Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

The Light We Need (2024)

(SAFELUX)

Define (Scope)

Deliverable D2.3

Date 13 January 2026

Start date of project:
1st June 2025

End date of project:
1st June 2027

Author(s) of this deliverable:
Cay Edwards, AECOM
Scott Stephenson, AECOM
Version: 1.0

Content

1 Introduction 5
2 Terminology and conceptual framework for SAFELUX 6
2.1 Key terms 6
2.2 Vocabulary in a simplified hierarchy 7
2.3 Illustrative scenarios 7
2.3.1 Scenario 1: A rural junction near a protected bat habitat 7
2.3.2 Scenario 2: Urban road close to residential area with public concern about safety 8
2.3.3 Scenario 3: Energy-constrained linear motorway segment 9
2.3.4 Scenario 4: Pedestrian crossing on a suburban truck road 9
3 Proposed themes for SAFELUX research, guidelines, and digital tool 11
3.1 Review of the DoRN 11
3.2 Investigating the impacts of road lighting 11
4 Prioritising the research focus 15
4.1 Pairwise comparison 15
4.2 Participants 15
4.3 Pairwise results 16
4.4 Pairwise findings 18
4.5 Ranking discussion overview 19
4.6 Impact of these findings on the next stage of SAFELUX 19
5 Proposed structure of the guidelines and digital tool 21
5.1 Long list to short list 21
5.2 Stage 1 – Determine whether lighting is justified or whether alternative visibility measures can deliver equivalent safety 22
5.3 Stage 2 – If lighting is justified, define the appropriate lighting strategy 23
5.4 Stage 3 – Plan for adaptability and long-term optimisation 24
6 Key metrics to scale the guidelines and digital tool (WP4 & WP5) 25
7 Thresholds or ranges of relevance for the digital tool 27
8 Conclusion 29
8.1 How this report responds to the scope defined in the DoRN 29
8.2 Relationship between the findings in this report and the expected outputs of the DoRN 29
8.2.1 Output: Overview and analysis of practices and research 30
8.2.2 Output: Guidelines on sustainable lighting 30

8.2.3 Output: Digital tool 30
8.2.4 Output: Pilot projects 30
8.2.5 Output: Final programme report and implementation guidance 30
8.3 Has the analysis changed the prioritisation of expected outputs? 31
Appendix A: 32

Tables

Table 1. Themes and sub-themes identified during the thematic analysis of the impacts of road lighting. 12
Table 2. Result of the pairwise comparison of the themes of the impacts of road lighting. 17

Figures

Figure 1. The regions represented durign the SAFELUX WP1 workshop. 16
Figure 2. A graphical summary of the participants of the pairwise ranking survey. 17
Figure 3. High-level overview of the proposed structure of the SAFELUX guidelines and digital tool. 22

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

1 Introduction

This report defines the scoped research priorities and decision-framework that will shape the next phase of SAFELUX – a CEDR-funded initiative to reduce the negative impacts of road lighting while ensuring that European road networks remain safe, efficient, and publicly acceptable. Building on the Description of Research Needs from the 2024 CEDR Call, the document consolidates literature evidence, expert input, and NRA stakeholder perspectives to structure how future guidance and a decision-support digital tool should be developed.

An initial long-list of 109 documented impacts of road lighting was gathered from specialists across multiple disciplines and refined through thematic analysis into a set of high-level themes covering safety, ecology, social wellbeing, and energy. These themes were then prioritised through a pairwise exercise involving 21 NRA representatives, followed by a deeper reasoning workshop. Road safety – specifically pedestrian and cyclist visibility – emerged as the highest stakeholder priority, though ecology, energy efficiency and human wellbeing were also strongly recognised as areas requiring equal strategic treatment. The findings confirm that road lighting decisions are multi-dimensional and characterised by inherent trade-offs; technical compliance alone is insufficient without explicit balancing of competing outcomes.

To guide this balance, the report proposes a structured, decision-led architecture for both the SAFELUX guidelines and digital tool. The process is organised into three sequential stages:

1. determine whether lighting is justified at all – considering safety exposure, social reliance, viable non-lighting alternatives, costs, and legal duties.
2. if lighting is necessary, define the lowest-impact appropriate strategy by weighing safety, ecological sensitivity, human experience, energy performance and visual/skyglow impact.
3. plan for long-term adaptability, enabling responsive, reversible, and policy-aligned lighting strategies as circumstances evolve.

Five core thematic pillars underpin this framework – road safety, activity (human behaviour and perception), ecology, energy, and policy/governance – with mitigation options such as dimming, spectral tuning, shielding and adaptive operation embedded throughout rather than treated as accessories. The report also identifies a focused set of scalable metrics that will form the backbone of the decision engine in the following SAFELUX work packages, and outlines how these metrics will inform lighting recommendations via influence ranges rather than rigid thresholds.

In summary, SAFELUX establishes a practical pathway toward lighting decisions that are proportionate, evidence-driven, and nationally adaptable. The next work packages will build on this foundation to quantify influence weightings, test mitigation strategies, and prepare the operational logic for implementation within the final guidelines and digital tool.

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

2 Terminology and conceptual framework for SAFELUX

A clear and consistent vocabulary is essential for developing the SAFELUX guidelines and digital tool, particularly because multiple disciplines – ecology, road safety, lighting engineering, social science and policy – use similar terms in different ways. This section establishes a shared terminology to support Work Packages 3 to 5. It clarifies the meaning of key terms used throughout the project, defines their relationships, and provides concrete examples to help avoid ambiguity in later stages.

2.1 Key terms

Term	Definition
Impact	A specific positive or negative effect resulting from the presence or absence of road lighting.
Causal factor	A condition or activity that contributes to the creation or severity of an impact. (This term is used to explain *why* an impact occurs.)
Decision factor	A variable that influences decision-making within the SAFELUX guidelines or digital tool. Decision factors shape recommendations, even if they are not the direct cause of an impact (e.g. traffic flow, ecological sensitivity, public perception of safety).
Theme	A broad conceptual category grouping similar impacts identified through thematic analysis (Road safety, Ecology, Social and community, Energy).
Sub-theme	A more specific dimension within a theme, used to categorise impacts at a finer level (e.g. within Ecology: Population, Behaviour, Habitat).
Pillar	A high-level organising domain used to structure the guidelines and digital tool. Pillars align the project structure with decision-making processes. The SAFELUX pillars are: Road safety, Activity, Ecology, Energy, and Policy.
Mitigation	The overall strategy or intent to reduce negative impacts of road lighting, or to optimise beneficial outcomes. Mitigation describes the *goal* (e.g. reduce skyglow, improve energy efficiency).
Measure	A specific, implementable intervention that achieves a mitigation. It is a concrete *action* (e.g. dimming, shielding, spectral tuning, applying part-night lighting, improving retroreflective markings).
Metric	A quantifiable or evidence-based variable used to assess conditions and inform decisions within the guidelines and digital tool. Metrics are the inputs used to scale recommendations (e.g. collision rate, annual operating hours, proximity to protected habitats).
Threshold / Influence range	A numerical or categorical boundary that alters the weighting of a metric in the decision logic. SAFELUX uses influence ranges rather than fixed thresholds to ensure proportional, context-sensitive recommendations.

2.2 Vocabulary in a simplified hierarchy

To ensure clarity between scientific concepts, decision-making elements, and implementation actions, SAFELUX adopts a three-part conceptual hierarchy.

A. Impact framework – how lighting affects the world

This model describes real-world mechanisms.

- **Impacts:** Observable or potential effects of lighting.
- **Causal factors:** Conditions that create or shape impacts.
- **Themes and sub-themes:** Categories used to group similar impacts for analysis.

