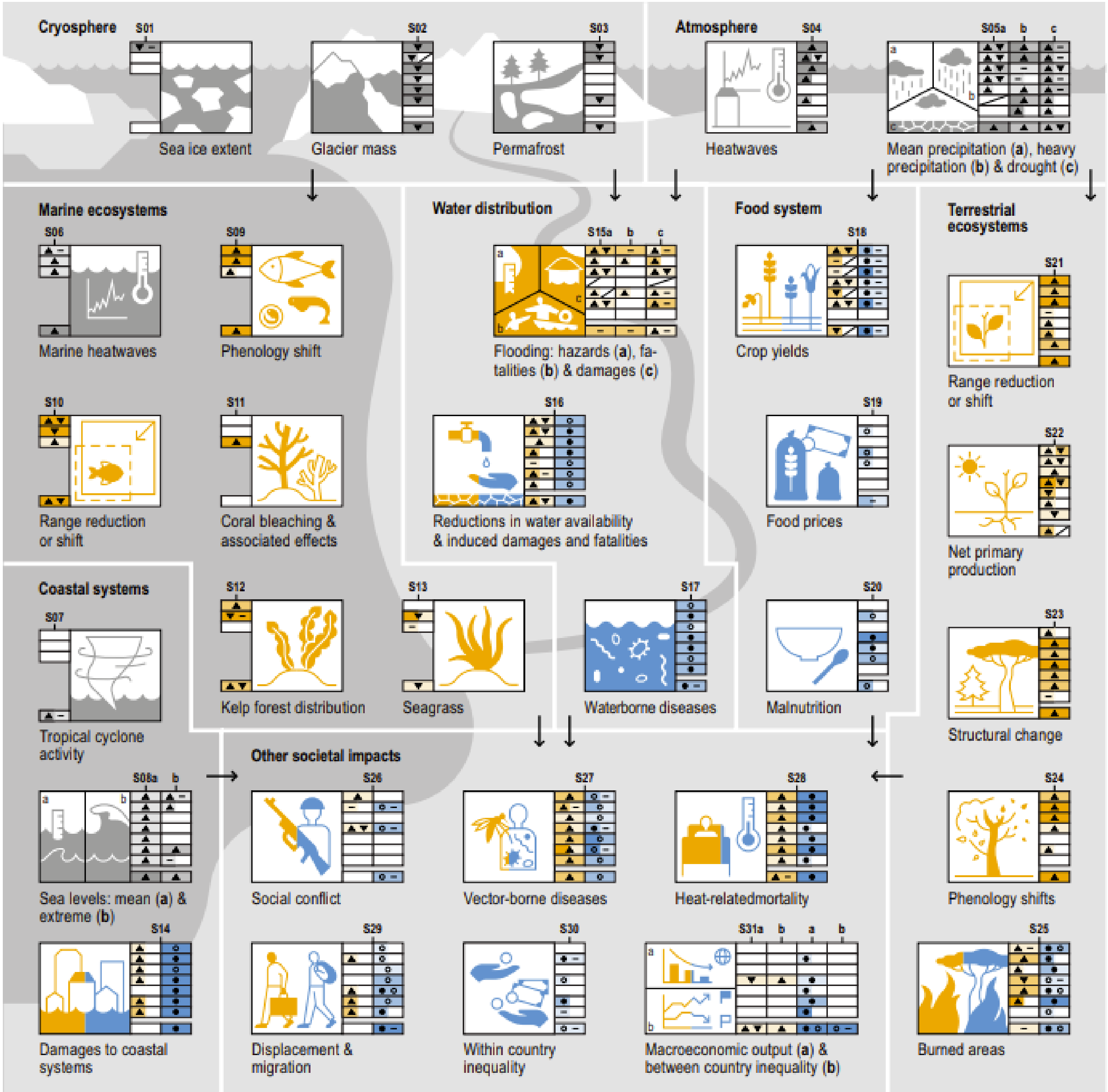

Figure 8. Climate change impacts causal chain. Source: IPCC GII AR6

‘Other societal impacts’ defined in Figure 8 are six: social conflict, vector-borne diseases, heat-related mortality, displacement and migration, within country inequality and macroeconomic output & between country inequality. This classification is interesting since they mix social and economic elements, thus considering societal as a synonym of socioeconomic. Although these impacts can be those more immediately linked to social impacts, all those highlighted in yellow or blue can have an impact on human systems, thus meaning implications in societies.

An interesting research field that can shed some light on the definition of climate change social impacts is Social Impact Assessment (SIA). It is an interdisciplinary social science area originally aimed at predicting social impacts as part of Environmental Impact Assessment (EIA), but with a focus on monitoring and evaluating impacts of planned project interventions, not hazards or climate change phenomena. Nevertheless, currently their applications are extending to other purposes, such as the study of disasters (Esteves et al., 2012). Even the World Bank has recommended the use of SIA to study natural disasters (World Bank, 2015).

Although SIA literature can definitely provide some insights to define climate change social impacts, their application is more focused on defining social principles to protect communities and involve them in processes that affect them. Since SIA usually works on specific case studies, it can be problematic to develop a 'checklist' of social impacts, because they can vary across scales, times, communities affected, etc. Yet despite acknowledging this, Vanclay (2002) proposes a generic conceptualisation of social impacts in order to contribute to awareness on their consideration. The author recognises the ambiguity associated with some social impact, which leads to a situation in which the bulk of the quantification focuses on economic or demographic aspects.

According to Vanclay (2002), *'social impacts include all social and cultural consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organise to meet their needs, and generally cope as members of society. Cultural impacts involve changes to the norms, values, and beliefs of individuals that guide and rationalise their cognition of themselves and their society'.*

Table 4 shows the seven categories of social impacts proposed by Vanclay (2002) and the elements within each one.

Table 4. Social impacts according to Vanclay (2002)

Social Impact	Elements
Health and Social Wellbeing	Death. Nutrition. Actual health and fertility. Mental health and subjective well-being. Changed aspirations. Autonomy. Social exclusion or marginalisation. Uncertainty. Feelings in relation to the planned intervention[1], annoyance, dissatisfaction, experience of moral outrage.
Quality of the Living Environment	Perceived quality of the living environment (work and home). Actual quality of the living environment. Disruption of daily living practices. Leisure and recreation opportunities and facilities. Aesthetic quality. Perception of the social quality of housing. Availability of housing facilities. Adequacy of physical and social infrastructure. Actual personal safety and hazard exposure. Actual crime and violence.
Economic impacts and material well-being	Workload. Standard of living (goods and services availability and costs). Access to public goods and services. Access to social services. Economic prosperity and resilience. Income. Property values. Occupational status. Employment options. Replacement costs of environmental functions. Economic dependency or vulnerability. Disruption of the local economy. Burden of national debt.
Cultural Impacts	Changes in cultural values. Cultural integrity. Experience of being culturally marginalised and structural exclusion. Profanation of culture (exploitation or modification of cultural heritage). Loss of local language or dialect. loss of natural and cultural heritage (destruction of historical or natural resources and meaningful places with aesthetic value).
Family and Community Impacts	Alterations in family structure. Changes to sexual relations. Obligations to living elders and ancestors. Family violence. Disruption of social networks. Changed demographic structure of

[1] Vanclay (2002) develops these categories in the context of Social Impact Assessments, so the author refers to planned interventions, but the concepts can be also used to climate change.

	the community. Perceived and actual community and cohesion. Social differentiation and inequity. Social tension and violence.
Institutional, Legal, Political and Equity Impacts	Workload and viability of government, formal and non-government agencies. Loss of legal rights. Violation of human rights. Participation in decision-making. Loss of subsidiarity. Equity.
Gender Relations Impacts	Women's physical integrity. Personal autonomy of women. Gendered division of production-oriented labour. Gendered division of household labour. Gendered division of reproductive labour. Gender-based control over, and access to, resources and services. Equity of educational achievement between girls and boys. Political emancipation of women.

Another interesting insight to be drawn from the study of Vanclay (2002) is the differentiation between social impacts and social change processes, which is related as well to the differentiation between first-order social impacts and higher-order impacts. According to the author, social impacts refer to those effects experienced by humans (at both individual and higher aggregation levels) in either corporeal/physical or cognitive/perceptual senses. In addition, social change processes are other kind of effects resulting from the intervention that can lead to other higher-order social change processes and also to other higher-order social impacts. These can be several: demographic processes, economic processes, geographical processes, institutional and legal processes, emancipatory and empowerment processes, sociocultural processes, or others. They can help to track and find higher-order impacts that are amplified by intervention.

The differentiation between first order and higher-order social impacts and social change processes is better understood through an example. Imagine that we have a planned intervention, such as a new regulation, which does not damage any infrastructure or human beings directly, but which causes a change in the way land can be used, both in terms of the area dedicated to a specific activity (extensification) or its use-intensity (intensification). We do not have any direct social impact, but we do have a social change process, which is the land change. In turn, we can obtain many second-order impacts across the seven categories, such as disruption of daily lives of farmers and consumers, increase of raw product prices, unemployment, malnutrition or even deaths. Of course, all these impacts are crossed by other social change processes, giving rise to complex causal chains, feedback loops, and the appearance of other higher-order social impacts and social change processes.

Although Vanclay's conceptualisation is focused on analysing impacts of interventions, the intervention actually is only the trigger for all impacts and processes, so his whole conceptualisation can be extrapolated to the analysis of the social impacts of climate change, replacing 'intervention' by 'climate change hazard'. Indeed, we have identified six studies that take Vanclay (2002) conceptualisation as a first point and extend it to the study of climate change social impacts (Arruda & Krutkowski, 2017; Aznar-Crespo et al., 2021; Graham et al., 2013; Keshavarz et al., 2013; Mahmoudi et al., 2013; Nunfam et al., 2018).

Aznar-Crespo et al. (2021) applies a systematic literature review on social impacts from floods with the aim of proposing the adaptation of SIA principles to this field. Mahmoudi et al. (2013) propose a hybrid model to combine social impact assessment and risk assessment that can be used to analyse impacts of natural hazards and disasters such as droughts and floods. Arruda & Krutkowski (2017) explore the socio-political implications of climate change in the Arctic, with a focus on governance and sense of place. Although they all make some progress in linking SIA and climate change impacts analysis, they do not propose a systematic definition or categorisation of social impacts that would serve our purposes.

The other three articles we have found that quote Vanclay do elaborate and extend his definition further. Keshavarz et al. (2013) jointly study social and economic impacts of droughts in Iran through qualitative social research methods. The categorization of impacts included is synthesised in Table 5.

Table 5. Social impacts of droughts in Iran according to Keshavarz et al. (2013)

Economic and Social Impacts	Description
Economic Impacts	Loss of farm income and reduced income diversity. Increased on-farm workload and decreased options for off-farm employment.
Basic needs	Food consumption insecurity and health problems due to drought related stresses and lack of income for adequate health care.
Education	Reduced household expenditure on education, which especially affects to younger people.
Marriage	Increase in the age of marriage and mate selection criteria.
Conflict and dependency.	Increased family and social conflict, social isolation, increased dependency on government assistance and government mistrust.
Emotional and psychological impacts.	Suffering from a sense of hopelessness, failure and loneliness.

Nunfam et al. (2018) study the social impacts of occupational heat stress due to climate change through a systematic literature review. They identify three main areas of social impacts, which are shown and described in Table 6.

Table 6. Social impacts of heat stress on occupational health according to Nunfam et al. (2018)

Social Impacts of occupational heat stress	Description
Health and safety	Heat-related illnesses and injuries of workers attributed to occupational heat exposure.
Productivity	Reduced productivity specially in industries like construction, agriculture and manufacturing. Productivity losses are due to absenteeism, reduced work pace and performance efficiency.
Social well-being	Inadequate time for tasks such as family care and household chores, increase in family break-down to fatigue, physical violence and interpersonal disputes. Erosion and loss of employment due to heat-related morbidity and productivity losses. Decrease in workers' social network relationship with their families and co-workers and access to community services. Extreme heat events presenting multi-stress vulnerabilities including financial situation, mobility, social relations and basic services.

The categorisation proposed by Keshavarz et al. (2013) and Numfam et al. (2018) have in common that they propose a categorisation of climate change social impacts from specific hazards and in specific contexts (the first one in a specific spatial area and the second one in a specific sectoral area). Both categorisations are interesting although direct impacts and indirect impacts are still intermingled, which does not allow for clear causal chains of harm to be seen and could lead to double counting (Rothman et al., 2003; Vanclay, 2002).

Probably, to fulfil our objective, the study of Graham et al. (2013) is the most useful among those starting from the conceptualisation of Vanclay (2002). Graham et al. (2013) suggest some ideas that can help to find a coherent and comprehensive way of mapping climate change social impacts. This study aims at creating a definition of social values at risks from sea-level rise. The authors work is based on social impacts from Vanclay (2002) and other SIA literature and conduct a review of literature on fields such as psychology, decision analysis, public policy and urban planning and human geographies in order to address gaps identified in SIA's approach. The study concludes on a conceptual framework that they call *'social values/lived values at risk'.*

Graham et al. (2013) define social or lived values as *'valuations that individuals make, in isolation or as part of a group, about what is important in their lives and the places they live. These evaluations may* *be articulated verbally or expressed through everyday activities'.* They include elements such as the sense of belonging, culture, community cohesion, identity, self-determination, and attachment to places that are central to the social construction of climate risks, and also in enabling or constraining adaptation. Figure 9 shows the categorization of lived values proposed by this study.

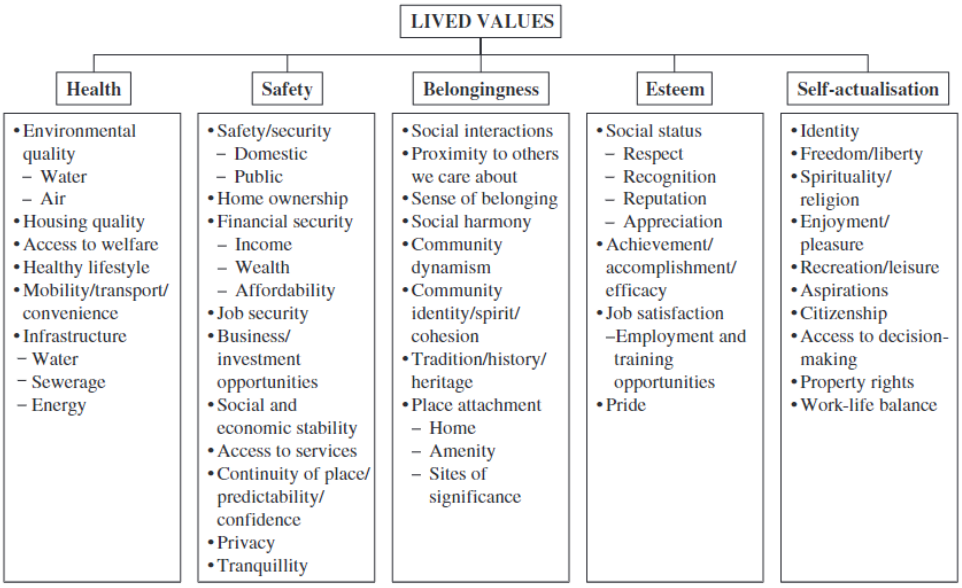

Figure 9. Categorisation of lived values that may be affected by sea-level rise. Source: Graham et al. (2013)

At this point of the review, it seems that climate change social impacts are a concept very related to well-being. Well-being has appeared in one way or another in most of the literature reviewed. Indeed, the recent study of Adger et al. (2022) published in *Nature* took this lived values framework of Graham et al. (2013) as a reference to build a well-being framework on which to explore climate change impacts. According to this study, wellbeing is *'feeling and functioning well, including experiencing positive emotions, positive relationships and the social freedoms and opportunities to realise the potential of individuals*'. This definition is generally shared by social sciences, although wellbeing components and measurement can vary across studies. Adger et al. (2022) consider that there exist objective and subjective dimensions of wellbeing, and they propose five well-being components, which are very similar to the five lived values. These are Health, Safety, Belonging, Place and Self. The authors argue that climate change affects these five elements through three mechanisms: material climate change impacts, climate information and climate policy. Examples of all the impacts that can appear across the three mechanisms and five areas are included in Table 7.

