Doing a jigsaw with pieces missing – the data challenges of performing climate change vulnerability assessments

Marta Bruno Soares[1], Alexandre S. Gagnon[2]

Abstract — A range of analytical and methodological approaches are used to assess the potential impacts of and vulnerability to climate change. Conventional approaches tend to utilize top-down scenario-based analysis to assess the impacts of a particular stressor or its effects on a particular sector. Alternative methodologies such as bottom-up approaches focus on the underlying processes and factors affecting people's vulnerability to climate. Both approaches are perceived as complimentary and instrumental to our understanding of climate change vulnerability particularly regarding assessments to inform and develop local adaptation policy. However, the application of methods and tools deriving from such approaches is often limited by the lack of suitable and accessible data. Focusing on the farming sector, this paper will reflect on the challenges encountered in performing an integrated vulnerability assessment framework that brings together these two different approaches and considers some of the key conceptual and methodological problems posed by this type of holistic approach to climate change vulnerability assessments. It concludes by suggesting that there is a need for more explicit debate about the nature and quality of the data required to perform climate change vulnerability assessments.

Keywords — Climate change, vulnerability assessment, data challenges.

1 Introduction

The study of climate change impacts and vulnerability can be pursued through different methodologies and analytical approaches. Conventional approaches such as the International Panel on Climate Change (IPCC) tend to utilize top-down scenario-driven approaches to assess the impacts of a particular stressor or its effects on a particular sector [1]. This type of approach tends to focus on the quantification of climate change impacts.

Alternative methodologies such as bottom-up approaches focus on the underlying processes, factors, and conditions affecting the vulnerability of a particular system to climate change and, as a result, provide a better understanding of the vulnerabilities at the local level [2-3].

Pursuing both approaches as complimentary is increasingly perceived as instrumental to our understanding of climate change vulnerability particularly regarding assessments to inform local adaptation policy development [4]. However, the application of methods and tools deriving from these approaches is often limited by access to data [5].

This paper reports the development of an integrated vulnerability assessment framework assessing the future vulnerability of local communities to climate change impacts and its application to the Ayrshire and Arran region in Scotland.

Focusing on the farming sector, the paper reflects on the challenges encountered whilst performing the vulnerability assessment and considers some of the key challenges and problems posed by this type of holistic approach. The paper is organised as follows. Section 2 introduces the research project and the case study region. Section 3 sets the context of climate change vulnerability assessments. Section 4 presents the vulnerability assessment framework developed and applied to the case study region. Section 5 reviews the main challenges encountered to date whilst performing the vulnerability assessment; and section 6 concludes the paper.

2 Case Study Region

The purpose of the vulnerability assessment is to provide an overall understanding of the main areas at risk, thereby supporting local decision-making processes and adaptation policy at the local level. The case study area – the Ayrshire and Arran region - is located in the SW of Scotland on the shores of the Firth of Clyde (Figure 1).

1. *Marta Bruno Soares is with the Environmental Initiatives Research Group, School of Science at the University of the West of Scotland. Paisley PA1 2BE, Scotland, UK. E-mail: marta.soares@ uws.ac.uk*
2. *Alexandre S. Gagnon is with the Environmental Initiatives Research Group, School of Science at the University of the West of Scotland. Paisley PA1 2BE, Scotland, UK. E-mail: alexandre.gagnon@ uws.ac.uk*

Fig. 1 – The case study region (Source [6]).

Ayrshire has a population of approximately 368,000 people, a total area of 3,400 sq km and 240 km of coastline [6]. It comprises three local authorities: East Ayrshire, North Ayrshire (including the Isles of Arran, Great Cumbrae, Little Cumbrae and Holy Island), and South Ayrshire (including the Isle of Ailsa Craig). The region is characterised by its many natural and physical attributes – rivers, lochs, harbours, and beaches – together with its numerous areas of biological and geological designations [7].

Traditionally a farming region, Ayrshire faced considerable changes in the 18th and 19th century with the expansion of manufacturing production and mining, and iron industries [7]. The 20th century was marked by the decline of heavy industry and manufacturing and the gradual increase in jobs in the tertiary sector [6], which now accounts for approximately 80% of all employment in the region [8].

3 Climate change vulnerability assessments

One of the primary objectives of climate change vulnerability assessments is to understand the vulnerability of a particular system (e.g. population, city, sector) to climate change and help policy makers find ways of adapting to those impacts and changes [9]. Vulnerability is "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" [10: 883]. It is perceived as a function of the exposure, sensitivity and adaptive capacity to that climate change and variability [10].

