School of GeoSciences

Reframing Environmental Impact Assessment in Scotland: Toward Adaptive and Reflexive Practice

Kara Moore

A dissertation presented for the degree of Master of Science
University of Edinburgh, 2021.

Ethical statement
The experimentation and work associated with this thesis has been conducted in accordance with the Ethical Guidelines of the School of Geosciences. A self-assessment of the work was conducted and considered within the project planning process. A copy of the self-assessment can be made available upon request

I assert my right to be identified as the author of this work in accordance with section 78 Copyright Designs and Patents Act 1978

THE UNIVERSITY OF EDINBURGH

ABSTRACT OF THESIS

(Regulation 3.5.13)

Name of Candidate **Kara Moore**

Degree **MSc Ecological Economics** *Date* **07-08-2025**

Title of Thesis **Reframing Environmental Impact Assessment Toward Adaptive Reflexive Process**

No. of words in the main text of Thesis **9687**

Environmental Impact Assessments (EIAs) are key regulatory tools used in the planning sector to evaluate and mitigate the potential impacts of major development projects prior to approval. However, the planning sector is confronting intensifying complex challenges, such as climate change, housing shortages, and the renewable energy transition. In the face of these, EIAs have been criticized for failing to account for the interconnected and dynamic nature of socio-ecological systems. This paper investigates how systems thinking can enhance the effectiveness of EIAs. Drawing on principles of complex adaptive systems, uncertainty, collaborative governance, and adaptive management, the research explores how these concepts can address current limitations in EIA practice. Using a framework synthesis approach, the study identifies pathways for integrating systems-based approaches into environmental impact assessment practice.

This inquiry is grounded in the Scottish hydrological context, where critical sustainability targets and development goals intersect with deep reliance on the hydrological systems. These conditions underscore the need for more adaptive and holistic planning tools to manage the socio-ecological risks at stake. Findings suggest that incorporating systems thinking into EIAs can improve their ability to guide decision-making by surfacing uncertainty, fostering social learning, and integrating reflexive monitoring. Anchored in adaptive management, these enhancements position EIAS to better respond to the social and ecological transformations currently reshaping the planning landscape.

Table of Contents

1. Introduction 6
2. Literature review 7
2.1. Role of Environmental Impact Assessments (EIAs) 7
2.2. Role of EIAs in Scotland 8
2.3. Policy perspective 9
2.4. Critical Appraisal of EIAs 9
2.4.1. Uncertainties and Complexities 10
2.4.2. Public Participation 10
2.4.3. Monitoring and Evaluation 11
2.5. Systems Thinking 12
2.6. Hydrology Context 13
3. Methodology 14
3.1. Methodology Literature Review 14
3.2. Methods 15
3.2.1. Phase 1: Familiarization 16
3.2.2. Phase 2: Framework Selection 16
3.2.2.1. Inclusion and Exclusion Criteria 16
3.2.3. Phase 3: Indexing 20
3.2.3.1. Case Study Selection 20
3.2.3.2. Analysis Boundary 20
3.2.3.3. Deductive Coding 21
3.2.3.4. Inductive Coding 21
3.2.4. Phase 4: Charting 22
3.2.5. Phase 5 and 6: Mapping and Interpretation 24
3.2.6. Methodological Limitations 25
4. Results 25
4.1. EIA's strengths in systems thinking 25
4.2. EIA's Gaps in systems thinking 26
4.3. EIA's opportunities in systems thinking 27
5. Discussion 30
5.1. Opportunity 1: Enhancing Consideration of CAS Characteristics 30
5.1.1. CAS Characteristics from an Ecosystem Perspective 30
5.1.2. CAS Characteristics from a Socio-Ecological Perspective 31

5.2. Opportunity 2: Acknowledging Uncertainty 33
5.3. Opportunity 3: Integrate the Social Feedback Loop 35
5.4. Opportunity 4: Improving confidence through Monitoring and Feedback 37
5.5. Opportunity 5: Foster an Adaptive Management Mindset 38
5.6. Current Policy Implications 39
5.8. Next Steps 41
5.9. Further Research 41
6. Conclusion 42
7. References 43
8. Appendices 51
8.1. Appendix A – Framework Selection Criteria 51
8.2. Appendix B – Foundational Frameworks 51
8.3. Appendix C – Code Relations Tables 51
8.4. Appendix D – Proposed Framework with Explanation 51

Acknowledgements

Thank you to my Supervisor Carly Maynard. Thank you to Nature Scot and Association of Environmental Clerks and Works for your support, specifically Grace Gubbins and Simon Knott. Thank you to the teaching department of Ecological Economics at the University of Edinburgh.