Table 7. Examples of the material, information and political climate change implications on the five core dimensions of well-being. Source. (Adger et al., 2022)

Dimension of well-being	Elements	Material Impacts	Climate Information	Climate Policy
Health	Environmental, quality, health care, critical infrastructure, ecosystem services	Access to food and places. Mental illness due to weather disaster and trauma.	Communicated risks causing distress. Eco-anxiety.	Maladaptation perpetuating marginalisation and increased vulnerability of health care systems. Clustering climate migrants in informal

				settlements, leading to mental health disorders.
Safety	Personal security, peace and justice, public goods, financial security	Heat-stress impacts on labour productivity and financial insecurity among workers. Threats to personal security and public services from loss of inhabited lands.	Insurance premiums rise due to information about weather risks. Underplaying of heat risks in the media.	Increased livelihood security and improved consumption patterns through early warning systems. Social cohesion through inclusive and planned relocation.
Place	Place attachment, social cohesion, cultural and physical heritage.	Displacement from extreme weather. Loss of community assets and places.	Representations of anthropogenic climate change affecting social cohesion and stalling community action. Social division due to scarcity narratives.	Disruption of place attachment due to engineering coastal defence. Forced relocation policies hindering physical heritage.
Self	Self-esteem, self-efficacy, positive emotion, dignified life	Declining efficacy of traditional knowledge in Indigenous communities. Decline in natural resources quality, leading to decreased capacity for ritual practices.	Climate change communication exacerbates anxiety and thus cognitive and functional impairments. Climate information creates perceived powerlessness and agency lack.	Increased personal satisfaction and fulfilled aspirations through investment in natural resources protection and management. Weakened identity due to migration policies.
Belonging	Identity, social status, voice, connectedness	Social status loss in land custodians due to erosion. Loss of identity for youth populations concerned about natural meaningful places loss.	Disempowerment of communities characterised as vulnerable.	Involvement in decision-making and community-based policy action shows enhanced self-determination, place attachment and empowerment.

The studies conducted by Lillywhite & Wolbring (2023) and Wolbring (2022) also rely on the concept of well-being to create a definition of 'the social' that after is used to conduct a systematic literature review on the role of 'the social' on risk narratives and quantum technologies. To define 'the social', they specifically use concepts such as *'the ability to have a good life, quality of life, health, equity and wellbeing'*. These concepts lead them to look into the components of indicators like the *OECD Better Life Index, the Canadian Index of Wellbeing, the Community Based Rehabilitation Matrix or the Social Determinants of Health (SDH)*, among others (see Lillywhite & Wolbring (2023)). They also use the Equity, Diversity and Inclusion (EDI) framework as a proxy of social impacts. According to the authors, this framework helps to identify key concepts and targeted collectives that are marginalised and suffer discrimination and are thus important to be considered when analysing social impacts of any nature. The marginalised collectives they identify are women, indigenous peoples, racialised and other minorities, disabled people, and lesbian-gay-bisexual-transgender-queer (LGBTQ) communities.

In Lillywhite & Wolbring (2023), several search strategies are used for conducting the review. Some of the words used for mapping the 'social' are 'solidarity', 'wellbeing', 'dignity', 'identity', interdependence', 'justice', 'autonomy', 'good life', 'social good', 'belonging', 'diversity', 'equity', 'inclusion', 'decolonization', 'accessibility', 'gender', 'women', 'ethnic groups', 'racialized', 'minorities', 'disability', 'indigenous', 'LGBTQ*', 'social' and 'societal', among others. In Table 8 we show the elements included in the indicators that were reviewed by Lillywhite & Wolbring (2023) and Wolbring (2022) to map 'the social'.

Table 8. Indicators measuring 'the social'. Source: Wolbring, (2022)

Indicator	Elements
Community Based Rehabilitation Matrix	Health, Education, Livelihood, Social, Empowerment,
Canadian Index of Wellbeing	Social Relationships, Social Norms, Democratic Engagement, Education, Environment, Healthy Population, Culture, Leisure, Living Standard
Better Life Index	Housing, Income, Jobs, Community, Education, Environment, Physical Environment, Civic Engagement, Health, Life Satisfaction, Safety, Work life balance.
Social determinants of health (SDH)	Income, Education, Unemployment, Job Security, Employment, Early Childhood Development, Food Insecurity, Housing, Social Exclusion, Social Safety Network, Health Services, Indigenous, Gender, Women with Disabilities, Race, Immigration, Globalization, Coping, Discrimination, Genetic, Stress, Transportation, Vocational training, Social integration, Advocacy, Literacy, Ethnic, Walkability, Physical Environment, Social Engagement, Social Status

Many of the well-being frameworks are influenced by universal human needs and basic needs framework (Adger et al., 2022; Brand-Correa & Steinberger, 2017). This kind of literature is also useful to identify social areas that can be affected by climate change. In fact, the areas in Adger et al. (2022) & Graham et al. (2023) match almost exactly the framework of Maslow (see Figure 10), although they eliminate hierarchy.

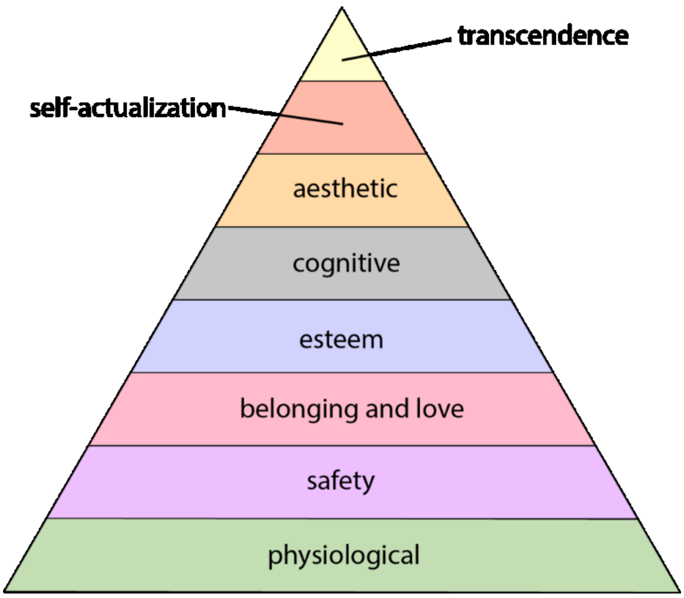

Figure 10. Maslow's hierarchy of needs. Source: ('Maslow's Hierarchy of Needs', 2023)

The eudaimonic understanding of well-being proposed by Brand-Correa & Steinberger (2017) makes up the lenses that are useful for our purposes by allowing us to identify social and objective areas that can be affected by climate change. According to the authors, a hegemonic understanding of well-being sees it primarily as maximising pleasure. In contrast, the eudaimonic perspective sees well-being as the *'enabling of humans to reach their highest potential within the context of their society'.* Thus, an eudaimonic approach allows us to find non-substitutable dimensions of human well-being, that can be defined differently depending on the framework. These authors propose a Human Needs (HN) approach based on the Max-Neef categorisation of human needs to define well-being (see Figure 11).

existential categories

axiological categories	BEING	HAVING	DOING	INTERACTING
SUBSISTENCE				
PROTECTION				
AFFECTION				
UNDERSTANDING				
PARTICIPATION				
IDLENESS				
CREATION				
IDENTITY				
FREEDOM				

Figure 11. Max-Neef's matrix of human needs and satisfier categories. Source: Brand-Correa & Steinberger (2017)

The human needs considered by this study are prerequisites for living well in society, and thus, they help to define wellbeing: only when these are satisfied can wellbeing be achieved'. They are conceptualised as a minimum basis and are considered unchanging and universal.

Also relying in the basic needs and capabilities approach, Rao & Min (2018) propose the concept of Decent Living Standards (DLS), which are *'a set of material requirements that are essential for human flourishing'.* According to the authors, this list of material satisfiers of human basic needs contributes to both physical and social wellbeing. When possible, the DLS dimensions are defined with specific quantitative thresholds. These are also defined for different levels: households, community and national, understanding that some of them need to be met at the individual level whereas others are necessarily collective. This approach is interesting in relation to climate change impacts since the authors emphasise that the framework was thought to be analysed in relation to environmental resources analysis. The Table 9 shows the DLS.

Table 9. Decent Living Standards (DLS). Source: Rao & Min, (2018)

Wellbeing	Decent Living Standard dimensions	Household Requirements	Collective Requirements
Physical	Nutrition	Total calories, protein, micronutrients. Fridge or other cooling technology.	
	Shelter	Solid walls and roof	
	Living conditions	Minimum floor space. Modern heating/cooling equipment. In-house improved toilets. Minimum, accessible water supply-.	Electricity, water and sanitation infrastructure.

	Clothing	Minimum clothing materials.	Washing machines per 1000 persons.
	Health care		Minimum health expenditure per cap.
	Air quality	Clean cookstoves	Restricted transport infrastructure.
Social	Education		Equipped schools. Teachers per 1000 persons.
	Communication	Phone (1 per adult)	ICT Infrastructure.
	Information access	Television/internet device	
	Mobility	Access to public transport, or vehicle, if essential	Public transport and road infrastructure.
	Freedom to gather/dissent		Public space, sq. m. per 1000 persons.

A very interesting framework to explore social areas impacted by climate change is the social foundations (Raworth, 2012), which also rely on human wellbeing and human needs logic, adding equity considerations through a human-rights approach, which has been highlighted by institutions such as United Nations to be in hazard by climate change impacts (UN), 2011). The social foundations allow *'all people to lead lives of dignity and opportunity'*. Table 10 shows the 11 social foundations grouped by clusters according to their objectives (meaning that each social foundation allows people to be well, productive, or empowered). The list of social foundation indicators has been enhanced by studies like Custodio et al. (2023). This concept has also been jointly used with the planetary boundaries (Rockström et al., 2009) framework to build the Doughnut Economics framework (Raworth, 2017) (see Figure 12).

Table 10. Social foundations. Source: (Raworth, 2012)

Cluster	Social Foundation	Illustrative Indicators
Well	Food Security	Population undernourished.
	Income	Population living below $1.25 (PPP) per day.
	Water and sanitation	Population without access to an improved drinking water source Sanitation.
	Health care	Population estimated to be without regular access to essential medicines.
Productive	Education	Children not enrolled in primary school. Illiteracy among 15-24-year-olds.
	Decent work	Labour force not employed in decent work.
	Energy services	Population lacking access to electricity Population lacking access to clean cooking facilities.
	Resilience to shocks	Population facing multiple dimensions of poverty.
Empowered	Gender Equality	Employment gap between women and men in waged work (excluding agriculture) Representation gap between women and men in national parliaments.
	Social Equality	Population living on less than the median income in countries with a Gini coefficient exceeding 0.35.
	Having political voice	Population living in countries perceived (in surveys) not to permit political participation or freedom of expression.

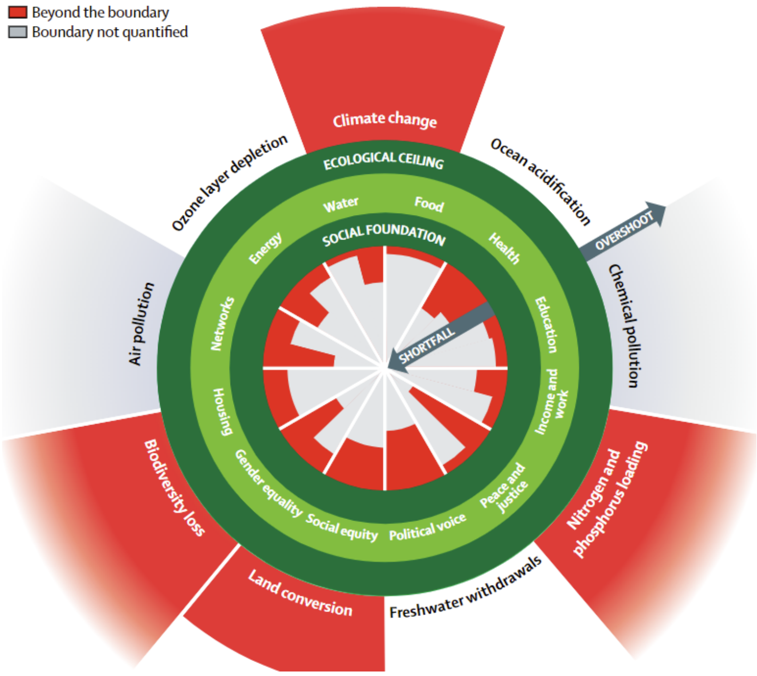

Figure 12. The Doughnut Economics. Source: (Raworth, 2017)

Raworth (2017) recognizes this framework to be useful to explore interactions across boundaries above and below. For instance, crossing some planetary boundaries or their regional thresholds could push people back below the social foundation or prevent them from achieving it. An example is climate change affecting many of the social foundations, directly and indirectly.

3.2. Setting the basis for modelling climate change social impacts: a systematic literature review on the representation of climate change social impacts in integrated assessment models.

The objective of the previous section 3.1 is to set a basis for a systematic literature review on the representation of climate change social impacts in Integrated Assessment Models (IAMs). IAMs are mathematical models characterised by integrating different spheres (society, economy, biosphere, atmosphere, etc.) in a sole modelling framework. This kind of models belong to the category of climate-economy models used to evaluate policies for the ecological transition (Nikas et al., 2020).

The above literature review has highlighted the difficulty associated with creating a definition and classification of climate change social impacts. So, in order to start the systematic literature review, the first step was to create a list of keywords to be used for a search of relevant papers. To achieve this, we have taken keywords from some of the above classifications and generated a larger table of keywords (see Table 11) by including also:

- Keywords related to integrated assessment modelling. We have included not only ‘integrated assessment model’ but other more flexible keywords, with the objective of capturing integrated models that do not consider themselves IAMs but integrated models or integrated modelling frameworks.
- Keywords related to climate change impacts. We have included ‘climate change’ AND ‘impact’ but also other climate change related phenomenon that can help to complement the search. We are only including in our review material impacts of climate change, not impacts of climate policy or climate information, according to the definition of Adger et al. (2022).
- Keywords related to ‘the social’ in general terms.

- Keywords related to specific social areas (Safety, Health, Place, Self & Belonging) according to classifications of Adger et al., (2022) and Graham et al. (2013).
- Keywords related to inequality, given that it is a transversal phenomenon that has been given prominence in the literature related to social impacts (Lillywhite & Wolbring, 2023; Raworth, 2012).

It is important to clarify that other frameworks of those previously reviewed and presented have been considered when selecting the keywords, although their categories do not match ours. However, for the sake of simplicity, we have left out of the analysis those elements too related to environmental impacts, such as impacts on ecosystem services or food, water, and energy access. In the beginning we planned to include them, but finally we saw that the approach of these articles was too biophysical and made the analysis too complex, so we decided to apply a stricter 'social lens'.[2]

Table 11. Climate change social dimensions and keywords

Integrated assessment modelling	Climate change impacts	Social dimensions					
		General	Safety	Health	Place	Self and belonging	Inequality
integrated assessment AND model, integrated model	climate change, impact, damage, sea level rise, extreme event, extreme weather event	social, society, wellbeing, well-being, human people, welfare	poverty, security, safety, vulnerab*, livelihood, life, built environment, infrastructures, financ*, income, wealth, productivity, labour, public, work, employ*, resilience, education, housing, home, access, famil*, economic, peace, conflict,	health, death, morbidity, disease, mortality, nutrit*	migra*, displacement, place, cultur*, heritage	leisure, identity, freedom, liberty, status, satisfaction, pride, spiritual, attachment, dignity, diversity, justice, belonging, aspiration, citizenship, property, respect, recognition, reputation, enjoyment, emotion, rights	inequality, gender, women, equity, minorities, inclusion

[2] In a first test, the terms 'ecosystem services', 'food access', 'energy access', 'water access', 'food safety', 'energy safety', 'water safety', 'food security', 'water security', 'energy security', 'food health', 'water health', and 'energy health', were included. The number of records obtained by including these keywords was only 2 records higher. This means that eliminating this barely affects the sample. But leaving out these keywords from our keyword classification help to be more specific in the analysis.