Exposure is "the nature and degree to which a system is exposed to significant climatic variations" [11: 7]; sensitivity relates to the ways in which the system is affected by that exposure to climate variability and change; and adaptive capacity is the capacity or ability of the system to perform the necessary adjustments in the face of climate change [10].

Moreover, conceptual and analytical elements such as engaging stakeholders in the vulnerability assessment process, understanding the different and interacting scales of analysis, understanding differential vulnerability, and managing uncertainty, are also normally addressed in this type of analysis [12]. Different methodological approaches can be used to assess vulnerability and climate impacts such as top down and bottom-up approaches [10]. Whilst top-down approaches normally use scenarios downscaled from global climate models to assess the impacts and vulnerability of a particular ecosystem or sector; bottom-up approaches start at the local level by considering the local conditions and factors which influence and affect the vulnerability of a particular system to climate change [1].

Table 1 illustrates some differences between these two types of approaches.

Table 1 – Differences between top-down and bottom-up approaches (based on [1], [2], and [5]).

Approach	Top-down	Bottom-up
Scale of analysis	National to global	Local to national/global
Methods and tools	Scenario; downscaling techniques; sectoral impact models	Vulnerability indicators; past and current climate risks; stakeholder tools; case study
Stakeholder involvement	Low	Medium/High

Increasingly, these approaches are perceived as complementary in the type of knowledge they provide, particularly in the context of decision-making and climate change adaptation policy [4].

However, despite advances in studies that attempt to integrate both top-down and bottom-up approaches, the application of methods and tools deriving from such approaches is often limited by the lack of, and accessibility to, quality data to perform such analyses [5].

An example is the use of indicators in bottom-up approaches to measure vulnerability and adaptive capacity which is often hindered by the absence of adequate data to perform the analysis [13].

4 The vulnerability assessment framework

The vulnerability assessment framework was developed by adapting the Adaptation Policy Framework (APF) of the United Nations Development Programme (UNDP) [14] to the Scottish context and case study region. Originally developed to provide guidance to developing

countries on national adaptation policy formulation, the APF considers different approaches and methods that can be used in the study of climate change vulnerability and adaptation. The APF is constituted by five analytical components and two cross-cutting elements (Figure 2).

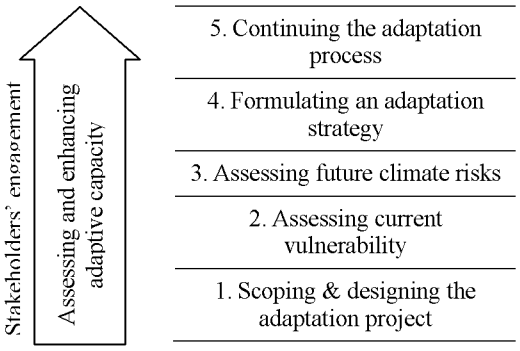

Fig. 2 – The components of the Adaptation Policy Framework (adapted from [14]).

The starting point – scoping and designing the adaptation project – sets out the objectives, activities and expected outputs for the project. It is also at this stage that the approach and methods are decided, the stakeholders are identified, and existing information on vulnerability and adaptation is reviewed [14]. Component 2 of the APF - Assessing current vulnerability – analyses the current situation of the system under analysis regarding the climatic risks and factors affecting vulnerability. To achieve this, key working definitions and the assessment and exposure boundaries need to be established first: 'who is vulnerable, to what, in what way and where' [15: 73]. The assessment of current climate risks together with a characterisation of the socio-economic conditions and the analysis of existing adaptation are also addressed at this stage [14].

The outcomes from this stage of analysis provide an understanding of the relevant relationships between climate and society within the system under analysis and their contribution to risk and, therefore, 'help to provide a roadmap from known territory into uncertain futures' [16: 42].

Component 3 – Assessing future climate risks – builds up from component 2 and assesses future climate risks in the system under analysis. To achieve this, climate change projections, future trends in socio-economic conditions and environment, as well as adaptation barriers and potential opportunities need to be characterised [17]. Methods such as climate change and socio-economic scenarios and storylines are normally considered in the analysis of future climate risks [14].

Component 4 – Formulating an adaptation strategy – brings together all the work from the previous components to inform the development of an adaptation strategy [18]. The final component – Continuing the adaptation process – sets out how to implement and support the adaptation strategy developed in component 4 [19].

