

**Table S1.** Information sheet for participants and consent form.

### **Information Sheet for Participants**

**Main title:** Metrology for Earth Observation and Climate (MetEOC)

**Subtitle:** Indicators of Adaptation and Resilience of Climate Change

**Research Fellow:** Dr Ana Andries

**Lead Supervisor:** Dr Emma Woolliams

#### **Section 1. Introduction**

I am inviting you to take part in this research as you have expertise in climate action policy, especially in adaptation and resilience to climate change.

The purpose of the interview is to understand how metrology improves the quality of climate adaptation and resilience and what is needed to bring metrological approaches into the policy frameworks.

I would like to inform you that participation is voluntary; choosing not to take part will not disadvantage you in any way. You should read this information sheet and if you have any questions, please do not hesitate to ask me or any from the research team. Before the interview is undertaken, you need to understand why the research is being done and what the participation will involve.

If you decide to take part, you will be given this information form to keep and will be asked to sign a consent form and then I will conduct an open-ended interview with you.

The interview will take approximately 40 minutes. We will arrange a day and a time that is convenient for you. The interview will be held only virtually, using one of the online available platforms (e.g., Zoom, Teams, etc).

During the interview, I, the researcher, will record audio and take notes. The tapes and notes will be stored in a safe place and only the researcher and supervisors have access to them. You will not be identified by name or any other person specific details unless you request this.

Later in the research, I will produce a final report summarising the main findings, which will be sent to you. I also plan to present the research findings through publications and conferences for education and scientific purposes only.

#### **Section 2. Data Protection**

Any information and data collected during the interview will be strictly confidential and will be held securely until the phase is finished.

All project data (raw and processed) will be held for at least 6 years and all research data for at least 10 years in accordance with university policy and the Data Protection Act.

All information gathered will be held on password-locked computers on the University servers. Hard files will be safely kept in locked places. No identifiable data will be accessed by anyone other than me or supervisors and authorised personnel from the University and regular authorities for monitoring purposes.

If you have any questions or require more information, please contact me using the following contact details:

Name: Dr Ana Andries

Email: ana.andries@surrey.ac.uk

#### **Section 3. Research Description**

I am a Postdoctoral Researcher at the Centre for Environment and Sustainability at the University of Surrey. I am currently working on Metrology for Earth Observation and Climate (MetEOC) (as part of the Horizon 2020 project within the **impact** work package. The overall goal of the project is to improve global observations of the Earth for climate change studies using metrology (the science of measurement). My role in this project is to carry out semi-structured interviews with civil servants and stakeholders – both at the policy level and at the technical level involved in policy development and implementation from relevant

organisations to understand what is the current state of adaptation and resilience policies and practices and how data quality can improve the climate adaptation and resilience.

MetEOC-4 is all about understanding, evaluating and improving satellite EO data sets so they are more valuable.

- MetEOC is developing methods to compare satellites to one another, so they are all on a common reference scale;
- MetEOC is validating and testing methods used to correct data sets, e.g. to get a surface product that corrects for the atmosphere and angle of view etc
- MetEOC is looking at the long-term consistency of data sets
- MetEOC is understanding the uncertainty of satellite data products

There are three main needs to understand climate change:

- In the climate area there are three main applications/needs:
  - Understanding climate change – making the observations and doing the modelling needed to have a full view of how and why the climate is changing (strong link to climate science)
  - Mitigating climate change – changing society to reduce greenhouse gas emissions and monitoring that those changes are happening (strong link to policy)
  - Adaptation and resilience – understanding how climate change is affecting human society and making the changes to enable us to cope with those effects (strong link to monitoring and policy)
- MetEOC has mostly focused on the first one so far – because that’s where low uncertainties are most desirable – because that’s where we need very long timescale measurements of subtle, global effects. The quality issue is in measuring globally for 30+ years and ensuring the “reference” is stable enough and consistent globally so that you can see the very subtle effect of climate change. This is where uncertainties really matter.
- Mitigation needs good measurements of greenhouse gas emissions so we can see how much is emitted, and ideally where from. It also needs good measurements of forests and peatlands so we can see whether they are absorbing carbon dioxide or releasing it. The inventories gather this information up – a lot of the data for inventories doesn’t come from measurements, and a lot of the data that does comes from in situ measurements. We are trying to change this – and NPL’s emissions group is improving in situ measurements.
- Adaptation and resilience – The interview will focus on these two areas, especially the right indicators to be measured. There are interesting questions on choosing indicators thinking about using different data early on and thinking about what quality issues there are.
- Assess quality issues of using (satellite) data in monitoring adaptation and resilience

Therefore, questions will be asked on the following topics:

1. What is the current state of thinking on adaptation and resilience indicators, what adaptation and resilience issues are most important (and how do these vary across Europe) (e.g. heat stress to crops in Southern Europe, flooding in Northern Europe)?
2. For one or two specific examples, e.g. flooding and heatwaves to understand in more detail what’s possible to be measured and what is data used/available?
3. Data quality. How reliable is the data used?

**Thank you for reading the information sheet and for considering taking part in this research.**

## CONSENT FORM FOR PARTICIPANTS IN RESEARCH STUDIES

**Please complete this form after you have read the Information sheet.**

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanations already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

By ticking each box, you are consenting to this element of study. It will be assumed that un-ticked boxes mean that you DO NOT CONSENT to that part of the study.

	Please tick or initial
1. I confirm that I read and understood the information sheet dated for the study. I have had the opportunity to consider and ask questions which have been answered satisfactorily.	<input type="checkbox"/>
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without being disadvantaged in any way.	<input type="checkbox"/>
3. I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be handed in accordance with the terms of the UK Data Protection Act.	<input type="checkbox"/>
4. I understand that my information may be subject to review by responsible individuals from the University of Surrey and/or regulatory authorities for monitoring and audit purposes.	<input type="checkbox"/>
5. Anonymity is optional for this research. Please select from the following 2 options: a. I agree to be fully identified b. I wish to remain anonymous	<input type="checkbox"/> <input type="checkbox"/>
6. I consent to my interview being audio-recorded	<input type="checkbox"/>

Name of participant

Date

Signature

Name of researcher

Date

Signature

**Table S2.** Interview Questions.

**Main title:** Metrology for Earth Observation and Climate (MetEOC)

**Subtitle:** Examining Adaptation and Resilience Frameworks: Data quality's role in supporting climate efforts

**Section 1. Adaptation and resilience indicators**

Q1. Please provide a brief background of your work experience.