We did the search in Scopus with the aim of finding all the records that contain combinations of these keywords in their abstracts, titles, or keywords defined by the authors keywords. The search query resulting from combining all these keywords is:

TITLE-ABS-KEY ((("climate change" OR "sea-level rise" OR "extreme weather event" OR "extreme event") AND ("impact" OR "damage") AND ("soci*" OR "society" OR "wellbeing" OR "well-being" OR "poverty" OR "security" OR "health" OR "death" OR "morbidity" OR "disease*" OR "inequality" OR "gender" OR "vulnerab*" OR "cultur*" OR "livelihood" OR "mortality" OR "life" OR "migra*" OR "displacement" OR "human" OR "people" OR "safety" OR "built environment" OR "living environment" OR "infrastructures" OR "financ*" OR "income" OR "wealth" OR "productivity" OR "labour" OR "public" OR "welfare" OR "work" OR "employ" OR "resilience" OR "education" OR "housing" OR "home" OR "access" OR "famil*" OR "nutrit*" OR "women" OR "equity" OR "minorit*" OR "inclusion" OR "leisure" OR "heritage" OR "place" OR "peace" OR "conflict" OR "identity" OR "freedom" OR "liberty" OR "status" OR "satisfaction" OR "pride" OR "spiritual" OR "attachment" OR "dignity" OR "diversity" OR "justice" OR "belonging" OR "social status" OR "aspiration" OR "citizenship" OR "property" OR "respect" OR "recognition" OR "reputation" OR "enjoyment" OR "emotion" OR "econom*" OR "rights") AND (("integrated assessment" AND "model") OR "integrated model*")))*

The search was conducted on April 15th of 2023, and we obtained 1407 records. At this stage, we reviewed all the abstracts to ensure these were within the scope we were looking for. We found out that sorting these items into the predefined areas was complicated and that there were many of them. In fact, we tested the same search including only the keywords belonging to the first two columns of the Table 11, and we only obtained 363 records more, which means that we had almost reviewed all the literature in Scopus about climate change impacts and IAMs, no matter the economic, environmental, or social dimension. Taking this into account, we decided to shift the strategy for the purposes of this deliverable, and we decided to conduct a focussed literature review on the areas of Health and Place. This decision is supported by various arguments:

- The keywords within the category 'General' are too broad and did not allow us to focus on specific social impacts.
- The keywords within the category 'Self & Belonging' are generally abstract and intangible and do not correspond to the social impacts represented in the IAMs. Rather, they blur the samples obtained to a large extent, giving rise to the out-of-sample records we are interested in finding.
- The 'Inequality' dimension can be considered as a transversal category, so we decide to assess inequality on the sample identified, but do not include specifically elements related to it.
- The 'Safety' dimension is more related to economic impacts. This is very interesting and important from a socioeconomic point of view, but for the sake of simplicity we decided to leave it out for the time being and explore it in tasks related to representation of economic damages (e.g., in WP4 related tasks).

In section 3.2.1 we explain the method used for systematic literature review (SLR); in section 3.2.2 we explain the main results; and in section 3.2.3 we provide a discussion on the results and some recommendations for future modelling.

3.2.1. Systematic literature review about the representation of climate change social impacts on health and place in integrated assessment models: method

This section contains information about the method conducted to carry out the systematic literature review on the representation of climate change impacts on health and place in IAMs. The method consists of two parallel systematic literature reviews conducted by using an adaptation of the PRISMA

(Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher et al., 2009). The PRISMA framework is widely used in SLRs, especially in the area of medicine and critical trials, although its use is extending to climate change research areas (Fan et al., 2022).

The study selection process consists of three main phases, which are Identification, Screening, and Inclusion.

In the **identification** phase, two independent searches are carried out in Scopus with the following search queries:

- Search query for Health:

TITLE-ABS-KEY ((("climate change" OR "sea-level rise" OR "extreme weather event" OR "extreme event") AND ("impact" OR "damage") AND ("health" OR "death" OR "morbidity" OR "disease" OR "mortality" OR "nutrit") AND (("integrated assessment" AND "model") OR "integrated model*")))*

- Search query for Place:

TITLE-ABS-KEY ((("climate change" OR "sea-level rise" OR "extreme weather event" OR "extreme event") AND ("impact" OR "damage") AND ("migra*" OR "displacement" OR "place" OR "cultur*" OR "heritage") AND (("integrated assessment" AND "model") OR "integrated model*")))*

Both searches were conducted on 19th April of 2023 in Scopus. The time period considered is 1995-2023. From both searches, those records that are not peer-reviewed papers are eliminated. Reviews were not considered either, since we were only interested in finding primary references, as is done in other systematic literature reviews in the IAMs field (Pastor et al., 2020). Duplicates were removed and articles neither in English nor Spanish nor with access for the reviewer were also deleted.

The **screening** phase is sub-divided in two stages: the screening and the eligibility. The screening consists of the abstracts reading and application of inclusion and exclusion content criteria, gathered in Table 12 and Table 13. When it was unclear whether a paper met the criteria by reading its abstract, it was moved to the eligibility stage. The eligibility stage is about the full-text reading and the application of the same criteria.

Table 12. Inclusion and exclusion content criteria for Health

Inclusion criteria	Exclusion criteria
i) The paper contains an integrated and quantitative model (including all those that considers themselves integrated assessment models (IAMs), integrated models (IMs) or similar) that combines sub-models or modules from different disciplines, specifically including the integration of climate change effects on human health, defined as mortality and morbidity.	i) The paper does not explicitly include climate change impacts on human health. ii) The paper includes effects of climate change mitigation on health, but not the effects of climate change as a natural phenomenon. iii) The paper includes effects of natural phenomenon, such as air pollution, but it does not explicitly assess climate change effects. iv) The paper does not include effects on human health but assess effects on ecosystem health or environmental quality indicators, without explicitly including health-related indicators. v) The paper does not provide a numerical integrated model or an integrated assessment model.

Table 13. Inclusion and exclusion content criteria for Place

Inclusion criteria	Exclusion criteria
i) The paper contains an integrated and quantitative model (including all those that considers themselves	i) The paper does not explicitly include climate change impacts on place.

integrated assessment models (IAMs), integrated models (IMs) or similar) that combines sub-models or modules from different disciplines, specifically including the integration of climate change effects on place, defined as migration or displacement of people or damages on culture or cultural assets.	ii) The paper includes effects of climate change mitigation, but not the effects of climate change as a natural phenomenon. iii) The paper includes effects of natural such as extreme weather events, but it does not explicitly assess climate change effects. iv) The paper does not provide a numerical integrated model or an integrated assessment model.

The **inclusion** phase basically refers to the selection of the articles to be included in the analysis and review.

Figure 13 and Figure 14 show the flow chart of all the phases described above for each systematic literate review, Health and Place, respectively.

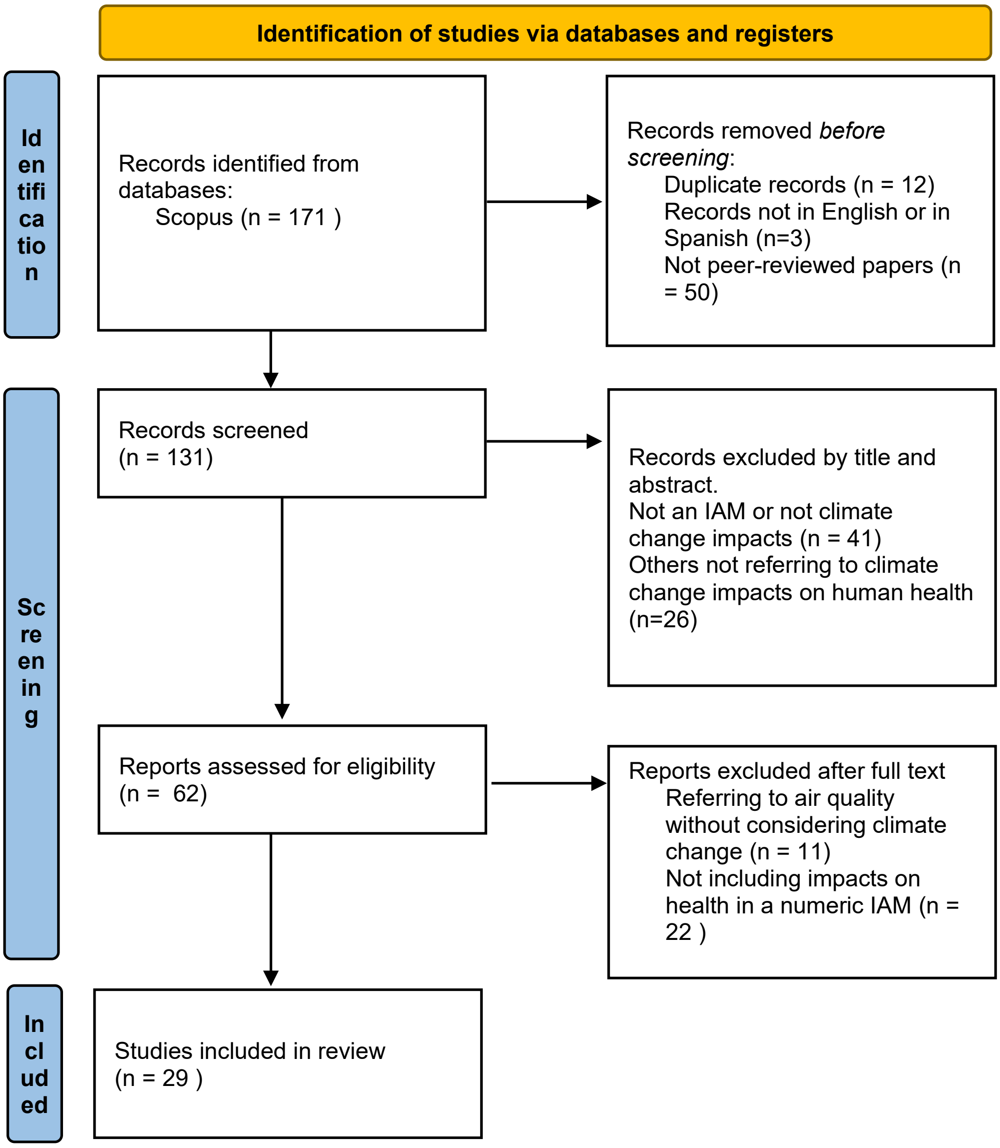

Figure 13. Flow-chart of the method to conduct the systematic literature review on Health. Adaptation of the PRISMA Framework

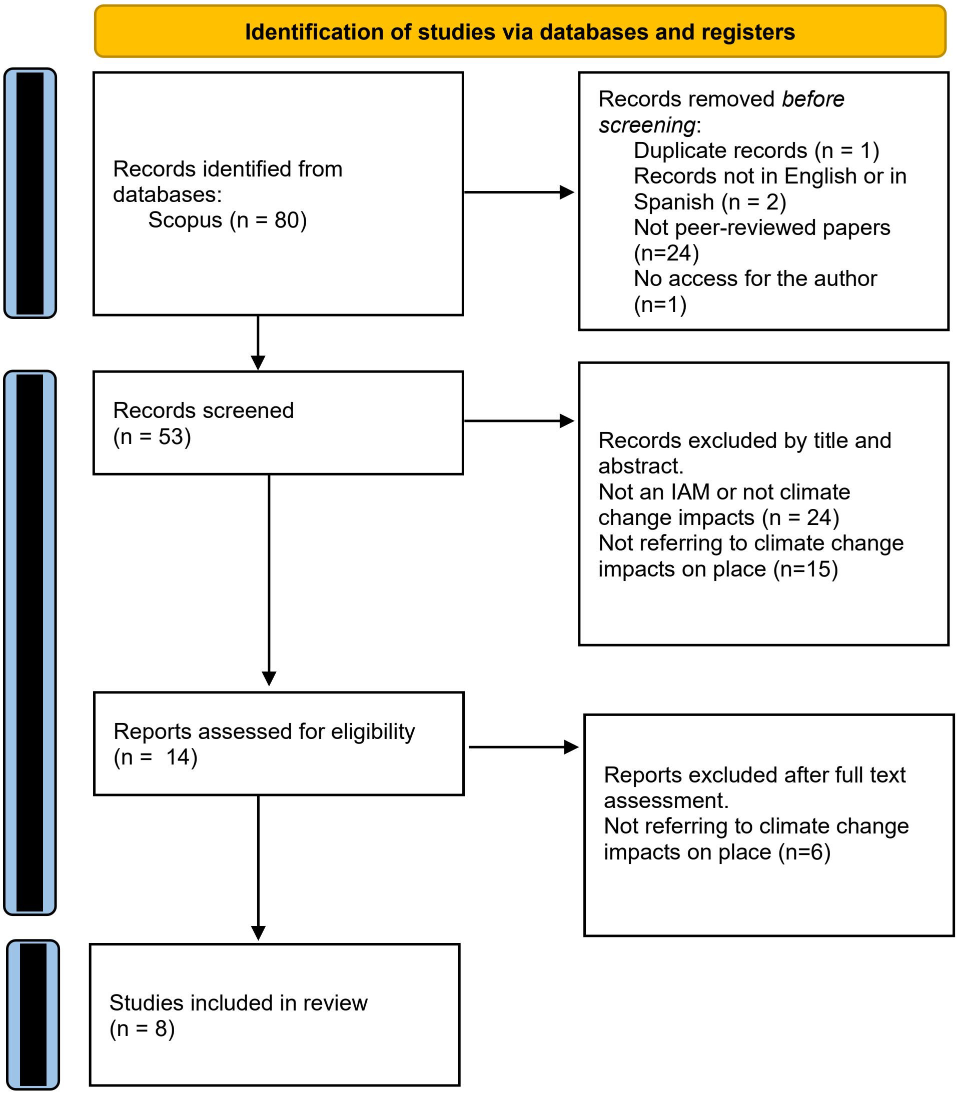

Figure 14. Flow-chart of the method to conduct the systematic literature review on Place. Adaptation of the PRISMA Framework

Finally, we included 37 papers in our review, 29 belonging to the Health area, and 8 to the Place area. To analyse the papers, we used a meta-analysis of the methods in a similar way as in Pastor et al. (2020). We created a database from which the following information was retrieved:

- Topic. According to the content found, we generate more specific sub-categories on which to classify the papers.
- Methods. Here we include information of the model or models used and of the specific technique used to quantify the impacts.
- Hazard. Here we include information on the specific hazard or climate change related driver that causes the impact.
- Affected variable. Here we include information on the specific variable or variables on which the impact is calculated.
- Regional scale. Here we include information of the spatial scale and regional disaggregation.

- Representation of inequality. Here we include information on the representation of inequality, attending to representation of heterogenous actors or elements, and how climate change affects them differently.

Our meta-analysis is focused on methods rather than on results because the objective is to set a research agenda and insights for the future modelling of climate change impacts on place and health within the NEVERMORE Project. Also, focusing on results could entail many challenges due to lack of homogeneity across the models, which use different methods, regional scales, and variables.

3.2.2. Systematic literature review about the representation of climate change social impacts on health and place in integrated assessment models: results.

In this section we describe the results found. Table 14 includes the database with the papers analysed, including information on the source, the category, the methods, the hazard, the affected variable, the regional scale, and the representation of inequality. The 37 papers analysed resulted in 37 models which are numerated in the database. There are two specific cases in which one paper corresponds to two models (Ciscar et al., 2019) and two papers corresponds to one model (Benveniste et al., 2020, 2022).

With respect to the topics, we firstly observe that impacts on health are much more recurrent than impacts on place.

From the whole sample, the most recurrent category is Temperature (meaning impacts on mortality or morbidity due to heat stress), which appears 29.73% of times, followed by Diseases. Diseases englobe a large set of different climate change related diseases, such as vector-borne diseases or others like diarrhoea or cardiovascular problems. In **Errore. L'origine riferimento non è stata trovata.** we show the percentage of models that are included in each thematic category. It is important to note that some models include more than one category, and that is why the percentages do not sum 100%.

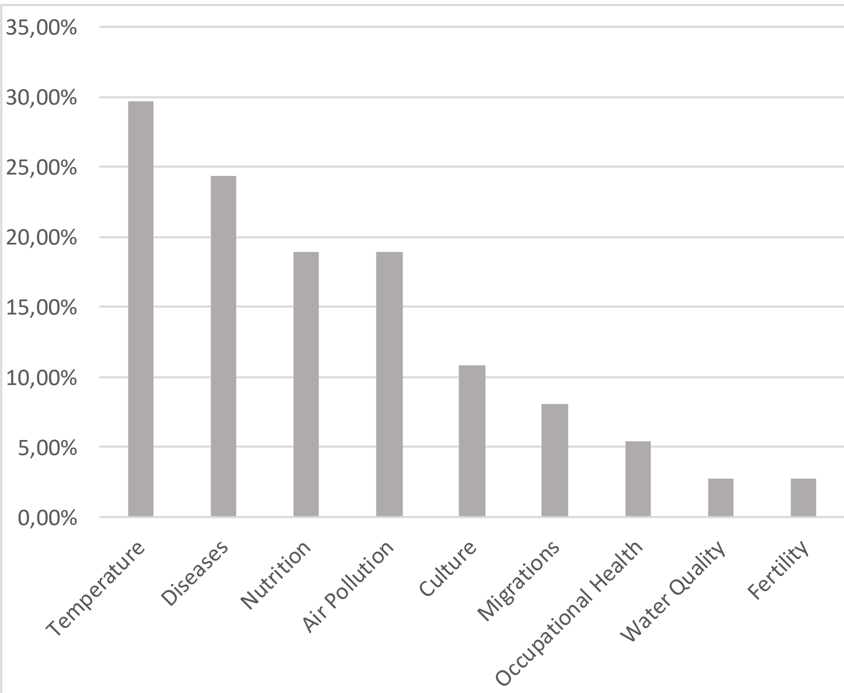

Figure 15. Percentage of models within each topic

Regarding the regional disaggregation, we observe that subnational scale is the most common, followed by global coverage disaggregated in lower scales. Also, almost he 30% of the models provide gridded data.

