Climate Adaptation

Proposed Methodology for Detailed Climate Risk Assessments

V3 January 2024

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1. Introduction

In December 2022, Transport Infrastructure Ireland (TII) published its updated Climate Adaptation Strategy[1]. This was a direct response to Action 297 of Ireland's Climate Action Plan 2021[2] – *"Improve climate resilience and adapt to climate change on the Light Rail and National Road Network"*. The strategy adopts a holistic approach to climate adaptation, considering both TII's physical infrastructure assets, as well as its people and offices – as shown in Figure 2.

The strategy includes several follow-up actions that TII will undertake over the next five years, to help reach the Strategy's aim "*to be an organisation that is adaptive to the impacts of climate change and maintain its commitment to sustainability*". To support this aim, TII needs to improve its *"understanding of climate hazards, risks and system impacts"*.

Figure 1: TII's Climate Adaptation Strategy[1].

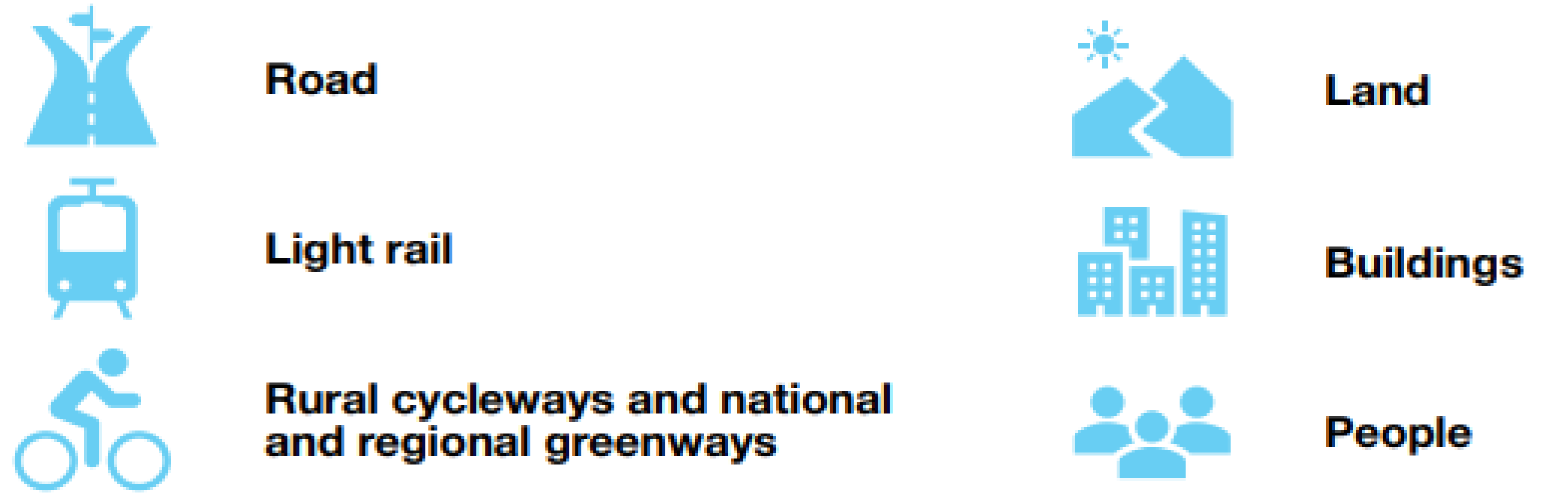

Figure 2: The six asset groups considered in the Climate Adaptation Strategy[1].

[1] Transport Infrastructure Ireland (2022) *Climate Adaptation Strategy 2022.* TII Publications, Dublin.

[2] Department of the Environment, Climate and Communications (2021) *Climate Action Plan 2021: Annex of Actions.*

1.1 – The Strategy's six-stage approach to climate adaptation

The Climate Adaptation Strategy[1] sets out a six-stage approach (Figure 3) to climate adaptation. Below details current progress on the stages to date and summarises the focus of this report.

- **Stage 1** (complete) – Climate Adaptation Strategy published in December 2022.
- **Stage 2** (complete) – Climate Impact Screening Assessments[3] undertaken for each of TII's six main asset groups.
- **Stage 3** (complete) – Asset-hazard pairings have been prioritised and are being taken through to inform Stage 4 – more detailed climate change risk assessments.

This report sets out the approach required to deliver **Stage 4 'Priority Impact Assessment'**, which is also referred to as 'detailed climate change risk assessments' (CCRAs). This approach aligns with the Climate Adaptation Strategy, and TII's Climate Standard[4].

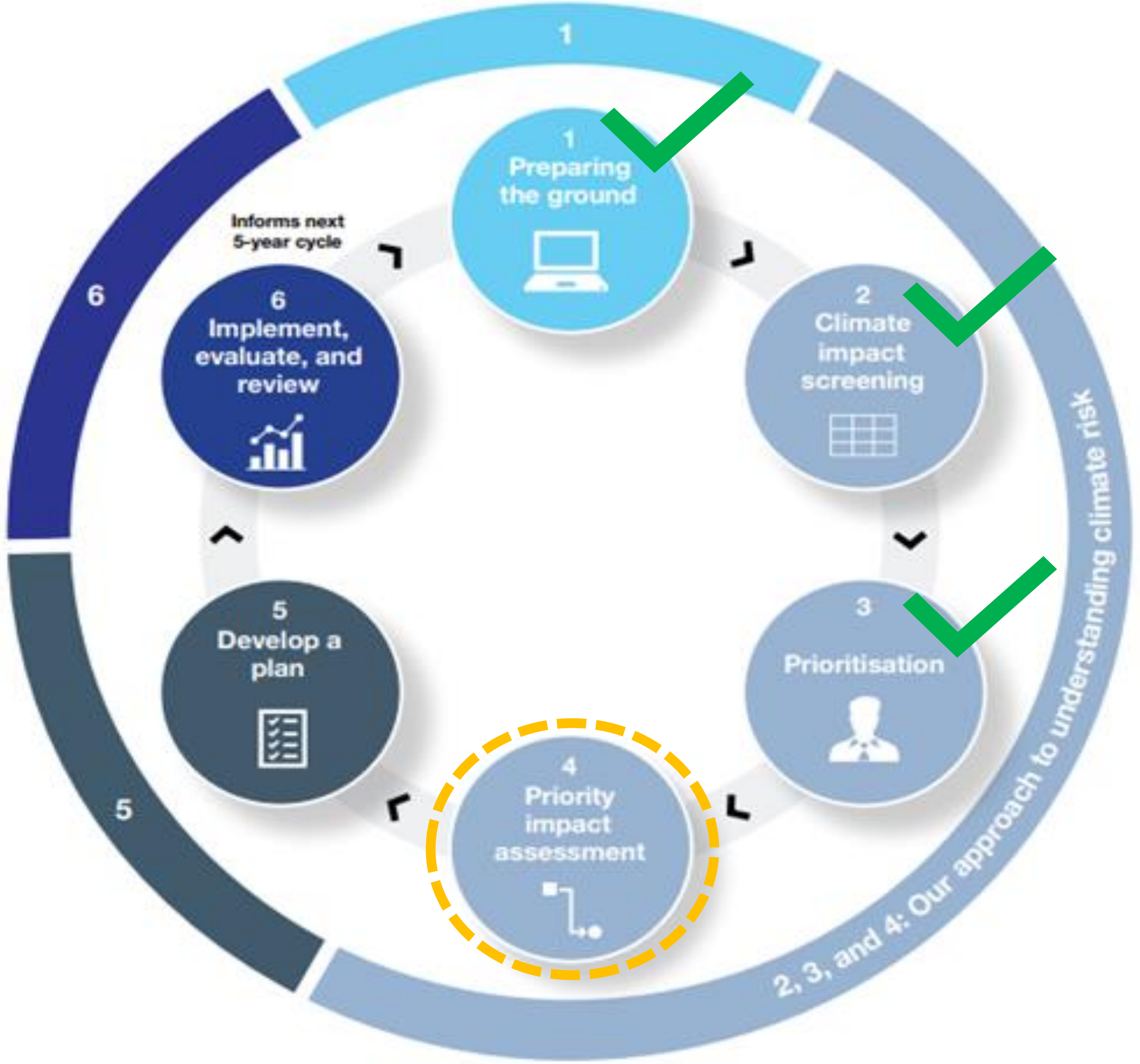

Figure 3: TII's six-stage approach to climate adaptation[1].

[1] Transport Infrastructure Ireland (2022) *Climate Adaptation Strategy 2022.* TII Publications, Dublin.

[3] Arup (2023) *Transport Infrastructure Ireland - Climate Impact Screening: Summary Report.*

[4] Transport Infrastructure Ireland (2022) *PE-ENV-01105 Climate Assessment of Proposed National Roads – Standard.* TII Publications, Dublin.

1.2 – TII’s existing guidance on assessing climate risks

Figure 4 shows how Stages 2 to 6 of TII’s approach to climate adaptation align with the two-stage climate risk assessment set out in TII’s Climate Guidance[5] and Standard[4] that was developed to support the assessment of climate risks to new national road schemes and was shaped by European Commission guidance[6].

The first of these two stages, the climate impact screening, considered the full range of TII's assets and their vulnerability to potential climate hazards. The output of the first stage was a list of priority asset-hazard pairings that require further and more detailed assessment. These form the scope of the more detailed Priority Impact Assessment.

1. Climate Impact Screening
is complete – covers Steps 2-3 in the TII six-stage approach.

2. Priority Impact Assessment
This report summarises a proposed methodology to undertake steps 4-7. Steps 8-9 to come later for TII.

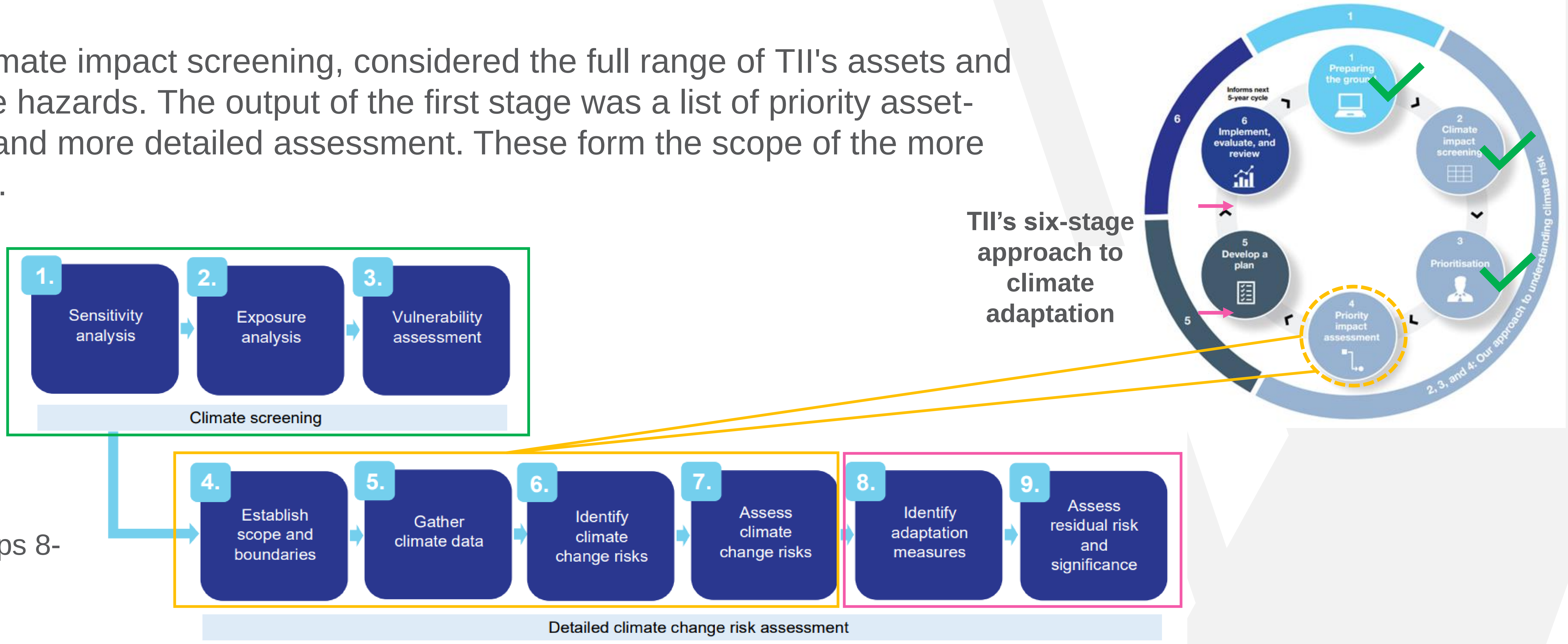

Figure 4: TII’s Climate Change Risk Assessment Methodology Workflow[4], and how it links with the TII six-stage approach to climate adaptation.