Q2. Is any of your work related to adaptation and resilience? If so, could you please provide some project work examples?

Q3. The projects in A&R you are currently involved where they take place and what are the aims and the expected outcomes

Q4. What is the impact and complexity of adaptation and resilience issues in your country (or region of your expertise)?

Q5. What is the current landscape (in terms of implemented, planned, and thinking status elements) on adaptation and resilience indicators in your country (or region of your expertise)?

Q6. What indicators do you have for the issues under Q3? Are those designed strategically (e.g. integrated into the DPSIR framework)?

Q7. Do you agree with those indicators, or do you consider that they should be improved?

Indicator adaptation example: Electricity supply disruption due to flooding (impact indicator)

Customers reliant on electricity substations in areas at flood risk

Indicator resilience example: Average emergency (police) callout response time

Percentage of houses which have passed local building code inspections;

Proportion of the population using safely managed drinking water services (SDG Indicator 6.1.1)

**Section 2. Data for measuring the adaptation and resilience indicators**

Q8. How are the adaptation/resilience indicators mentioned under Q4 measured? (e.g. NSO data, economic data, in situ measurements, satellite measurements)

Depending on the interviewees' answers, ask the following questions: Why / why not satellites – advantages and disadvantages?

- i. Trust of satellite vs. in situ vs. other types of data
- ii. What applications are best suited to satellites?
- iii. What types of satellites – are they just “pictures” or do you use quantitative information about spectral reflectance, or radar data or ...
- iv. How processed is the data – processing “raw-ish” satellite data or using ARD or using maps that others have created from satellite data?

**Section 3. Data quality**

Q9. What data are used to measure these indicators?

Q10. How does the quality of data matter? What do accuracy and uncertainty mean for you (in comparison to another data set)?

Q11. Is the data cost-efficient compared with other sources?

Q12. What are the quality issues – how stable (long term) do you need it to be? What uncertainties are needed? How frequently should it be measured? Does image quality (or equivalent) matter?

**Section 4. Roundup**

Q13. Do you have any other comments/observations?

**Thank you for taking part in this survey. Your answers are very valuable for this research.**

**Table S3.** Quotes associated with the KC/Rs within Theme 1: Complexity and challenges in the interviewees' current or past projects.

<b>Theme 1: Complexity and challenges in the interviewees' current or past projects</b>			
Sub-theme	Key concerns	Respondents	Relevant Quotes
1.1. Social issues	KC/R 1. Adaptation planning must be aimed at a group of people/sectors (e.g., vulnerable people)	8	<p>"In our previous A&amp;R projects, we have issues of social vulnerability and high risk because of potentially poor people, who maybe are older, younger, who are particularly vulnerable to, for example, heat. We have a certain amount of deprivation and inequality. That is definitely going to affect different communities differently. And so social isolation, which is another potential indicator of whether, if somebody's going to survive a heat wave, we have all of these different kinds of issues too, that exacerbate the potential risk or increase the vulnerability of some populations. So that's a common area of complexity. And then of course these risks like flood, heat, and drought also hit across different sectors differently. Therefore, heat affects us through the built environment and the quality of our homes, the orientation of buildings the urban heat island effect, and all those kinds of things."</p> <p>"To implement adaptation plans, the local governments must look at the vulnerability of people and the coping capacity to deal with climate risks, at local scale.....to look at indicators, for example, how many people were able to stay at the shelter, how many people were able to find their way to the shelter, but also how many energy systems survived, and not just survive by staying in one piece, but survive in terms of also being functional when the disaster happened."</p> <p>"The challenge comes when it is needed to measure how many people are vulnerable before a hazard/disaster, thus impose difficulties to get a better adaptation intervention..."</p>
	KC/R 2. Prioritise adaptation strategies	5	<p>"A good example that I would give you is frequently when people are kind of just starting in this area and haven't fully kind of understood, what adaptation is. The first thing they'll tell you, is we need better climate projections, which indeed we need, but we also must have actions and adaptation solutions because the storm is going to hit anyway."</p>
	KC/R 3. The need for cultural change and education about the adaptation solutions	3	<p>[The respondent provided an elaborated example about how different communities from Latin America that are normally affected by strong storms, responded to hydro and solar energy systems installed in their household]..... "the majority of men would say that, yes, they used the system and they found it very reliable, that you just turn on the switch rather than have to look for a candle and look for a match and turn it on.... But most women about 80 to 90 % of them would say that during a storm they'd rather use a candle because the candle was safer, the electricity could cause a short and then they would die electrocuted.... So that leads back to the social-cultural indicators of, you know, is it cultural belief? Is it fear?"</p>