It should be noted that components 4 and 5 of the APF were not considered in our study as the scope of the research project did not include the development of an adaptation strategy. Therefore, only the three first components of the APF were considered for developing the vulnerability assessment framework (see section 4.1.).

Engaging stakeholders is a cross-cutting element in the APF as involving stakeholders from the outset of the project is considered instrumental in the analysis and development of the adaptation strategy [20].

Adaptive capacity is also regarded as a cross-cutting element and its analysis is ongoing and parallel to the other APF components. However, although the APF suggests ways of assessing adaptive capacity under each component [21] it does not present an analytical framework *per se*. As a result, to assess the adaptive capacity of the farming community in Ayrshire a framework was developed based on [22], [23]. These frameworks address and analyse the determinants of adaptive capacity, which are the conditions and resources that define the system's capacity to adapt to changing climatic conditions [24], [25]. These determinants are generally associated with economic wealth, information and skills, technology, infrastructure, institutions, social capital, natural resources, and equity [25], [26].

The use of indicators and indices for measuring adaptive capacity is common in vulnerability studies although this is a contested area due to the uncertainties associated with their use (e.g., selecting appropriate indicators for each determinant and establishing the direction and dynamics of the relationship between indicator and determinant) [15], [27]. At the local scale, the adaptive capacity will be largely determined by the type of climatic hazard faced and the system under analysis and, as a result, potential indicators to be used in the analysis need to be tailored to that particular case [21]. Alternative methods are also used to assess and inform the analysis of adaptive capacity (as well as exposure and sensitivity of the system) including interviews, focus groups, community workshops and door-to-door surveys [28], [29].

The sections below describe how the vulnerability assessment and adaptive capacity frameworks were adapted and implemented to assess the vulnerability to climate change in the Ayrshire region.

4.1 Developing the vulnerability assessment

The vulnerability assessment framework was divided into three main analytical stages: scoping stage, assessing current vulnerability, and assessing future vulnerability. Table 2 illustrates the stages of the vulnerability assessment framework and the main methodological approach used.

Table 2 – The analytical stages of the vulnerability assessment framework.

	Stage 1	*Stage 2*	*Stage 3*
	Scoping	**Assessing current vulnerability**	**Assessing future vulnerability**
Aim	Characte-rise and identify main issues within case study	Understand main climatic events, sensitivities to climate and factors affecting the system's capacity to adapt	Use scenarios of climate change to understand future vulnerability in Ayrshire
Main approach	Bottom-up	Bottom-up	Top-down

The starting point of the analysis – the scoping stage – aims to understand the case study area and its problems and issues, specifically those most susceptible to climate. It is at this stage that the topics/themes for analysis in stage 2 are selected (see section 4.1.1). To assess current vulnerability the main climatic events currently affecting the region together with the existing capacity to adapt to changing conditions were characterised (see section 4.1.2). The final stage – assessing future vulnerability – will use the outcomes of stage 2 as a starting point to assess the potential future impacts of climate variability and change in the region.

The stages of the vulnerability assessment framework are similar to the three first components of the APF. At the time of this paper only the two first stages have been accomplished; these will be further explained in the sections below.

4.1.1 The scoping stage

The scoping stage consisted on performing preliminary research to help us understand the main issues and problems in the case study area.

For this, local stakeholders were involved from the outset so that their knowledge and experience of the region could contribute towards this preliminary analysis.

Back in 2009/early 2010 a total of 22 interviews were conducted with people from various departments across the three local authorities in Ayrshire as well as other organisations such as the Ayrshire Joint Planning Unit, Scottish Natural Heritage, Scottish Environment Protection Agency, Scottish Agriculture College, and the Forestry Commission.

A postal survey was sent to all 70 community councils[1] in Ayrshire covering a range of issues regarding their area, its environment and climate change-related issues. The total response rate was 54% and although this was not representative of the whole region, it provided insights to the experiences and concerns of some of the local communities.

A documentary analysis of relevant reports, books and statistical data on the region was conducted to further improve our knowledge of the case study.

Table 3 lists the main data sources utilised in the scoping stage.

Table 3 – Data source used in stage 1 of the vulnerability assessment.