B. Decision framework – how SAFELUX provides guidance

This model underpins the guidelines and digital tool.

- **Pillars:** Broad organising domains structuring decision processes.
- **Decision factors:** Key variables evaluated when considering lighting interventions.
- **Metrics:** Quantified representations of decision factors.
- **Influence ranges:** Gradual shifts in metric values that alter recommended strategies.

Decision factors and metrics defined here are operationalised in the staged decision process described in Section 5.

C. Action framework - how outcomes are changed

This model informs the practical interventions proposed.

- **Mitigation:** The intent or strategy to reduce impacts or improve outcomes.
- **Measures:** Specific actions that deliver mitigation.

This hierarchy ensures consistency: themes help understand impacts, pillars structure decisions, metrics scale those decisions, and measures apply the outcomes.

This hierarchy is applied throughout the report to maintain consistency between impact analysis, decision-making, and implementation. In particular, the distinction between impacts, decision factors, and metrics underpins the proposed guideline structure in Section 5 and the metric logic described in Section 6. The translation of these elements into influence ranges for the digital tool is described in Section 7.

2.3 Illustrative scenarios

The following simplified scenarios demonstrate how impacts, factors, metrics, mitigations and measures will interact in practice. They show how the vocabulary may be used throughout the SAFELUX decision process (the guidelines and digital tool).

These scenarios help to illustrate how the proposed decision stages (Section 5), metrics (Section 6), and influence ranges (Section 7) would operate in practice.

2.3.1 Scenario 1: A rural junction near a protected bat habitat

This scenario is particularly relevant to the ecological sensitivity metrics discussed in Section 6 and the ecological influence ranges described in Section 7.

Framework	Scenario illustration

Impact	• Increased mortality risk for light-sensitive bat species caused by road lighting • Potential reduction of driver detection distances at night if lighting removed
Decision	Descision factors: • Ecological sensitivity (protected habitat within 100 m) • Task complexity (junction, turning conflicts) • Traffic flow moderate, with small peak in evening Metrics: • Species sensitivity classification • Night-time collision rate • Seasonal activity period
Action	Mitigation: • Reduce ecological disturbance while ensuring minimum safe visibility Measures: • Install warm-spectrum or PC amber luminaires • Apply shielding to block upward and lateral spill • Use part-night or seasonally adaptive dimming aligned with bat activity • Maintain enhanced retroreflective signage to support lower lighting levels

2.3.2 Scenario 2: Urban road close to residential area with public concern about safety

Framework	Scenario illustration
Impact	• Fear of crime if no lighting • Intrusive light into bedrooms • Pedestrian tripping risk if no or low levels of lighting
Decision	Decision factors: • High night-time pedestrian presence • History of complaints related to personal safety • Facade proximity and window sensitivity Metrics: • Surveyed perceived safety • Recorded crime statistics • Glare or light trespass measurements

Action	Mitigation: • Increase perceived safety while minimising light nuisance Measures: • Re-aim or replace luminaires to limit backlight • Install warmer spectrum lighting to reduce glare • Introduce modest dimming in very late hours • Improve pathway markings to support reduced lighting levels

2.3.3 Scenario 3: Energy-constrained linear motorway segment

Framework	Scenario illustration
Impact	• Energy consumption and carbon emissions from lighting equipment • Driver fatigue and speed compliance if not enough lighting
Decision	Decision factors: • Very low pedestrian activity • High operating speed • Electricity grid capacity limitations • No nearby ecological sensitivities Metrics: • Annual energy cost • Peak load constraints • Collision data (night-time proportion)
Action	Mitigation: • Maintain safety performance while significantly reducing energy demand Measures: • Introduce adaptive lighting based on real-time traffic volume • Implement part-night dimming during off-peak hours • Reduce lighting class where standards permit • Replace aging luminaires with high-efficiency optics

2.3.4 Scenario 4: Pedestrian crossing on a suburban truck road

This scenario aligns closely with the prioritisation of pedestrian and cyclist safety identified in Section 4.6 and informs the safety-led decision logic in Stage 1 (Section 5.2).

Framework	Scenario illustration

Impact	• Risk of pedestrian-vehicle collisions if under-lit • Glare affecting approaching drivers if poorly lit
Decision	Decision factors: • High VRU activity at dusk • Speed limit 50-60 kph • Some driver complaints about glare Metrics: • VRU counts • Stopping sight distance • Glare rating (threshold increment or discomfort)
Action	Mitigation: • Enhance VRU visibility with minimal increase in light spill Measures: • Add targeted high-uniformity lighting at the crossing only • Use pedestrian-activated lighting to avoid permanent high levels • Apply anti-glare optics or lower mounting height • Enhance retroreflective markings and advance signage

3 Proposed themes for SAFELUX research, guidelines, and digital tool

This section outlines how the proposed themes to be used to focus the subsequent research in SAFELUX were identified. These will consequently be used to structure the guidelines and digital tool.

3.1 Review of the DoRN

Priority 1: Understand and mitigate environmental impacts of road lighting

The Description of Research Needs (DoRN) highlights a strong scientific consensus on the ecological consequences of light pollution. The document notes that road lighting can disrupt circadian rhythms, alter phenology, and affect population dynamics and migration patterns in flora and fauna. In response, the SAFELUX project was proposed to focus on developing practical and sustainable lighting guidelines that reflect these concerns and demonstrate the broader consequences of lighting choices on the ***environment, safety, energy use, and economy***. The SAFELUX aim is to significantly reduce the impact of road lighting on nature and skyglow through evidence-based planning and design.

Priority 2: Improve road safety with minimal lighting

The DoRN also emphasises the need to explore alternative, cost-effective methods for improving road visibility without relying on traditional lighting. It identifies solutions such as reflectors, anti-glare systems, road markings, and speed management as viable options. The SAFELUX research will build on this by investigating how these approaches can ***maintain or enhance safety while reducing energy consumption and light pollution***. This priority supports the development of low-impact visibility strategies that align with environmental and operational goals.

3.2 Investigating the impacts of road lighting

As part of SAFELUX Work Package 2 (WP2), specialists provided targeted input to support the development of a long list of the impacts of road lighting. A total of 109 impacts were gathered, representing a wide range of contributions from across disciplines. The purpose of the long list was to create a comprehensive foundation that could be used to identify themes and help understand NRA priorities. This approach allowed for broad input and ensured that diverse perspectives were captured before moving into the prioritisation and refinement stages.

The list was reviewed by members of the SAFELUX Project Executive Board (PEB), whose comments were incorporated to support further refinement. Impacts that were considered similar were consolidated. The structure of the long list was designed to enable systematic analysis and included the following headings:

- **Impact ID**
- **Specific impact**: The particular issue or effect being considered.
- **Causes**: Factors or activities that lead to the specific impact.
- **Mitigation measures**: Potential actions or strategies to reduce or manage the impact.
- **Comments / reference / website**: Supporting information, sources, or links relevant

to the impact.

- **Contribution by**: The individual or team who provided the input.
- **Similar impacts (IDs)**: Cross-references to related impacts within the list.
- **Priority**: An initial indication of whether the impact is considered a priority by PEB members.

A thematic analysis was then performed to identify patterns of meaning, resulting in a set of high-level themes and more specific sub-themes. This resulted in the addition of two further headings:

- **Impact theme**: Broad category of impact.
- **Impact sub-theme**: A more specific area within the main theme.

The themes and sub-themes identified through the thematic analysis are shown in Table 1. The long list and its thematic structure are subsequently used to inform both the stakeholder prioritisation in Section 4 and the selection of core metrics in Section 6.

Table 1. Themes and sub-themes identified during the thematic analysis of the impacts of road lighting.