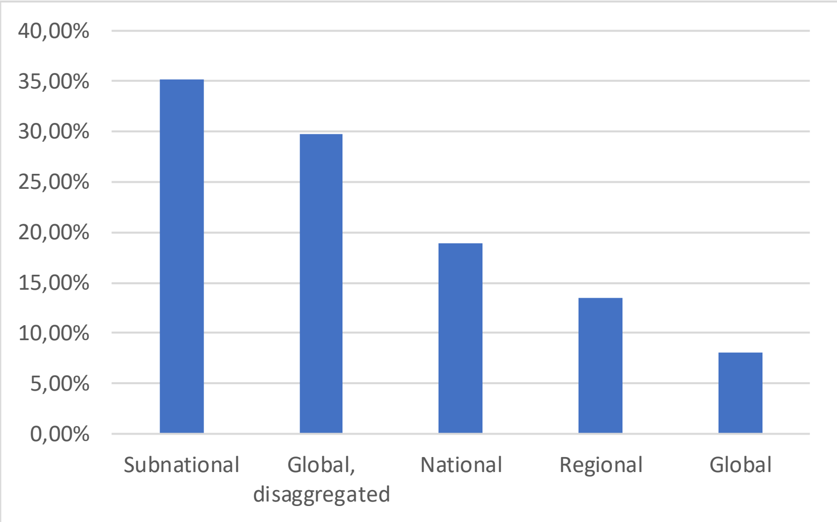

Figure 16. Percentage of models within each regional scale category

From the 23 models that have either national, regional[3] or subnational coverage, 39% of them are case studies of Europe. Asia, Africa, Oceania (Australia only) and North America have the same representation (13% each one) whereas only 8.70% of the non-global models are case studies of South America. The representation of inequality is an important element to analyse, as it has generally been an underrepresented element in IAMs (Asefi-Najafabady et al., 2021). Here, we consider inequality to be represented in an IAM as long as heterogeneous actors of any kind (e.g., regions, age, gender, socio-economic status, etc.) are represented. In our sample, most models represent inequality in some way, with disaggregation by region predominating (see **Errore. L'origine riferimento non è stata trovata.**).

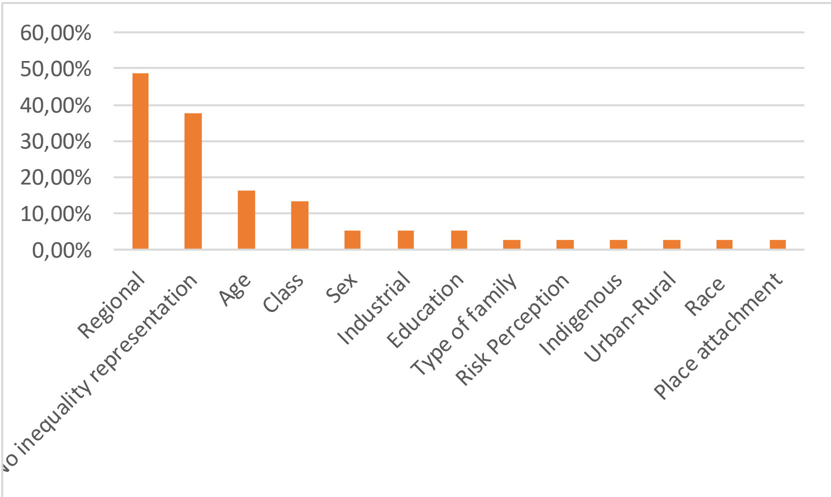

Figure 17. Representation of inequality across the models

Table 14 shows with higher detail information about the methods, hazards and variables affected in each model.

[3] In this context, regional means a scale that is in between of national and global. This is, a group of countries following political or geographical criteria (e.g., Europe, European Union, Sub-Saharan Africa, etc.).

Table 14. Results of the analysis of the articles included in the systematic literature review

	Source	Topic	Methods	Hazard	Affected variable	Regional scale	Representation of inequality and focus on vulnerable groups
Health							
1	(Sahani et al., 2022)	Air Pollution, Diseases, Nutrition, Temperature	This study combines different analysis methods such as a global climate model simulating specific health-sector climate indices, studies studying risk of childhood to air pollution and haze, and community surveys among different places to study the role of marginalized children under climate change. All these methods are used to build an integrated model.	Heat extremes affecting air pollution [gender & age 3 groups]. Heat extremes and rain extremes and sea related extremes, multiple channels.	Respiratory diseases (daily hospital admissions). The rest is studied through surveys more in a qualitative manner and connected through the model, including malnutrition, deaths due to ewes, cognitive function and development, heat related illnesses and vector borne diseases and food and water borne diseases.	Subnational, Malaysia	Children, differentiating by age, gender, race, type of family and education
2	(Shen et al., 2022)	Air Pollution	This integrated modeling framework puts together the MESSAGE-GLOBIOM IAM, an Emission Factor & simplified Chemical Transport Model and a Relative Risk Model & Exposure-Response Function (ERFs). Impacts on mortality due to O_3 and	O_3 and $PM_{2.5}$ concentration induced by GHG emissions once temperature rise and other climate impacts are applied in many sectors.	Mortality (number of premature deaths) and its monetization.	National, China.	

			$PM_{2.5}$ concentration are calculated by the exposure-response functions and are after monetized by using the Value of Statistical Life (VSL). Climate change is introduced through an earth model (BCC_SESM) that calculates atmospheric GHG concentrations, temperature rise and other climate indicators, inducing damage to all the sectors. Once damages are represented, GHG emissions are calculated and introduced in the GAINS model to calculate air pollutants. In this sense, air pollution levels contain climate change impacts.				
3	(Malik et al., 2022)	Nutrition	This integrated model uses an input-output table to assess supply chain impacts of climate change on food supply. The table is linked to data on food composition to create nutrient availability and dietary quality indicators. Climate change is introduced exogenously by affecting the input-output elements by means of 'shocks'. There are 8 climate change scenarios differing in crop and food production losses due to different assumptions on climate change, adaptation, and extreme weather events impact.	Losses in food production due to general climate change effects on yields, including extreme weather events.	Consumption losses, macronutrients losses, diet quality and healthy diet losses.	Subnational, Australia.	Consumption patterns differentiation across vulnerable communities, including rural/urban, indigenous, education, attainment, age and tenure type.
4	(Sharma et al., 2022)	Temperature	The DICE-EMR is an IAM with an endogenous mortality response developed in a previous article. This	Rise in average surface temperature.	Mortality (excess deaths) and its	National, Australia.	

			study uses it for a specific regional application.		monetized impacts.		
5	(Bressler et al., 2021)	Temperature	*This study does not use an IAM but suggests damage functions to be specifically included in IAMs. The authors develop mortality-temperature damage functions for different RCP scenarios. Income is also included in the functions to capture the effect of wealthier populations to protect themselves from extreme heat.	Heat and cold, represented by the increase in yearly average temperatures at the country level.	Mortality.	Global, disaggregated to 163 countries.	Regional differentiation.
6	(Bressler, 2021)	Temperature	The DICE-EMR is an extension of the DICE-2016 IAM, including Endogenous Mortality Response (EMR). It includes a reduced-form mortality damage function projecting the effect of climate change on the mortality rate. It is calibrated by using three comprehensive articles providing estimates on climate-induced damages on mortality due to temperature. By using the VSL, they calculate the Mortality Cost of Carbon, which represents the expected temperature-related excess deaths globally from 2020 to 2100 caused by an additional ton of CO2 equivalent emissions.	Heat damages, represented by the increase in global average temperature.	Mortality and its monetized impacts (calculation of the Mortality Cost of Carbon).	Global, 1 world-region.	
7	(Lupi & Marsiglio, 2021)	Temperature	This study creates an extended version of DICE called DICED that includes demography and mortality response to temperature. Mortality affects population growth, and this	Heat damages, through Increase in Global Average Temperature Above Preindustrial	Mortality	Global, 1 world-region	

			interrelates with the economic module in different ways. The parameter of the damage function is calibrated by a previous study. SCC attributed to mortality is not directly calculated but it is given, and it is higher than in DICE since mortality damages have effects on economic model.				
8	(Pottier et al., 2021)	Temperature, Diseases and Nutrition.	This study pulls a population dynamics model into the RESPONSE IAM, which receives climate change feedback on mortality rate, calibrated by previous literature on the World Health Organization. Climate change is introduced exogenously through three RCP scenarios that make the temperature increase evolve, affecting directly to mortality rates, which in turn affect population levels. Mortality is measured as the number of deaths in physical units. Monetization is not carried out since the authors consider it to involve some normative decisions on valuation of premature mortality that are difficult to take.	Heat, diarrheal disease, malaria, dengue, and undernutrition; the proxy used is Global Temperature Increase.	Mortality, (the number of life-years lost), and indirectly, population levels and unborn people.	Global, 1 world-region.	Age differentiation, including five age cohorts and sex differentiation.
9	(Matsumoto et al., 2021)	Occupational health	This modelling framework consists of a Computable General Equilibrium (CGE) coupled with an Earth system model (EMIC) of intermediate complexity, with multiple interactions between them. The CGE model obtains GHG	Heat stress, through wet bulb globe temperature (WGBT).	Labour productivity and subsequent effects on GDP.	Global, disaggregated in 18 regions.	Regional and industrial differentiation.

			emissions, feeding the EMIC model, which calculates temperature and relative humidity, inputting again the CGE by affecting the labour productivity. The relationship between climate change and labour productivity is introduced by a function of labour productivity depending on the wet bulb globe temperature. Three scenarios of emissions are introduced and are compared both with and without climate impacts.				
10	(Nakajima et al., 2020)	Diseases	This study combines the Asia-Pacific Integrated Model-Enduse (AIM/Enduse) with climate and atmospheric models, and with specific impact models to calculate damages on health, agriculture, and flood risks. Exposure-response functions are developed to calculate health outcomes of high temperature provoking heat-related mortal diseases. Different SRES emission scenarios are considered to induce different climate change pathways.[4]	Stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infection, with current temperature (compared to an optimum temperature) as a proxy.	Excess mortality.	Global, with a grid resolution of 1.4º.	Regional differentiation.

[4] This study also includes health effects of $PM_{2.5}$ and but as explained before since specific impacts oc ff by this via are assessed, we do not include this information in the table.

11	(Zhao et al., 2020)[5]	Diseases	This study uses the FUND model in combination with the BCC_SESM climate model which projects different climate change scenarios. Climate change impacts on health are represented by exposure-response functions of additional deaths calibrated in previous literature. After, these are monetized by using VSL.	Diarrhea; Vector-borne diseases (malaria and dengue), cardiovascular and respiratory, on different indicators of temperature (Current global temperature of the hottest month, temperature increase, current temperature levels).	Mortality (premature deaths) and its monetization.	Global, disaggregated in 16 regions.	Regional differentiation.
12	(Kozicka et al., 2020)	Nutrition	This study combines the IMPACT integrated modelling system with the bioeconomic farm-household model FarmDESIGN. Climate change is introduced through exogenous scenarios that affect biophysical variables in the crop and water models that conform IMPACT. The IMPACT outputs related to price and crop yields variations due to climatic conditions are introduced in FarmDESIGN to obtain results on nutrition at the farm level.	Changes in crops and water	Production of dietary nutrients, particularly Vitamin A, expressed in consumer units that can be eaten given the farm production level.	Subnational (farm level), Uganda.	
13	(Lin et al., 2019)	Temperature	This is an integrated analysis that combines a region-specific health model with a climate change valuation module. Excess mortalities of climate warming due to black carbon are estimated through a relative risk long-lineal	Black carbon induced by global warming.	Mortality.	Subnational, China.	Age differentiation: children and adults.

[5] This study is an improvement of the health damages representation in FUND. Further work will include in this database original documentation on FUND that did not appear through our search.

			relationship dependent on temperature change caused by black carbon. After, the study calculates an 'Attributable Function' (AF) that is eventually used to calculate the excess mortality by multiplying the AF by the baseline mortality rate and the exposed population.				
14	(Ciscar et al., 2019)	Temperature	The JCR PESETA III project includes mortality impacts by relying on exposure-response functions based on previous literature. Monetization is included by using VSL.	Heat, through temperature.	Mortality (deaths) and its monetization.	Regional, Europe.	Regional differentiation, including five groups of countries.
15		Temperature	The ACP project includes mortality impacts by relying on econometric models. Monetization is included by using two methods: VSL and CGE, including economic damages of lost labour.	Heat and Cold, through temperature.	Mortality (changes in death rate and deaths per 100000 persons) and its monetization.	National and subnational, USA.	Regional differentiation, including states and counties.
16	(Saari et al., 2019)	Air Pollution	The MIT Integrated Global System Model is an IAM that combines an economic general equilibrium model with an Earth System Model of intermediate complexity. To represent health impacts, concentration-response functions (CRFs) are used to measure induced climate change impacts on health due to air pollution. Air pollution is measured through O_3 and $PM_{2.5}$ concentrations. Climate change is included by different exogenous scenarios and is isolated by	O_3 and $PM_{2.5}$ concentrations induced by natural climate variability.	Adult Mortality, Morbidity, and economic valuation. Morbidity includes: i) acute myocardial infarction, hospital admissions due to respiratory, cardiovascular, and	National, US.	

			comparing results between a climate change scenario and a non-climate change scenario. The BenMAP (Environmental Benefits Mapping and Analysis Program) is used to monetize the impacts.		emergencies; ii) respiratory symptoms, including upper respiratory symptoms, asthma exacerbation and acute bronchitis; and iii) loss productivity, including work loss days, school loss days and minor restricted activity days.		
17	(Bertone et al., 2019)	Water Quality	This study develops a system dynamics (SD) model that accounts for uncertain parameters thanks to a combined Monte Carlo-fuzzy logic approach that also uses Bayesian Networks. The model includes population growth projections and climatic variables such as extreme weather events (EWEs) to evaluate the ability of a water utility to deliver safe potable water. Climate change is introduced through scenario variation of the climatic variables according to the 'Best', 'Median' and 'Worst Situation'.	EWEs, using as a proxy downscaled climate change projection in terms of evaporation, wind strength and rainfall amount.	Customers' health is measured through the number of people getting sick from drinking treated water.	Subnational, Australia.	
18	(Takakura et al., 2018)	Occupational Health	This study uses general circulation models (GCMs) to calculate the heat exposure index Wet Bulb Globe	Heat exposure, through WBGT.	Indoor and Outdoor Labor	Global, disaggregated in 17 regions	Regional and industrial differentiation.