1.2. Strategy and planning	KC/R 4. The need for better knowledge about the impacts and risks of climate change	10	<p>"I remember in one of those places in the upper watershed, they would disconnect the whole solar energy system and put it inside the house. And then after the rainy season would pass, they would reconnect the system. They did this because they didn't want the system to be damaged during the rain. After all, different hard objects taken by the strong winds could crash on the solar PV panel. So, like in that specific area, their priority was to keep the hardware safe, rather than their wellbeing."</p> <p>"Something that is out of control is when we implement adaptation solutions, but the climate change impacts damaged them to some extent. For instance, we can build green roofs for tackling urban heat, however, if droughts hit those areas and there is a shortage of water, the plants will die."</p> <p>"Prioritise action should be first on tackling vulnerability and understanding the risk assessment of climate change and then adopting adaptation solutions and make your city (area) more resilient."</p> <p>"The assessment of the major climate risks [referring to a particular area] and the adoption of appropriate measures should require the participation of individuals with a wide range of skills, experience, and knowledge. Asking for assistance when prioritising vulnerabilities, evaluating climate risks, and coming up with action plans brings attention to the difficulty of coping with climate change and ensures that your evaluations and plans are based on the greatest available knowledge and experience."</p> <p>"We also identified another complexity, with the London Climate Change Partnership around a lot of information and help mechanisms on the ground for people when the physical impacts of climate change are being felt through third sector organizations and not very well coordinated. So, it's one thing to do a risk assessment and even to mask quite a bit of climate information, but the minute you want to deploy an adaptation activity, you need to be looking at the knowledge systems, how you're going to change, not just the professional practice, but also those different third sector organizations that do the action in situ."</p>
	KC/R 5. Lack of adaptation and resilience indicators (in the planning, monitoring, and evaluating process)	6	<p>"We are trying to sort of monitor the progress from adaptation, and right now we are moving from a qualitative to a quantitative process because as you can imagine member states or countries have different processes to measure adaptation, and sometimes, they understand it differently and they use it differently. So, we're trying to develop a common way to quantitative process through indicators mainly."</p> <p>"And that's because the UK government removed national indicator 188. I remember that we had a national indicator in adaptation where all local authorities had to report on their adaptation activity. There was a lot of progress. There was even a really good index that was developed on adaptation capacity building, some really good work and a lot on actually monitoring and measuring adaptation indicators"</p>

			<p>via the environment agencies, climate-ready programs with the different environmental climate change partnerships, regional ones, but then the government scrapped that dismantled all of that infrastructure said all that was really left, the legitimate adaptation action was under the sort of civil response.”</p> <p>“There is some guidance available on adaptation and resilience, formulated in the IPCC report, more recently by the European Commission (see Climate ADAPT) but a well-established list of A&amp;R indicators is patchy and unclear with local authorities, local government, whether they are measuring any adaptation specifically at all. However, I think one thing to notice is that they did have to previously under indicator 188, which was a long time ago, and they now don't have to.”</p>
	KC/R 6. Cost efficiency of adaptation solutions	4	<p>“After you have decided on the need for an adaptation solution, one key step is to consider the cost. What is the cost, who should pay it, how should responsibility be shared, and who can help? Would be a particular group impacted? Who is going to pay for future climate change impact?”</p> <p>“When we talk about adaptation processes, stakeholders usually want to know how much it will cost to do adaptation. So, this factor also goes into our thinking, and we kind of need to prove that what we call NbSs are not only effective but cost-beneficial for them in order to be included in an adaptation process. Therefore, all these things have to fit into this puzzle because of either the adaptation process or adaptation indicators. The last part that we started dealing with is what we call adaptive capacity, or sometimes you can find it as resilience and it's actually how much a region can afford to have the capacity to adapt because in many cases it goes back to the cost of benefits and trade-offs. Sometimes the most suitable solution could not be implemented because the region itself doesn't have the adaptive capacity to do so.”</p>
	KC/R 7. Lack of economic capacity (funding)	8	<p>[Lack of funding for A&amp;R projects] “It could be from a technical capacity but also economic capacity. Many regions don't have the economic means to invest in adaptation and this could be due to different reasons not only the funding that is provided through the sources either governmental or EU but also maybe the region or the city, depending on the scale we are talking about, doesn't have the proper process to develop this investment properly. Maybe they have different priorities, and this influences the adapted capacity of the region.”</p> <p>[Respondents discussed the UK government's decision to remove indicator 188 (which used to measure adaptation) and now the adaptation action and measure is under the civil or NGO voluntary work].....</p> <p>“It wasn't just not understood its importance [about indicator 188]. Now, nobody wants to fund an adaptation solution, or deal with it at all.”</p>

			<p>[unsuitable funding capacity] After a disaster you can see how a whole area was affected and you can think of it like in India, in the Pacific Islands and Central America, Sub-Saharan, even in Europe with the floods, so many people were affected and so many million dollars or euros were invested, the question is how was it invested for reconstruction adaptation? How, does reconstruction funding work? Often, they have very short timeframes so like, in this place, some donors, in Guatemala decided to give orange trees to plant, even though they weren't suitable for those areas. People were asked by the donor to plant orange trees after they lost their maize and bean crops."</p>
	KC/R 8. Challenges of implementing and measuring adaptation solutions	7	<p>"In many cases, adaptation solutions are not feasible because the area does not have the adaptive capacity (resilience), thus, during much extreme weather (e.g. hurricanes) all adaptation and resilience solution implemented in place are destroyed.... But of course, it can help you determine afterwards, like when we evaluate the damage. Did people die because of the adaptation solutions in place or how many people wouldn't have died, had the system not been in place or died injured or in a shelter?"</p> <p>"I think first, let's say challenge and difficulty is to have a reliable assessment of what is going on, regarding the implementation of adaptation actions. So which adaptation actions are applied, in different sectors? So, the first difficulty is to assess the progress of adaptation actions. And the second, and I would say even, the higher challenge is to assess the effectiveness of adaptation actions, and there, it becomes very difficult also considering the dynamic nature of climate change, so something effective today may not be effective, under higher levels of warming. So, there comes the question of a baseline and so on. I think to measure the progress and to measure the effectiveness of adaptation actions are two big challenges that lie in the field."</p>
	KC/R 9. Lack of resilience infrastructure and vulnerability assessment	4	<p>"Many critical infrastructures in developing countries suffer from a lack of resilience. This is caused by a number of dynamic challenges. First of all, there is no common understanding of what resilient infrastructure is and a lack of vulnerability assessment, then the absence of funding for embracing the current technology. Also, there is a need for a common set of indicators to measure resilience and construct policies based on those. Last but not least, [there is] poor data on disaster damage and indirect losses."</p> <p>"We have recently developed an online platform, which has a sort of step-by-step process for developing an adaptation plan, tailored to what Northern Ireland specifically needs to do, and the resources required. So that is one piece of work. Now, I'm looking at how we make these plans to take action in places, where the necessary step should be to perform vulnerability assessments, to some extent, to understand how we</p>