Impact theme	Impact sub-theme	Definition
Road safety	Pedestrian and cyclist safety	Visibility of vulnerable road users, perceptions of safety and security, crossing behaviour.
	Visibility	Detection of hazards, glare and over-illumination, visual adaptation.
	Driver performance	Speed choice, braking response, lane changing, risk-taking behaviour, fatigue and alertness
	Environment interaction	Interaction with signage, markings, and reflective materials. Wayfinding and navigation.
	Collision risk	Frequency of collisions, temporal patterns
	Psychological and social	Perceived safety and security (fear of crime), public acceptance, risk compensation.
	Health and long-term impacts	Circadian disruption on drivers (shift workers, long distance drivers), light pollution affecting sleep patterns of nearby residents (influencing their alertness when driving).
Social and community	Cultural and social life	Social use of spaces, social interaction patters and inclusivity, cultural values of darkness, amenity.
	Environmental perceptions and values	Awareness of light as environmental issue, conflict between safety and preserving dark skies, aesthetic impacts (nightscape character).
	Environmental justice and	Unequal distribution of lighting, disproportionate

	equity	impacts on vulnerable groups (e.g. children, elderly, low-income), community involvement.
	Health and physiology	Sleep disturbance, circadian rhythm and associated health effects, mental health.
	Wellbeing and quality of life	Sense of personal safety and security, comfort and convenience for night-time activities, social equity.
Ecology	Population	Population size, distribution, and density. Reproductive success. Mortality (e.g. roadkill).
	Biodiversity	Species richness, abundance changes, altered species interactions (predator-prey, competition, pollination), community composition.
	Physiological	Circadian rhythms and melatonin production. Stress responses. Sleep, energy, and overall health.
	Behaviour	Altered foraging and hunting patterns. Migration and navigation. Activity timing. Attraction/repulsion responses to light.
	Ecosystem processes	Nutrient cycling, primary production (e.g. plant photoperiods), trophic cascades, pollination and seed dispersal.
	Temporal	Day-night cycles, seasonal timings (phenology - flowering, breeding, migration), light-dark regimes.
	Habitat	Fragmentation, barrier effects, quality, edge effects, and connectivity or corridors.
Energy	Carbon emissions and climate impact	GHG emissions, opportunities for efficiency or emissions reduction, alignment with climate change mitigation goals and net-zero policies.
	Demand and efficiency	Total consumption, efficiency of sources, over-lighting or wasteful spill.
	Economic costs and resource use	Operation costs, long-term maintenance, life-cycle energy footprint (including recycling or circular use of materials).
	Pollution (non-light)	Atmospheric chemistry, disposal of materials.
	Systems perspective	Interaction with broader energy grid (peak demand, load balancing), smart city integration.
	Policy, governance, and equity	National and local targets, regulations or standards, distribution equity.

	Technological innovation and transitions	Shift from legacy lighting, integration with renewable sources, emerging technologies.

These themes form the analytical backbone for the prioritisation exercise described in Section 4 and are later regrouped into the five pillars that structure the guidelines and digital tool (Section 5).

4 Prioritising the research focus

To ensure that the SAFELUX research agenda reflects the priorities of key stakeholders, a structured process was undertaken to identify and rank areas of greatest impact. This involved engaging National Road Authorities (NRAs) and other relevant participants to review themes derived from an initial long list of potential impacts. As part of Work Package 2 (WP2), a dedicated workshop was held to facilitate this engagement and gather informed perspectives. Using OpinionX, participants completed a pairwise comparison survey designed to highlight which themes they considered most critical.

This prioritisation exercise provides an evidence-based link between stakeholder values and the structural design choices made later in the report, particularly the staged decision process (Section 5) and the weighting of metrics in the digital tool (Section 7).

4.1 Pairwise comparison

As part of WP2, a workshop was held to engage participants in exploring and prioritising potential impacts. During the session, OpinionX was used to conduct a structured pairwise survey aimed at gauging the priorities of attendees. Pairwise comparison is a method where participants evaluate two items at a time, choosing which one they consider more important. This approach helps to rank options based on collective preferences, providing a clearer picture of relative priorities. This interactive approach enabled participants to reflect on the extracted themes from the long list of impacts and provide input on which areas they considered most critical. It is important to note that the results of the pairwise comparison were not intended to strictly steer future research. Instead, they serve as a tool to understand the priorities of NRAs and to shape guidelines so they align with these priorities. The results from the pairwise survey help to inform the next stage of analysis and support the alignment of future work with stakeholder perspectives.

4.2 Participants

Name	Organisation
Erling Fjeldaas	Statens vegvesen (Norwegian Public Roads Administration)
Arild Engebretsen	Statens vegvesen (Norwegian Public Roads Administration)
Erik De Bisschop	Flemish Agency for Roads and Traffic, Belgium
Judith Wouters	Flemish Agency for Roads and Traffic, Belgium
Sarah-Jane Phelan	Transport Infrastructure Ireland (TII)
Colin Murphy	Transport Infrastructure Ireland (TII)
Owen Smith	Transport Infrastructure Ireland (TII)
Maik Hoemke	Bundesamt für Strassen (ASTRA) – Swiss Federal Roads Office
David Roberts	National Highways
Haydn Yeo	National Highways
Bernard Matej Kobav	University of Ljubljana, Lithuanian
Viktoras Lapinas	VIA Lietuva – Lithuanian Road Administration

Lukas Jančauskas	VIA Lietuva – Lithuanian Road Administration
Gaardbo Anders Møller	Vejdirektoratet – Danish Road Directorate
Saulius Balčiūnas	VIA Lietuva – Lithuanian Road Administration
Tibor Mocsari	Magyar Közút Nonprofit Zrt. – Hungarian Public Roads
Roberto Llamas Rubio	Ministerio de Transportes y Movilidad Sostenible, Spain – Directorate General of Roads
David Greisch	Ponts et Chaussées Administration - Luxembourg
Alexander Nowotny	Austrian Road Safety Fund (BMK)
Barbora Dvořáková	Ředitelství silnic a dálnic – Directorate of Roads and Motorways, Czech Republic.
Victor Loehr	Rijkswaterstaat – The Netherlands. (Completed the pairwise exercise post-meeting)

Figure 1. The regions represented durign the SAFELUX WP1 workshop.

There were 21 participants in the survey (approximately 70% of the workshop attendees). The average time to finish the survey was 5 minutes.

4.3 Pairwise results

Each participant was required to make 25 pairwise comparisons. This is much lower than would be required to provide a statistically robust outcome (a minimum of 51 pairwise comparisons would be required from each of the 21 participants), but the outcome was not designed to rigidly fix the direction of the SAFELUX research. In addition, using a smaller number allowed the meeting to quickly move on to a more productive discussion session.

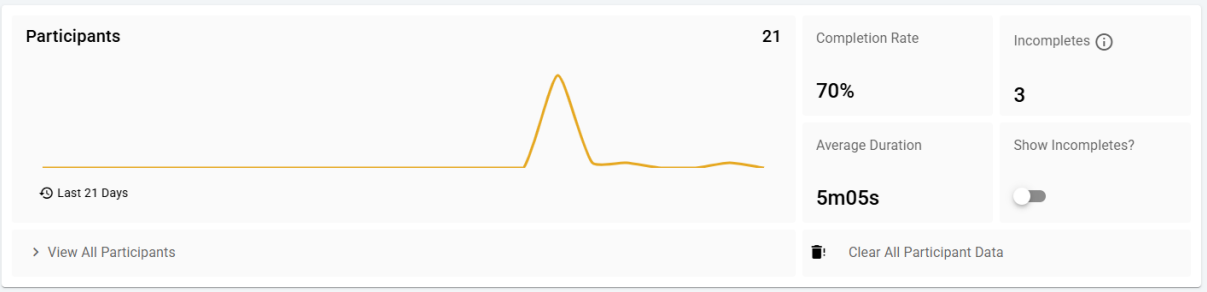

Figure 2. A graphical summary of the participants of the pairwise ranking survey.