[1] Transport Infrastructure Ireland (2022) *Climate Adaptation Strategy 2022.* TII Publications, Dublin.
[4] Transport Infrastructure Ireland (2022) *PE-ENV-01105 Climate Assessment of Proposed National Roads – Standard.* TII Publications, Dublin.
[5] Transport Infrastructure Ireland (2022) *PE-ENV-01104 Climate Guidance for National Roads, Light Rail, and Rural Cycleways (Offline & Greenways). TII Publications, Dublin.*
[6] European Commission (2021) *Technical guidance on the climate proofing of infrastructure in the period 2021-2027.*

1.3 – The detailed Climate Change Risk Assessment

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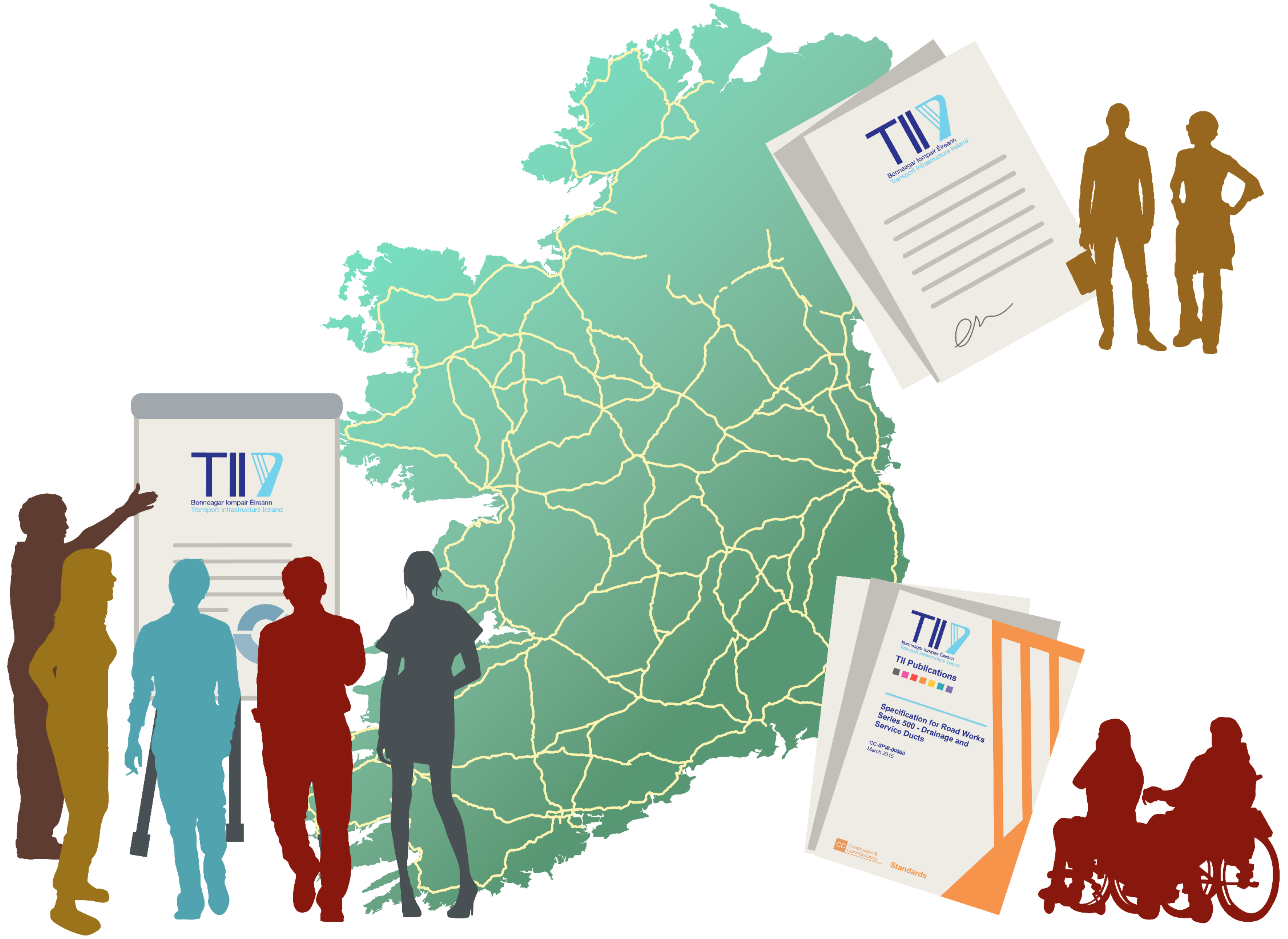
The two-stage approach to climate risk assessment (Figure 4) in TII's Climate Standard [4] has principally been developed for use on new projects/schemes. However, the action required in the Climate Adaptation Strategy will be considering the risks posed from climate change to TII's existing assets. This report has therefore considered where there may need to be flexibility in the approach to enable the assessment of existing assets, particularly where asset data may be limited, as well as how to handle significant amounts of data associated with national networks.

Through engagement with TII asset specialists, it was agreed that to assess the impacts of climate change to assets, the detailed climate change risk assessment would need to be spatial wherever possible. This will help identify where there are potential hotspots that are at increased risk of climate change, supporting the prioritisation of more detailed site-specific assessments.

This report describes the methodological approach that will be undertaken as part of the next phase of work.



[4] Transport Infrastructure Ireland (2022) *PE-ENV-01105 Climate Assessment of Proposed National Roads – Standard.* TII Publications, Dublin.

1.4 – National Roads – re-categorising assets

The climate impact screening completed for the National Roads asset group made use of the Specification Series. While these categories are commonly used in new road projects, additional engagement with the Network Management team found these categories would need refining to align with how road assets are managed on-the-ground, and how they experience climate impacts.

Prior to carrying out the detailed climate risk assessment, the assets will be re-categorised in consultation with the Network Management team.

Figure 5: The National Road network[7].

[7] Transport Infrastructure Ireland (n.d.) *Our National Road Network.* [Online]. Accessible here: https://www.tii.ie/roads-tolling/our-road-network/

2. Proposed methodology for detailed climate change risk assessment

We recommend the detailed CCRA follows the steps set out in the TII Climate Standard and guidance[4,5]. We present these below, with additional detail on how we interpret these steps in the context of requiring full portfolio-scale CCRAs.

Step	Description	Report section
Establish scope and boundaries	*Review climate impact screening to set out data requirements, and establish future climate scenarios to use for detailed risk assessment, factoring in assets' design life*	Section 2.1
Identify climate change risks	*Through stakeholder engagement and a literature review, this step will document how climate hazards can impact TII's assets and service delivery, in terms of asset damage and operational impacts. The aim is to identify weather design and operational thresholds for all priority asset-hazard pairings that can be used when gathering climate data.*	Section 2.2
Gather data	*All relevant climate and hazard data will be collated and organised into a database, for all priority asset-hazard pairings. Each pairing will be assessed based on data availability, to inform the risk assessment approach taken in the next stage. This stage will also gather information on criticality and wider impacts to support the impact assessment.*	Section 2.3
Assess climate change risks	*All priority asset-hazard pairings will be assessed for current and future hazards. The hazard assessment will be combined with exposure and vulnerability to give overall climate risk. The consequence of the risk to each asset will also be assessed using criticality.*	Section 2.4
Visualise - scoping	*The assessment will be supported by a scoping of a visualisation tool that would help a range of TII users engage with the detailed climate risk assessments to inform investment and decision-making.*	Section 2.5
Reporting	*The assessments will be supported by a number of reports, aimed at different audiences.*	Section 2.6

2. Rolling out the detailed CCRAs methodology

We recommend staggering the five detailed climate change risk assessments. This will allow any lessons learnt from the initial CCRA to be easily translated to later assessments.

Note that the approach to the people screening assessment included detailed assessment and as such the methodology outlined here is not applicable to that asset group.

Light rail

Given the geographically constrained area of the Luas, we recommend starting with the light rail network.

National Roads

The national roads network assessment would come next, commencing a few months after the start of the light rail assessment.

Greenways and cycleways; land; buildings

These final three asset groups would be assessed after the initial two groups.

2.1.1 – Establish scope and boundaries

Establish scope and boundaries

The scope and boundaries of the proposed detailed climate change risk assessments (CCRAs) are set out in Table 1.

Table 1: Scope and boundaries of detailed CCRAs.

Scope item		Response
Spatial boundary	Coverage	**Roads, greenways and land:** the whole of Ireland. **Buildings:** Parkgate offices in Dublin **Light rail (Luas):** Dublin.
	Resolution	Aim for each asset to have its own climate risk score, but for some climate hazards (i.e. the non-flood related hazards), the hazard component will be based on the spatial resolution of the climate projections (e.g. one hazard value for each 3km grid square), with that hazard result attributed to all the assets within that square. For linear assets, study will look to split the assets up into sensible areas/lengths for assessment (e.g. the road network could be split into the 100m sections used in the 'TII Flood Risk to Roads' modelling – more detail in Section 2.3.4).
Temporal boundary	Coverage	Influenced by design life of asset components (e.g. roads considered to have an average design life of 60 years[4], ranging from 10-120 years depending on the particular asset).
	Resolution	The assessments will represent an average for each climate period, usually 20 or 30 years (e.g. a 2050s hazard rating will be based on climate projection data for the period 2041-2070).
Climate hazards		Those identified and prioritised from the climate screening[3].
Project receptors		The assets identified and prioritised from the climate screening[3]. For the national roads assessment, the assets will be re-categorised based on engagement with Network Management.

[3] Arup (2023) *Transport Infrastructure Ireland - Climate Impact Screening: Summary Report.*

[4] Transport Infrastructure Ireland (2022) *PE-ENV-01105 Climate Assessment of Proposed National Roads – Standard.* TII Publications, Dublin.

2.1.2 – Establish scope and boundaries: outputs

Establish scope and boundaries

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To support the scope and boundaries as presented in Table 4, this stage will include developing the following outputs:

Outputs:

a) **5 x data requirements note (1 per asset group):** The climate impact screenings will be reviewed to set out data requirements for the detailed CCRAs. Examples of data needed include asset information required and types of hazard data.

b) **5 x short technical note on future climate scenarios (1 per asset group):** Related to the CCRAs' temporal boundaries, there will be a task to establish future climate scenarios to use for detailed risk assessment. Future time slices used for assessments are likely to vary from asset to asset, based on their design life.

2.2.1 – Defining climate risk and consequence

Identify climate change risks

In order to identify the climate change risks facing TII, it is important to first define what is meant by 'risk'. Following a review of different definitions, we use the **climate risk equation**:

Climate Risk = **Hazard** × **Exposure** × **Vulnerability**

- A **hazard** is the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
- **Exposure** is the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
- **Vulnerability** is the propensity or predisposition to be adversely affected.

Where available, asset/network criticality will also be considered as an important factor in the risk calculation. We will engage with the TII Resilience project looking at asset/network criticality for the national roads which will help to inform criticality assessment. We will explore criticality data for the other asset groups.