			can make these plans more cohesive. So, what principles do we need to include? What indicators might everyone need to include if we were to choose some priorities?"
1.3. Role of governments in implementing adaptation and resilience strategies	KC/R 10. Biasing information	6	<p>"I think the government does not capture well the benefits that they can have in using satellite data. I think it is still rooted in the fact that while we are going to use statistical data for doing the measuring, adaptation measures, and things like this, they are not looking more broadly at what we can benefit from satellite observation as well, not only satellite observation data but also other non-traditional data types."</p> <p>"Satellite imageries and other technologies bring simple evidence of what is happening. I do remember that a couple of years ago we developed an emergency data technology that would support and monitor key features of the RAMSAR Convention. Even though the product was reliable many countries were reluctant to implement that technology. They were not managing their protected areas and, wetlands, they were not reported properly, and they had the feeling that we were kind of a big brother. That is upsetting because you have the technology that you can provide this information that is a common good but then some policymakers keep relying on outdated data."</p> <p>[previously the respondent discussed the A&amp;R indicators and their challenges] "... the selection of indicators is also not based on purely scientific rationales. There's also more of a political component to it. And not everybody wants to know everything. There are good reasons not to know something from a more political perspective. I do not know if that makes sense, but sometimes data that is being collected can also be used and misused in holding governments accountable, for example, the progress that they are making or the lack of progress. And I think that is an often overlooked component of studies looking at data availability and data quality. Sometimes there is no incentive to improve the measuring because the data is then threatening the political stability to some extent."</p>
	KC/R 11. The need to compare different datasets before making decisions	4	<p>"In the era of technology, policy should be written based on a comparative analysis of different datasets and complement to each other, but not only in this field (A&amp;R), in general."</p> <p>"I think the government should take into account different types of data, to compare the results of these and also the cost efficiency to have in mind, when they select different data."</p>

**Table S4.** Quotes associated with the KC/Rs within theme 2: Current landscape of A&R indicators.

Theme 2: Current landscape of A&R indicators			
Sub-theme	Key concerns	Respondents	Relevant Quotes
2.1. Challenges with the current A&R indicators	KC/R 12. Lack of A&R indicators at any scale that support certain adaptation policies	12	<p>“London Climate Change Partnership created in the past adaptation metrics but the outcome is unknown due to the political interests at that time (<a href="https://climatelondon.org/resources/getting-started-basic-adaptation-resources/">https://climatelondon.org/resources/getting-started-basic-adaptation-resources/</a>)”</p> <p>“UK government removed national indicator 188..... we had that national indicator, all local authorities had to report on their adaptation activity. There was a lot of progress. There was even a really good index that was developed on adaptation capacity building, some really good work and a lot on actually monitoring and measuring adaptation indicators via the environment agencies, climate-ready programs with the different environmental climate change partnerships, regional ones, but then the government scrapped that dismantled all of that infrastructure: the legitimate adaptation action was under the sort of civil response.”</p> <p>“First of all, it is patchy among local authorities, local government, whether they are measuring any adaptation specifically at all, in a way that they measure. So, I think one thing to notice is that they did have previously measured under the indicator 188 but that was a long time ago, and they now don't have to.”</p> <p>“There are baseline indicators available in the literature that can be used for adaptation and resilience plans, where the data is also available even at the local scale. Good examples of baseline indicators are measurements of demographic characteristics, such as the “percentage of the elderly population”. Having this number, we know the people that can suffer from heat waves, and where our adaptation plans could be implemented. The baseline indicators assist policymakers in designing and implementing more effective policies. However, the issue is we do not have policies for climate adaptation or resilience”.....” the primary role of baseline indicators is to help policymakers obtain a better understanding of the setting they are operating in and the challenges they have to respond to. For example, the expected sea level rise over the next three decades is beyond the control of any single local government, but many policy decisions need to act on the related long-term infrastructure investments.”</p> <p>“I sat in one of the UN statistical offices, climate data consultation processes, and it was as if adaptation didn't exist, they were still very hung up on climate data.”</p> <p>“It's very much focused on early warning rather than on adaptation.... It is on climate data or projections or forecasting as a tool for planning adaptation. These are things that people can measure</p>

			<p>easily. Otherwise, you see things that are around numbers of vulnerable people or vulnerable communities, but it's never very clear to me how those are put together. It is in my view what adaptation indicators should be getting at, but I don't think at the moment that there's a good methodology for doing that."</p> <p>"Because some organizations and certain ministries or departments create their own indicator sets, which are not necessarily aligned to the overarching indicator sets that are often embedded in national climate policies or national climates programs. For example, there's sometimes a bit of confusion about what is actually trying to measure. And what is the thing that we're trying to understand?"</p> <p>"There is a lack of lack of indicators about the buildings type and how resilient are to climate change."</p>
	KC/R 13. The existing A&R indicators are not designed for the local needs	6	<p>"Technical adaptation like nature-based solutions can help a lot, in cities, for example, green roofs, extended parks, etc. But when climate change increases and then drought kicks in, then you don't have enough water to water these green areas, and so they become less effective, as an adaptation option and you have to apply complementary measures as well. That's why indicators should be locally designed to understand how the community is adapted to climate change."</p>
2.2. Type of climate risk	KC/R 14. Droughts	5	<p>[Here people mentioned how climate impact/risk affects their country or a specific area within their projects.]</p> <p>"In London, our big issues are heat drought and flooding we have lots of different types of flooding. We have water scarcity issues in the Southeast of England and overheating."</p> <p>"So, things like wildfires or the risks for forest fires is, for example, something relatively new to the Netherlands."</p> <p>"Last year we had finalized a study on droughts because many countries are regularly facing now, important droughts even in Switzerland."</p> <p>"For example, in Finland, our climate risk is eutrophication due to the increasing temperatures and heatwaves."</p> <p>"Hurricanes and tropical storms have been always an issue in Latin America, however, the intensity significantly increased in the past years"</p>
	KC/R 15. Urban heat/ Heatwaves	7	
	KC/R 16. Floods/ extreme precipitation	6	
	KC/R 17. Wildfires	3	
	KC/R 18. Storms	2	