Nevertheless, the results of the pairwise ranking of the themes/sub-themes is shown in Table 2. There is a notable emphasis on road safety within the ranking. This is likely a result of the inherent and historical priorities within NRAs and the safety-related roles of the attendees within the meeting. However, it provides a reminder to the SAFELUX project that any subsequent guidance needs to consider this is a common perception amongst practitioners.

Table 2. Result of the pairwise comparison of the themes of the impacts of road lighting.

Rank	Impact theme (sub-theme)	Score
1st	Road safety (Pedestrian and cyclist safety)	88
2nd	Road safety (Visibility)	82
3rd	Road safety (Driver performance)	79
4th	Road safety (Environment interaction)	77
5th	Road safety (Collision risk)	76
6th	Road safety (Psychological and social)	71
7th	Ecology (Population)	59
8th	Social and community (Wellbeing and quality of life)	58
9th	Energy (Economic costs and resource use)	55
10th	Energy (Policy, governance, and equity)	54
11th	Road safety (Health and long-term impacts)	53
12th	Ecology (Biodiversity)	51
13th	Energy (Technological innovation and transitions)	50
14th	Social and community (Environmental perceptions and values)	49
15th	Energy (Carbon emissions and climate impact)	48
16th	Social and community (Economic and practical)	47
17th	Ecology (Physiological)	46
18th	Ecology (Habitat)	44
19th	Energy (Demand and efficiency)	43
20th	Ecology (Behaviour)	39
21st	Ecology (Ecosystem processes)	35
22nd	Social and community (Cultural and social life)	32

23rd	Energy (Systems perspective)	29
24th	Social and community (Environmental justice and equity)	29
25th	Social and community (Health and physiology)	25
26th	Ecology (Temporal)	20
27th	Energy (Pollution (non-light))	14

4.4 Pairwise findings

The results clearly indicate that road safety emerged as the highest-ranked theme across all categories. This outcome is not unexpected: **road safety is the primary justification for installing road lighting, and NRAs have a statutory responsibility to maintain safe operating conditions on the network.** As a result, safety considerations typically dominate decision-making in lighting policy and practice. The strong emphasis on road safety in the ranking therefore reflects both the professional roles of many participants and the central importance of safety within all National Road Authorities.

Although the participant group contained a high proportion of safety-focused professionals, the results nevertheless reveal several meaningful patterns within and across themes. Particularly striking is the **overwhelming prioritisation of pedestrian and cyclist safety**, which received the highest individual score of all sub-themes. This aligns with broader trends in European transport policy and with the DoRN's emphasis on balancing sustainability with the protection of vulnerable road users. Other high-ranking road-safety sub-themes – visibility, driver performance, and environmental interaction – highlight the specific visual and behavioural tasks that NRAs consider most sensitive to lighting decisions. Beyond safety, the pairwise results also show that **wellbeing and quality of life** (Social and Community), **population-level ecological effects** (Ecology), and **economic and resource considerations** (Energy) consistently outranked other sub-themes within their respective categories. This internal structure of priorities provides valuable insight into which dimensions NRAs consider most consequential when lighting levels or operational strategies change.

These findings have guided the development of the proposals later in this document in several important ways. First, they reinforce the need for a **staged decision process** (Section 5), where safety risk and vulnerable road user exposure are treated as primary decision factors, but balanced within a framework that also integrates ecological sensitivity, activity patterns, energy performance, and governance requirements. Second, they influenced the selection of **key metrics** in Section 6: high-priority areas such as VRU safety, wellbeing, and population-level ecological effects are explicitly represented in the proposed metric domains and will therefore shape the logic of the digital tool. Third, they informed the emphasis on **measures** that target both safety and environmental outcomes – such as adaptive lighting, spectral tuning, shielding, and alternative visibility measures – which respond directly to the trade-offs highlighted by stakeholders. In this way, the pairwise results do not simply reflect stakeholder preferences; they actively underpin the structure, priorities and balancing mechanisms embedded throughout the SAFELUX approach, ensuring that the project remains aligned with both NRA practice and the holistic expectations of the DoRN.

Importantly, while other aspects will be explored in depth, road safety remains a foundational priority. This aligns with the DoRN and reinforces the view that any future developments should build upon this essential baseline.

4.5 Ranking discussion overview

Following the initial pairwise survey conducted during the WP2 workshop, the top-ranked themes and sub-themes identified by participants were transferred into Mentimeter for further exploration. This second stage aimed to gather deeper insights into the reasoning behind participants' selections. For each of the top sub-theme in each of the main themes, attendees were asked two key questions: **"Why is this a priority?"** and **" How is it measured?"**This approach helped to capture qualitative perspectives and contextual understanding, enriching the prioritisation process and supporting a more informed evaluation of the long list of impacts.

This activity provided participants with the opportunity to share more detailed input beyond initial prioritisation. This was found to be particularly beneficial, as it provided a richer level of insight. The additional context and reasoning offered by participants has strengthened the SAFELUX understanding of stakeholder perspectives and added depth to the evidence gathering work.

The output of the Mentimeter responses can be found in Appendix A.

4.6 Impact of these findings on the next stage of SAFELUX

The activities carried out above demonstrate that decisions about road lighting involve several important, yet often competing, themes. This highlights the complexity of achieving sustainable road lighting, which cannot be resolved through technical compliance alone. Looking ahead, Work Package 3 (WP3) should consider how a holistic, evidence-based approach can help explore the relationships between these themes. This includes examining how different priorities influence design and policy decisions, identifying where trade-offs may be necessary, exploring opportunities to align multiple objectives, and understanding the role of stakeholder perspectives in shaping balanced and effective solutions.

It will be important to bring this discussion back to the DoRN framework and the main priorities – ecology, energy and road safety – and to contextualise these based on the proposed mitigations to be explored. WP3 should not focus solely on analysing the impacts of Artificial Light at Night (ALAN) on key themes, but rather emphasise mitigation strategies that can deliver balanced outcomes. This approach will also create a strong foundation as SAFELUX transitions into WP4.

Moving forward, WP3 and WP4 should specifically consider how to balance competing priorities in a way that reflects real-world practice. This includes not only identifying where trade-offs are necessary, but also recognising that **different contexts may legitimately justify weighting one objective more strongly than another**. In some cases, ecological protection may lead to reduced or earlier curfews for lighting; in others, safety or social considerations may appropriately take precedence. Several NRAs already apply this type of context-sensitive balancing – such as in the Netherlands where greater darkness is provided in areas of high ecological sensitivity (N2000 sites) while more illumination is provided along comparable routes elsewhere. The SAFELUX framework should therefore support this nuanced decision-making, enabling NRAs to make proportionate adjustments that reflect local conditions, policy commitments and risk profiles.

In addition, WP3 should consider the future work in WP4 (producing guidelines) and WP5 (developing a digital tool). Specifically, there needs to be focus on:

- **integrating metrics** to build a robust framework for synthesising disparate data sources, combining objective metrics (e.g. collision statistics, energy consumption)

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

with subjective public perceptions (e.g. sense of safety, wellbeing) to create a comprehensive evaluation of impact.

- **long-term value** to shift the economic calculation beyond initial installation costs to model the full life-cycle energy footprint and long-term Return on Investment (ROI) across all four themes, ensuring sustained, future-proof solutions.