A note on definitions:

This risk equation and associated definitions come from IPCC AR5[8].

This approach differs from the risk equation in the TII Climate Standard (risk = likelihood × magnitude). The IPCC equation is more suited to this methodology which is focused on existing assets.

***Criticality** is the relevance of an infrastructure element or section to the availability of an infrastructure system (e.g. of system - road, light rail, greenways and cycleways network).*

[8] IPCC (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

2.2.2 – Aligning hazard and vulnerability – identifying asset/network relevant climate hazard thresholds / return periods

Identify climate change risks

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The aim of this stage is to identify the ways in which the climate **hazard** in question makes an asset **vulnerable**, in terms of asset damage and/or operational disruption – and therefore puts the asset or wider network at **risk**.

This enables a more targeted approach to gathering hazard data and helps to ensure the data supports a quantitative assessment of the identified climate risk. Having defined quantitative asset-hazard relationships will facilitate a more robust climate change risk assessment, as it will make a clear link between the climate hazard rating (e.g. the likelihood of a disruptive/damaging event occurring) and the vulnerability rating (e.g. the result of that event on TII's assets/networks). Engagement with TII asset specialists will be essential to identify thresholds or return periods.

Examples of asset-relevant climate data that links with a threshold:

- At which an asset is known to be vulnerable (e.g. at which the asset is no longer designed to withstand). *An example of this is 43ºC for rail tracks – at or above this temperature they are prone to buckling, as shown in Table 2.*
- At which an operational weather threshold is reached, as documented in a severe weather plan *(e.g. Met Éireann yellow/orange/red warning days used for the Luas).*
- At which a past event occurred (e.g. identifying a weather threshold from the historical record, linking to an adverse event that affected the network).

Table 2 - Examples of threshold values for road and rail networks[9].

High temperature – daily maximum temperature		
Threshold	**Impacts**	**Consequences**
≤ 25°C	Fatigue among bus-drivers and truck-drivers.	Possible increased crash rate in road transportation.
≤ 32°C	Damage to pavement, e.g. softening, traffic-related rutting, migration of liquid asphalt, roadway buckling. Restrictions in road maintenance and construction.	Increased accident rate, delays, diversion.
≤ 43°C	Rail equipment failure, rail track buckling, heat exhaustion.	Increased accident rate, delays, diversion.
Heavy precipitation		
Threshold	**Impacts**	**Consequences**
≤ 50 mm/24 h	Flooded roads, reduced pavement friction.	Damage to secondary (sand-covered) roads, increased collision risk on roads.
≤ 100 mm/24 h	The sewer system fills up; water rises to street level from drains. Rainwater fills underpasses and lower lying streets. Drain well covers may become detached and cause danger to street traffic. Reduced visibility, flooded underpasses.	Increased rate of road accidents, delays, damaged roads.

However, if this is not possible (e.g. there is no climate data available for the identified threshold/return period), we will use the climate data that is available as proxy data that will indicate future trends that can be used to support future decision-making.

[9] Leviäkangas, P. , A. Tuominen, R. Molarius and H. Kojo (eds.) (2011). *Extreme Weather Impacts on Transport Systems.*

2.2.3 – Engagement and outputs

Identify climate change risks

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This step of the detailed CCRA involves the following engagement activities:

- 2 workshops per asset group (10 in total)
  - The first will help the project team to better understand qualitatively how climate hazards affect assets and direct the team to any key design standards, operational thresholds or other information that could provide evidence of how to assess the hazard quantitatively.
  - The second will review the identified asset/network relevant climate or weather thresholds or design standards which the team will use in the next step when gathering climate data.

Outputs:

a) 5 x technical note summarising asset-hazard thresholds (1 per asset group)
b) 5 x technical note on criticality information and impact assessment (1 per asset group)

2.3.1 – Data requirements

Gather Data

The following data is required to assess the hazard, risk and consequence of each climate hazard-asset pairing:

Climate hazard data

- **Geospatial climate hazard data – baseline and future**. This is needed to show how risk may vary spatially across Ireland.
- **Relevant climate hazard threshold/return period for asset**. Page 14 provides more detail on this.

Asset data

- **Geospatial asset data**. This enables a spatial approach to assessing the climate risk for hazard-asset pairs.
- **Asset exposure and vulnerability information**. This can inform our understanding of asset vulnerability – like asset condition, value or sub-network type for the national roads network. Age could be used to inform choice of future time period, and when/if adaptation measures are required.
- **Asset criticality information**. Without this information, the risk assessment will provide useful insights about risk at the asset scale. However, an understanding of criticality can help to prioritise assets for adaptation based on their relative importance at the network scale. *There is opportunity to link up with a separate work package on 'Resilience' which is looking at criticality of the road network.*

This step will gather all available data for these five data requirements, for each of the prioritised asset-hazard pairings from the climate impact screening assessments. Each pairing will be evaluated, to record whether these five data requirements are met.

Where information is limited, we may need to consider using proxy data. An example of proxy data is using non asset/network specific climate hazard data.

This will also help identify gaps in knowledge or understanding related to climate impacts and suggest recommendations for further research or data development/recording. These insights will help to shape the proposed Climate Adaptation Plans (Stage 5 of the strategy).

2.3.2 – Data review: climate and asset data

Gather Data

A preliminary review of these five data requirements has been conducted as part of this CCRA methodology development phase. Table 3 summarises the findings from the climate and asset data review - more detail is available in Appendix A .

Table 3: Scope and boundaries of detailed CCRAs.

Asset group	Geospatial climate hazard data – baseline and future	Relevant climate hazard threshold / return period for asset	Geospatial asset data	Asset criticality information	Asset vulnerability information (e.g. age, design life, condition)
National roads	Variation across the different climate hazards – see Section 2.3. The full review is presented in Appendix A.	At present, this has not been assessed and will be undertaken in Step 6 (e.g. design standards, evidence from past events, severe weather plans, global examples).	Good – acknowledge that some asset information is not currently captured, or there is a plan to collect this in the future.	To be confirmed in next phase (e.g. Subnetwork type, traffic data - AADT , lifeline roads) **Potential to link in with 'Resilience' work package.**	The TII Climate Standard suggests a road scheme has a typical design life of 60 years, but individual asset's lifespans can range from 10-15 years for utilities, to 120 years for bridges.
Light rail			Good	Unknown – to be gathered in this Step 6.	Unknown – to be gathered in this Step 6. Greenways – know that there are a lot of legacy historic rail assets (e.g. bridges and buildings) - which are probably beyond their intended design life.
Greenways and cycleways			Very limited – existing assets are not owned by TII.		
Buildings			Very limited – but could be inferred from location on Parkgate St, Dublin.		
Land			Very limited – unclear what is owned/managed by TII.	Data gathering to involve expert judgement, via engagement with TII asset specialists, and/or literature review	

2.3.3 – Gather data

A key requirement for undertaking a detailed CCRA is having appropriate climate hazard data, available in a spatial data format, cover TII's networks, and show present-day climate baseline and future climate projections. A preliminary review of climate hazard data has been conducted as part of this CCRA methodology development phase, which is summarised in Table 4. The climate hazards reviewed have been derived from the prioritisation following the climate impact screening (Stage 3). More detail is available in Appendix A.

Table 4: Climate hazard GIS data availability.

	Climate hazard														
Present-day or future data?	**Flooding (coastal) - including sea level rise and storm surge**	**Flooding (fluvial / river)**	**Flooding (pluvial / surface water)**	**Flooding (groundwater)**	**Extreme heat**	**Extreme cold**	**Wildfire**	**Drought**	**Extreme wind**	**Light-ning**	**Hail**	**Natural landslide**	**Engineered slope failure**	**Fog**	**Coastal erosion**
Present-day	OPW TII Flood Risk to Roads	OPW TII Flood Risk to Roads	TII Flood Risk to Roads	OPW	TRANS-LATE	TRANS-LATE	'Think Hazard' tool	TRANS-LATE	CORDEX – to be investigated			GeoHive	Potential to use Arup/UCD research into failure mechanisms		OPW
Future with climate change	OPW	OPW	TII Flood Risk to Roads		TRANS-LATE	TRANS-LATE		TRANS-LATE							OPW

Key climate data gaps:

- Currently, official sources do not have future climate projection data for lightning, hail and fog – this was expected as it is internationally recognised that there is low confidence in the current modelling of these hazards. It is therefore proposed that these hazards are not taken forward for this assessment. However, there is potential for a wider literature review to inform a more 'qualitative' assessment of the potential impact from these hazards. It is important to note that the modular approach to climate risk assessment facilitates future inclusion of these additional climate hazards to the assessment.
- There is no future climate projection data for groundwater flooding, wildfire or natural landslides, which was anticipated. It is proposed to assess for present-day only, or qualitative description from literature review as to how frequency may increase/decrease.

2.3.4 – Data review: climate hazard data

Gather Data

The data review has identified the following key sources of climate data:

- **Office for Public Works (OPW)[7]:** Fluvial and coastal flooding and coastal erosion maps.
- **TII Flood Risk to Roads[8]**: Some coastal, fluvial and pluvial flood maps have been developed by JBA Consulting. A screenshot of the spatial platform for these maps, hosted by TII, is shown in Figure 6.
- **TRANSLATE[9]:** This will form the latest 'off the shelf' climate projections for Ireland, developed by Met Eireann. This will include a wide range of indicators in spatial format (e.g. number of icing days, number of days with max. temp > 25^{o}C), but primarily for temperature and precipitation. This data will improve on data currently available to view (but not download) from Climate Ireland's Data Explorer.
- **Think Hazard tool[11]:** Wildfire susceptibility mapping for the present-day.
- **GeoHive:** natural landslide susceptibility mapping from the Geological Society of Ireland[12].

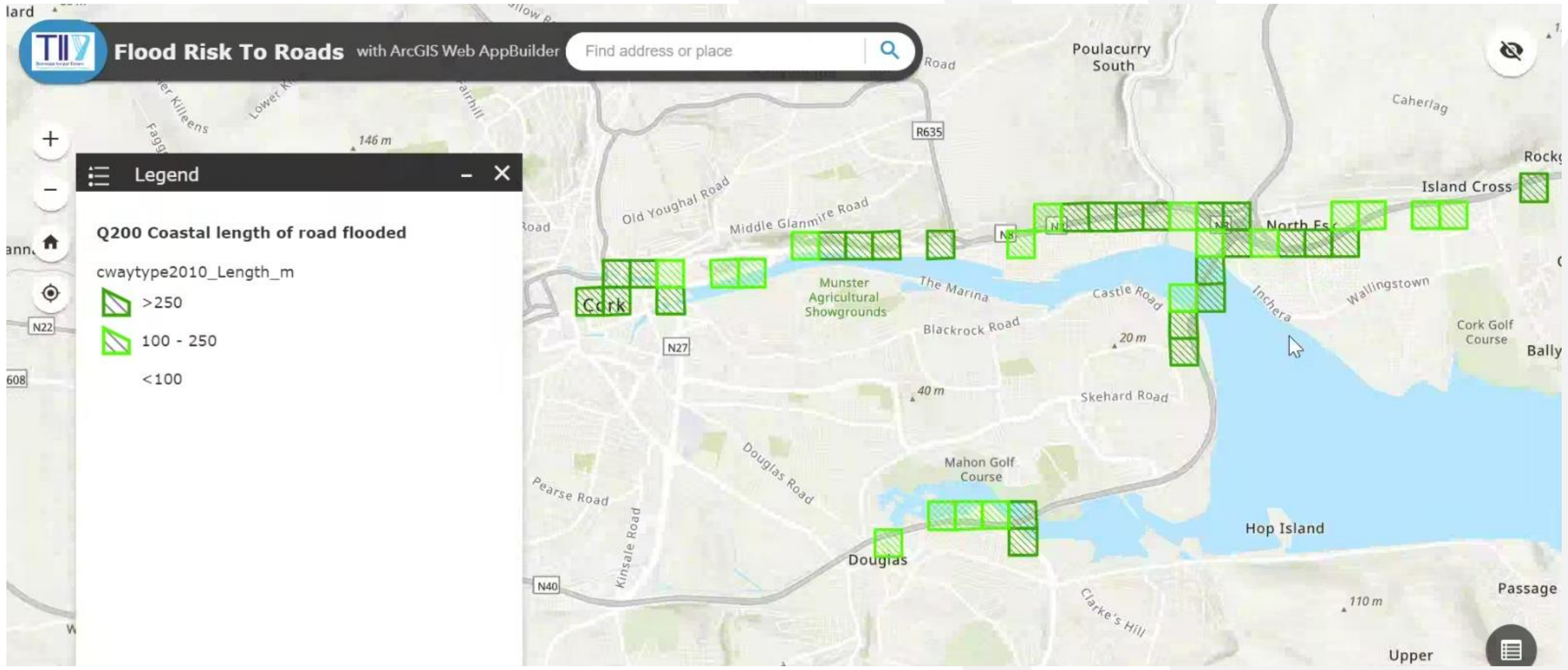


Figure 6: TII Flood Risk To Roads – spatial risk data shown on an ArcGIS web map.