2.3. Challenges and opportunities in developing the A&I indicators	KC/R 19. The need to develop a common approach for planning/measuring adaptation	6	<p>“If we create a monitoring process, we need to know what is the baseline and all these things that come into place when we create any type of indicator. What we have tried to do the last years is to go from what we call exposure indicators, like what percentage of the population is living in a flood-prone area, and then take it all the way to see what the actual key measured policy that we need to address with this indicator? In this case, we are talking about relocation. Can the region use this indicator to see how much a relocation process will cost? And if there is a relocation idea suitable for that region then we are trying to link it like that. And we are going through not only population but also buildings like hospitals, schools, or more infrastructure that needs to be protected and it's a different assignment to a policy measure. I don't think that we will have an accurate set by the end of the year, but we will have a proposal that needs to be revised and made more suitable not only to a different sector but also to the regions.”</p> <p>“We are not dealing with one country or one region specifically we're dealing with European national and subnational which makes it even more complicated. Then you have the different governance mechanisms at each level which it's very different from country to country and that makes the reporting but also the identification of these adaptation processes more difficult. Once we pass this stage we need to find a common ground to formulate the indicator on the different sectors. We need to think for each process what is the most appropriate indicator, or which is the most appropriate guidance for this sector, so we can guide the policy makers or the stakeholders to create a proper adaptation action or proposal.”</p>
	KC 20. Lack of indicators in monitoring adaptation actions and resilience	5	<p>“I would say there is not much work, regarding indicators for measuring the results of adaptation. There is much work in measuring risks. So indirectly you can measure the effect of adaptation, although, it changes in climate change, risks are not, easily attributable to adaptation actions. So maybe you observe, lower, higher risks, but the connection to adaptation is not straightforward because you must have very good knowledge of what adaptation actions are in place and what the additional adaptation, which occurred at a specific time interval, and then attribute a part of all of the change that you observe in risks to these adaptation actions and come to conclusions about their effectiveness.” ..... “When the risk is estimated then they try to apply different, adaptation measures, nature-based solutions, like changing crop dates or crop rotations and so on, and then measure the crop yield (adaptation effect).”</p>

	KC/R 21. Design A&R indicators	<p>“Any type of indicators we have to consider, what is the data available, or, and also what is the cost efficiency to measure that those indicators, because maybe we formulate those indicators where the data doesn't exist, or maybe it's really hard to measure, or maybe it's very expensive to be measured.”</p> <p>“I think that we are quite a way behind in terms of even gathering information for adaptation and resilience. The priority should be to measure the same indicators so that you can measure something consistently. At the moment we haven't gotten into the quality of measurement, how you measure things, or whatever else I think that's important, and hopefully, that will come. I think the priority is still to get something in terms of a consistent approach to this. So, it's quite early in the process in that sense, which is not good.”</p> <p>“When A&amp;R indicators are developed, a key step is to take into consideration the mitigation action plans and climate change risk of a particular area. For instance, knowing the greenhouse gas emissions, or a particular risk, we would know what the best adaptation solutions could be, thus the indicators can be better designed.”</p> <p>“You can have nice theoretical ideas of how a perfect system would look like, but you have them to be practical and have access to available data, and they must be collected over time, consistently, and time series.”</p> <p>“If we create a monitoring process, we need to know what is the baseline and all these things that come into place when we create any type of indicator. What we have tried to do the last years is to go from what we call exposure indicators, like what percentage of the population is living in flood-prone areas let's say, and then take it all the way to see what the actual key measured policy that we need to address with this indicator? In this case, we are talking about relocation. Can the region use this indicator to see how much a relocation process will cost? And if there is a relocation idea suitable for that region then we are trying to link it like that. And we are going through not only population but also buildings like hospitals, schools, or more infrastructure that needs to be protected and it's a different assignment to a policy measure. I don't think that we will have an accurate set by the end of the year, but we will have a proposal that needs to be revised and made more suitable not only to a different sector but also to the regions.”</p> <p>“To implement adaptation measurements, we should first look at mitigation and risk indicators and combine that information to take a picture of adaptation.”</p> <p>“Adaptation should be always linked to resilience in the face of how increasing resilience or decreasing vulnerability in the face of specific climate risk.”</p> <p>“Datasets already available must be improved, particularly at the local level”</p>
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		<p>“When indicators are developed the data availability must be taken into account that can track progress over time.”</p> <p>“I think that heat, urban heat and a couple of other things just should be measured because all the effort is going into trying to measure these different indicators and not actually in utilizing that information to make the adaptation measures and to then monitor what's working, what's not and learned from it. And we don't have the time to have mild adaptation. So, I think it would be better when we've invested so much public money funds in making data open access to maybe go the next step.”</p> <p>“Many regions don't have the economic means to invest in adaptation and this could be due to different reasons not only the funding but also the skills to manipulate the data that measure A&amp;R indicators”</p> <p>“There is a need to create A&amp;R indicators with nuances of socio-cultural features, such as people's habits inside their homes”</p> <p>“We are trying to have different profiles of experts in agencies to work in these adaptation indicators because we need to look at it from different angles. We need to look at it from what data is available and what is the potential of a region or a country to use this data and then what are our targets what we actually want to measure?”</p> <p>“In Latin America countries, despite their vulnerability to climate risk, their governments are very mitigation centric, and adaptation is often ignored..... where adaptation is in place there is a need to look at feasibility assessment, to understand how feasible an adaptation option is”</p> <p>“Often adaptation policies are failing to fully incorporate risk-related information and knowledge. Understanding the current and future risks becomes crucial to assess whether they will effectively contribute to reducing vulnerability and increasing resilience. Exploiting the synergies between the well-established discipline of disaster risk reduction and climate adaptation is crucial.”</p> <p>“Key steps in developing indicators to measure the adaptation and resilience is to stay engaged with experts, measure the effectiveness of adaptation actions and nature-based solutions (after implementation), and ensure that the data are available and ideally consistent, and open-accessed.”</p>
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**Table S5.** Quotes associated with the KC/Rs within theme 3: Data for S&R indicators.