			Temperature (WBGT) and then calculate the labor capacity losses due to heat exposure at grid cell level. Climate change is introduced exogenously by RCP scenarios affecting the WBGT estimation and the cooling degree-days, which also have effects on air conditioning penetration, affecting indoor conditions. The labor capacity estimate losses are included in the AIM/CGE model to estimate the GDP losses under different adaptation and mitigation measures.		Capacity losses and GDP losses.	for GDP losses, and at grid cell level for the labor capacity losses (0.5°x0.5°).	
19	(Semakula et al., 2017)	Diseases	This study develops an integrated model combining Geographical Information System (GIS) and Bayesian belief networks (BBN) to predict malaria hotspots under different RCP scenarios that allow to capture variations in climatic variables. Malaria prevalence is modelled considering different climatic, environmental and sociodemographic drivers.	Temperature and rainfall changes.	Malaria prevalence among children under 5 years.	Regional, sub-Saharan Africa, at grid level (25kmx25km).	
20	(Hendriks et al., 2016)	Air Pollution	The Greenhouse Gas-Air Pollution and Synergies (GAINS) IAM is used in combination with the Global Biosphere Model (GLOBIOM) and the chemistry transport model (LOTOS-EUROS). Climate change is introduced as a 'Future Climate' scenario simulating temperature of European 2003 summer, which was significantly higher than the long-	O_3 concentrations changing due to changes in temperature and weather patterns.	Relative Risk of Mortality	Regional, Europe, at grid level (0.5°x0.25°).	

			term average. O_3 concentrations are modelled considering the effects of temperature and other weather conditions. The Relative Risk of mortality is calculated by using the SOMO35 (the sum of daily maximum 8-h means over 35 ppb) and World Health Organization data.				
21	(Geels et al., 2015)	Air Pollution	This study combines the Danish Economic Valuation of Air Pollution (EVA) model system with two climate models and two Chemical Transport Model (CTMs) to assess effects on premature mortality due to air pollution and its sensitivity to climate, emissions, and demographic changes. The EVA models receive outputs of the CTM models to, through exposure-response (ERF) functions, include morbidity and mortality outcomes related to exposure to O_3 and $PM_{2.5}$. Climate change is introduced through the climate models forcing CTM models to change the O_3 and $PM_{2.5}$ values by inducing 'climate penalty' effect.	O_3 concentrations changing due to warmer climate; $PM_{2.5}$ concentrations changing due to precipitation patterns.	Mortality and Morbidity, including chronic bronchitis, restricted activity days, congestive heart failure, lung cancer, respiratory and cerebrovascular hospital admissions, asthmatic children, and asthmatic adults.	Regional, Europe, at grid level, (50kmx50km).	Regional differentiation. Age differentiation for asthma, differentiating between children and adults.
22	(Ikefuji et al., 2014)	Temperature, Diseases and Nutrition	This study makes an improvement on the RICE model by including climate change and air pollution effects on health. With regards to climate change's impacts on health, they create functions capturing the proportion of population suffering climate-related diseases to	Climate-related diseases, using temperature as a proxy.	Disability-adjusted life-years lost (DALYs) due to malaria, cardiovascular diseases,	Global, disaggregated in 11 regions	Regional differentiation.

			determine the fraction of healthy people that can conform to the labor force. Functions are simplistic and calibrated through previous literature. Climate change's health impacts have macroeconomic effects on GDP by means of changes in labour force. Climate change is represented by temperature trends which are calculated endogenously due to CO_2 emissions and aerosols emissions coming from the economic module.		diarrhea, and malnutrition.		
23	(Reilly et al., 2013)	Air Pollution	The MIT Integrated Global System Model is used and improved to account for climate change effects on health mediated by air pollution, specifically ozone concentrations. Instead of calculating predicted illness or death and multiplying it by its cost or the VSL, they use an expanded Social Accounting Matrix able to represent health effects. In this way, more complex effects of health on the economy are calculated, such as effects on consumption and leisure. Other impacts are included following other methods.	O_3 concentrations, due to a change in temperature patterns and other changing meteorological variables (e.g. water vapor).	Social Accounting Matrix	Global, disaggregated in 16 regions[6].	Regional differentiation.
24	(Ciscar et al., 2011)	Temperature	This study integrates a set of coherent, high resolution climate change projections and physical	Heat and cold, through temperature.	Mortality.	Regional, Europe, at	Regional differentiation.

[6] This information is not specified in the article and we have retrieved it from the MIT model documentatt

			models into an economic modeling framework. Health impacts are considered non-market impacts affecting mortality and are not monetized. These are included through epidemiologically derived temperature-response functions capturing heat-related and cold-related mortality. Climate change is introduced through outputs of RCM and GCM models based on different SRES scenarios.			grid level, (50kmx50km).	
25	(Ibarrarán et al., 2010)	Fertility and Nutrition	This study integrates the Vulnerability-Resilience Indicators Model (VRIM), the Boyd-Ibarrán computable general equilibrium model, and the projections of the MiniCAM IAM to evaluate Mexico's resilience to climate change through a wide set of indicators, including human health and nutrition indicators. Climate change-related variables are obtained through the MiniCAM model which is fed by SRES emission scenarios.	Warmer temperatures, severe climate events (especially droughts), and sea level rise.	Fertility rate, Life expectancy and Protein consumption per capita. Population with access to safe drinking water and population at risk of disruptions from sea level rise.	National, Mexico; and subnational, at Mexico states level.	Regional differentiation (within Mexico, states). Age differentiation.
26	(Barthel et al., 2009)	Diseases	This study proposes an integrated modelling exercise combining a hydrological model with climate scenarios, spatial hydrogeological analysis and health analysis. Climate change is introduced through exogenous IPCC scenarios and generated by GCM models, affecting water availability. Regarding health impacts, diarrhea prevalence is	Temperature and precipitation changes, leading to a decrease of groundwater recharge.	Diarrhea prevalence.	Subnational, Benin: Ouene basin, at grid level (3kmx3km).	Regional differentiation. Class differentiation through 5 clusters of households with different geographical and water access characteristics.

			studied in relation to climate change, mediated by groundwater quality and water availability, which are spatially defined by the hydrological model and hydrogeological analysis.				
27	(Tol, 2008)	Diseases	This study introduces an improvement in the modelling of malaria in the FUND IAM. Malaria is modelled as dependent on income per capita and temperature, capturing both adaptive capacity and climate change, respectively. There is a feedback loop between malaria and economic growth. Climate change is calculated through the climate model of the IAM based on exogenous scenarios of emissions.	Malaria, through global temperature increase.	Mortality (Deaths) and Morbidity (Years of life diseased).	Global, disaggregated in 16 regions	Regional differentiation.
28	(Knowlton et al., 2004)	Air Pollution	This study applies an integrated modelling framework linking global climate models, regional climate models and regional air quality models to produce surface O_3 concentrations on 36-km grid over the New York metropolitan study area. O_3 concentrations are modelled so that effects from emission precursors and climate change can be separated. The effects on health are analysed by using a risk assessment framework to calculate O_3 -related daily mortality by using concentration-response functions (CRFs) calibrated	O_3 concentrations induced by climate change, considering temperature-dependent changes.	Mortality (Daily deaths).	Subnational, US: New York metropolitan area, at grid level (36x36 km).	Regional differentiation.

			on results from epidemiologic literature and interpolating with climate model outputs. Climate change effects are isolated through maintaining constant emission effects.				
29	(Lüdeke et al., 1999)	Nutrition	This study integrates quantitative models and qualitative elements (including fuzzy logic and linguistic variables) in a mathematical algorithm. Climate change is introduced in the model by calculating climate projections for a scenario of $2xCO_2$ atmosphere and subsequent effects on climatic variables (e.g., temperature, irradiation, precipitation) that in turn affect food production-related variables in the NNN neural-net-based model and the MEGARUS model related to food production conditions, such as water availability and plant productivity. Both depend on climatic variables. These biophysical variables enter the fuzzy logic qualitative model.	Temperature, irradiation and precipitation affect plant productivity.	Disposition towards the 'Sahel Symptom' of malnutrition.	Global, at grid level (0.5°x0.5°).	Regional differentiation.
30	(Martens et al., 1995)	Diseases	This integrated systems approach used here combines an IAM with GCM models and epidemiological and population models. Climate change is introduced through climate scenarios generated by the IMAGE IAM on different scenarios of emissions. Temperature outputs of the IAM are translated into regional	Mosquito and parasite characteristics, through changes in temperature and precipitation.	Malaria risk, through disability-adjusted life years (DALYs).	Global, at grid level (5°x7.5°).	Regional differentiation.

			seasonal temperature and precipitation by standardizing these outputs on a GCM. Finally, anthropogenic climate change effect on malaria incidence is calculated using a standard population model combined with an epidemiological model for infectious diseases.				
Place							
31	(Tierolf et al., 2023)	Migrations	The DYNAMO-M is an agent-based model that includes a migrations module based on a gravity model. Climate change is introduced exogenously through RCP scenarios affecting flood depth-damage functions.	Floods through sea-level rise.	Internal coastal induced migrations and migration costs.	National, France.	Household heterogeneity in migration decisions, considering place attachment, income, and risk perception differences.
32	(Benveniste et al., 2020, 2022)	Migrations	The FUND integrated assessment model is combined with a gravity model of migrations. Climate change is introduced exogenously according to RCP scenarios and several sectoral damage functions are in the end aggregated to affect income, which in turn and indirectly affect migrations.	Resource deprivation (income losses) caused by climate change impacts on many sectors.	International migrations and remittances.	Global, disaggregated in 16 regions.	Regional differentiation, considering income differences across regions (Benveniste et al.,2020), and within regions (Benveniste et al., 2022).
33	(Pouso et al., 2019)	Culture	The System Dynamics Model for recreational fishing is composed of an ecological sub-model and a social sub-model that interrelates to represent the study socio-ecological system. Climate change is activated or deactivated by the modeler.	Total ammonium load spilled to the estuary and water running, due to changes in precipitation patterns.	Recreational fishing satisfaction, active recreational fishers.	Subnational (Nerbioi Stuary), Spain.	
34	(Kaspersen & Halsnæs, 2017)	Culture	The Danish Integrated Assessment System (DIAS) is a framework composed of various modelling	Temperature, precipitation, wind, and air pressure.	Historical and cultural assets.	Subnational, Denmark.	

			tools, including climate data processing (downscaling and extreme value analysis), hydrological and agricultural impact models, and economic valuation and cost-benefit models.				
35	(Andersson et al., 2015)	Culture	This integrated modelling approach includes climate models (ECHAM5/CCLM), a process-based ecosystem model (FinnFor), a forest projection model (FTM) and a model that assesses the probability of wind damage (WINDA-GALES). The climate models are used to produce a climate change scenario for the SRES A1B emission scenario.	Wind changes.	Recreational forest services (Recreation Index).	Subnational, Sweden.	
36	(Kirchner et al., 2015)	Culture	This integrated modelling framework involving a climate model (ACLiRem), a forest growth model (Caldis vâtis), a crop model (CropRota), a biophysical process model (EPIC), a land use model (PASMA), an energy system model (BeWhere) and a dynamic multiregional input output model. Climate change scenarios are generated by the ACLiREm model by projecting several temperature and precipitation patterns.	Solar radiation, maximum and minimum temperatures, precipitation, relative humidity, and wind speed.	Landscape esthetic (Shannon Diversity Index).	National, Austria.	
37	(Barbieri et al., 2010)	Migrations	This integrated model has as its central part the computable general equilibrium model (IMAGEM-B). Climate change is introduced through SRES A2 and B2 scenarios affecting directly economic variables	Temperature and land availability for cultivation.	Net migrations, considering only national migrations.	Subnational, Brazil.	

			in the agricultural sector, such as income and employment. Outputs of IMAGEM-B are used in the mathematical model of Migration Rate (MR) which captures migration sensibility to economic variables impacted by climate change.				

3.2.3. Discussion and research agenda for modelling climate change social impacts

In addition to the descriptive results presented above, it is worth presenting some insights that can be drawn from our meta-analysis.

IAMs research area is very broad. Before starting the systematic literature review, we evaluated the list of IAMs included in the list of *I2AM PARIS (n.d)*[7] and we did not find any IAM that includes climate change social impacts[8]. Taking this into account, we decided to conduct a systematic literature review to capture what is the real state-of-the-art in the representation of social impacts in IAMs, no matter if these are broadly known IAMs or not. We are aware that the IAMs we have found are not the most representative. In fact, while it is common for IAMs to have a name, many of the models found do not even have a name, corroborating that many of them have been created for a specific purpose and (at least for the time being) have not been followed up. But this does not make them less valid. Indeed, some of them explicitly mention that their methods can be extrapolated and integrated in other IAMs (Bressler et al., 2021; Tierolf et al., 2023).

Within the health area, we observe that many articles use concentration-response functions (CRFs) or exposure-response functions (ERFs) calibrated through empirical epidemiological studies (Ciscar et al., 2011; Knowlton et al., 2004; Martens et al., 1995; Saari et al., 2019; Shen et al., 2022). There are also recurrent variables like the disability-adjusted life-years lost (DALYs) (Ikefuji et al., 2014; Martens et al., 1995). As it is common in IAMs, temperature is the most recurrent indicator used as a climate change driver of the impacts, either for representing impacts from heat or other hazards such as diseases. O_3 and $PM_{2.5}$ concentrations are also very much used to represent impacts from air pollution health, although, as mentioned in Table 12, we only include the kinds of models where climate change effects on air pollution are explicitly considered.

We also observed that many of the models assessing climate change impacts on health use the VSL monetize the health impacts and integrate these costs in cost measures like the Social Cost of Carbon (SCC) (Ciscar et al., 2019; Shen et al., 2022; Zhao et al., 2020). The VSL is an estimate that monetarily measure the value of life and that can be obtained in different ways, resulting in very different values. We only found one article that explicitly regrets to use it due to the subjectivity and moral problems linked to this method (Pottier et al., 2021), although Ciscar et al. (2019) recognize that its use introduces high uncertainty.

By comparing our results with the framework of McMichael et al. (2006), we identify some gaps on the representation of impacts on mental health and of natural catastrophe effects of extreme weather events on mortality and deaths.

Within the place area, climate change impacts on migrations are represented in three models, but neither of them considers forced international migrations, which is a key concern in climate change research. Cultural damages are represented in different manners, and the development of indicators based on environmental variables is especially interesting but that are suggested as useful to measure cultural performance (Andersson et al., 2015; Kirchner et al., 2015). This approach could be easily implemented in many environmental models and helpful to bridge the gap between environmental and social assessments of climate change.

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[7] At least, the documentation on the IAM2Paris webpage does not report a representation of climate change social impacts. We are aware that some of the models included there could have been improved in later studies. This is what happens with DICE, which is within our database.

We did not find any IAM jointly assessing the climate-health-migration nexus nor the cascading impacts that climate change impacts on migration can have on health, or vice versa. However, this area is of high interest since there are many linkages (Issa et al., 2023).

We consider that the analysis done can be very useful to set the basis for modelling of social impacts in the NEVERMORE models. Although the review is focused on IAMs, and not on other types of models, the models analysed are diverse enough to provide insights on how to model climate change impacts on health and place in models of different nature.

Further work regarding the systematic literature review could be the enlargement of the database, considering other IAMs that we have likely missed in the search, by using techniques such as snowball sampling or searching in other databases. Also, we recommend enlarging the social categories by including the 'Safety' dimension. Further work regarding how to capitalize on the results to improve the NEVERMORE models will be carried out in the scope of WP4 and WP6.

4. Behavioural change and lifestyle transformations

The potential of changes in behaviour and lifestyles are essential to an accelerated mitigation. Most of the global mitigation pathways that aim to limit the global temperature increase to 2°C or lower assume substantial behavioural and societal change to low-carbon lifestyles (Shukla et al., 2022). The IPCC recognizes that individual behavioural change is not sufficient for strong climate change mitigation unless it is embedded in structural and cultural change. Unfortunately, current levels of people's engagement with sustainable lifestyles are too low.

The existence of limits to adaptation to climate change indicates that transformational and structural behavioural change is almost compulsory in a society that aims to be sustainable. We need societal change not only to be able to adapt to climate change, but also to alter economic and social structures that contribute to a stronger climate change and social vulnerability (Intergovernmental Panel on Climate Change, 2014).

This section explores behavioural change and societal transformations in different senses: i) trying to better understand the mechanisms of behavioural change as to be able to identify the most powerful leverage points for speeding up social change and ii) setting the basis for future modelling of behavioural change and their drivers and barriers.

The research questions that will be addressed in the following sections are:

1. What is behavioural change and what are the research priorities related to it?
2. Which behavioural and lifestyle changes are suitable for inclusion in the NEVERMORE project?
3. What are the drivers and barriers of lifestyle and behavioural change?
4. How can lifestyle and behavioural change be represented in the NEVERMORE models?

To answer these questions, the following sections are organised as follows: section 4.1 contains a definition of behavioural change and lifestyles, as well as a general description of research priorities; section 4.2 contains a review of the representation of behavioural change in integrated assessment models; section 4.3 describes the modelling framework proposed for representing behavioural change in NEVERMORE and section 4.4 contains a review of drivers and barriers (including psychological and sociological mechanisms and data) of different behavioural changes.

4.1. Preliminary ideas on behavioural change: definition and state-of-the-art

Behavioural change and *lifestyle* have different meanings depending on the context and discipline, which can cause common misunderstandings. Therefore, a common ground with shared concepts has to be carefully defined (van den Berg et al., 2019).

According to Akengi & Chen (2016), a sustainable lifestyle is a 'cluster of habits and patterns of behaviour embedded in a society and facilitated by institutions, norms and infrastructures that frame individual choice, in order to minimise the use of natural resources and generation of wastes, while supporting fairness and prosperity for all'.