[10] OPW (2019) Flood Maps. Available: https://www.floodinfo.ie/map/floodmaps/.

[11] JBA Consulting (2013) Assessment and Management of Flood Risks at a Structural Level on the National Road Network - Delivery Report.

[12] Met Éireann (n.d.) TRANSLATE. Available: https://www.met.ie/science/translate.

[13] Climate Ireland (n.d.) Climate Data Explorer. Available: https://climateireland.ie/#!/tools/climateDataExplorer.

[14] GFDRR (2020) Think Hazard - Ireland - Wildfire. Available: https://www.thinkhazard.org/en/report/119-ireland/WF.

[15] Geological Society of Ireland (2022) *Landslide Susceptibility Classification 1:50,000 Ireland ITM* | *GeoHive Hub.* Available: https://www.geohive.ie/maps/66569e7d878744a69169ab8c422b8720/about.

2.3.5 – Data to be gathered

Gather Data

The climate data review has identified that some data is available for several climate hazards, including a range of different climate scenarios. However, there remain some unknowns about what this data will potentially look like, especially in terms of relating it to a loss of performance in TII's assets.

From Arup's experience with other clients in undertaking CCRAs, it is recommended that this preliminary phase considers available climate hazard data layers, which can be assessed by asset specialists to explore the data and better understand future trends. This will help identify specific climate hazard thresholds that are directly relevant to asset management and decision-making in Step 6. This will be supported by a literature review of severe weather plans and extreme weather-related components of asset standards, including wider Arup knowledge and experience on CCRA for transport clients globally.

Figure 7 shows the wide range of future climate data being produced by the Met Éireann TRANSLASTE programme. This highlights just three of the decisions that will need to be made to choose which data to use in the detailed CCRAs:

- Different future climate emissions scenarios (e.g. RCP 4.5, RCP 8.5)
- Timeframes: e.g. 2030s, 2050s, 2080s. We would also look to include a present-day or baseline timeframe (e.g. 1981-2010).
- Climate sensitivity: lower, middle, upper

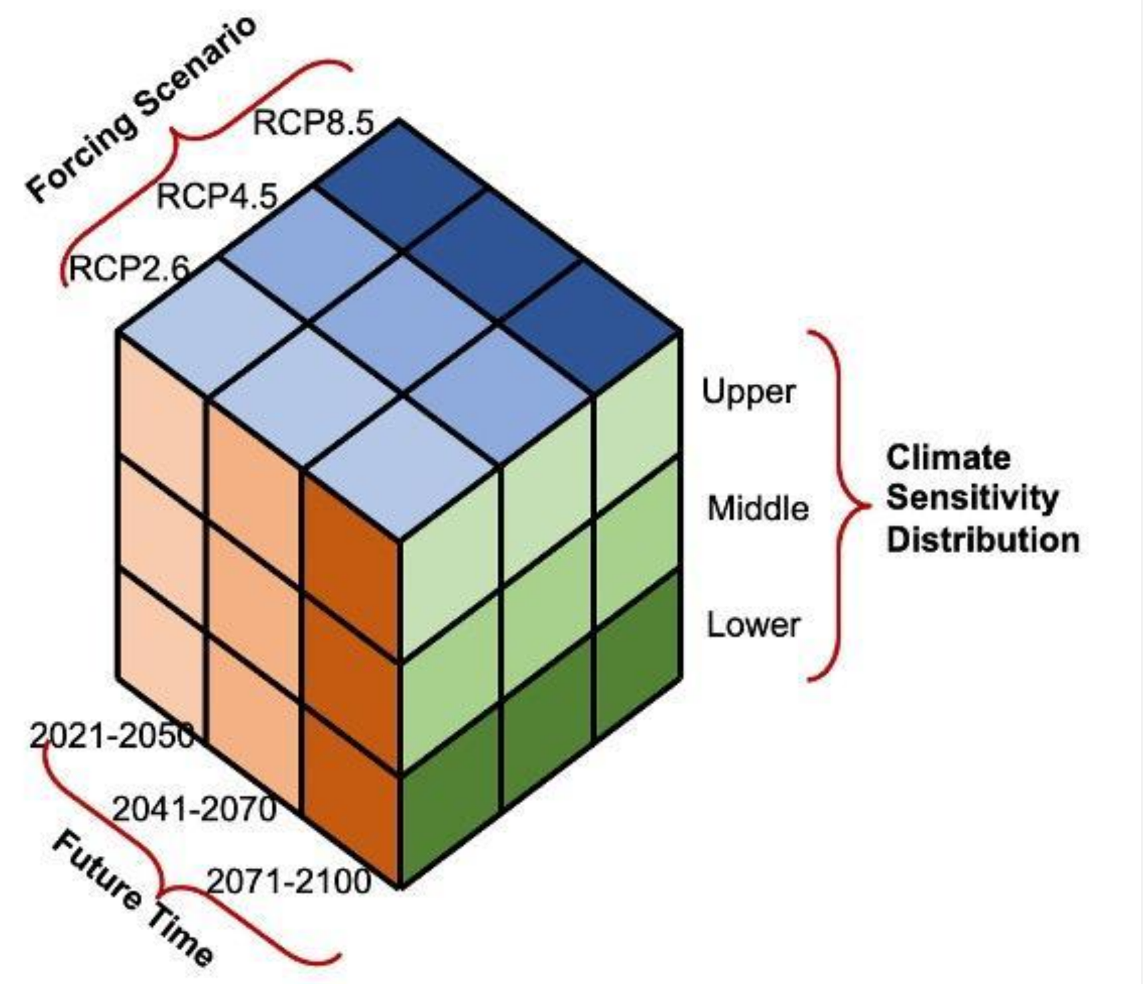


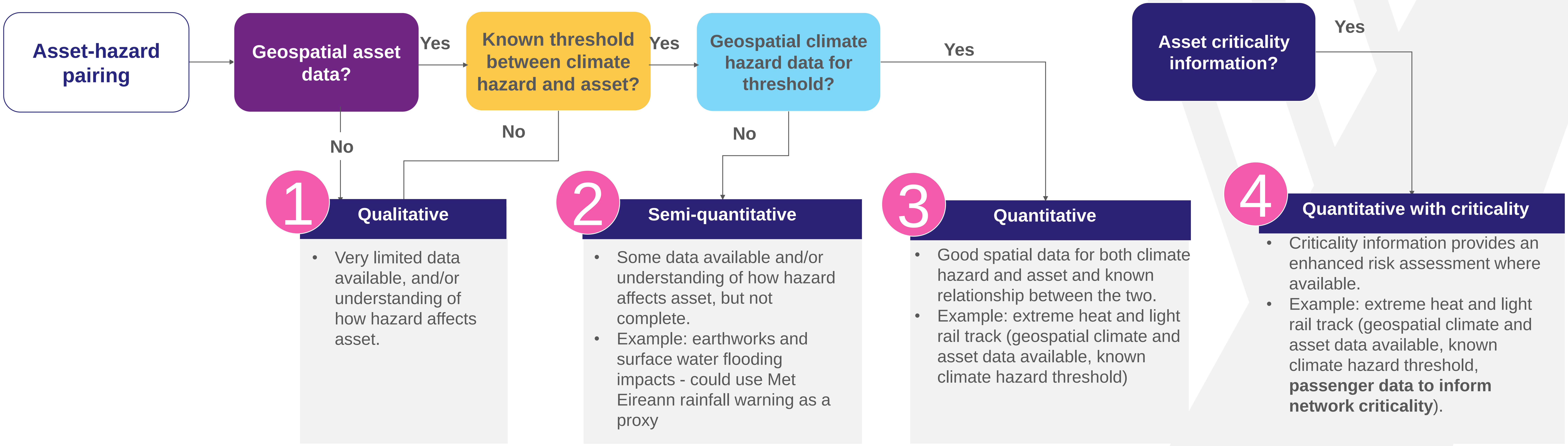
Figure 7: Conceptual matrix diagram showing the range of future climates (time period, emissions scenario and climate sensitivity) under which TRANSLATE climate projection data is being produced.

2.3.6 – Evaluate data availability and understanding of climate risk and consequence

Gather Data

To evaluate all asset-hazard pairings based on data availability and our understanding of the climate impacts, we propose to use the workflow below which assigns all pairings a value from 1 to 4. This will inform the chosen approach to undertaking the climate risk and consequence assessments in the following step.

Workflow



2.3.6 – Evaluate data availability: worked example

Figure 8 provides an example of the geospatial data expected to be used for one asset-hazard pairing.

- **Hazard** – e.g. geospatial grid data. Underlying data shows average annual count of days where maximum temperatures exceed 35ºC. This temperature was specifically identified as a known threshold for the asset being assessed (see section 2.2.2).
- **Exposure** - asset geospatial data (e.g. lines. This could also be polygons/points for discrete assets, such as Luas stops).
- **Vulnerability** - asset geospatial data (different colour lines represent different asset typologies that have different vulnerabilities to the climate hazard)
- **Criticality** - asset geospatial data (different colour lines also contain data on average passenger count)

Evaluating this data against the previous workflow:

Geospatial asset data? ✓

Known threshold between climate hazard and asset? ✓

Geospatial climate hazard data for threshold? ✓

Asset criticality information? ✓

Risk

4

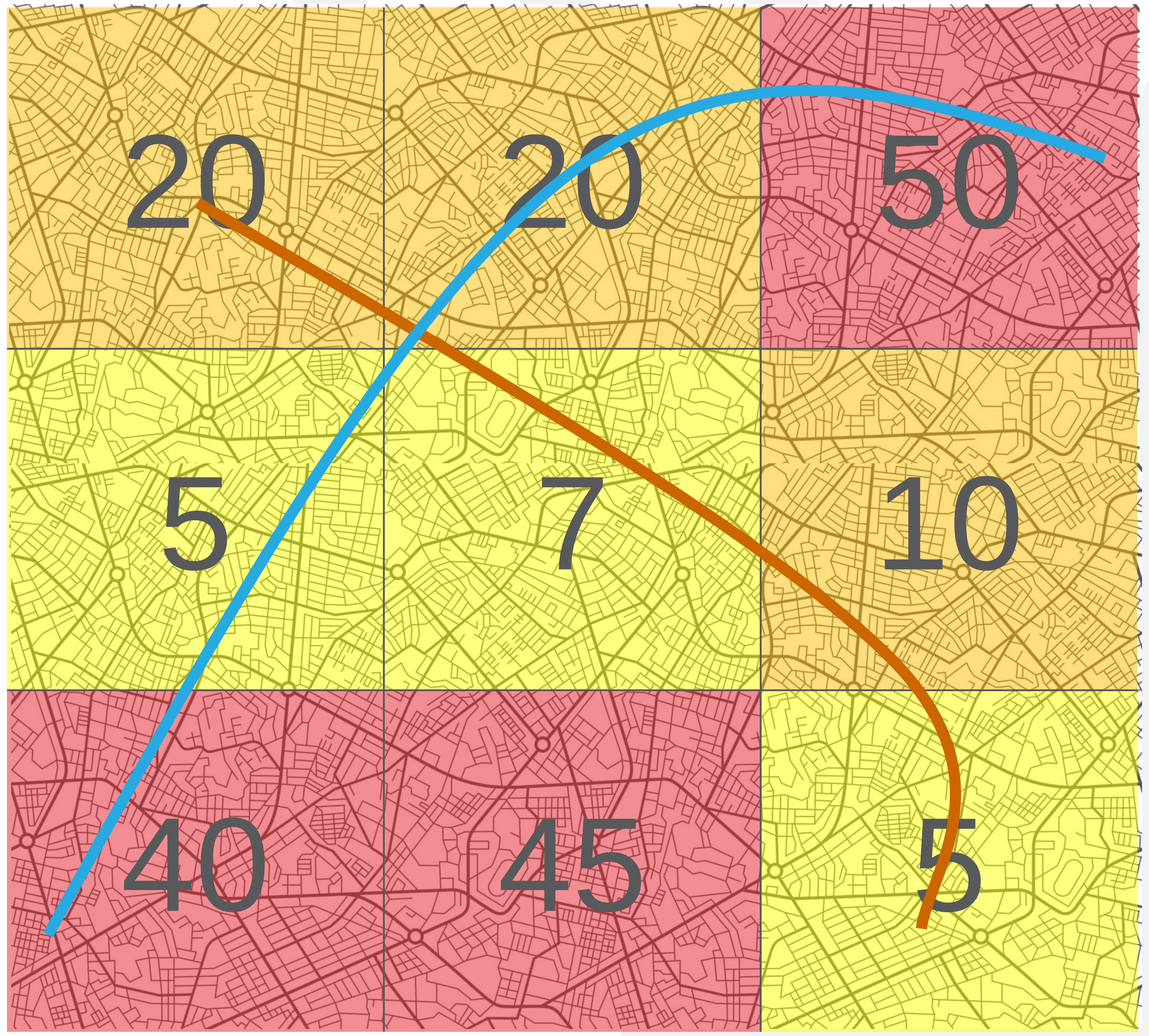


Figure 8: Mock-up of geospatial data expected for one asset-hazard pairing.

2.3.7 – Engagement and outputs

Gather Data

This step of the detailed CCRA involves the following engagement activities:

- Given the uncertainties associated with data availability and the potential impacts to methodology, it will be important to engage with other climate risk assessment experts. We anticipate this will be in the form of Arup 'Design Technical Review' meetings (1 per asset group).
- We anticipate having several regular meetings with the asset managers, to help provide the team with asset data and discuss the potential climate data to be gathered and used in the detailed CCRAs. For roads, this meeting will be with the Network Management Working Group (9-10 people).
- We would also hold three Steering Group Meetings, during which we would present the proposed approach (1 for light rail, 1 for national roads, 1 for other 3 groups).
- We will also engage with and request data from providers such as OPW and Met Eireann.

Outputs:

a) 5 x database of climate hazard data layers (1 per group)
b) 5 x database of asset data (1 per group)
c) 5 x Excel-based summary for all priority asset-hazard pairings showing their data availability, a summary of data gaps and proposals for how these gaps could be filled and approach to CCRA (1 per group)

2.4.1 – Assess climate change risks

Using the understanding of data availability obtained in the previous step, this final step aims to make best possible use of the available data to provide a robust assessment of climate risks to each of the priority asset-hazard pairings. The risk and consequence for each priority pairing will be assessed, through examining the details of the hazard, exposure, vulnerability and criticality of each pairing.

Where possible, a full climate risk assessment would be undertaken for each prioritised asset-hazard pair. This will make use of geospatial processing tools. However, it is likely that for several asset-hazard pairs, this will not be possible at present. Therefore, a more qualitative approach will need to be taken. Gaps in data to support the full risk assessment will be identified which can be used to prioritise activities going forward as part of the development of a climate change adaptation plan.

Alongside undertaking the assessment, a clear record of how each asset-hazard pairing has been assessed will be recorded.

Risk = **Hazard** × **Exposure** × **Vulnerability**

2.4.2 – Hazard assessment

The hazard assessment considers the likelihood of a climate-related hazard event affecting assets/networks. The previous step will have evaluated whether there is climate hazard data of direct relevance for each of the assets and/or networks, and gathered the most applicable data. Section 2.4.5 demonstrates the differences in methodology associated with different types of hazard data.

In this hazard assessment stage, the climate data could be categorised into high/medium/low hazard ratings. Some examples of how to do this:

- Number of average days per year above a threshold. Example shown in Figure 9.
- Return periods under which assets are exposed. An example for flooding:
    - Low = asset sits outside of flood risk area.
    - Medium = asset sits in a flood risk area but likelihood of event is very low (e.g. return period is 1 in 1000 years).
    - High = asset sits in a flood risk area which is likely to flood (e.g. return period is 1 in 100 years).
    - Very High = asset sits in a flood risk area which is expected to flood (e.g. return period is 1 in 30 years).

When assigning high/medium/low hazard ratings, it will remain important to capture the relative scale of hazards between hazard types (e.g. if flooding is the largest hazard for TII, this should come through during the hazard assessment). Undertaking a quantitative approach across hazards would allow a more robust comparison.

20	20	50
5	7	10
40	45	5

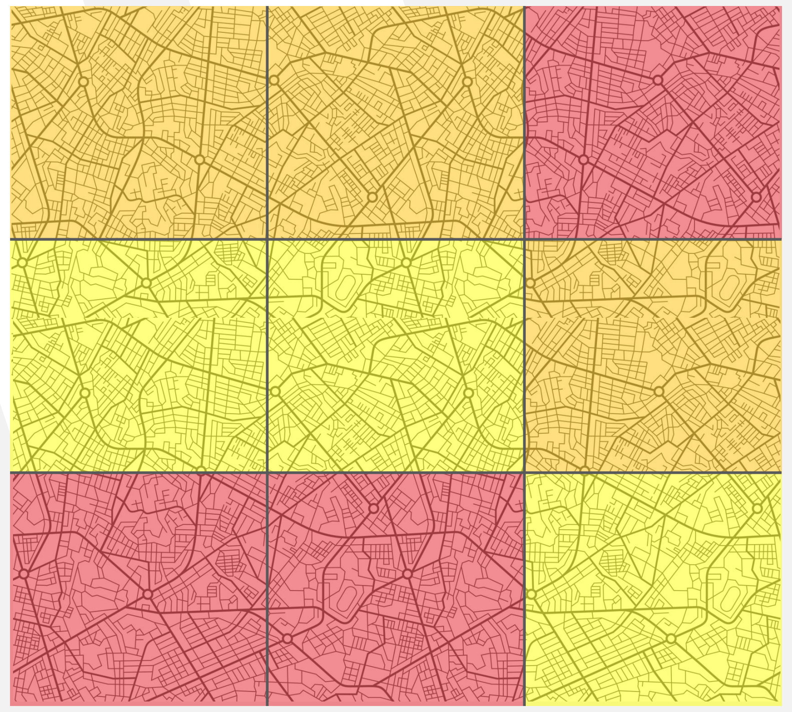


Figure 9: Worked example data – categorizing underlying climate data into 3 equal interval bands (low = yellow, medium = orange, high = red).

2.4.3 – Exposure assessment

Assess climate change risks

An exposure assessment identifies the presence of relevant assets (such as people, environmental functions, infrastructure, or other assets) in places and settings that could be adversely affected[8].

Where spatial data is available, exposure assessment will consist of identification of the asset locations, their geometries and elevation.

Where no spatial information is available, the exposure assessment will be carried out through engineering judgement informed by interviews with asset specialists and literature review.

Adapted from: [8] IPCC (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

2.4.4 – Vulnerability assessment

Assess climate change risks

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We define vulnerability as 'the propensity of exposed elements such as […] assets to suffer adverse effects when impacted by hazard events'[16]. To better understand assets' vulnerability to climate-related events, we will:

- Determine the characteristics and condition of the assets. This can come from asset management databases, where present.
- Where specific asset data is not available, we will meet with asset specialists to understand the variations in assets that may make some more/less vulnerable.
- We will carry out a review of international best practice such as the CEDR ICARUS report on impact chains[17] to document how asset components may be vulnerable to climate hazards.
- Quantitative vulnerability functions, where available in the literature, will be assessed for suitability for use in this assessment (e.g. shown in Figure 10).

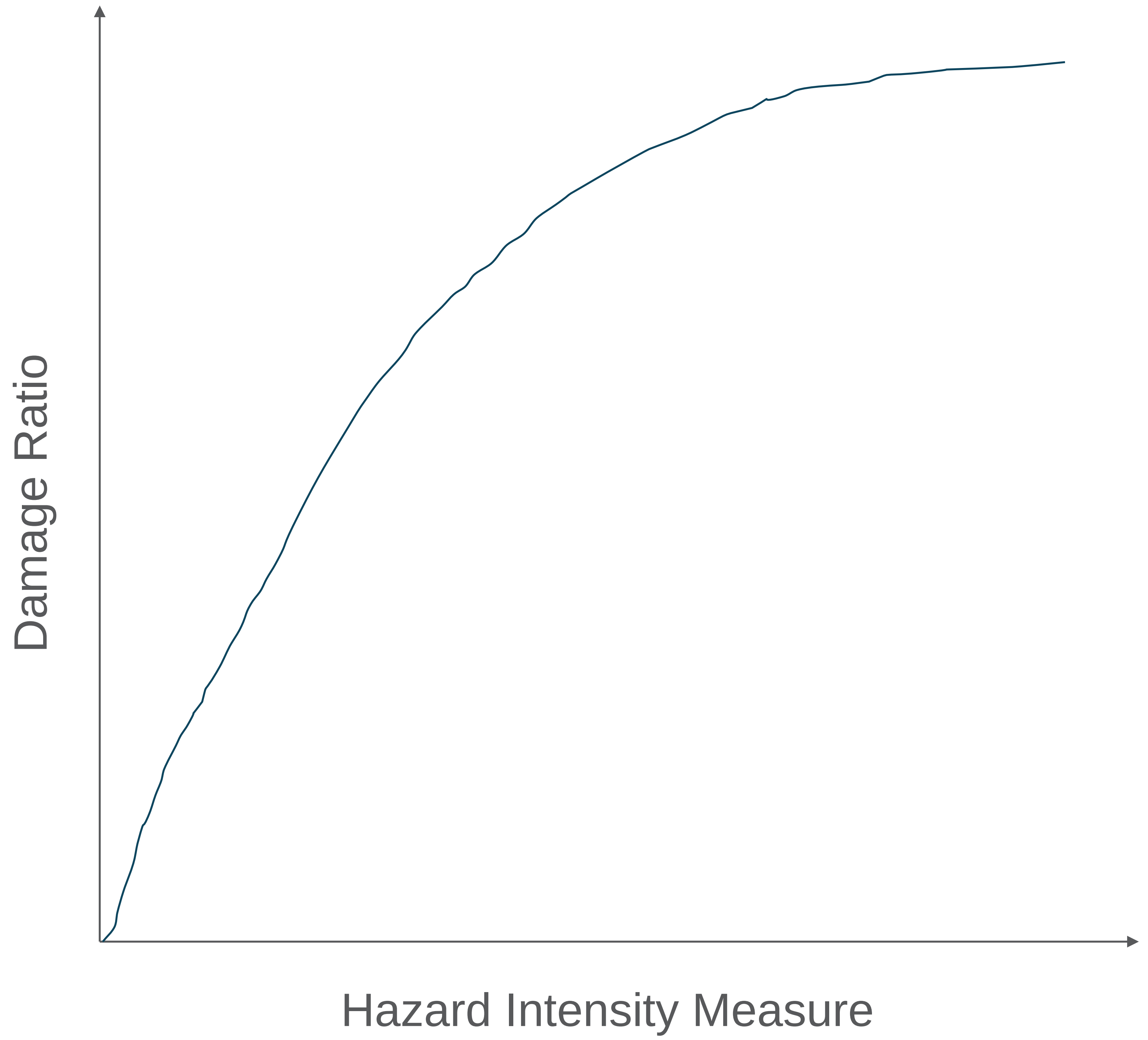

Figure 10: Example graph showing level of damage done by a hazard of varying intensity.