Theme 3: Data for A&R indicators			
Sub-theme	Key concerns	Respondents	Relevant Quotes
3.1. Data availability	KC/R 22. Lack of data and quality data especially at the local level and in developing nations.	10	<p>“So, the types of data they are using, this is partly why we came to the discussion with satellite data because heat data in cities is very patchy. I know we got great big web weather predicting systems, but the actual ground in situ data that is robust and consistent is really difficult to find.”</p> <p>“Data availability, how to process the data, but also what data they need to use for certain events. That is no understanding almost about all.”</p> <p>“First of all, data are patchy with local authorities, local government, whether they are measuring any adaptation specifically at all, in a way that they measure.”</p> <p>“I think probably if you have a method. If there is a clear sort of cookbook, then many countries have the capacity to follow the recipe, especially if the recipe has variations. If your national data look like this, here is the way to go about it. But the capacity, even on the monitoring, even for generating this data is patchy so yes, the data exists, but they exist quite patchy.</p> <p>“I find a good repository of data for India. However, some old datasets (say before 1980) are in PDF form which takes a lot of time to make reusable. Sometimes datasets are also not publicly available.”</p> <p>“The 111 indicators that the WBG identifies for adaptation and resilience can be collected from secondary sources. For the national level and above these are easily available, however for sub-national and lower levels- it takes time to find such data and here primary survey helps.”</p> <p>“It is a bit difficult to get everybody on the same page when we are talking about measuring adaptation because adaptation is very local, and the monitoring process has a lot of problems that are generated from the scale. Also, another part of the limitation is cost and benefits.”</p>
	KC/R 23. Technical capacity for data availability, access, processing, and modelling	6	<p>[previously the respondent discussed other data limitations] “.....right technical capacity is a limitation, both in generating the data and in using them for indicators. But even in high-capacity places where is the data used for adaptation indicators? I don't know, maybe because high indicators are often not very well defined.</p> <p>“So, I suppose is a useful prompt for me to say two other things. Firstly, there is a lack of capacity to understand adaptation, at all levels of government and all levels of society in general. I do not see that there is a quick understanding of what can be used (in terms of data), how it can be used in simple steps that are stopping people who may analyse data already, but just the lack of the expertise to know exactly what the meteorological data is they can use or what are those integrate models they should be used for certain events or that is all missing. Secondly then, which is the lack of ability to process the data as well, as the skills to do that. Everyone who wants to do that has a consultant. There's no in-house understanding of it. It means that somewhat affects the decision process as well. It's not like there's an interesting person that they can, you know, build understanding with, in these big organizations and that really affects them going forward as well. I think that's maybe the thing to kind of finally leave on as well. There's just no clear understanding of adaptation and resilience.”</p>

			“Facilitating the access to the data is the key for measuring indicators (in general)..... The provision or the barriers to access the data, following some analysis or some work with the data that is super important.”
	KC/R 24. Lack of citizen science data	5	“Not much citizen science and this is vital for understanding local resilience and other issues.” “Citizen science data works well in urban and well-developed nations due to the cultural trends in trusting sharing data, but there might be barriers in people's perceptions in many other countries.”
3.2. Data sources	KC/R 25. Use of “Big Data”	4	<p>“I think it is important to know that in the absence of data, there is a lot of modelling prediction. And sometimes the modelling is performed without considering all those data already available, Big Data or the fact that quality of data has improved especially validated satellite data.”</p> <p>“Weather station that is normally used to measure temperature and precipitations, but we do not have data an urban microclimate effect, so that's why satellite data, they can get the day night-time temperatures and that's important, frequently and consistently. There are these things called urban observatories under the EPSRC program, and they've been looking at things like big data, MET office data and crowdsourcing, weather data.”</p> <p>“And sometimes even in London, I think the kind of weather station that is normally used is actually in Heathrow. So, you don't have an urban microclimate effect, being recorded on that. So that's why there is an interest in the satellite data, they can get the day and night-time temperatures and that's really important, frequently and consistently”</p> <p>“The data itself from the climate change that we are trying to provide to the public through our collaboration with different larger organizations like the Copernicus services that's the first part. And then we have the socioeconomic data which has to be included in any type of monitoring process when we talk about adaptation. Each country and region has a different process for collecting the data. What we usually do is collect them from international organizations, like Eurostat or Copernicus, and so on. It's a bit difficult to get everybody on the same page when we are talking about adaptation because adaptation is very local and the monitoring process has a lot of problems which is generated from the scale that we are working on, and then it's the process itself. Also, another part of the limitation is its cost and benefits.”</p> <p>“I think the national statistics have certainly a lot of interesting data sets and indicators to support the adaptations measure and resilient measures, same for the EO satellite data. We clearly need the integration of national traditional statistics together with satellite data and citizen science. .... I am currently developing a platform where we integrate land cover mapping for Switzerland, and 4 million points of ground data across the country, generating new data sets every six years. We have satellite</p>
	KC/R 26. Value of satellite data (e.g., Copernicus Climate Change Service)	10	
	KC/R 27. Weather data and climate projections	7	
	KC/R 28. Use of crowdsourced data	4	
	KC/R 29. Socio-economic survey data (e.g.National statistical data, Eurostat, Public health data)	11	
	KC/R 30. All different types of data	5	
	KC/R 31. In-Situ measurements	4	