Vulnerability assessment stage	**Data source**
Scoping stage	Interviews
	Survey to Community Councils
	Statistical data
	GIS layers
	Documentary analysis

Based on the information from the interviews, analysis of documents, and survey results, a report was prepared covering the main issues on the economic, environmental, and social conditions in the region. The report highlighted existing problems and issues and identified three topics considered as susceptible to climate change and relevant to the future development of the region: farming, tourism and flooding. The report was sent to stakeholders for feedback on the findings and the majority of the responses agreed with the topics suggested for analysis in stage 2 of the vulnerability assessment.

The first topic to be analysed was farming and, as a result, the remainder of this paper will focus on the assessment of current vulnerability of the farming community in Ayrshire to climate variability and change.

[1] A community council is a non-statutory organization run by volunteers whose role is to act as a channel for the views of local communities.

4.1.2 Assessing current vulnerability

The process of assessing current vulnerability is composed of four sub-stages: assessing climatic hazards; assessing the sensitivity of farming activities to those risks; assessing the adaptive capacity of the farming community; and assessing current vulnerability of the farming community to climate events.

Table 4 shows the sub-stages and main data sources for informing each of the sub-stages.

Table 4 – Sub-stages and data source used in stage 2 of the vulnerability assessment.

Vulnerability assessment stage	Sub-stage	Data source
Assessing current vulnerability	Assessing current climatic events affecting farming activities	Interviews Survey to farmers
	Assessing farming sensitivity to climatic events	Statistical data GIS layers
	Assessing adaptive capacity of the farming community	Literature on farming
	Assessing current vulnerability of farming community	Based on outcomes from previous sub-stages

To understand farming's exposure and sensitivity to climatic events information from interviews, and a survey distributed to farmers were used to establish the dynamics between climate and farming practices, i.e., how and when particular climatic events affect farming production in the region. Literature on farming in Scotland and the UK was also used to further our understanding of the dynamics between farming and climate.

Some of the responses from the farmers' survey are still missing and, as a result, our knowledge regarding exposure and sensitivity of farming is still limited. Nonetheless, a preliminary analysis of the main climatic events currently affecting farming includes rainfall, flooding, and snow lying on the ground. Farming activities most vulnerable include those related to harvesting and planting crops, production of silage and other animal feed, birth of animals, and rearing the animals which are most susceptible during the spring and summer months.

When finalised, the information on current exposure and sensitivity to climatic events will then be mapped into a Geographical Information System (GIS) in order to represent the relative exposure and sensitivity of farming to climatic events across the region.

To analyse the adaptive capacity of the farming community the main determinants of adaptive capacity were identified based on information from interviews, a survey sent to farmers, and a literature review on farming in Scotland and the UK. The indicators selected to calculate the determinants were developed taking into consideration those factors relevant to farming such as farm income, farming community, access to subsidies, etc; as well as the existence and availability of farming-related data in Ayrshire and Scotland.

The various indicators used to calculate the adaptive capacity index were normalised based on the UNDP Human Development Index (HDI) [30]. Weights were then attributed to each indicator/determinant based on information from interviews, farmers' survey, statistical data, and literature on farming. The adaptive capacity index was mapped using a GIS to show the distribution of the farming community adaptive capacity per agricultural parish across the Ayrshire region.

The final sub-stage – assessing current vulnerability of the farming community – is based on the outcomes of the three previous sub-stages. By mapping and overlapping the various index on current exposure, sensitivity, and adaptive capacity an overall map of current vulnerability was produced showing the distribution of the farming community vulnerability per agricultural parish.

Applying the vulnerability assessment framework to the farming sector in Ayrshire has been a process replete of experiences and challenges. The following section describes the methodological and conceptual challenges that arise from our study up to now.

4.2 Performing the vulnerability assessment - Doing a jigsaw with pieces missing

Performing the climate change vulnerability assessment on the farming community in Ayrshire has been a demanding process with a number of challenges and compromises.

One of the first challenges encountered related to the difficulty in establishing contacts within organizations. In the scoping stage, for example, it took approximately three months to establish the appropriate contact within the Scottish Environmental Protection Agency to discuss flooding. When the contact was finally established (and after clarification over the nature

of our intentions regarding an interview) the best arrangement managed was to have our questions answered by email rather than an interview[2].