[16] Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation[Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108. https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/determinants-of-risk-exposure-and-vulnerability/

[17] CEDR (2023) ICARUS D1.2 – Report on impact chains, vulnerability and hazard classification.

2.4.5 – Risk assessment: different methods based on different data availability

Assess climate change risks

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The three categories below were used in Step 6 (Identify climate change risks), to evaluate each asset-hazard pairing based on the climate hazard data availability. Here, we show how these three categories translate to four different detailed climate change risk assessment methods.

	1	2	3	4
Data availability	• Very limited data available, and/or understanding of how hazard affects asset • *Example: wildfire impacts*	• Some data available and/or understanding of how hazard affects asset, but not complete, or threshold/relationship not known. • Example: earthworks and surface water flooding impacts - could use Met Eireann rainfall warning as a proxy	• Good spatial data for both climate hazard and asset and known relationship between the two. • Example: extreme heat and light rail track (geospatial climate and asset data available, known climate hazard threshold	• As in 3, but with additional criticality information to inform vulnerability / exposure. • Example: extreme heat and light rail track (passenger data to inform network criticality).
Method name and type	**Risk assessment method 1:** Qualitative climate trend assessment without asset data	**Risk assessment method 2:** Semi-quantitative spatial climate trend assessment with asset data	**Risk assessment method 3:** Quantitative spatial climate hazard assessment with asset data	**Risk assessment method 4:** Quantitative assessment with criticality information
Relative confidence in hazard assessment	If available, use climate hazard data layers to see how hazard is projected to change across Ireland. *Collaborate with TII asset specialists to develop geospatial asset data and ascertain understanding of how climate hazard would impact asset. Collaborate with geospatial hazard data providers to produce asset-relevant data*	Spatial assessment of how climate hazard is projected to change and how this may affect assets, including which assets may be more vulnerable based on their geographic location. *Research needed to understand threshold, and collaborate with geospatial hazard data providers to produce asset-relevant data.*	This will involve overlaying the geospatial climate data and asset data, to identify the overall risk exposure across Ireland, as well as identify key hazard 'hot spots'.	This will involve overlaying the geospatial climate data and asset data, to identify the overall risk exposure across Ireland, identify key hazard 'hot spots' and where these intersect with critical parts of the network.
	Low confidence	Medium confidence	High confidence	High confidence

2.4.6 – Risk assessment: worked example

Assess climate change risks

This worked example links to that evaluated in the previous stage, and therefore uses the CCRA method 3.

Hazard

Underlying data (numbers in the grid cells) shows average annual count of events where maximum temperatures exceed 35ºC. Have been categorised into 3 equal interval bands.

- Yellow (low): rating = 1
- Orange (medium): rating = 2
- Red (high): rating = 3

×

Exposure

- All lines are exposed to hazard (rating = 1)

×

Vulnerability

- Blue line is less vulnerable as asset typology used is more heat resistant (rating = 1)
- Brown line more vulnerable as asset typology used is known to wear more during extreme heat events (rating = 3)

=

Risk

- Maximum rating: 6, brown line in orange cells = 2 (hazard) x 1 (exposure) x 3 (vulnerability)
- Minimum: 1, blue line in yellow cells = 1 (hazard) x 1(exposure) x 1 (vulnerability

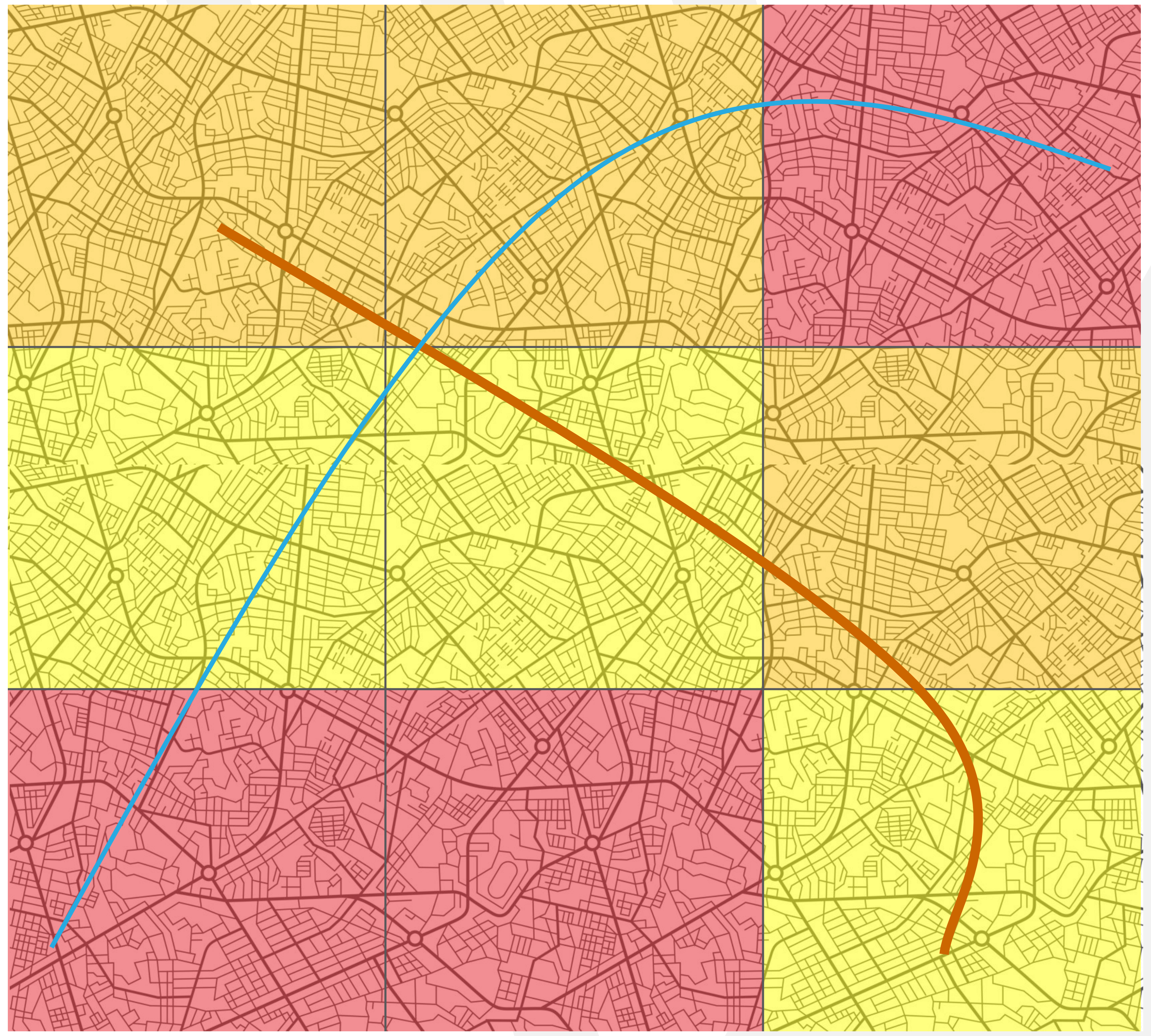

Figure 11: Mock-up of geospatial data to assess for one asset-hazard pairing.

- **Hazard** - geospatial grid data
- **Exposure** - asset geospatial data (lines)
- **Vulnerability** - asset geospatial data (different colour lines represent different material)
- **Criticality** - asset geospatial data (different colour lines also contain data on average passenger count)

2.4.7 – Criticality assessment

Assess climate change risks

Criticality is the relevance of an infrastructure element or section to the availability of a road infrastructure system. Criticality can be physical, functional or social[18]:

- **Physical** concerns the economic consequences such as loss or damage to the element in question.
- **Functional** concerns the operational consequences that loss or damage would represent, and that impact connectivity or mobility.
- **Social** concerns the social characteristics in the area around the element, e.g. for TII the “lifeline roads” which provide access to people, jobs and services irrespective of demand.

The parallel TII Resilience Task (1.8f) has carried out a spatial criticality assessment of the national roads network (e.g. Figure 12). This includes assessment by the network management team of locations of most concern to them. The criticality takes into consideration the management of the network through inclusion of their views. At the next stage where adaptation options are assessed, management of the network will be a primary consideration.

For a non-spatial criticality assessment, engagement with asset specialists and others within TII, as well as literature review, is required.

Figure 12: Redundancy analysis of the Motorway and National Primary road networks that forms part of the criticality analysis[19].

[18] PIARC (2023) *International Climate Change Adaptation Framework.* World Road Association, France.

[19] Arup for TII (2023) *National road network critical links – draft technical note, issue 3*

2.4.8 – Storing and managing the climate risk assessment data

Assess climate change risks

We anticipate the scale and size of the climate and asset geospatial data to be significant, covering a range of:

- **Climate hazards**
  - Different future climate emissions scenarios (e.g. RCP 4.5, RCP 8.5) or warming levels (e.g. 1.5ºC, 2ºC, 4ºC)
  - Timeframes: e.g. present day or baseline, 2050s or mid-century, 2080s or end-century
- **Assets** (e.g. like those outlined in Figure 14)

As such, there will be a need to consider the most appropriate technology solution for processing, storing and managing this data. It may be that data could be stored into TII's existing GIS system. Alternatively, Arup has a commercial agreement with Amazon Web Services (AWS), who can provide a 'cloud' based platform for undertaking the processing and storage of large amounts of geospatial data. The 'trial' phase of the project will help determine what this will look like in practice.