			<p>data, then what you can do it's to merge the two data sets, use the points to train machine learning models, and use the satellite data to classify the data. And then you come up with annual resolution thematic special and temporal data, but I cannot do that with the statistical data."</p> <p>"I know from doing the work through London Climate Change Partnership, and Space for Climate, trying to bring the satellite heat data and green areas and public health to measure at local government city, and national government levels to understand heat resilience in particular."</p> <p>"When you're looking at nature-based solutions and services, that's where I think things like satellite data can help because they can help planning, monitor and help us understand the efficacy of whether an adaptation action is working or not."</p> <p>"Regarding the cost of data, I think that there are also some additional methods that you may use to reduce costs, crowdsourcing, which can help also, collect data, in a way, which is not very expensive but of course, the quality of data plays a major role, so you have to have comparable data."</p> <p>"Also, social-cultural assessment agency that collects socio-economic aspects that help to understand vulnerable groups."</p> <p>"For measuring A&amp;R indicators mostly need data on socio-economic aspects, and a more significant part of that is collected by the researchers doing primary survey/ in situ measurement. Regional observations are essential for taking region-specific policies, and one of the best ways to collect those data is to go for primary survey. If there are lack of resources (time and money), generally proxies are used for: e.g., people are reluctant to report their income, so one way to get an idea about it is by asking about their expenditure- which they happily say."</p> <p>"For the national level and above these are easily available, however for sub-national and lower levels- it takes time to find such data and here primary survey helps."</p> <p>"Satellite data are most useful for measuring, green areas, urban heat, floods, related to forest fires exposure and adaptation. EO for Climate adaptation is key data to predict and prepare for the immediate impact of climate risk, provide real-time impact assessment and response support, as well as monitoring infrastructure and helping in planning resilient solutions."</p> <p>"For the national level and above these are easily available, however for sub-national and lower levels- it takes time to find such data and here primary survey helps."</p>
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3.3. Data quality	KC/R 32. Data quality is very important	10	<p>"Quality of the data, uncertainty, accuracy and resolution are super important and often are linked to the level of consistency in data collection and the time series available."</p> <p>"The quality of the data is super important, but it has many aspects to it now. Yes. Uncertainty and accuracy link to resolution all those types of things, but also very important is the time timing is that the regular updates."</p> <p>"I think it's really important to know that in the absence of data, there is a lot of modelling predicting. And sometimes the modelling is done without questioning that maybe the data availability or the quality of data has improved, and we then don't need to have the modelling assumption in because we've got good in validated satellite data."</p>
	KC/R 33. Quality assurance is missing for some datasets	6	<p>uncertainty and confidence of the statistical data;</p> <p>"That's an important measure, I guess. I think this is something that tend to miss currently. We have the tendency to provide data without these measures, accuracy, validation, and uncertainty. And then the drawback is that we give the impression that's super nice, super precise, and you can fully trust these new data sets and you don't have to care about that. Then when you start working and investigating the information power of these data sets, at the end, you realize that you come up with a high variability of conclusions that you can draw from the same data sets depending on the model that you will use. For example, land degradation. If you think about land productivity here in Europe, we have these two or three major data sets for land productivity. And with the exact, same values for the sub-indicators, just using different data sets you come up with completely different maps of land degradation across Europe. And if you do not provide this uncertainty accuracy, information, then you will just give in the end of the decision makers, wrong information and then they will build wrong decisions."</p>
	KC/R 34. Data robustness and data measurement network	5	<p>"In the Netherlands, we have a very strong measurement network where we monitor a lot of the ongoing changes. So the network of measurements is dense. And that sort of increases the robustness because if there are any outliers, you would probably easily pick those up and you can correct those in the actual measurements or the actual investments. This is particularly true for water and flood risks, but for other measures, it's less. Things like forest fires or the risks for forest fires are, for example, something relatively new to the Netherlands. And for that we have, we don't have a strong measurement network to collect real-time data. For others, we have strong measurement networks, but we don't necessarily use them in the context of climate changes."</p> <p>[here the respondent is referring to the Geneva GRID product] "So, we decided to be fully compliant with the Open Geospatial Consortium (OGC) standards, trying to properly document all data sets that we will generate with all the metadata, according to the ISO standards, being standardized. That was highly appreciated because it was super easy for them to connect to the services we were providing</p>

			<p>and then really make their own adaptation measures based on the data we were providing. From a technical perspective that's extremely important because makes location information and services Findable, Accessible, Interoperable, and Reusable (FAIR)."</p> <p>"I think accuracy, I guess we would want the most, there are a couple of different points in there. Because I think there are questions about how accurate the data itself is."</p>
3.4. Data interoperability/consistency	KC/R 35. Lack of interoperability within the same country or with other countries (from local to national)	7	<p>"Lack of collaborations within the same country (complexity in measuring adaptation indicators and another type of indicators stay in lack of data and lack of collaboration within the UK territories."</p> <p>"I think I would be doing an injustice to this exact part of the world if I did not mention the connection, across borders, the Irish difficulties over the years and things, but there is a difference then between the data that the MET office use and the data that is used in Ireland. They have some sort of memorandum of understanding, but the data does not link up, even though the MET office gathers all the data right across Ireland as well and vice versa. I think, there is quite a lot of data gathered, but those data sets do not link up. And so, you have water bodies that straddle Northern Ireland and Ireland, which are mapped by different data sets on either side and do not meet. So, I would just also acknowledge that I am sure if you have been talking to people across Europe as well, I do not know how those transfers over there, but I would imagine, if they are using the same European agencies, it is reduced, over here, that is not the case. There is a border in terms of those data sets between Ireland and the UK. We keep telling them that it is so important that these things link across and that they work together more."</p>
	KC/R 36. Importance of coverage, comparability, consistency in data collection, ground truth data, and historical data	7	<p>"You can have nice theoretical ideas of how a perfect system would look like, but you have them to be practical and use available data and available data is either you find that from scientific studies or people collide and collect datasets and that could be great, but often they're not maintained. And then they're useless too because it's a snapshot of time and you don't have it over time, or you try to have institutionalized data sources. And those are much more important, much more relevant because they are reliable. They will be produced in the future too. There's the funding behind it. There's a business model behind it. There's you know, it's part of the statistical system, for instance, or it's part of the SDGs that countries have to record them."</p> <p>"Comparability is an issue which can be addressed through continuity. This means that we have to regularly perform observations and data collection. In Greece, it is very often the case that, there is, an assessment done at a certain point in time, based on, a collection of data. And then this process is not, regularly repeated. So, you don't have, an idea of how things, go, do they get worse? Do they go better? And this is a problem, so consistency in continuity, and good data collected by reliable methods and by trained people and good equipment they are very much, needed."</p> <p>"The vital aspects of tracking risk, planning and monitoring adaptation is the continuity of the datasets, consistency in continuity, reliable methods developed by qualified personnel which can answer technical questions about the modelling."</p>