In stage 2 – assessing current vulnerability – the challenge was more related with the lack of contacts within the farming community. The idea of obtaining farmers' contacts and approach them directly was quickly put aside by the Scottish Government due to data sensitivity-related issues. This situation was further exacerbated by the lack of farming-related organizations in Ayrshire. The only existing organization in the region is the National Farmers Union Scotland (NFUS) which provides support and help to farmers across Scotland. Although only approximately 51% of the farmers in Ayrshire are members of the NFUS [31], [32], this organization was the only available point of contact between us and the farming community. The existence of a specific point of contact - a regional manager for Ayrshire - within the NFUS facilitated the access to knowledge and expertise in the area and also provided us some farmers' contacts. Without the NFUS' help the analysis of the farming community's vulnerability in Ayrshire would have been extremely difficult.

Throughout the interviews conducted it was felt that a 'snow ball effect' was occurring where often the interviewee would suggest other relevant people for us to contact. Although this did not represent a challenge it did add to the time scheduled for interviews in our study.

Another challenge was the non-representativeness of some of the data. The postal survey sent to the 70 community councils during the scoping stage had a considerable response rate of 54%. However, despite asking the community councils to respond to the survey as a group, i.e., during one of their meetings, many of the responses had been clearly filled in by one person as the answers given were in the form of "I'm not sure…" and "My community council…".

The survey sent to farmers in stage 2 of the vulnerability assessment was also non-representative of the farming population due to the reduced number of farmers' contacts available (up to 15 contacts). Nevertheless, their responses helped us to refine our understanding the exposure and sensitivity of farming practises to climatic events in Ayrshire.

Obtaining GIS layers also required extensive negotiation with some organizations. Since many of the GIS layers are produced for commercial purposes organizations charge considerable amounts of money for their use. For example, the free access and use of both the Land Cover Use 1988 for Scotland and Scotland soils shapefiles had to be negotiated with the Macaulay Land Use Research Institute. Luckily, the research project was closely aligned with some of their core research topics, which allowed them to fund us the lease for both shapefiles. Without this data the vulnerability analysis of the farming community in Ayrshire would be seriously compromised.

Other GIS datasets, such as those provided by the Ayrshire Joint Planning Unit, were free of charge although not all were made available due to data sensitivity issues. Moreover, some of the datasets were owned by third parties and therefore their release had to be agreed in advance to their use.

Access to certain datasets was also a challenge in some situations. The idea of obtaining agricultural census data per farm/farmer was quickly put aside by the Scottish Government due to the sensitivity of the data. After negotiating with the Government, the compromise made was to obtain the data per agricultural parish rather than per farmer/farm unit. This led to a significant loss of analytical detail: approximately 1477 farmers/2770 holdings aggregated into 47 agricultural parishes. Moreover, interpreting and explaining the relationships at lower levels (i.e., below the agricultural parish level) also became more difficult with further implications in the ability to generalise the findings of the vulnerability assessment [33].

Deciding to use the agricultural parish as the main unit of analysis also led to various compromises regarding the vulnerability assessment. For example, the discrepancy between the agricultural parishes' boundaries and census data boundaries (e.g. localities, wards, local authority) limited the use of census data to inform the assessment of adaptive capacity (e.g., education levels of the farming community; percentage of population working in agriculture).

The trade-off in this case was to find a scale of analysis were valid and accessible data existed to perform the analysis and be sufficiently representative of the vulnerability of the farming community but also a scale that allowed involving stakeholders in the assessment process.

Normalising different types of data (e.g. statistical, GIS layers) also raised some operational issues and challenges. For example, the data used to calculate the indicators of adaptive capacity were normalised according to the UNDP HDI [30]. However, in some cases it was not possible to use this method as some data were in the form of GIS layers and, as a result, it was represented 'spatially' rather than numerically. For example, the data on soils was in the form of a GIS layer where the various types of soils were represented spatially throughout the region. Using GIS techniques it was possible to overlap this layer with the agricultural parishes'

[2] It should be noted that all our other contacts within the Scottish Environmental Protection Agency were very helpful and this situation was with a particular individual in that organisation.

boundaries allowing the classification of soils per agricultural parish. However, as the type of soil varies considerably within the same parish a compromise was made by classifying each agricultural parish according to the main type of soil rather than accounting for the various types of soil. Table 5 summarises the challenges described as well as the compromises and implications made to overcome those challenges.

Table 5 – Main issues, challenges and compromises whilst performing the vulnerability assessment.