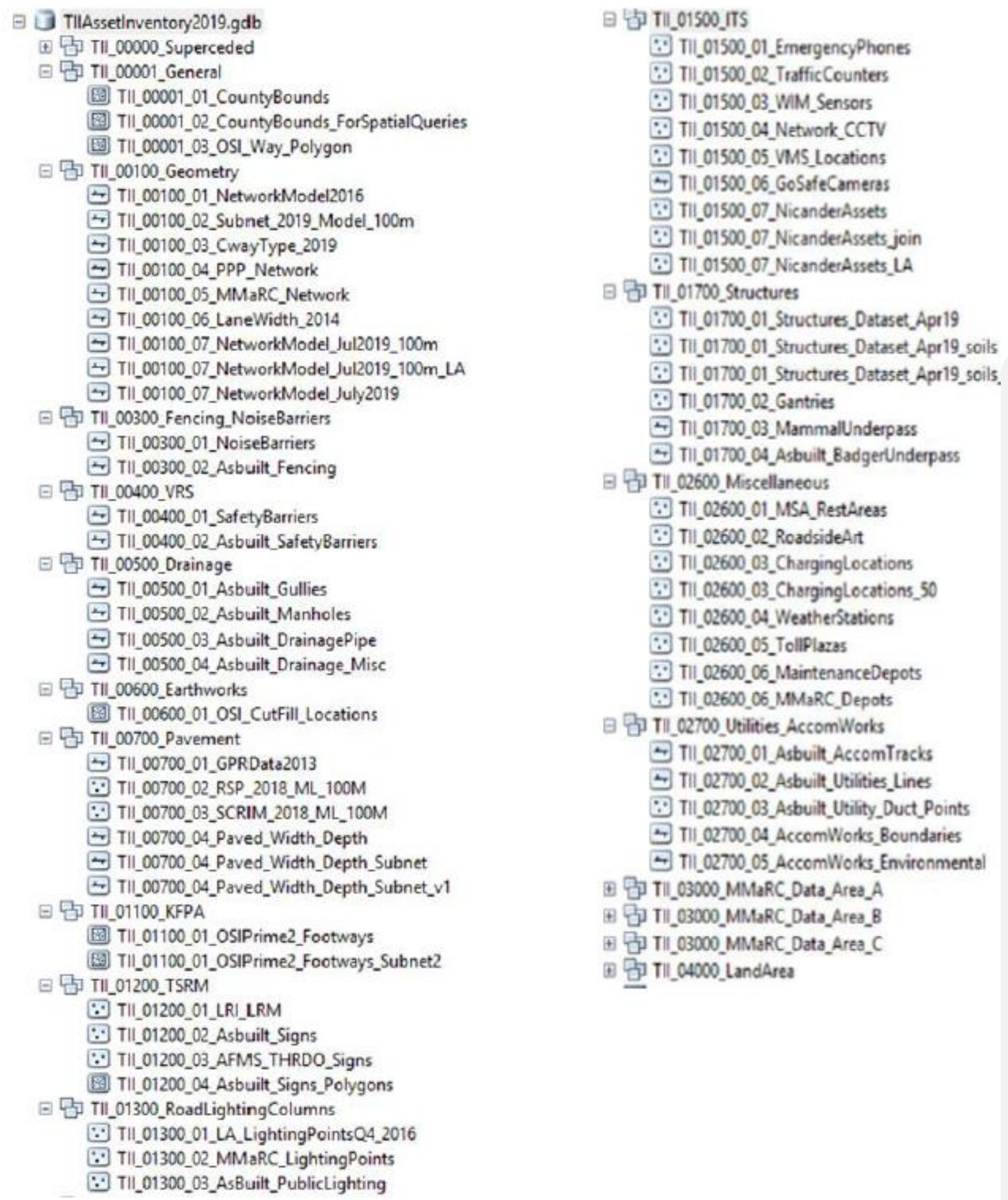

Figure 14: National Roads – extract of geospatial database presented in Asset Management Strategy[20].

[20] Transport Infrastructure Ireland (2021) *AM-GEN-00002-01 Asset Inventory (Roads) – Summary Report.* TII Publications, Dublin.

2.4.9 – Engagement

Assess climate change risks

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During this phase, we anticipate there will be a need for significant engagement with asset/network specialists.

- We propose, for each of the five asset groups, three meetings with the TII asset project manager – one each for hazard, vulnerability and criticality, making a total of 15 meetings. For roads, this meeting will be with the Network Management Working Group (9-10 people).
- In addition, we propose six Steering Group Meetings – two each for (i) roads, (ii) light rail, and the other three asset groups (buildings, land and greenways and cycleways)

To gather best practice from other Arup teams and regions, we propose to have five Arup design technical review meetings, inviting asset and climate risk experts to review and input to the method approaches (one per asset group).

2.4.10 – Outputs

Assess climate change risks

We see the following outputs as the final deliverables of the detailed climate change risk assessment process:

Outputs:

(a) Spatial map of current climate hazard where data available
(b) Spatial map of future climate hazard where data available
(c) Where possible, processed **'climate risk' geospatial data layers** that combine hazard, exposure and vulnerability assessment data.
(d) Suite of static maps to present the findings of the various hazard, risk and consequence data layers.

Hazard

Risk

2.5.1 – Visualise climate change risks

We believe it is vital the results of the detailed CCRA can be visualised via a user-friendly dashboard. This will allow a range of end users, including asset specialists, to access and engage with the data at the right time for them (e.g. to inform asset management planning, MMaRC contract development).

Before this dashboard / platform begins to be developed, we recommend significant engagement with the TII geospatial information systems (GIS) team, to understand best options for hosting this. For example, it could link in with existing GIS databases, such as the TII Flood Risk to Roads map. We also believe it is vital to engage with TII asset specialists and decision-makers, to understand their requirements from the platform.

Figure 15 is a ‘strawman’ example of what the final dashboard could look like. The drop-down options on the left-hand side would provide the user with the opportunity to filter down what is shown on the map output. This includes:

- **Asset group:** to shorten the list of assets in following option. *Examples of options: light rail, national road etc.*
- **Asset:** to only show data for specific asset within the asset group. *Examples of options: pavement, structures, lighting etc.*
- **Climate hazard:** to show specific asset-hazard pairing. *Example of options: extreme heat, flooding (fluvial), natural landslides etc.*
- **Hazard or risk:** allows the user to choose whether they want to see just the climate hazard data with asses overlaid, or if they want to show the climate risk scores, calculated using the risk equation: risk = impact x vulnerability.
- **Management of the network:** allows the user to filter data by who manages the network. For example, the national road network is managed by TII, PPPs, Local Authorities.

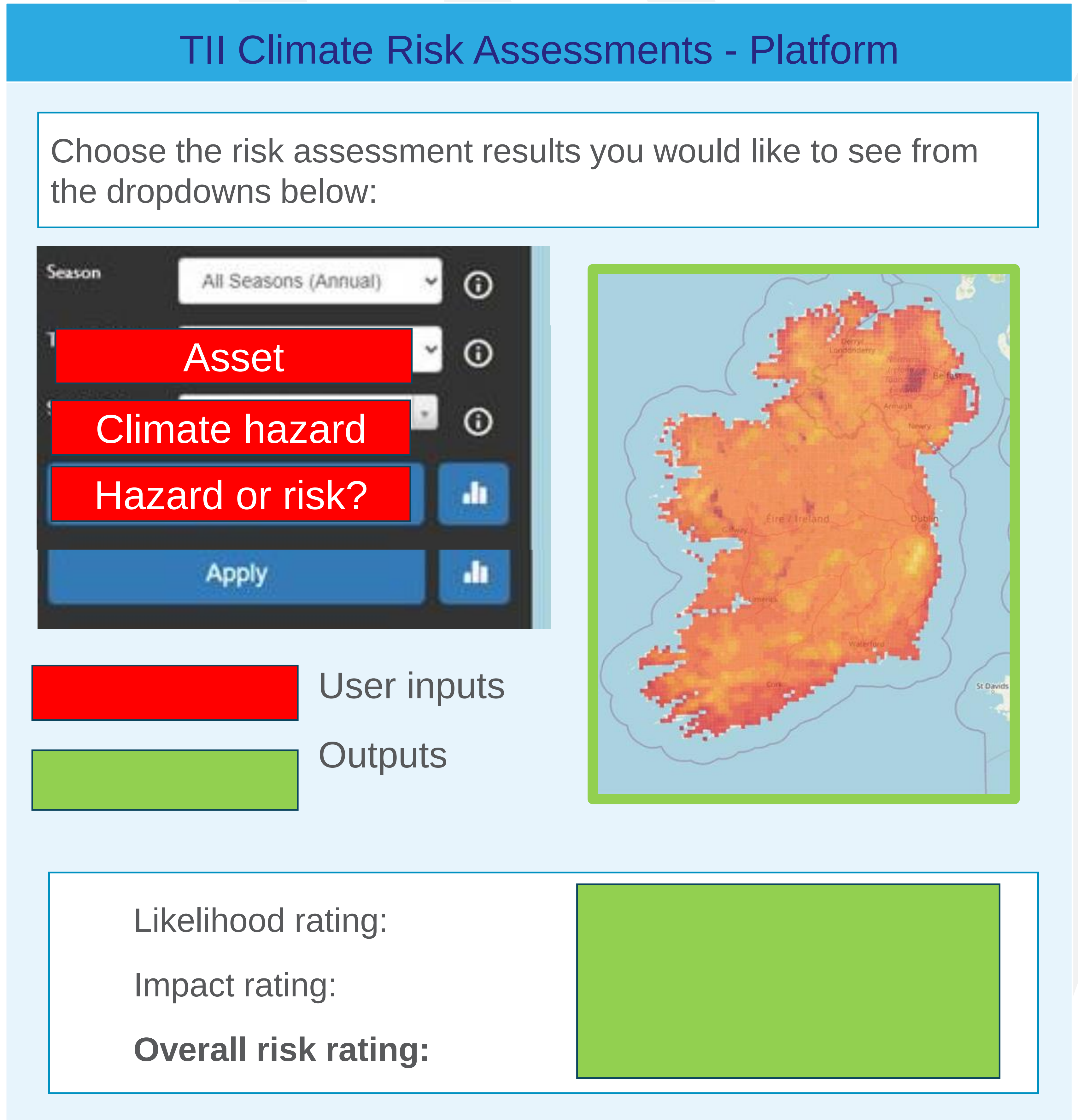
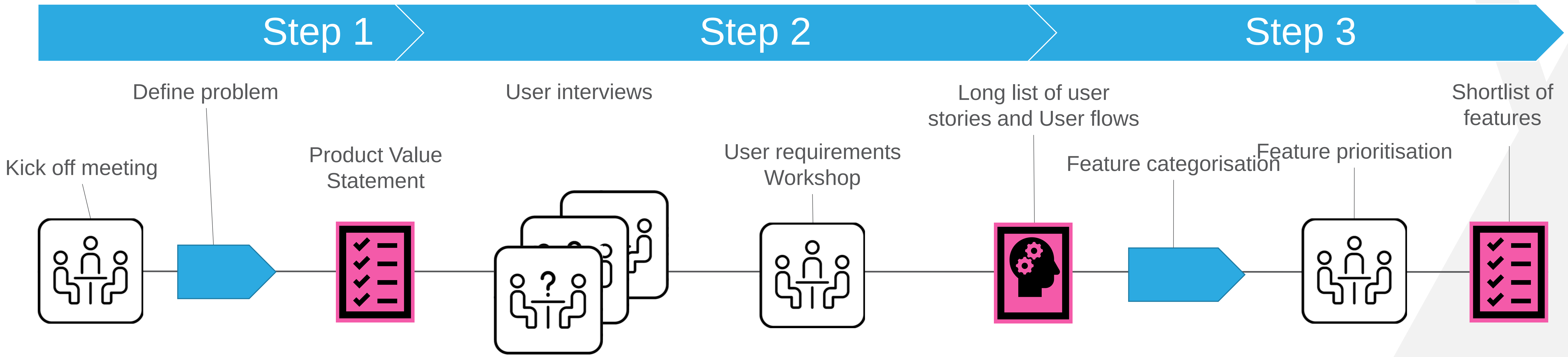


Figure 15: Draft mock-up of climate risk assessment dashboard / platform.

2.5.3 – User needs assessment

Before creating the dashboard and final outputs from the detailed CCRAs, a user needs assessment should be carried out to define the requirements. This initial output will define how to build a functional and effective digital product, enable the detailed CCRAs to feed into future work (e.g. the climate adaptation implementation plans) and support wider asset management efforts.

- Step 1: Define the problem. There needs to be a clear, shared understanding of what the problem is so that everyone involved is talking about the same thing. This will be the focus of the kick-off meeting. Output: **Product value statement**.
- Step 2: Understanding user requirements. This step will answer questions such as: Who is our target user? Are there multiple user types? What information do they need to make decisions? What are they familiar with/what are they expecting? What is the right level of detail? When and where will they be using this product? How will the user move through the tool? How do they get from the home screen to the information they're looking for? Output: **Longlist of user stories** and **User flows**.
- Step 3: Feature prioritisation. The features gathered from the users are categorised and through a workshop are prioritised. Output: **Shortlist of features and summary of required outputs from the detailed CCRAs.**



2.5.3 – Outputs

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We see the following outputs as the initial deliverables for the visualisation:

Outputs:

(a) Product value statement **report** for a dashboard, currently proposed to visualise and interrogate the climate change risk assessment data and information.
(b) Excel-based **database** of user stories and **report** on user flows.
(c) **Report** containing a shortlist of features.