The workshop marked a key milestone in the SAFELUX project. Its primary purpose was to identify and shortlist the most influential factors that will guide the development of subsequent Work Packages. Through collaborative discussion and expert input, the workshop surfaced critical insights into the interplay between ecological concerns, energy use, social and community impacts, and road safety.Participants recognised that sustainable road lighting requires more than technical optimisation, it demands a nuanced understanding of stakeholder values, shifting societal perceptions, policy constraints, and environmental trade-offs.

As a result, the workshop produced a refined shortlist of influential factors that will directly inform the design of mitigation strategies in WP3, the development of guidelines in WP4 (the structure of the guidelines is proposed in Section 5), and the creation of the digital tool in WP5 (the selection of key metrics is described in Section 6 and the development of influence ranges rather than fixed thresholds is described in Section 7). This outcome ensures that future work is grounded in shared priorities and real-world complexity, providing a clear and actionable foundation for the next stages of the project.

5 Proposed structure of the guidelines and digital tool

Based on the original DoRN, investigation of the impacts of road lighting, and engagement with stakeholders to understand NRA priorities, this section proposes a logical structure that will be used to organise the SAFELUX guidance and the digital decision-support tool.

Rather than presenting a list of impacts or mitigation options in isolation, the structure follows the sequence of decisions a NRA must make when considering whether and how to provide road lighting. This ensures that guidance is directly aligned to real-world decision processes and that the digital tool can guide users dynamically based on context.

The structure proposed in this section builds directly on the vocabulary and conceptual hierarchy defined in Section 2, and integrates the stakeholder priorities identified in Section 4.

To maximise impact and usability, the SAFELUX outputs will be clearly differentiated in terms of target audience, form, and content:

- The guidelines will be targeted towards regulatory bodies, such as NRAs and policy-makers, offering strategic and practical advice for revising national lighting standards. The guidelines will be structured in two parts:
    - **Part A**: Project-related guidance aligned with the digital tool.
    - **Part B**: Regulation-related guidance to support standard-setting and policy development.
- The digital tool will be primarily targeted towards the construction, operation and maintenance of roads, supporting project-level decision-making with dynamic, context-sensitive recommendations.

This dual approach ensures that SAFELUX supports both implementation and regulatory evolution, increasing its relevance and long-term impact.

5.1 Long list to short list

The short list has been developed by combining two key elements: the five pillars and the long list spreadsheet. The approach is built on five pillars: road safety, activity, ecology, energy, and policy. The first four were the original focus areas, while policy has been added as it is essential for compliance and governance.They provide a clear structure for the work and reflect the main areas of focus identified through stakeholder engagement.

The long list adds depth by capturing specific topics that stakeholders considered most important. This ensures the short list reflects real priorities and keeps the focus on what matters most to those involved.

As the project moves into the guidance development phase, the long list will remain an important reference point. It will guide decisions on where to focus effort, such as selecting case studies or highlighting best practice examples around the highest priorities. This approach ensures the final guidance stays closely connected to the priorities identified early on while maintaining a strong link between strategic themes and practical actions.

The proposed structure is therefore organised around three core decision stages:

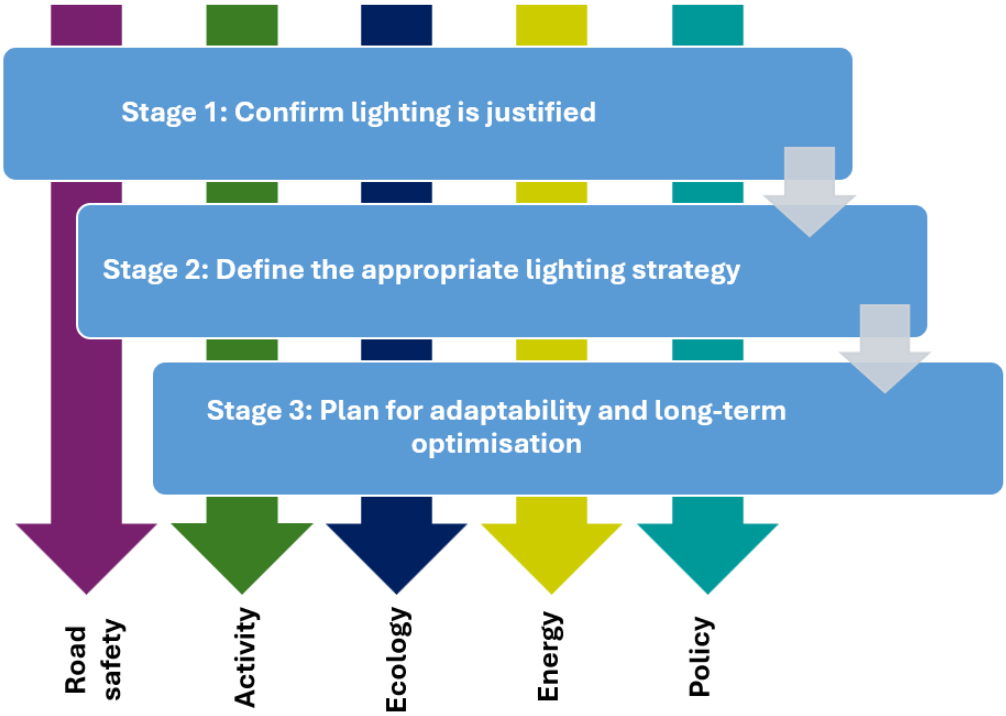

Figure 3. High-level overview of the proposed structure of the SAFELUX guidelines and digital tool.

Each stage is described in more detail in the following sub-sections.

5.2 Stage 1 – Determine whether lighting is justified or whether alternative visibility measures can deliver equivalent safety

This stage asks whether permanent lighting installation is required at all, considering both legal duties and the availability of alternative measures. The guidance and tool will group themes such as:

- **Safety exposure and risk** – AADT and traffic mix, presence of vulnerable road users, historical collision data including night-time crash data, conflict points such as junctions or roundabouts, roadworker safety at night). In addition, see note below about the Safe System approach.
- **Perceived safety and social acceptability** – fear of crime, community reliance on lighting, accessibility needs, and potential rejection of unavoidable light pollution (e.g. complaints, stakeholder concerns).
- **Ecological sensitivity** – potential effects on biodiversity, habitats and species (including protected species, migration corridors, and light-sensitive taxa), risk of habitat fragmentation, proximity to Natura 2000 or other conservation areas, potential for ecological disturbance during critical periods.
- **Energy and carbon considerations** - expected operational hours, energy cost exposure, carbon reduction targets, and whether lower-impact alternatives could meet objectives with significantly reduced consumption.

- **Existence of viable non-lighting alternatives** – road markings, reflectors, retro-reflective materials, anti-glare systems, traffic-calming or speed management, signage improvements, and intelligent visibility measures. In addition, see note below about the function of lighting.
- **Policy or regulatory obligations** – national lighting requirements, local curfews or dark-sky protections, environmental zoning, and alignment with broader government strategies (biodiversity, net-zero, light pollution mitigation).

Note on the Safe System approach and the use of collision data:

While historical night-time crash data can offer useful contextual insight, relying on past collisions as the primary basis for deciding whether lighting should be installed is inconsistent with the Safe System approach, which is increasingly recognised internationally as the most effective foundation for road-safety policy. The Safe System philosophy emphasises proactive, systemic measures that prevent serious collisions before they occur, rather than reactive decisions driven by recorded incidents. Furthermore, collision numbers at specific locations are typically low and often influenced by chance, making them statistically unreliable and a weak basis for consistent policy-making. For this reason, the SAFELUX framework should treat collision data as one input among many, with greater emphasis placed on forward-looking indicators such as task complexity, road-user exposure, vulnerable road user presence, and systemic risk factors.