The IPCC mentions that behavioural change is one of the demand-side strategies that lead us towards sustainable development (Shukla et al., 2022). Thus, behavioural change can be defined as the means to achieve a sustainable lifestyle. Therefore, following the IPCC, our understanding of behavioural change is based on two fundamental ideas: i) it is about people's/citizens' preferences and actions and ii) it can have different levels: from individual actions with little potential for mitigation to structural and transformational changes that involve disrupting existing developmental trends.

The first fundamental idea mentioned above is important because it determines who is the 'political subject'. We are assuming that only people, citizens, families, and households can lead to behavioural change. This leaves out other types of private institutions, such as governments or companies. Actions carried out by governments to face climate change are called 'policies' (these are explored in WP5), while actions carried out by private companies are within the category of supply-side actions[9]. Behavioural change occurs at the individual level, although due to data availability it is usually modelled at higher aggregation level, such as household level. Behavioural change can be about consumption (purchase of food or clothing), home practices (use of one or another energy source for heating and cooling) or everyday life (political life, association, etc.). It is very common to conceptualise behavioural change like that from an integrated modelling perspective (van den Berg et al., 2019).

Although behavioural change is usually linked to mitigation solutions, some actions can represent mitigation and adaptation at the same time. For instance, the use of a cleaner source of electricity may also be motivated by an availability that is less dependent on water scarcity or climate variability.

Classifying behavioural change decisions and lifestyle changes is not an easy task because there exist multiple frameworks and approaches. In the area of modelling behavioural change and lifestyle transformations, modellers usually make a hard distinction between *efficiency*, *technological substitution* and *lifestyle*: efficiency represents the provision of an output with a low amount of input; technological substitution represents the provision of an output by using an alternative combination of inputs; and lifestyle changes replaces the output for a different one, or avoids the use of that output (van den Berg et al., 2019).

Another classification is the one commonly used by the IPCC (Shukla et al., 2022) to categorise mitigation strategies: The Avoid-Shift-Improve (ASI) framework. According to this framework, '*Avoid*' refers to those mitigation options that reduce unneeded (in the meaning of not being obliged to provide the desired service) resources use by redesigning service provisioning systems; '*Shift*' concerns to the change to already alternative ways of providing a service that already exist; and '*Improve*' means improving the efficiency of an existing technology.

Regarding which domain or driver promotes a behavioural change in one or another category, we could say that 'Avoid' measures are related to socio-cultural shifts; 'Shift' options relate to the

[9] Supply-side actions are those carried out in the production side of the economy (e.g., companies, government, etc.).

availability of infrastructure and 'Improve' actions are very close to technologies. Evidence shows that 'Avoid' and 'Shift' decisions usually require more effort than 'Improve' options because they face more psychological barriers of shifting habits and routines towards new lifestyles that can imply social costs, although they usually involve higher emission savings. In some sense, some of these decisions are conceived as a loss of quality of life. That is why it is extremely important to evaluate individual and collective wellbeing when analysing mitigation solutions (Shukla et al., 2022).

Another proposition is the one made by Samadi et al. (2017) that distinguish between *efficiency*, *consistency,* and *sufficiency*. Efficiency is the improvement of the input-output relation; consistency is the substitution of an input (e.g., from non-renewable to renewable resources) to obtain the output; and sufficiency is a change in the level of output that is demanded.

As highlighted by van den Berg et al. (2019), all these definitions actually overlap. Whereas for many IAM modellers a lifestyle change is only related to a reduction of demand. Those who use the ASI framework consider that lifestyle change is also technological substitution ('Shift' options, if these are from the demand-side). Figure 18 shows how the three mentioned frameworks are related and some examples for different behavioural change domains.

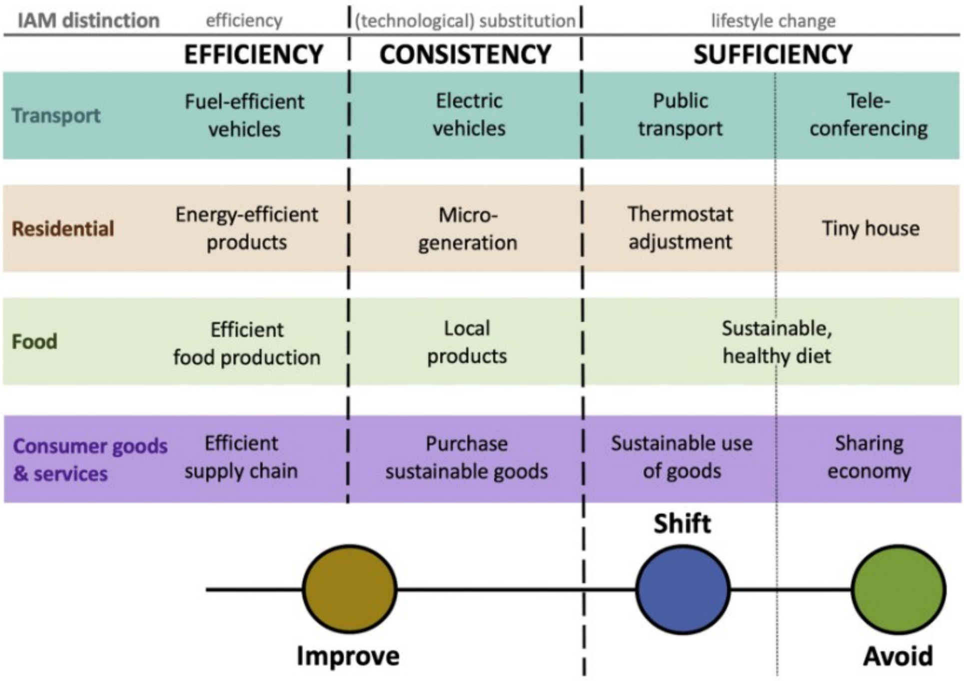

Figure 18. Different behavioural change decisions categorised in the different frameworks. Source: (van den Berg et al., 2019)

However, when it comes down to practice and examples, it is sometimes difficult to find measures that fit into just one category. For instance, in which category should electric vehicle adoption be included? On the one hand, one could say that this is an 'Improve' / 'Consistency' / 'Technological substitution' measure. The consumer still uses a car but instead of being driven by fuel, it is driven by electricity. But in a context where there is inadequate infrastructure to adopt electric vehicles, it could be considered a 'Shift' / 'Lifestyle Change' because these vehicles won't be able to offer as much service availability as fuel-based vehicles, so the service provided is different.

Most of the research done on behavioural change focuses on why people behave environmentally friendly and how to promote this kind of behaviour, but literature of IAMs is scarce in exploring what are the potential benefits of pro-environmental behaviour: the bulk of the studies on the potential of behavioural change just add up the emission savings of separately calculated behavioural change options or on sector-specific models, but they do not usually use multi-sectoral IAMs (van de Ven et al., 2018). These tools have a huge potential to quantitatively assess behavioural changes in different scenarios, but they are usually used to evaluate supply-side mitigation solutions (Nikas et al., 2020).

Drivers and barriers that motivate climate change are complex and varied. The IPCC mentions that individual motivation is essential, but that capacity and infrastructure are also needed for change. Drivers include socio-demographic and economic predictors, with an important role of resources such as income, being a very important predictor of environmental behavioural change. But drivers also go beyond these categories including psychological variables such as awareness, perceived risk, subjective and social norms, values, and perceived behavioural control. There are also many barriers, and it is not only lack of drivers, but also inequalities and social structures that constraint some people to achieve lifestyle changes.

According to the IPCC, to be able to address the challenges linked to low-carbon transition feasibility and governance, it is essential to improve the robustness of the evaluation of the different scenarios and pathways proposed by mixing qualitative and quantitative analytical techniques. Social scientific research is thus fundamental to complement analysis of IAM scenarios and pathways by proposing the question of ‘is this socio-politically feasible in terms of social acceptance and legitimacy?’. This, combined with novelty and improvements in modelling (e.g., increasing granularity of behavioural changes and heterogeneous agents) can help to identify ‘transition bottlenecks.’ But increasing complexity should not be obtained at the expense of usability and applicability.

According to the IPCC (Shukla et al., 2022), more research is needed in the following areas:

1. Representation and understanding of causal mechanisms of structural drivers of change at different levels (individual, social and structural) and their interactions and variations over time.
2. Narratives associated with specific technologies and group identities and their impact (enabling or constraining) mitigation outcomes.
3. Social media influence on the development of impacts and narratives about low-carbon transitions.
4. Effects of social movements such as climate activism on social norms and political change, especially in less developed countries.
5. Dynamic understanding of low-carbon transition feasibility.
6. Effects of shocks and disasters such as pandemics on willingness and capacity to change.

As mentioned in Goldberg et al. (2020), there exists feedback between climate change dissemination and legitimacy. In this sense, representation of behavioural change in IAMs could help also to increase social awareness and, eventually, enable behavioural change.

4.2. The representation of behavioural change in integrated assessment models

As mentioned above, the representation of behavioural change in IAMs is something relatively new, especially for those decisions that belong to the ASI categories ‘Avoid’ and ‘Shift’ (Nikas et al., 2020; van de Ven et al., 2018). Among those IAMs that do represent behavioral change with a certain level of detail, there exist, to our understanding, two major different approaches (Table 15).

Table 15. Different strategies for representing behavioural change in IAMs

MODELLING APPROACH	DEFINITION	OBJECTIVE	EXAMPLE
Exogenous modelling of behavioural change	This approach does not include explicit modelling of drivers and barriers. It is the modeller or the user who decides to activate/deactivate the behavioural change. Numerical levels are also pre-defined.	To assess the consequences of a behavioural change on the rest of the model (e.g., emission reduction potential, effects on land-use changes, etc.)	GCAM, IMAGE
Endogenous modelling of behavioural change	This includes explicit modelling of drivers and barriers. The internal dynamics of the model provoke a behavioural change to be reached or not.	To assess the consequences of behavioural change but also to assess its feasibility and which factors lead to its occurrence.	FeliX, C-ROADS

Until now, there exists a clear dominance of the exogenous modelling approach in IAMs. For the sake of feasibility and simplicity, most of the IAMs choose this option by focusing on the quantification of the environmental impacts of some behavioural changes (‘impact-oriented perspective’). The disciplines that have focused more on the motivations, drivers, and barriers for change (‘intent-oriented perspective’) generally belong to social sciences (e.g., psychology, behavioural economics, sociology, or philosophy). As pointed out by van de Ven et al. (2018), it is essential to combine both strategies to get ‘the full picture’.

Following van de Ven et al. (2018), the exogenous modelling can be carried out by using narratives and scenarios. Qualitative research can help in understanding the role of behavioural change across different scenarios. Even if this framework is very dependent on external assumptions, it still is a valuable option. Examples of exogenous modelling are the use of stylised assumptions coherent to narratives and storylines that can be executed ad-hoc or informed by social science or participatory processes. The same study also differentiates between different degrees of endogeneity, depending on the level of detail in the representation of drivers and barriers.

The IPCC also highlights the need of improving the representation of behavioural change in IAMs on several occasions in the last WGII report, with a chapter almost fully dedicated to behavioural change (see Chapter 5 in Shukla et al., 2022). The IPCC says that this research field presents an opportunity to create scenarios that allow us to reach the Paris Agreement goals, and to reduce the dependence on supply-side policies and efficiency-based demand-side solutions. Efficiency-based measures have been criticised because they imply risks of rebound effects: input savings are displaced to other productive sectors, leading to absolute increases in emissions. Since socio-behavioural factors, in contrast to efficiency-based solutions, are underrepresented in IAMs, it is important to prioritise the research on ‘Avoid’ and ‘Shift’ measures.

4.3. The NEVERMORE modelling framework for representing behavioural change

In this section, we present a new modelling framework to represent behavioural change. It has been developed with an eye towards being used in the WILIAM Integrated Assessment Model (de Blas Sanz et al., 2021), but its use is not limited to this model. It has the following features:

- It is based on the Avoid-Shift-Improve conceptual framework.

- The behavioural domains are 'Food', 'Transport', 'Housing', 'Other Goods and Services' and 'Cross Sectoral Political Behaviour'. The first four domains are an aggregation of the categories included in the Classification of Individual Consumption by Purpose (COICOP) which WILIAM relies on. 'Other Goods and Services' include the following subcategories: 'Appliances', 'Textiles', 'Furniture', 'Leisure', and 'Basic Services'.
- Endogenous modelling is the prioritised modelling strategy since it allows a more detailed representation of lifestyle choices. Modelling of drivers and barriers will be informed by social science analysis (section 4.4).
- For those cases in which endogenous modelling is too challenging, exogenous modelling will be considered to obtain an environmental impact assessment of some lifestyles. Lifestyles must be coherent with narratives and scenarios (T4.1) and, if possible, also informed by social science analysis.
- In some cases, a blended strategy (behavioural change is half endogenous and half exogenous) is taken.
- By adopting a combined endogenous and exogenous strategy (prioritising endogenous modelling but considering exogenous modelling coherent with scenario design) we guarantee to cover a wide portfolio of lifestyle measures.

The process of modelling that we propose here requires following a number of steps:

- Step 1. To create a portfolio of behavioural changes, including implementation levels.
- Step 2. To select which drivers and barriers enable or constrain the behavioural change.
- Step 3. To select proxy variables for each driver and barrier.
- Step 4. To define the mathematical relationship between behavioural change and drivers and barriers.
- Step 5. To calibrate the equation and set the parameter values.

Steps 1 and 2 require an interdisciplinary social science-based analysis supported by disciplines such as sociology, psychology, or behavioural economics, among others. Steps 3, 4 and 5 require an iterative process between social scientists and modellers. Steps 4 and 5 are probably the most challenging since data may not be widely available.

This deliverable is focusing on Steps 1 and 2, whereas steps 3, 4 and 5 will be carried out in the modelling-related tasks in WP4 and, if possible, WP6. Nevertheless, here we present some preliminary ideas on the modelling framework that we consider useful to have a general overview and orient steps 1 and 2.

We will explain the preliminary modelling process to be conducted using an example. Imagine that, once we have selected our portfolio of measures (Step 1), we want to model the behavioural change measure 'Using public transport' that falls in the category 'Avoid' and in the 'Transport' Domain. Also imagine that through Step 2 we know that this behavioural change depends on drivers such as the level of income and the place of living (people living in cities have more possibilities than those living in villages). These variables are part of the WILIAM model, although they are of different nature, as is explained later. This behavioural change could be implemented in two ways: i) assuming that all the population uses public transport (which is rather unrealistic) or ii) assuming that some part of the population uses public transport whereas others do not. Our methodology allows implementing option (ii) by differentiating between different 'levels of implementation'. In our example, different levels of implementation are related to more or less people using public transport, but the materialisation of the level of implementation will vary according to each behavioural change and how the variables involved are modelled. For instance, we can choose three levels of implementation of the behavioural change:

- Level of implementation 1: *high* population uses public transport as the main transport means.
- Level of implementation 2: *most of* the population uses public transport as the main transport means.
- Level of implementation 3: *all* the population uses public transport as the main transport means.

Levels of implementation should always be ordered in ascending order regarding effort and structural implications. As Figure 19 shows, the different implementation levels show how a specific behavioural change can range from a *convenient* to an *enthusiastic* way of action (van de Ven et al., 2018), or from an individual to a structural transformation, depending on the state of the drivers and barriers that enable or constrain it. This means that there exists a direct relationship between the degree of change, or the enthusiasm of a society about sustainability, and the effort required. Logically, behavioural change maintains a direct relationship with drivers and an indirect one with barriers. Obviously, mitigation/adaptation potential will be different in each level of implementation.