Challenges	**Compromises and trade-offs**	**Analytical implications**
Establishing contacts in organisations	Information provided by some did not supply the level of detail and knowledge expected	Try to overcome this with information from other sources e.g. interviews, surveys, literature on the subject
Lack of representative organisations	Limited access to knowledge and expertise from organisations	Try to overcome this with information from other sources e.g. interviews, surveys, literature on the subject
Data non-representative	Limited use of some data to inform the vulnerability assessment	The data was used to provide insights into issues rather than informing the analysis
Inaccessible data due to its sensitive nature	Data provided at larger scale in order not to compromise farmers' identities	Loss of analytical detail therefore producing a more 'coarse' analysis of vulnerability
	No access to some data and GIS shapefiles	Try to overcome this with information from other sources e.g. interviews, surveys, literature on the subject
Third-parties GIS data	Free access to GIS shapefiles in exchange of referencing data sources and a copy of the final project report	N/A
Scale of analysis	Unable to use some data due to scale discrepancies with agricultural parish boundaries	Unable to use data to further complement analysis of vulnerability
Data normalisation/ integration	Different types of data required different normalisation techniques	Some data generalised to 'fit' categories in order to allow normalisation and integration of data

Performing the vulnerability assessment of the farming community has been a process rich in experiences, exchanges and compromises with stakeholders in the region. Most challenges posed by the data required to perform the analysis have been overcome although not without its trade-offs and implications to the analysis (Table 5).

Continuing applying the vulnerability assessment framework to the case study will certainly add more challenges to those described above, particularly regarding the subjects selected for the vulnerability assessment (i.e., farming, tourism and flooding). The different nature of these subjects together with discrepancies in terms of data availability, periodicity, and scale, will influence the analysis of vulnerability. Different subjects will also imply working with different stakeholders which will have different requirements and trade-offs regarding data accessibility. All of these factors will not only influence the way in which the subjects will be conceptualised (i.e., who's vulnerable to what and how) but also which methods and tools can be used in the analysis of vulnerability.

Other perceived future challenge relate to the use of different approaches (bottom-up/top-down) in stage 2 and 3 of the vulnerability assessment (assessing current vulnerability and assessing future vulnerability, respectively). In the assessment of future vulnerability a top-down approach will be used based on scenarios of potential future changes. Employing this approach will most certainly raise issues of data integration as climate change scenarios tend to be at bigger scales (e.g., regional) than the data used to assess current vulnerability (e.g., data at the local level).

5 CONCLUSION

The study of climate change vulnerability and impacts can be performed using different methodological approaches, methods and tools. Common approaches include the so-called top-down and bottom up approaches. These approaches tend to differ in the aim and scale at which the analysis is performed and also in the methods and tools applied. Despite differences,

they are both perceived as complementary particularly in the context of adaptation policy making.

Assessing the vulnerability of the farming community to climate change in Ayrshire has been a 'learning curve' full of experiences, exchanges and compromises not only regarding the application of the vulnerability assessment framework to the case study region but also in the involvement with stakeholders.

Much more than developing the conceptual and methodological approaches to be used, performing the vulnerability assessment has been a process of adapting and normalising existing and accessible data to perform the analysis. In fact, the various data-related challenges and difficulties encountered whilst carrying out the assessment went beyond our initial expectations. Nonetheless, the various challenges have been, to a certain extent, overcome although not without its trade-offs and implications to the analysis.

Looking back on these challenges they seem to lay between two types: those associated with the processes of collecting and gathering data; and those linked to the operational and analytical dimensions of handling the data.

The challenges of collecting data related for example with the difficulties in establishing the appropriate contacts within relevant organisations; the quality of the data provided which not always supplied the level of refinement needed; and the inaccessibility of some data (due to sensitivity issues or ownership rights) which influenced the way in which the analysis was performed.

The operational and analytical challenges of handling data included the difficulties of normalising different types of data in order to use it in the analysis; and the compromises and trade-offs regarding the scale of analysis. The choice of scale to perform the analysis was based on the existence, availability and quality of data which led to a compromise in terms of analytical detail. This trade-off led to further implications regarding the potential to generalise the findings of the vulnerability assessment.

The accessibility, ownership, quality, and representativeness of data are just some of the issues one needs to address when considering performing a climate change vulnerability assessment at the local level. These influence the way in which the analysis of vulnerability is performed and the type and level of involvement by stakeholders and ultimately the way in which the findings of the vulnerability assessment are utilised to inform the development of adaptation policy.

It is therefore essential that issues such as the nature, access and quality of data required to perform climate change vulnerability assessments are explicitly debated and considered. This will not only facilitate carrying out this type of analysis but also improve the quality of the assessment and consequently the type of information provided to support the development of adaptation policy.

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