Note on the function of lighting beyond road guidance:

While non-lighting measures such as markings, retroreflective elements and anti-glare systems can improve guidance and visibility, it is important to recognise that these interventions cannot always fulfil the core functions of road lighting. For example, in the Netherlands it is long-established policy that such measures are not considered full alternatives to lighting, because guiding the road's course is not the principal reason for installing illumination. Lighting plays a critical role in enabling drivers to accurately determine their position on the road, assess their speed and trajectory relative to other users, and perceive potential hazards in time to react. To date, no non-lighting solution has been found that fully replicates these perceptual and situational-awareness benefits. The SAFELUX framework therefore should treat non-lighting measures as valuable complementary options rather than universal substitutes for lighting.

5.3 Stage 2 – If lighting is justified, define the appropriate lighting strategy

Once the case for lighting is established, the next decision is the type, intensity and operational profile of lighting. The themes presented within this stage will support evidence-based trade-offs between safety, environment, and operational efficiency. Themes include:

- **Safety performance** – task difficulty, visual adaptation, hazard detection, glare risk, uniformity, additional physical hazard created by new roadside equipment, and the needs of vulnerable road users.
- **Ecological sensitivity** – proximity to protected habitats or species, temporal patterns such as breeding or migration periods, and required measures to avoid disturbance (e.g. spectrum adaptation, shielding, or reduced operational hours).
- **Regulatory or permitting obligations** – requirements arising from environmental legislation, protected-species permits, planning conditions or local lighting controls. These obligations may necessitate solutions that constrain other themes (e.g.

mandated low-blue spectrum in sensitive areas, earlier curfews, or stricter spill-light limits), even where such measures influence visual perception or safety design preferences.

- **Energy and carbon performance** – achievable reductions in operational hours, potential for adaptive operation or dimming, lifecycle performance, and alignment with national or organisational carbon targets.
- **Human experience and social needs** – wellbeing, comfort, night-time usability, perception of safety, inclusivity, and accessibility for diverse road users.
- **Visual and environmental quality** – minimising skyglow, light trespass, obtrusive light, and impacts on nightscape or cultural/heritage settings.

Decisions under this stage will explicitly balance the four core goals defined in the CEDR DoRN: reducing impacts on nature, mitigating skyglow, improving road safety, and reducing energy consumption. They will then lead to tailored strategies such as adaptive dimming, spectral tuning, shielding or part-night lighting configurations.

5.4 Stage 3 – Plan for adaptability and long-term optimisation

The final stage recognises that lighting conditions and societal priorities change over time, and that guidelines must remain practical today while adaptable to future unknowns. The guidance and tool will therefore embed adaptability as a core principle. Themes covered include:

- Capability for monitoring and remote control (e.g. Central Management System readiness)
- Trigger conditions for adjustment (e.g. changes in night-time footfall or ecological sensitivity)
- Alignment with future policy trajectories (e.g. net-zero commitments, protected dark-sky areas)
- Lifecycle optimisation and maintenance planning
- Changes in human perception or cultural views of lighting (for instance, lighting is generally viewed as good for safety, but these views may change as the impact on ecology is more broadly understood)

Integration of mitigation options

Mitigation measures such as part night lighting, dimming, trimming, shielding and trespass reduction, minimisation of lighting points, and spectral tuning will be embedded across the decision stages above, rather than treated as standalone options. Where appropriate, a combination of these mitigations may be considered, recognising that multiple measures might be required to effectively address specific circumstances.The guidance and tool will present these options dynamically where they deliver the greatest net benefit, based on the input conditions.

This step-based structure ensures that the guidelines and the digital tool are intuitive, defensible, and scalable. It ensures that decisions are transparent and evidence-based, and that trade-offs can be clearly explained and justified to stakeholders.

6 Key metrics to scale the guidelines and digital tool (WP4 & WP5)

To ensure that the guidelines and digital tool are scalable, repeatable, and applicable across different national contexts, this section identifies a focused set of metrics that influence the intensity, configuration or necessity of road lighting. The metrics described in this section provide the quantitative and evidence-based inputs required to operationalise the staged decision process set out in Section 5. These metrics act as input variables – shaping whether lighting is justified, and if so, which strategy should be adopted. They are chosen not as an exhaustive list of factors, but as the key levers that materially change decision outcomes.

Further research will be carried out through the subsequent work packages in SAFELUX to determine the availability of the data and the feasibility of its use in such metrics, although it may be more appropriate to consider whether evidence rather than data is the more suitable concept in this context, depending on the nature of the metrics and the intended outcomes.

The following core metrics are proposed, grouped within the five pillars:

1. Road safety: Exposure and task complexity

Metrics that reflect the level of safety risk, particularly for vulnerable users:

- AADT or traffic mix (current/expected % heavy vehicles, % pedestrian/cyclist movements, hourly traffic distribution)
- Historical collision frequency (including VRU involvement)
- Operating speed and stopping sight distance requirements
- Task difficulty (e.g. junctions, crossings, complex geometry)
- Where data is unavailable, risk must be predicted based on projected conditions (the guidelines and tool should use standard data where possible if no country-specific data is available)

2. Activity: Vulnerable road user and community activity patterns

Metrics to capture how people use the road or surrounding public realm at night:

- Peak and off-peak pedestrian/cyclist volumes (daily, weekly and seasonal)
- Presence of socially sensitive locations (schools, transport hubs, residential areas)
- Perceived safety or fear of crime indicators (survey data or complaint records)

3. Ecology: Sensitivity and environmental protection zones

Metrics that determine whether lighting could significantly impact nature or skyglow:

- Proximity to Natura 2000 or other protected habitats
- Known presence of legally protected, rare, keystone or light-sensitive species, as well as those that play an important role in ecosystems
- Environmental zoning (e.g. CIE/ILP E1–E4 skyglow classifications)
- Seasonal or time-based ecological (e.g. migration, breeding periods, peak activity periods)

4. Energy: Energy, carbon, and lifecycle performance

Metrics that influence operational efficiency and long-term sustainability:

- **Annual operating hours and tariff-based energy cost exposure**, including the potential for **part-night lighting to extend luminaire lifespan**

- Grid or renewable integration potential (e.g. CMS or off-grid systems)
- Carbon cost or alignment with net-zero policy requirements
- Maintenance access and lifecycle replacement impacts

5. Policy: Policy, governance, and legal obligations

Metrics to reflect obligations or constraints imposed by regulation or strategy:

- National lighting standards or mandatory illumination policies
- Local authority curfew or environmental protection rules
- Strategic policy targets (e.g. biodiversity recovery, Dark Sky commitments)
- Level of decision autonomy (e.g. centralised vs municipal discretion)

These metrics will be used to scale guidelines dynamically – driving transitions between no lighting, minimal adaptive lighting, and full lighting strategies. They will form the primary input categories in the digital tool, informing thresholds and weightings in the decision logic developed in Section 7.

7 Thresholds or ranges of relevance for the digital tool

This section explains how the metrics identified in Section 6 will be interpreted by the guidelines and digital tool. Rather than applying fixed pass/fail thresholds, the tool will ***evaluate each input as a continuous influence on the decision space*** – gradually strengthening or weakening the case for different lighting strategies. This ensures that the framework is adaptable across national contexts and sensitive to shared but not identical priorities among NRAs.