			<p>"But also very important is the regular updates, especially if you want to start tracking risk and adaptation and changes, you need datasets that are produced regularly, and that are available consistently over time."</p>
	KC/R 37. Fitness for purpose of data	4	<p>"Also, it's very important to look at the fitness for use. There can be a dataset that is perfect and very accurate and all, but it doesn't meet the need, for instance, one of the indicators in this risk framework, because it's already covered by another indicator. I don't know, you have to see how fit it is at which scale you're working."</p> <p>"And then there's also, I think a question there about does that data tell you what you want to know, you're using, oftentimes we're trying to use proxy data to understand like risk and resilience. We are trying to get a picture based on what information we have. And I think we always have to be a little bit careful about that."</p>
3.5. Uncertainty information	KC/R 38. Evaluating and communicating uncertainty is very important	10	<p>"Uncertainty of model is very important to communicate properly to policymakers, especially when two results are compared. The error associated will be strictly linked to the data used and methodology used."</p> <p>"If uncertainty is quantified it is manageable, if it is too high, then we find people don't believe anything, but one of the things the IPCC has done for the world is to get it more used to thinking about uncertainty and people are able to make a rational judgment based on those ranges."</p> <p>"Quality of data is of course important, but I think it's most important when you're looking for an indicator that's actually used for monitoring [...]. I mean either when you're doing a comparison or when you're looking at patterns over time. Uncertainty is also important, if it's quantified is manageable, [...] It's very purpose dependent, [...], let's say a dataset that measures a certain indicator has a particular level of uncertainty around it, that you can use it to inform certain kinds of decisions and not to inform other kinds of decisions."</p> <p>"It is especially important to consider uncertainty in our climate modelling, whether it is for climate mitigation or adaptation, it is important to recognize it, and if possible, quantify it. It is very purpose dependent, and that is one of our challenges is to make it clear what we can do with, let us say measuring an indicator that has a particular level of uncertainty around it, that you can use to inform certain kinds of decisions and not all of them."</p>

	KC/R 39. Challenges of evaluating uncertainty	10	<p>[how to communicate it] “I agree that you cannot decide on what you cannot measure so we need measurements, but then we need also to provide this information about uncertainty and that is a big challenge to communicate it properly.”</p> <p>“Not only quality data matter also the models used and how the uncertainty is translated to policymakers.”</p> <p>[establish uncertainty baseline] “When we talk about climate model data, we are aware of the uncertainties and what is happening in the climate modelling chain and in a certain way we accept that. I mean we cannot alleviate all the uncertainties and the problems that data have; we support the proper guidance when using the data rather than eliminating uncertainties. We will always have uncertainties in the data even today in observations. So, it is important to be aware and consistent with that certain level of uncertainty and to choose wisely the data type for measuring a particular indicator. For instance, is its higher resolution that will give us better results? Or starting to use more socioeconomic data when we talk about adaptation and so on? It is not only to put more weight on the data quality, but it is more actually what is the relevancy of data used.”</p> <p>[uncertainty acknowledged] “All sorts of data have an inevitable degree of uncertainty that needs to be aware of and translated in clear words to research and policy arenas.”</p>
3.6. Accuracy and cost efficiency	KC/R 40. Different data—better accuracy	4	<p>“Using different data that can consistently measure an indicator would give higher accuracy of the results and become trustworthy for policymakers.”</p> <p>“The more data added, the broader the overview of the problem, creating increased accuracy and trust in the results.”</p>
	KC/R 41. Trade-off between accuracy and cost	4	<p>“There is a trade-off between being too precise but then it is super costly and a little bit less precise, but then you have a cost-effective mechanism. And part of the debate I regularly have with the government is because they often say “Well, with satellite imagery of 10 meters it's not that precise.” Well, maybe it is not super precise, but then we are covering the entire country. Depending on the indicator or information that you want to extract out of the satellite imagery, that is sufficient.”</p> <p>“If you get more accuracy for more cost then it may not be equally cost efficient. What do you regard as a good outcome from greater investment? It could be more accurate. But alternatively, one of the things about adaptation and resilience is that they have a number of facets. And if you spend an enormous amount of resources on something that tells you in great and wonderful detail about one of those facets, (you may not have the resources to look at another)”</p> <p>“Well often where there is a budget allocation, we have to think about the cost and data, and we end up having a trade-off between the quality of data and cost.”</p>

	KC/R 42. To be considered	10	<p>"Cost efficacy is important depending on how you define efficiency and how define the cost deficiency"</p> <p>"When we talk about adaptation processes, stakeholders usually want to know how much it will cost to implement adaptation solutions. So, this factor also goes into our thinking, and we need to prove that what we call nature-based solutions are not only effective but cost-beneficial for them in order to be included in an adaptation process. So, all these things have to fit into this puzzle because of either the adaptation process or adaptation indicators. The last part that we started dealing with is what we call adaptive capacity, or sometimes you can find it as resilience, and it is actually how much a region can afford or has the capacity to adapt because in many cases it goes back to the cost of benefits and trade-offs. Sometimes the most suitable solution could not be implemented because the region itself does not have the adaptive capacity to do so."</p> <p>"I mean there would be several different metrics in terms of deciding what the priority data is, what they can measure. I would argue that they have not put much effort into it yet, it is that we are coming from a baseline of having put no money into it, which would suggest that cost-effectiveness will be one of the highest priority metrics, by which they will decide what data to use."</p>
	KC/R 43. Availability of open-access data	5	<p>"More money should be invested in open access data and data platforms for A&amp;R climate change."</p> <p>"Data should be as open as possible as well as reproducible and fairly compliant."</p> <p>It is important to have a level of open access data and I think essential climate services. It's not enough to do open data that people are unable to utilise."</p>