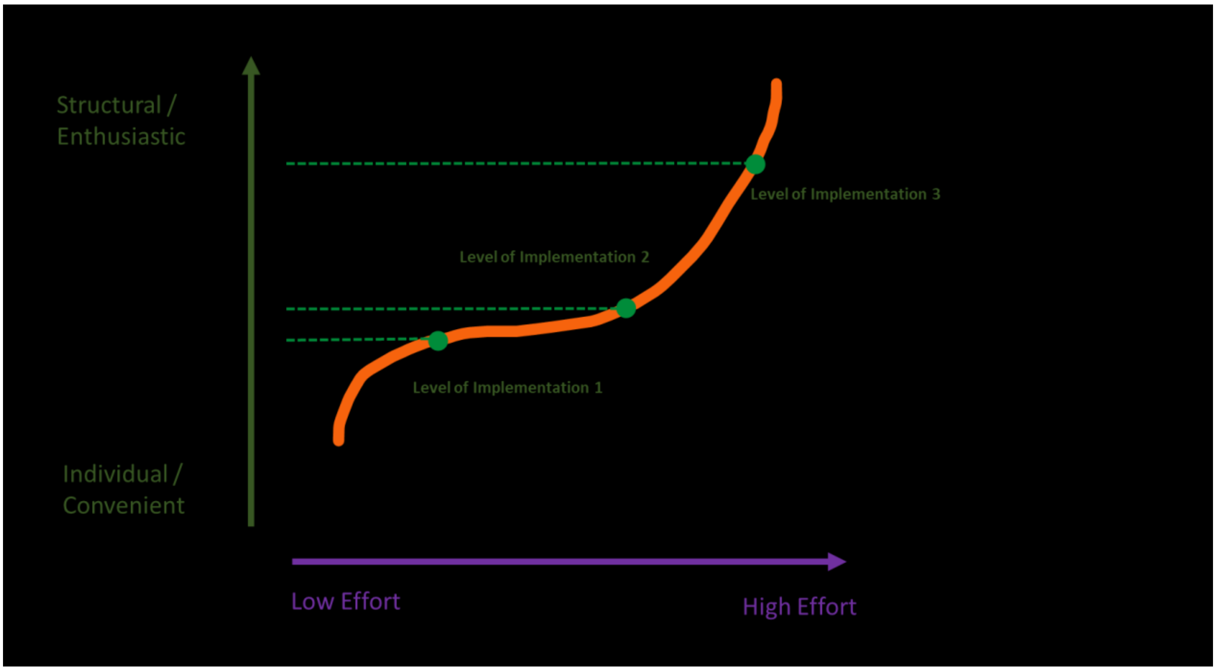

Figure 19. Simplification of the NEVERMORE endogenous modelling strategy of behavioural change

In the example mentioned, as well as in Figure 19, there are three levels of implementation. This means that the function 'Behavioural Change' should be defined between 0 and 3. Therefore, although our behavioural change function is continuous, for the sake of simplicity, there can only be N + 1 (being N the Number of Levels of implementation) values that the behavioural change can take:

- If 0 < Behavioural Change < 1, 0: there is no behavioural change. The use of public transports follows historical trends.
- If 1 < Behavioural Change < 2, 1: the level of implementation 1 is activated.
- If 2 < Behavioural Change < 3, 2: the level of implementation 2 is activated.
- If 3 < Behavioural Change < ∞, the level of implementation 3 is activated.

We consider two ways when mathematically defining the relationship between behavioural change and drivers and barriers (Step 4): functions or indicators. Although both are equations, it is useful for us to make this differentiation because the process of calibrating (and searching data for doing that) is different.

Coming back to our example, we could have a function such as (1) in which α and b can be obtained directly from the literature or through econometric or statistical models if we obtain enough data from the variables *Use of public transport*, *Income* and *Place of living*. However, historical data may not be enough when exploring alternative future pathways of behavioural change.

$$Use\ of\ public\ transport\ =\ \alpha * Income\ +\ b *\ Place\ of\ living \quad (1)$$ [10]

In this sense, it is important to mention that it is quite possible that, if we model public transport use in terms of these two variables alone, we will never capture very transformative levels of implementation. That is why it is extremely important to include other variables related to attitude, motivation, or awareness, which are more challenging to model, but which really make a difference and are worth it in terms of reaching specific sustainable lifestyles. In this sense, some 'Awareness' parameter or variables should be modelled and included in the equation as a third argument, or by affecting α and b.

The other way could be to obtain a composite indicator of *Income* and *Place of Living* (and 'awareness or similar indicator) that serve us for explaining our behavioural change. The indicator could be theoretical or empirical and generally based on previous literature.

The proxy variables selected for representing drivers and barriers (Step 3) can also be endogenous or exogenous. For instance, in the WILIAM model, *Income* is an endogenous variable that depends on wages, financial and capital rents, state transfers, etc., whereas *Place of Living* is exogenous. This means that we must make assumptions on their value, which can be set across scenarios (see Deliverable 4.1 for more information about policy assumptions).

In this case, Place of Living is a policy assumption that varies across scenarios, so we must qualitatively define its role to define the parameter quantitatively afterwards (this will very likely be a 'dichotomic variable' that can only take two values, depending on the rural or urban place of the household). Since WILIAM is planned to have heterogeneous households, this can be accounted for. Table 16 captures the role of Place of Living in the different WILIAM scenarios.

Table 16. The role of the exogenous driver Place of living across the different scenarios

BEHAVIOURAL CHANGE EXOGENOUS DRIVER OR BARRIER	ROLE IN A BUSINESS-AS-USUAL SCENARIO	ROLE IN A GREEN GROWTH SCENARIO	ROLE IN A GREEN DEAL SCENARIO	ROLE IN A POST GROWTH SCENARIO
Place of living (urban or rural)	Historical trends (people go from rural to urban)	No specific policies on ruralization	No specific policies on ruralization	Strong ruralization. Reversal of historical trends

In our example, the behavioural change depends on an endogenous variable and an exogenous variable. This means that we are following a blended strategy, not a strictly endogenous modelling strategy.

[10] This equation does not pretend to be realistic or represents all drivers of public transport. It is only a practical example aimed at explaining guidelines on the modelling of behavioural change in an endogenous manner.

Regarding endogenous drivers and barriers, it could happen that we have a feedback loop between drivers and barriers and behavioural change. Figure 20 shows a causal loop diagram (CLD) that captures the relationship between use of public transport and income with a feedback loop, whereas Figure 21 shows another way of representing this relationship without feedback.

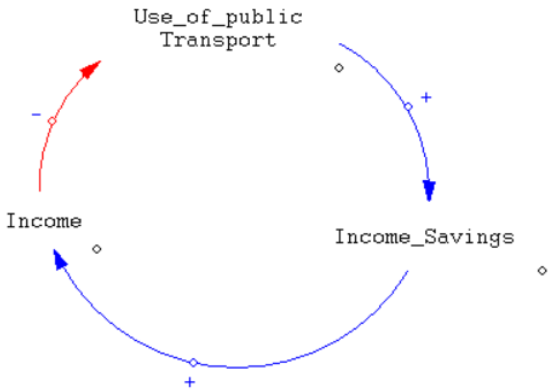

Figure 20. Causal loop diagram showing the relationship between income and use of public transport with feedback

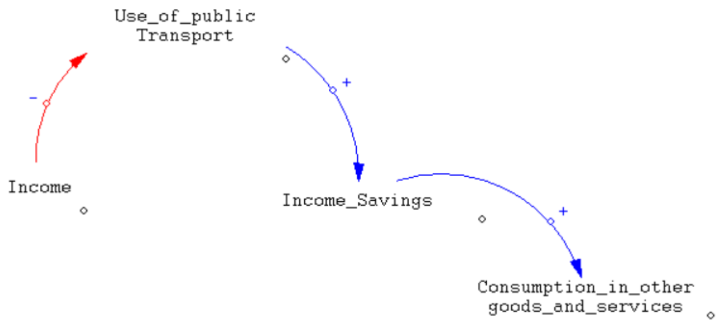

Figure 21. Causal loop diagram showing the relationship between income and use of public transport with no feedback

Red arrows with '-' symbol means a negative or indirect mathematical relationship (when income grows, the use of public transport decreases) whereas blue arrows with '+' symbol represent a positive or direct mathematical relationship (when the use of public transport increases, income savings increase). In Figure 20, there is a feedback loop because income savings are not used for consumption of other goods and services, whereas in Figure 21 they do. Obtaining one or another situation will depend on the model structure. It is important to note that in the first situation, the negative feedback can make the behavioural change function grow more slowly than in the second one. In WILIAM it is planned that the consumption is guided by income levels but also by relative prices. There exist also heterogeneous agents with different income and prices elasticities, so that we will have both situations, depending on the household preferences.

The inclusion of feedback loops is very common in system dynamic models such as WILIAM. However, the more feedback loops, the more unstable the model will become, so we have to be careful when increasing the complexity.

Decisions on endogenous and exogenous drivers should be as far as possible informed by literature review or other social science techniques (e.g., stakeholders' consultation, workshops, surveys, etc.). We are aware that a lot of uncertain assumptions must be made to model behavioural change. Also, we cannot know to what extent we will be able to model such social and complex dynamics in a coherent way. It is very likely, that all we can do will be very stylised. It is important to note that models cannot avoid uncertainty, but all assumptions should be rigorously documented so that we maintain transparency. Also, where possible, uncertainty statistical ranges will be given.

Although modelling will be carried out in Task 4.4, one of the objectives of this task is to set the basis for modelling. In section 4.4 we explain the work done on the portfolio of behavioural changes by including a selection of lifestyles as well as information about their drivers and barriers.

We intend our modelling framework to go beyond the state-of-the-art in different ways:

- The model provides a strategy for explicit modelling drivers and barriers, which is a gap in the current literature (Shukla et al., 2022; van den Berg et al., 2019).
- We extend behavioural domains. While most of the IAMs stay in energy consumption, at most differentiating between 'Food', 'Transport' and 'Housing', we include two other categories: 'Other goods & services' which has as many sub-categories as well, and 'Political Behaviour' that captures many other cross-sectoral behavioural changes.
- We link qualitative social science analysis of drivers and barriers and integrated assessment modelling, which is a necessary research path as pointed out by the IPCC (2022).

We also expect our modelling framework to be useful to policy making in two senses. Firstly, it supports the evaluation of top-down policies: in cases in which top-down policies endogenously affect drivers and barriers, the appearance of a behavioural change can be accounted for as a policy outcome. This enhances the policy evaluation by adding a new category of policy outcomes. Second, it allows identifying socio-economic tipping points that can lead to deep political changes (H van Ginkel et al., 2020)

4.4. Analysis of behavioural change, drivers and barriers from a social science perspective

In this section, we include the outputs of the Steps 1 and 2 defined above. Section 4.4.1 includes the portfolio of measures we have developed, and section 4.4.2 includes the selection of drivers and barriers.

While we have reviewed modelling literature for the development of the measurement portfolio in section 4.4.1, 4.4.2we have reviewed literature mainly from the fields of psychology and sociology for section 4.4.2. The review on drivers and barriers has been inspired by the previous selection of the portfolio measures. We have attempted to guarantee as much alignment as possible, however, we have had to face some challenges and difficulties due to the different disciplinary approaches taken by the partners involved. Nevertheless, we believe it is very enriching to bring together different methodologies for a joint modelling proposal that we will keep working on it for the rest of the project.

4.4.1. Behavioural change portfolio of measures

Table 17 shows the results of carrying out Step 1: a portfolio of behavioural change measures. The first column contains the behavioural change domain; the second column contains the households' consumption category considered in the WILIAM model; the third column considers the Avoid-Shift-Improve category; the fourth column contains the behavioural change measures; the fifth column contains the levels of implementation, if any; the sixth column includes the references on which the measures are based. Some of the cells are empty since no information was found/defined yet.

This portfolio of measures will be improved and modelled in the scope of WP4&WP6.

Table 17. Portfolio of behavioural change measures

DOMAIN	Household's consumption Categories in WILIAM	TYPE (following the 'A-S-I' approach)	BEHAVIORAL CHANGE	Level of implementation	References
FOOD	FOOD	Avoid	Healthier food consumption		(van de Ven et al., 2018; van den Berg et al., 2019)
			Waste Food Reduction		
		Shift	Diet Change	Few people consume less meat	
				Half of the population consume less meat	
				Most of the population consume less meat	
				Few population changes to a vegetarian diet	
				Half of the population hangs to a vegetarian diet	
				Most of the population changes to a vegetarian diet	
				Few population changes to a vegan diet	
				Half of the population changes to vegan diet	
				Most of the population changes to a vegan diet	
			Organic food	- National food.	
				- Local food.	
TRANSPORT	TRANSPORT	Avoid	Reduced travel demand		(Aamaas et al., 2013; Vita et al., 2019)

			Avoid short flights		(van de Ven et al., 2018)
			Carpool		(Dietz et al., 2009; van de Ven et al., 2018)
			Carsharing		(van de Ven et al., 2018)
			Teleworking	5/5 days in-person job and 0/5 totally home-based job	(Lacroix, 2018; van de Ven et al., 2018)
				4/5 days in-person job and 1/5 totally home-based job	
				3/5 days in-person job and 2/5 totally home-based job	
				2/5 days in-person job and 3/5 totally home-based job	
				4/5 days in-person job and 3/5 totally home-based job	
				5/5 days in-person job and 0/5 totally home-based job	
		Shift	Mode shift to cycling		(Girod et al., 2013; Stanley et al., 2011; van de Ven et al., 2018; Vita et al., 2019)
			Mode shift to public transport		(Girod et al., 2013)

			Mode shift to walking		(Girod et al., 2013; Stanley et al., 2011; Vita et al., 2019)
			Mode shift airplane to train		(Marcucci et al., 2019)
		Improve (efficiency)	Eco driving		(Dietz et al., 2009; Lacroix, 2018; van de Ven et al., 2018)
			Reduce extra-urban limit speed		(Dietz et al., 2009)
			Switching to an alternative fuel car		(Marcucci et al., 2019)
			Switching to a fuel-efficient car		(Dietz et al., 2009)
HOUSING/BUILDING	HOUSING/BUILDING	Avoid	Reduce dwelling size		(van de Ven et al., 2018; van den Berg et al., 2019)
			Reduce water temperature		
			Reduce heating temperature		
		Shift	Renewable electricity		
			More compact cities		
		Improve (efficiency)	Building insulation		
			High tech Ecovillage		
			Passive house		

OTHER GOODS & SERVICES	APPLIANCES	Avoid	Reduced appliance use		
			Reduced purchasing of goods		
		Shift	Sustainable use of goods		
		Improve	Purchase sustainable goods		
			Efficient Appliances		
			Digitalise goods		
	LEISURE				
	TEXTILES				
	FURNITURE				
	BASIC SERVICES				
POLITICAL BEHAVIOUR / CROSS-SECTORAL IMPACTS	POLITICAL BEHAVIOUR / CROSS-SECTORAL IMPACTS	Avoid	Minimalism		
			Time use shifts		
			Slower lifestyle		
			Climate change activism / Social change movements		

4.4.2. Drivers and barriers of behavioural change

Behavioural change by individuals and households can be motivated by drivers or constrained by barriers. These drivers and barriers can be of very different nature, including those related to *attitude and motivation to change* (option availability/knowledge) and those related to *capacity to change* (material/resources to initiate and main change) (Shukla et al., 2022).

Step 2 (selection of relevant drivers and barriers for behaviour change), has been conducted by reviewing previous research, primarily from the field of (environmental) psychology. Results are shown in Table 18. Each of the selected drivers and barriers is presented in relation to the specific behaviour they have been found to be relevant for. Comparing the drivers and barriers with the portfolio of behavioural change measures reveals some differences regarding the selected behaviours. The differences between disciplines might account for this slight mismatch, as psychology tends to focus on other types of behaviours than integrated assessment modelling. Nevertheless, we aimed to provide a degree of alignment between the two steps without obscuring the discipline differences.

The research and literature informing Table 18 were found using a two-fold strategy. Firstly, one of the authors drew from her previous work on behaviour in the environmental context and could contribute based on previously completed literature reviews, in addition to snowballing literature. Second, additional research was identified by searching in Google Scholar with the terms "pro-environmental behavior", "environmental behavior", and "environmental behavior change". All studies that looked at any pro-environmental behaviour as an outcome variable were considered.

The types of behavioural measures, measures of dependent variables, research designs, and samples vary greatly within environmental psychology. For instance, a paper from 2018 identified 16 different instruments for measuring environmental attitudes and 7 different instruments to measure general pro-environmental behaviour (thus, excluding measures focussing on one specific behaviour; (Cartwright & Mitten, 2018)). Behaviour itself can be measured in several ways, including laboratory tasks, self-assessment questionnaires, observations, or device measurements indicating energy use or emissions (see Lange & Dewitte (2019)). To handle this variety, meta-analyses and systematic literature reviews were a primary focus for synthesising drivers and barriers, but of course, original studies were also considered. In the beginning, the drivers and barriers of pro-environmental behaviour were collected in a table, containing columns indicating the same domains as Table 17; the behaviour explained by the drivers and barriers, followed by the drivers and barriers themselves; a column for indicating whether the research specifically considered vulnerable groups and how; a column for indicating treatments or interventions which have been found to causally affect a certain pro-environmental behaviour; a column for indicating how the behaviour was measured; and a final column for references.