Each metric domain will be represented as an influence range or threshold, where shifts along that range or that meet the threshold change the likelihood of the tool recommending one of the following:

- no lighting or alternative measures
- minimal or adaptive lighting (e.g. dimmed, part-night, spectral control)
- full or higher-intensity lighting with targeted optimisation

These influence ranges or thresholds are proposed to operate according to the following principles:

1. Road safety: Safety and task complexity metrics

Increasing safety risk – especially involving vulnerable road users or complex visual conditions – progressively strengthens the justification for lighting. However, if safety risk increases while ecological or environmental sensitivity is also high, the tool will emphasise adaptive or reduced-impact solutions rather than defaulting to full illumination.

2. Activity: Human activity and perception metrics

Higher night-time pedestrian or cyclist presence will increase the priority of maintaining sufficient visibility for safe, comfortable use of the road environment. While public perceptions of insecurity can be one relevant indicator, these perceptions should not automatically lead to higher illumination levels, as evidence shows that brighter lighting does not always correspond to improved safety. Instead, where heightened perception of insecurity arises, the tool will highlight both lighting and non-lighting responses, including the potential benefits of communication or public education to explain why lower-impact lighting solutions may still be safe and appropriate. Where night-time activity is intermittent or seasonal, the tool will favour adaptive or responsive strategies rather than permanently elevated lighting levels.

3. Ecology: Ecological sensitivity metrics

Higher ecological sensitivity will increasingly constrain the lighting response, prioritising mitigations such as spectral tuning, shielding, or curfews. Where sensitivity is very high, the influence may override safety or social convenience unless supported by critical risk or legal obligation. The tool will encourage reversible and minimally invasive solutions in such cases.

4. Energy: Energy, carbon, and lifecycle performance metrics

Where energy or carbon pressure is elevated, the tool will gradually favour lower operational hours, reduced lighting intensity or off-grid or smart adaptive solutions – especially if safety and ecological conditions do not strongly counterbalance this. Conversely, in contexts where efficiency penalties are low, energy will remain a secondary weighting rather than a primary driver.

5. Policy: Policy and governance metrics

Regulatory obligations – including national lighting standards, local environmental protections, and requirements associated with planning or permitting – will shape the range of acceptable

lighting strategies. In some jurisdictions, such as Flanders, new road construction requires an environmental or building permit and is accompanied by an environmental impact assessment in which lighting-related mitigation measures must be identified. Because these obligations arise at different stages of a project, the tool must support users in understanding which measures are appropriate at each phase – from early planning and permitting through to detailed design and operational adjustments. The tool will therefore incorporate policy constraints as structural weightings that influence decision outcomes, ensuring that recommendations remain both legally compliant and aligned with broader strategic ambitions such as biodiversity recovery, Dark Sky commitments, and net-zero targets.

This approach ensures that the tool behaves consistently and transparently, while avoiding rigid threshold logic. Instead of forcing binary decisions, it enables evidence-weighted recommendations that scale lighting responses proportionately to context – supporting both immediate applicability and long-term adaptability.

8 Conclusion

The Description of Research Needs (DoRN) sets the foundation for the entire SAFELUX programme and defines both the **scope** of the project and the **expected outputs** that must be delivered for participating NRAs. As outlined in the DoRN, the central aim of the Call is to produce practical, evidence-based guidance that reduces the negative impacts of road lighting on nature and skyglow, improves road safety, and reduces energy consumption, supported by a digital decision-support tool and a pilot project to test solutions . These expectations form the benchmark against which all research activities, including the work in WP2, must be aligned.

These conclusions **do not change the scope or outputs defined in the DoRN**. Instead, they clarify how the DoRN's objectives should be operationalised to reflect real-world NRA decision-making, ensuring the guidelines and digital tool are both ambitious and usable.

The 'what' has not changed from the DoRN. It remains valid to produce guidelines, a digital tool, and perform pilots. The 'how' has been refined – for instance, the guidelines should emphasise staged decisions, there should be a safety baseline, there needs to be proportional trade-offs.

This approach **reduces delivery risk**, because it avoids producing outputs that are theoretically sound but operationally rejected by NRAs.

The following sections show the alignment of these findings with the DoRN and implications for project priorities.

8.1 How this report responds to the scope defined in the DoRN

The DoRN requires the project to take a **holistic, interdisciplinary approach** that addresses environmental, safety, energy and social dimensions of road lighting and to demonstrate how decisions can balance multiple, often competing objectives. This report directly supports this goal by:

- Consolidating a long list of 109 impacts across ecology, road safety, social wellbeing and energy.
- Carrying out thematic analysis to reveal the underlying structure of these impacts (themes and sub-themes).
- Engaging NRAs to understand their operational priorities and decision drivers.
- Identifying some of the variability and trade-offs that NRAs routinely face.
- Proposing a staged decision process and thematic pillars to guide the development of both the guidelines and the digital tool.

This work creates the **analytical foundation** needed for the project's later outputs: the guidelines, digital tool, and pilot project recommendations.

8.2 Relationship between the findings in this report and the expected outputs of the DoRN

The DoRN specifies several outputs that SAFELUX must deliver, including:

1. An overview of practices and research

2. Practical guidelines on sustainable road lighting
3. A digital tool
4. Recommendations for pilot projects
5. A final programme report and training resources .

This report contributes to these outputs in the following ways:

8.2.1 Output: Overview and analysis of practices and research

The thematic structure developed in this report – grounded in evidence from multiple disciplines – serves as the classification system through which WP3 will review and synthesise European research and practices. It ensures that the review required by the DoRN is organised according to the real-world impacts NRAs prioritise.

8.2.2 Output: Guidelines on sustainable lighting

The three-stage decision structure proposed in this report maps directly onto the DoRN requirement to provide **practical guidance** showing how tools such as adaptive lighting, spectral control, reflectors and alternative visibility measures can reduce negative impacts while preserving road safety.

This report identifies which themes and decision factors matter most to NRAs, helping to shape the structure and emphasis of the forthcoming guidance.

8.2.3 Output: Digital tool

The DoRN calls for a tool that is intuitive, adaptable, and capable of balancing biodiversity, energy, and safety in real-world contexts. This report provides:

- The **pillars** that will form the organising logic of the tool.
- Example **metrics** that will act as inputs.
- Example **influence ranges** that will determine how the tool's recommendations scale with context.
- The **decision stages** that translate user inputs into transparent, evidence-led guidance.

This ensures that the tool's design is grounded in stakeholder priorities, supporting both usability and credibility. Activities in WP3 and WP4 will capture more detail on specific metrics and influence ranges to populate the tool.

8.2.4 Output: Pilot projects

The prioritisation exercise identifies where NRAs see the greatest need for practical demonstration. For example, the strong emphasis on road safety – particularly vulnerable road user visibility – suggests that pilot sites exploring **reduced-impact safety interventions** (e.g. adaptive lighting, alternative visibility measures) may provide the highest value.

Likewise, ecological sensitivity themes help identify where pilots could test mitigation measures for protected species or dark-sky objectives.

8.2.5 Output: Final programme report and implementation

guidance

The vocabulary, thematic clarity and decision structure developed in this report provide the conceptual consistency required for coherent final recommendations and clear implementation pathways.

8.3 Has the analysis changed the prioritisation of expected outputs?

While the DoRN assigns equal importance to reducing ecological impacts, mitigating skyglow, improving road safety, and reducing energy consumption, the WP2 stakeholder engagement revealed **how NRAs prioritise these themes operationally**. Road safety – especially for vulnerable road users – was consistently ranked highest, reflecting regulatory responsibilities and organisational culture. Ecology, wellbeing, and energy efficiency were also valued but perceived as requiring careful balancing rather than dominance.