2.6 - Reporting

In addition to any technical notes listed as outputs in the previous stages, we see the following reporting outputs as key deliverables to summarise and communicate the findings from the detailed climate change risk assessments:

Outputs:
(a) 5 x summary report of climate risk (1 per asset group)
(b) 1 x Technical Report
(c) 5 x presentations to Steering Group and Asset PM (1 per asset group)
(d) 5 x presentations to Sustainability Assurance Board (1 per asset group)
(e) 5 x accessibility text for summary reports (1 per asset group)

2.7 - Governance

Additional members will be added at later stages when specific expertise are required

Steering Group

Chair of Steering Group

Arup project team

Climate Adaptation Reviewer

Road

Light rail

Cycleways & greenways

Land

Buildings

People

Adaptation Costings

€

Anthony Duffy

Internal Network Management Working Group

3. Programme and actions

The actions included in TII's Climate Adaptation Strategy were accompanied with some outline timelines (Table 5), to guide the organisation towards delivering its six-stage approach within the proposed five-year cycle that commenced with the publication of the Strategy in December 2022.

The next page presents a proposed programme, summarising how the steps outlined in this detailed CCRA methodology could be delivered in line with the Strategy timelines.

Action No.	Action	Indicative Dates
0	Publish TII's *Climate Adaptation Strategy.*	December 2022
1	1.1 Develop governance and resourcing requirements.	Commence in Q1 2023
	1.2 Complete climate screening (see Stage 2 of TII's climate adaptation approach in Section 5.2) for National Roads, light rail, greenways and cycleways, land, buildings, and people.	In progress Complete by Q1 2023
	1.3 Identify priority climate hazards through climate screening (see Stage 3 of TII's climate adaptation approach in Section 5.3) for National Roads, light rail, greenways and cycleways, land, buildings, and people.	In progress Complete by Q2 2023
2	Undertake a more detailed climate risk assessment for all climate hazards identified as priorities (see Stage 4 of TII's climate adaptation approach in Section 5.4).	Dependent on completion of Action 1 Complete flood risk assessment for National Roads Complete by Q4 2024
3	Develop and implement climate adaptation implementation plans (see Stage 5 of TII's climate adaptation approach in Section 5.5). These plans will include estimates of resourcing, time frames, measurement, and monitoring of proposed adaptation measures.	Dependent on completion of Action 2 Commence in Q1 2025
Partnerships & Research		
4	Provide support to the Department of Transport with its upcoming Transport Climate Change Sectoral Adaptation Plan.	Ongoing
5	Continue TII's working relationship with Climate Ireland and University College Cork (UCC) to support the definition of a final list of climate resilience indicators. This will support Action 3.	To commence in 2023
6	Continue engagement with Met Éireann's TRANSLATE project. [14]	Commenced in Q3 2022 and due to be complete by Q2 2023
7	Continue TII's working relationship with climate-focused groups, including, but not limited to, the Conference of European Directors of Roads (CEDR), the Urban Transport-Related Air Pollution (UTRAP) Working Group, the European Union Committee on Transport and Tourism (TRAN), and the International Association of Public Transport (*Union Internationale des Transports Publics*; UITP).	Ongoing

Table 5: TII's Climate Adaptation Strategy actions and timelines[1].

[1] Transport Infrastructure Ireland (2022) *Climate Adaptation Strategy 2022.* TII Publications, Dublin.

3.1 Proposed programme

As identified as a key lesson learnt on other portfolio-scale geospatial climate risk assessments, we recommend testing our proposed CCRA methodology on two of TII's asset groups (road and light rail), before 'rolling out' across the other three asset groups: greenways, land and buildings.

It will also be important to set out the governance for this work going forward. It is assumed to keep the same project managers as set out in the Climate Impact Screening. However, the project would also benefit from a steering committee to check and challenge the approach, set the needs for the outputs and to sign off on deliverables/outputs. The programme has been developed to reflect this. First drafts of the CCRA are expected to be drafted by the end of Q4 2024, which aligns with the timeframe for the action set out in TII's Climate Adaptation Strategy. This indicative programme is subject to TII governance in place prior to project commencement.

Table 6: Indicative high-level draft programme for delivering detailed climate change risk assessments.

Time	2024												2025		
	Q1			Q2			Q3			Q4			Q1		
Category	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25
Methodology development	Sign off CCRAs method														
Governance	Sign off task order			Steering group meeting		Steering group meeting		Steering group meeting		Steering group meeting		Steering group meeting			Sign off detailed CCRAs
Asset specialist engagement	Regular engagement with asset PMs throughout												Sign off detailed CCRAs		
Light rail		Establish scope and boundaries	Identify climate change risks and gather climate data		Assess climate change risks										
National roads		Network Management engagement	Establish scope and boundaries	Identify climate change risks and gather climate data			Assess climate change risks								
Greenways													Start detailed climate change risk assessment		
Land															
Buildings															
People	People detailed CCRA already complete														
Visualise	Scope visualisation tool			Dashboard or platform development to host climate risk assessment process and outputs											
Reporting	Ongoing reporting (e.g. technical notes, presentations) to communicate progress and thought processes												Write up summary reports		

4. Next steps

We propose the next steps for this project to be the delivery of Stage 4 of TII's six-stage approach to climate adaptation (the detailed Climate Change Risk Assessment, or CCRA), including:

1. TII to sign off proposed methodology
2. Arup to develop scope of works for next phase of the project that aligns with the proposed programme
3. TII to agree on governance requirements
4. Further engagement with TRANSLATE and access to climate data/review
5. Engage with TII asset specialists throughout the development of the detailed CCRAs

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Appendices

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Appendix A - Steps involved in development of the proposed methodology

Grounded in best practice literature and available data

To inform the development of the detailed climate change risk assessments (CCRAs) methodology, we have undertaken detailed reviews of:

- Relevant available guidance on undertaking detailed climate risk assessments, including TII's Climate Guidance[5] and Standard[4]
- Available and upcoming climate hazard data
- Available asset data from TII
- Existing TII climate change assessments – TII's 'Flood Risk to Roads'[11] project and collaboration with UCC to understand drainage impacts.
- Research on climate change adaptation being undertaken by the Conference of European Directors of Roads (CEDR), through their ICARUS programme (e.g. Report on impact chains, vulnerability and hazard classification[17]).

These reviews are detailed within the literature and data review in Annex A.

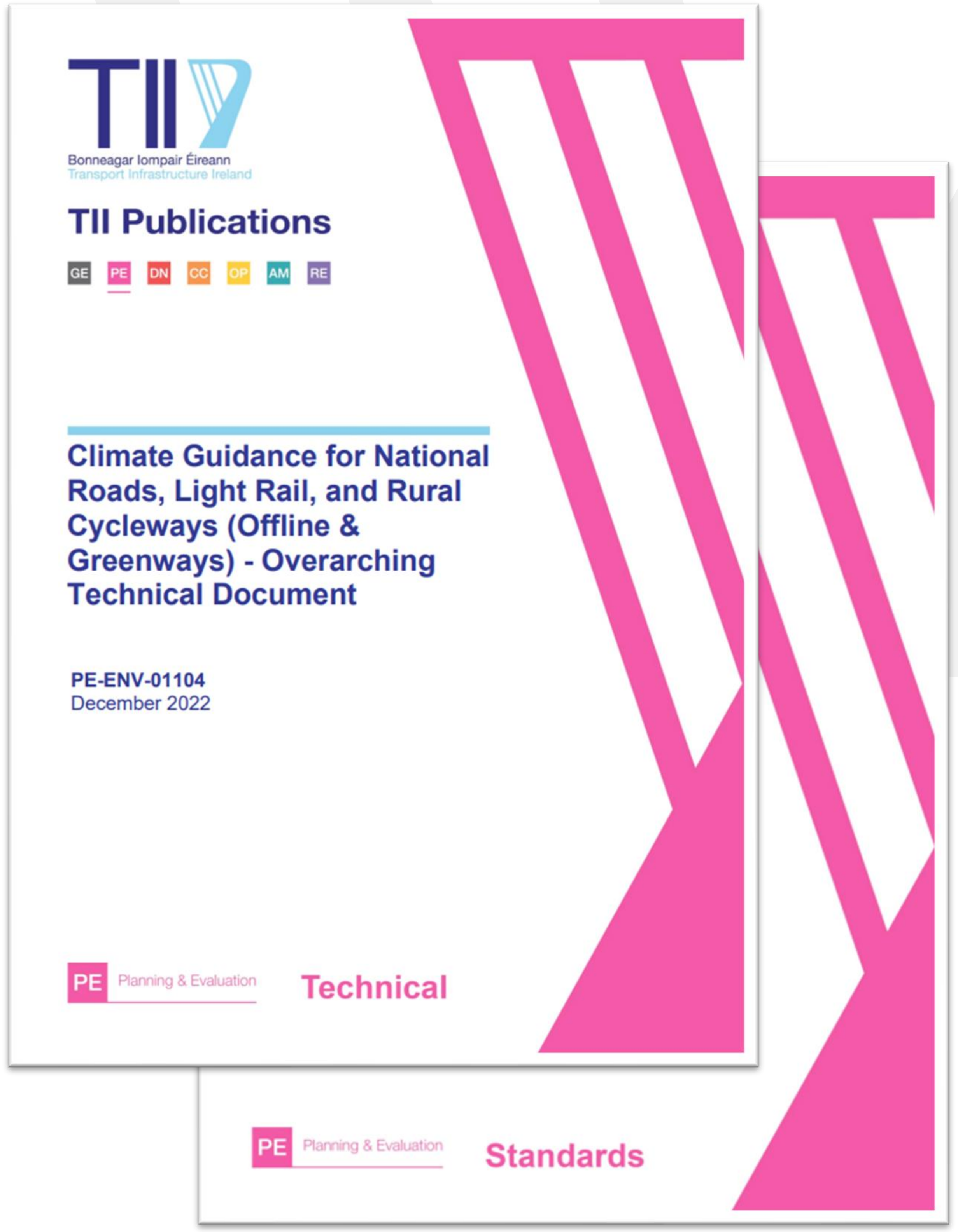

Figure 16: TII's Climate Guidance[5] and Standard[4].

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Learning lessons from Arup's global portfolio of climate risk assessment work

Two 'Design Technical Reviews' were undertaken with Arup specialists who have or are currently undertaking portfolio-scale climate change risk assessments for rail and energy infrastructure organisations in the UK.

Arup specialists who have helped shape our approach

- Dr Juliet Mian, Director - Climate and infrastructure resilience
- Dr Matt Free, Director – Climate and natural hazard risk management
- Pasquale Capizzi, Associate Director – Climate resilience and adaptation
- Dr Lisa Horrocks, Associate – Digital Climate
- Richard Bowden, Associate Director – Digital
- Claire Fitzgerald – GIS

Table 7 summarises the key lessons learnt from this engagement, and how we propose to account for these lessons within the methodology we are setting out in this report.

Table 7: Key lessons learnt from engagement with climate risk and infrastructure experts.

Lessons from other projects	Applying these lessons for TII
Recommended to trial any methodology on a sub-selection of assets.	We propose to trial the methodology with the light rail and national roads asset groups. This prototype should allow a wider group of potential users to see and interact with something more tangible and can increase "buy in" as they see the potential benefits for their area.
Providing asset managers or specialists with climate hazard data – as well as an overall evaluation of climate risk – can be very useful.	We propose to share climate hazard data layers early in the climate risk assessment process to help decision makers and shape the following assessment steps. We envisage this being particularly relevant for climate hazards where the impact to assets is less well-defined, or where climate data is not tailored to the known impact to assets (e.g. extreme wind and wildfire). Additionally, it may help to identify areas where historic climate or weather information is used by asset specialists, that could be supplemented with future climate data to inform asset management decisions (e.g. pavement management). We also propose to enable the final dashboard to show both climate hazard data and risk "scores".
There is often a lack of accessible and/or available relevant climate and asset geospatial data, or in-depth understanding of how climate change may impact assets.	We propose to build the climate risk assessment process in a modular way that facilitates easy updates of independent components when further information or understanding is developed or available.