When discussing this table within the NEVERMORE WP2 team, it was found that it was too detailed and complex to be useful for modelling. Thus, a second version was created which subsumed certain drivers and barriers that were too specific under one term, in order to be comprehensible also for people not familiar with psychology. The second and final version is the Table 18. In addition to merging drivers and barriers, some behaviours were also merged in the second version, for instance "overall household energy use", "energy use per capita", and "energy conservation behaviour", previously considered three separate behaviours due to being different measurements, are now "Reduced energy consumption". The structure for presenting drivers and barriers was slightly changed, so that each driver or barrier (called indicator in the table) is in a separate row and includes a description of its relationship with the behaviour. Overall, the final version of table presents 75 different drivers and barriers and their relationships with a total of 19 different behaviours.

Further information about drivers and barriers and proposed indicators will be included in Deliverable 2.2 'Analytical framework for socio-economic factors

Table 18. Drivers and barriers of pro-environmental behavioural change

Domain	Behavioural Change	Indicator	Type of Indicator	Explanation	References
	Behaviours influenced by drivers or barriers	*What influences the behaviour*	*Is indicator a driver or barrier*	*Meaning of indicator and direction of relationship with behaviour. Most indicators are explained in ZSI's consolidated list of indicators.*	*Literature showing relationship between indicator and behaviour*
Food	Reduced meat consumption	Social Support	Driver	Social support facilitates diet change	(Graça et al., 2019)
		Environmental Norms and Values	Driver	More environmental concern, more propensity to reduce meat consumption. Examples are interest in healthy/sustainable diets and animal welfare	
		Meat Prices	Driver	The higher the meat prices, the lower its consumption.	
		Availability of meat substitutes	Driver	It is easier to shift to alternative diets if there are meat substitutes available.	
		Perception of reduced lifestyle quality	Barrier	Social/cultural perception of meat as a crucial protein source	
		Limited environmental knowledge	Barrier	Lack of information, knowledge, and skills about alternatives, prejudice towards plant-based diets and consumers	
	Buying organic products	Environmental Norms and Values	Driver	Environmental concert facilitates consumption of organic food.	(Kushwah et al., 2019)
		Social status	Driver	Perceived health benefits (e.g., less pesticides) and potential to improve social status (i.e., High symbolic value of organic production in certain social groups).	
		Limited environmental knowledge	Barrier	Doubts regarding labelling and certification.	
		Prices	Barrier	High cost relative to potential advantages.	

	Reduced food waste	Social distrust	Barrier	Low priority is given to reduction of food waste since it is perceived as a relatively minor problem. Perceived exemption from responsibility (e.g., the food industry or the store is to blame).	(Graham-Rowe et al., 2014).
		Limited environmental knowledge	Barrier	Insufficient knowledge of how certain food should be stored.	(Hebrok & Boks, 2017)
		Income	Barrier	Low cost of food relative to income means perceived value of food.	
		Household size	Driver	Larger households have lower waste per person.	(Stangherlin & de Barcellos, 2018)
		Living in a rural area	Driver	Rural people tend to waste less food.	
		Environmental Norms and Values	Driver	Environmental concern and social norms concerning food waste facilitate its reduction.	
		Prices of food	Driver	Price awareness: the higher the price, the lower the food wasted.	
Transport	Reduced air travel	Environmental Norms and Values	Driver	Knowledge of climate change and emotional response to it (anxiety, guilt, concern). Feeling of moral obligation.	(Fogt Jacobsen et al., 2022)
		Social Support	Driver	Social network (a disperse one could avoid this behaviour to take place).	
		Political distrust	Driver	Perceived exception from responsibility, feeling that politicians are responsible.	
	Increased use of public transport	Lower income	Driver	People with lower income are more likely to use public transport	(Lévay et al., 2021)
		Homeownership	Barrier	Owning a house vs living in an apartment; people that own a house are less likely to use public transport	(Lévay et al., 2021)
		Low public transport coverage	Barrier	If there is less public transport coverage and less public transport is available, people are less likely to use public transport	(Carroll et al., 2021)
		Long perceived travel time	Barrier	If the time it takes to travel with public transport, people are less likely to use it	(Van Exel & Rietveld, 2010)
		Long distance to public transport	Barrier	If people need to travel a long distance to get to public transport, they are less likely to use it	(Truden et al., 2022)
		Information about travel	Driver	Providing information about travel times with public transport can increase use	(Van Exel & Rietveld, 2010)

		times with public transport			
		Flexible, on-demand public transport services	Driver	Providing flexible and on-demand public transport services (e.g., in rural areas) increases willingness to use public transport	(Velaga et al., 2012)
	Increased working from home	Low socio-economic status	Barrier	Remote work is primarily available for white collar professions.	(Davies, 2021)
		Living in a rural area	Barrier	Limited access to remote work in rural areas, generally with low income, low education, and high age, working as barriers to household investment in Information and communication technology (ICT).	
		Time savings	Driver	Time savings from reduced commuting time	(Hensher et al., 2022).
Housing/Building	Installing PV at home	Income	Driver	More income, more likely to install PV at home	(Clark et al., 2003)
		Environmental Norms and Values	Driver	Stronger environmental norms, more likely to install PV at home	(Clark et al., 2003; Wolske et al., 2017, 2018)
		Household size	Barrier	The larger the household, the less likely they are to install PV at home	(Clark et al., 2003)
		Social support	Driver	Perceived social support from family and friends in performing behaviour. More support increases likelihood of installing PV at home	(Wolske et al., 2017, 2018)
		Personal benefit	Driver	The more benefit people think they will get from the behaviour, the more likely they are to install PV at home	(Wolske et al., 2017)
Use of Resources	Reduced energy consumption	Income	Barrier	More income, lower tendency to reduce energy consumption behaviour includes studies using meter readings of energy use per household, self-reported energy use, energy use per capita, and Co2 emissions as outcome variable	(Frederiks et al., 2015)
		Household size	Barrier	Larger household, lower tendency to reduce energy consumption	(Frederiks et al., 2015)
		Dwelling size	Barrier	Larger dwelling, lower tendency to reduce energy consumption	(Frederiks et al., 2015)
		Environmental Norms and Values	Driver	Stronger environmental norms, stronger tendency to reduce energy consumption	(Abrahamse et al., 2007; Farrow et al., 2017; Frederiks et al., 2015)

		Living in a rural area	Barrier	People living in a rural area have a lower tendency to reduce energy consumption	(Frederiks et al., 2015)
		Living in a colder climate zone	Barrier	People living in a colder climate zone have a lower tendency to reduce energy consumption	(Frederiks et al., 2015)
		Children live in household	Barrier	Household with children have a lower tendency to reduce energy consumption	(Frederiks et al., 2015)
		Homeownership	Barrier	People owning a home have a lower tendency to reduce energy consumption	(Lévay et al., 2021)
		Environmental Self-Efficacy	Driver	Higher environmental self-efficacy, higher tendency to reduce energy consumption. See ZSI list of indicators for information about this indicator	(Frederiks et al., 2015)
		Environmental knowledge	Driver	Increased knowledge, stronger reduction in energy consumption	(Cappa et al., 2020; Delmas et al., 2013; Osbaldiston & Schott, 2012)
		Perception of reduced lifestyle quality	Barrier	If people think reduced energy consumption will reduce their lifestyle quality, they have a lower tendency to reduce energy consumption	(Frederiks et al., 2015)
	Investing in energy-efficient technology	Homeownership	Driver	Owning a home increases tendency to invest in energy-efficient technology	(Frederiks et al., 2015)
		Environmental Norms and Values	Driver	Stronger environmental norms and values, increased tendency to invest in energy-efficient technology	(Frederiks et al., 2015)
		Income	Driver	More income, stronger tendency to invest in energy-efficient technology	(Frederiks et al., 2015)
	Recycling and reducing waste	Environmental Norms and Values	Driver	Stronger environmental norms and values, more recycling and less waste	(Farrow et al., 2017; Fogt Jacobsen et al., 2022; Hornik et al., 1995; Knickmeyer, 2020)
		Environmental knowledge	Driver	Better environmental knowledge, more recycling and less waste	(Osbaldiston & Schott, 2012)
		Financial incentives	Driver	Receiving monetary incentives increases propensity to recycle.	(Hornik et al., 1995); (Fogt Jacobsen et al.,

					2022); (Osbaldiston & Schott, 2012)
		Environmental Attitudes	Driver	More positive attitudes towards the environment, stronger tendency to recycle	(Hornik et al., 1995); (Fogt Jacobsen et al., 2022)
		Frequency of waste collection in area	Driver	If waste is collected often (e.g., by the city), very much higher tendency to recycle	(Hornik et al., 1995); (Knickmeyer, 2020)
		Locus of Control	Driver	Higher locus of control, higher propensity to recycle	(Hornik et al., 1995)
		Engagement with Recycling	Driver	Here specifically, commitment and knowing about recycling are drivers of recycling	(Hornik et al., 1995); (Knickmeyer, 2020)
		Availability of recycling bins	Driver	Better availability of recycling bins, more recycling	(Knickmeyer, 2020); (Hornik et al., 1995)
		Social trust	Driver	Higher social trust, more recycling and less waste	(Knickmeyer, 2020)
		Political trust	Driver	Higher political trust, more recycling and less waste	(Knickmeyer, 2020)
		Low socio-economic status	Barrier	Low socio-economic status, less tendency to recycle	(Knickmeyer, 2020)
		Limited environmental knowledge	Barrier	Less knowledge about environmental problems and recycling/reducing waste, less tendency to recycle / reduce waste	(Knickmeyer, 2020); (Fogt Jacobsen et al., 2022)
		Social capital	Driver	More social capital, more recycling and less waste	(Fogt Jacobsen et al., 2022)
		Formal education	Driver	Higher level of formal education, more recycling and less waste	(Fogt Jacobsen et al., 2022)
		Low income	Barrier	Less income, less waste reduction	(Fogt Jacobsen et al., 2022)
		Required effort	Barrier	If recycling waste/reduction requires effort, less propensity to do it	(Fogt Jacobsen et al., 2022)
	Reducing gas consumption	Perceived Behavioural Control	Driver	Higher perceived behaviour control (= behaviour is perceived as easy), less gas consumption	(Osbaldiston & Schott, 2012)

		Environmental knowledge	Driver	More knowledge, less consumption	(Osbaldiston & Schott, 2012)
	Reducing water consumption	Environmental knowledge	Driver	More knowledge, less consumption	(Osbaldiston & Schott, 2012)
	Support for new energy infrastructure	Lenght of residence	Barrier	The longer people reside in a region, the less support	(Devine-Wright, 2013)
		Perceived positive impacts of energy infrastructure	Driver	Higher perception of positive impacts, more support	(Devine-Wright, 2013)
		Perceived negative impacts of energy infrastructure	Barrier	Higher perception of negative impacts, less support	(Devine-Wright, 2013)
		Institutional trust	Driver	Higher institutional trust, more support	(Devine-Wright, 2013, 2013)
		Lower formal education	Barrier	Lower levels of formal education, less support	(Devine-Wright & Batel, 2013)
Cross-sectional political behaviour	Climate activism	Environmental Norms and Values	Driver	Stronger environmental norms and values, stronger tendency to engage in climate activism	(Bamberg et al., 2015)
		Perceived Behavioural Control	Driver	Higher perceived behavioural control, stronger tendency towards climate activism	(Bamberg et al., 2015)
		Environmental Self-Efficacy	Driver	Higher environmental self-efficacy, stronger tendency towards climate activism	(Bamberg et al., 2015; Gulliver et al., 2022)
		Climate Change Engagement	Driver	More climate engagement, more likely to engage in climate activism.	(Roser-Renouf et al., 2014)
		Risk perception	Driver	Higher climate risk perception, stronger tendency towards climate activism	(Roser-Renouf et al., 2014); Smith & Mayer, 2018)
		Social trust	Driver	Higher social trust, stronger tendency towards climate activism	(Smith & Mayer, 2018)

		Little Ressources (financial or time)	Barrier	Less Resources in terms of time and money, less tendency towards climate activism	(Castiglione et al., 2022)
	Environmental Policy Support	Political trust	Driver	Higher political trust, higher environmental policy support	(Fairbrother, 2019; Fairbrother et al., 2019; Kulin & Johansson Sevä, 2021; Lim & Moon, 2020)
		Climate Change Engagement	Driver	More engagement with the topic of climate change, higher environmental policy support	(Eom et al., 2018; Fairbrother et al., 2019)
		Political interest	Driver	Higher political interest, higher environmental policy support	(Fairbrother, 2019); (Fairbrother et al, 2019)
		Formal education	Driver	Higher level of formal education, higher environmental policy support	(Lim & Moon, 2020); Eom et al., 2018)
		Income	Driver	Higher income, higher environmental policy support	(Lim & Moon, 2020); Eom et al., 2018)
		Area of residence	Driver	Specifically, living in a coastal area increases environmental policy support.	(Mayer et al., 2017)
		Risk perception	Driver	Stronger perception of climate risk, higher environmental policy support	(Lim & Moon, 2020); Mayer et al., 2017)
		Risk exposure	Driver	Stronger exposure to risks due to climate change (perceived or actual), higher environmental policy support	(Lim & Moon, 2020); (Mayer et al., 2017)
	Supporting an environmental campaign	Environmental Norms and Values	Driver	Appealing to a person's environmental norms and values increases support	(Bolderdijk et al., 2013)
		Personal Norms and Values	Driver	Appealing to a person's personal norms and values (e.g., being a good person in general) increases support	(Bolderdijk et al., 2013)
General/mixed adaptation and	Agricultural adaptation measures	Risk perception	Driver	Risk perception fosters adaptation measures (in agricultural practice)	(Abid et al., 2016)
		Limited resources	Barrier	Limited resources for farmers are a barrier to adaptation measures	(Abid et al., 2016)

mitigation behaviours		Lack of knowledge	Barrier	Lack of knowledge about agricultural practices and farming is a barrier to agricultural adaptation measures	(Abid et al., 2016)
		Lack of institutional support	Barrier	Lack of support from local public or private institutions is barrier to agricultural adaption measures	(Abid et al., 2016)
	Participating in community adaptation measures	Social trust	Driver	Higher social trust, more participation of individual in community adaptation measures	(Paul et al., 2016)
	Mitigation behaviours	Psychological distance	Barrier	When a person perceives higher distance to climate change effects, they are less likely to engage in mitigation behaviours.	(Jones et al., 2017)
		Environmental Norms and Values	Driver	Stronger environmental norms and values, more mitigation behaviours	(Brick et al., 2021)
		Environmental knowledge	Driver	More environmental knowledge, more mitigation behaviours	(Brick et al., 2021)
		Environmental Self-Efficacy	Driver	Stronger environmental self-efficacy, more mitigation behaviours	(Brick et al., 2021)
		Personal Norms and Values	Driver	Stronger personal norms and values, more mitigation behaviours	(Brick et al., 2021)
		Locus of control	Driver	Stronger locus of control, more mitigation behaviours	(Brick et al., 2021)
		Trust in Science	Driver	More trust in science, more mitigation behaviours	(Brick et al., 2021)
		Political Trust	Driver	Stronger political trust, more mitigation behaviours	(Brick et al., 2021)

Conclusions

In this deliverable, we have tried to lay the groundwork for modelling the relationships between climate change and society in several directions.

In section 2, we have described the role of social science in climate change research. Social sciences play a key role in providing guidance for modelling, especially but not only in the area of solutions to the climate crisis. In last years, we have seen that social science is also contributing to define ontologies and epistemologies of climate change, and to provide a research agenda.

In section 3, we carry out a narrative review on climate change social impacts and a systematic literature review on the representation of climate change social impacts in IAMs. In the end, we provide some ideas that can help to establish a research and modelling agenda.

Finally, in section 4, we establish a modelling framework to include behavioural change and lifestyle transformations in the WILIAM model. Also, we develop a portfolio of measures and a database of drivers and barriers that enable or constrain those measures.

We consider that interdisciplinarity and multidisciplinary form a central part of the NEVERMORE project, and that although they involve great efforts in terms of understanding and alignment work, they can be a great enrichment. The disadvantages of this can be difficulties in translating tasks into practice or a lot of time and effort spent on understanding between partners. We have faced some of these challenges during the development of this deliverable. But there are also many advantages, such as mutual enrichment and creativity in thinking of new tools and solutions to tackle the climate crisis.

We expect this deliverable to be useful in setting up guidelines for the WP4 and WP6 modelling exercises.

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