It is important to note that the strong weighting toward road safety reflects the professional backgrounds of many workshop participants. However, this emphasis is not merely an artefact of sampling. Road safety is consistently identified by NRAs as a primary responsibility and a dominant criterion in infrastructure decisions. The high ranking of safety themes therefore aligns with the structural priorities of the industry, and SAFELUX outputs should acknowledge this whilst continuing to balance it with ecological and energy considerations.

This does **not** change the DoRN's mandated outputs, but it does influence how they should be structured and weighted:

- **Guidelines and digital tool** should spotlight road safety as a baseline requirement but give equal prominence to ecological and energy considerations in determining *how* lighting should be delivered.
- **Pilot project selection** should focus on situations where safety and environmental pressures intersect, demonstrating balanced solutions that reflect the DoRN's holistic intent.
- **Thresholds and influence ranges** within the digital tool should reflect the real-world tensions identified in this report. For example, safety often pushes towards more light, whereas ecology and energy encourage restraint.

In this sense, the findings of this report do not reprioritise the DoRN outputs, but they **clarify how they must be delivered to remain meaningful and acceptable** to NRAs who will ultimately use the outputs.

Appendix A:

Road safety (Pedestrian and cyclist safety) Visibility of vulnerable road users, perceptions of safety and security, crossing.

WHY is this a priority?

- less accidents
- vunerability and many children
- Vulnerable road users have no physical protective systems from motorised vehicles and are therefore at a high risk of injury.
- More chaotic than highways: visibility more omportant for navigation
- pedestrians and cyclists can cross at any spot, sometimes unexpected behaviour --> visibility for reaction speed is important
- Approximately half of all deaths on roads in Ireland are from vulnerable road users
- Because ensuring visibility for pedestrians and cyclists reduces or prevents accidents, vulnerable users are safer and more protected, mobility is more inclusive
- They are easy to overlook. Lighting on VRUs part of the road is often neglected
- Perhaps more holistic - about drivers AND those who rely on street lighting on the road network.
- From research we know road lighting has high impact in streets with many pedestrians cyclists.
- vulnerable road users are mostly not lighted by themselves and therefor a decent road lighting is needed
- There is a clearly an important need for security/safety at night
- road safety of VRU, see when tey cross, see where they are when you are able to displace yourself safely you can take part of life's activities,
- Many alternative road safety features deployed to mitigate this risk; however, perceived greater consequence due to incident between vehicles and pedestrians.
- See as far as your safe stopping distance

HOW is this measured?

- Public perceptions - measured using social science techniques
- STATS19 data in the UK is the means by which accident causes and effects are measured.
- Identify where and when accidents are most likely to occur
- by pilot testing in different scenarios? Accident statistics or collision rates? maybe surveys?
- This is measured by the DfT in the UK using STAT19 and ambulance data.
- Perceptions can be driven by social media but the actual quantifiable facts can be collected by statistics.
- Dimensioning of the lighting according to standards. EN13201
- number of accidents?
- - crash rate/fatalities - nearby crashes - public polling
- Accident statistics. Mark: there are few results about cycle and foot-paths. So we now mostly about the impact of street lighting on cyclists and pedestrians on roads combined with motorised vehicles

- objective and perceived security

Social and community (Wellbeing and quality of life) Sense of personal safety and security, comfort and convenience for night

WHY is this a priority?

- Mobility for all
- Lots of evening activities needing lighting to get between spaces and/or use of outdoor space
- Public perception that illuminated area is more safe
- Use of taxpayers money- they want safe, efficient transport networks.
- Because people are lazy in the 21st century
- well-being, reduces fear and increases confidence to move at night, quality of life
- People want to be able to run away when theu detect danger, but then they have to able to see
- Hard to meassure. Very individual.
- Because otherwise the community want accept changes in how we illuminate
- This is important as it helps with the economy, if people feel safe at night they are more likely to go out at night.
- Many old people in the future
- reduce barrier to take part in activities during dark time
- The perception of crime driven by social media hype and poorly maintained street lighting can make people feel unsafe and vulnerable and keep themselves indoors at night. Socially deprived areas are a
- It is important that people feel safe and secure, so that more people choose to walk, cycle and take public transport instead of driving
- night time training

HOW is this measured?

- survey
- Calculate changes in lit areas/number of lights. Before and after surveys of people in the areas.
- Crime statistics is factual but doesn't reflect the personal sense of security.
- Could include some mitigations/new technologies - area does not need to be constantly lit
- Har du meassure. Very individual.
- number of road user (pedestrians) in the area
- Analysis of crime rates/reports in area that has been recently illuminated
- number of each type of road users (mobility mix/shift)
- evolution of complaints
- surveys, statistics of crimes, public space usage, nighttime activity participation
- The local constabulary would have data appertaining to crime at night that can be used to determine if road lighting is having a positive affect or not in a geographical area.

Ecology (Population) Population size, distribution, and density. Reproductive success. Mortality (e.g. roadkill).

WHY is this a priority?

CEDR Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

- problem to biodiversity
- Global evidence for declining biodiversity - roads and associated lighting has been a part of this, lo ts of legacy issues on network remain
- Reasons of biodiversity and sustenance. It is the basis of the system we live in and depend on.
- eco-system conservation
- We know little about the local impacts effect on the population
- Can be irreversible damages
- ecological impacts assessments
- Growing evidence for negative impacts on plants and animals. ALAN is now considered a major driver of biodiversity loss
- We need to maintain the natural balance in nature. Every species is part of a cog in the bigger machine
- Disruption to ecological processes, e.g. pollination
- Some species are protected by law
- Roads go through protected areas/habitats
- As an arms length organisation we have a duty to evidence we are taking steps to safeguard the environment. Several species are protect by law.

HOW is this measured?

- Biomonitoring
- This would be measured by DEFRA.
- Looking at population-level responses can be difficult for most taxa
- Citizen science
- Environmental surveys and studies
- Sampling
- Camera surveys of mitigation (i.e mammal underpass) effectiveness
- mortality statistics (waarnemingen.be in Flanders)

Energy (Economic costs and resource use) Operation costs, long-term maintenance, life-cycle energy footprint.

WHY is this a priority?

- Climate adaptation and mitigation goals, every entitiy needs to do their share to reach goals set by different governments
- Again, taxpayers money we have to justify every penny spent!
- budget reductions from government
- Reduce energy conumption as part of reducing greenhouse gasses
- Much of the road lighting is not socio-economically beneficial
- The UK undertake VfM analysis to determine optional solution, taking into account these factors and many others. Guidance can be found in the HM treasury green book and more specifically DMRB TA501.
- Before it is desided whether or not a road should be illuminated, other road safety meassures with lower cost, material use and energy use, should be concidered
- Global overshoot day
- multiple savings for longer-lasting lamps, particularly if used as part of mitigation
- Energy costs is used within the cost benefit ratio to demonstrate whether lighting is a financially beneficial preventative measure towards the reduction in road collision's.

- Energy costs have increased in the past years, and energy consummation for lighting turned on 4200hours a year is a key factor. ROI for modern LED lighting turns into profitable within few years
- Reduction in maintenance costs and reliability also contributes towards the benefit cost ration
- efficient use of public funds, one of the biggest expenses

HOW is this measured?

- annual energy per capita for street lighting
- Reduction of power installed
- evolution of annual road lighting spending (per capita?)
- Installed power by operating time
- Operation costs measured by CMS systems or unmetered supplies. Long term maintenance reactive and routine maintenance costs. Life cycle energy footprint by CMS total energy used and dim using CMS
- Energy budget cost
- Should be many internal documents about socio-economically benefit. It could be interesting to check the coherens between these internal studies and actual lighting practice
- HM treasury green book, DMRB TA501.
- Operation time of armatures (compare those with PN-lighting and this with full operation time)