List of Tables

Table 1: EIA Procedure Breakdown (Environmental Impact Assessment Handbook, 2019) 8
Table 2: Project Protocol 17
Table 3: A priori Systems Thinking Framework 19
Table 4: Inductive Coding Themes 21
Table 5: Final Framework of Systems Thinking in Impact Assessment Procedure 23
Table 6: EIA's Strengths in Systems Thinking, the numbers represent the quality occurrences of each theme per case study 26
Table 7: EIA's Gaps in Systems Thinking, the numbers represent the quality occurrences of each theme per case study 27
Table 8: EIA's Opportunities in Systems Thinking, the numbers represent the quality occurrences of each theme per case study 27

List of Figures

Figure 1: Visual Graphic of Methodology Process 15
Figure 2: Opportunities already seen in EIA work 28
Figure 3: Opportunities ranked based on their likelihood to create more inefficiencies in the process than benefits 29
Figure 4: Opportunities ranked based on Importance of Implementation 30

1. Introduction

Public planning and policy involve a constant balancing act, between the three pillars of sustainability: environmental, social, and economic (Sala *et al.*, 2013). Maintaining the balance is becoming increasingly challenging as society faces mounting pressures from climate change, housing shortages, and population growth (Giacomoni and Berglund, 2015). In response, planning authorities are expected to act and take responsibility for addressing these socio-ecological challenges. However, these intensifying ecological and societal changes reflect a shift toward what has been defined as "a post-normal science" context, characterized by higher levels of uncertainty and the necessity of urgent decisions (Saltelli *et al.*, 2023). The intersecting pressures of post-normal science reveal the limitations of traditional scientific approaches and call for new procedures capable of addressing complex and uncertain conditions (Bond *et al.*, 2015).

Environmental Impact Assessments (EIAs) are a key tool in guiding these planning decisions (Smart *et al.*, 2014). Despite their widespread use, a growing body of literature criticizes EIAs for their limitations around accuracies in predictions (Tenney and Gjerstad, 2006; Jha-Thakur and Fischer, 2016). EIAs are conducted to identify potential environmental and socio-economic impacts and evaluation mitigation tactics for impacts prior to significant developments (*Environmental Impact Assessment Handbook*, 2019). The primary purpose of the assessment is to inform decision making, identify and prevent environmentally detrimental projects, develop mitigation strategies, and engage potentially impacted communities (Smart *et al.*, 2014; Nita *et al.*, 2022).

EIAs have been found to lack engagement of inherent complexities of socio-ecological systems based on their dynamic and interconnected nature (Fernando Martinez *et al.*, 2019). This follows the trend identified by Ehrlich (2022) noting the siloed approach to environmental analysis. The International Association for Impact Assessment (IAIA) has pushed for a more integrated approach, concurring with consensus among professionals, however, EIA practice and policy remain largely unchanged (Vanclay, 2014). Nieminen and Hyytinen (2015) argue, accelerating change, growing social complexity, and the increasing interconnectedness between local and global systems demand an evolution to a systems-oriented approach to impact assessment.

Systems thinking has been defined as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects" (Arnold and Wade, 2015). This research draws on the theory of systems thinking emphasizing complex adaptive systems, collaborative approaches, and adaptive management. The aim of this work is to contribute to existing literature by assessing strategies to improve EIAs in order

to better face today's planning challenges. Through framework synthesis the research aims to analyse how systems thinking can operationalize to strengthen the EIA procedure.

The relevance of this inquiry is especially evident for hydrological systems in Scotland, where ambitious sustainability targets and development goals require robust and effective planning strategies. By 2030, Scotland aims to transition 50% of its energy section to renewable sources, and by 2032, commits to building 110,000 affordable homes (*Scottish energy strategy*, 2017; *Housing to 2040*, 2021). These efforts, while necessary, place pressure on vital hydrological ecosystems, such as peatlands, and increases flood risk due to reduction of permeable surfaces (Zischg, 2018; Jorat *et al.*, 2024). Decisions around these developments are fragile and must reduce impacts to these systems. Smart *et al.* (2014) found that 88% of responses by stakeholders agree that EIAs play an important role in planning decisions in Scotland. Due to their significance, it is vital EIAs are effective and reflect the complexity of the systems they assess to determine the best routes forward for Scotland.

The literature review discusses the role of EIAs in today's planning sector, the current critiques of EIAs, and the Scottish hydrological system the study focuses on. The methodology includes an analysis of the choice of the framework synthesis method and the process the researcher used. The results reveal the findings of strengths, gaps, and opportunities of operationalizing systems thinking in EIAs. The discussion dives into the benefits and implementation strategies of the opportunities through a review of existing work and feedback from a workshop discussion.

This research contributes to the growing call for reform in environmental assessment by exploring how systems thinking can offer a more responsive, integrated, and adaptive framework for EIAs in the face of accelerating socio-ecological change.

2. Literature review

2.1. Role of Environmental Impact Assessments (EIAs)

Stemming from the Brundtland Report 1987, planning sector policy has focused in on the term sustainable development (Wichaisri and Sopadang, 2018; Nita *et al.*, 2022). Today, sustainable development is defined by the intersection of economic development, environmental resilience, and social inclusion and held accountable by the UN Sustainable Development Goals (Mariani *et al.*, 2022). EIAs fall into the toolset to reach sustainable development through their work to balance the social progress and environmental protection while maintaining economic growth (Snow, 2021).

EIAs are completed through 5 stages as demonstrated in Table 1 (*Environmental Impact Assessment Handbook*, 2019). The process follows the mitigation hierarchy of damage starting with avoiding as the prioritized option and working down through minimizing, rectifying, reducing, and offsetting

(*Environmental Impact Assessment Handbook*, 2019; *National Planning Framework 4*, 2024). After completion of the EIA, they are used in the decision process of competent authority, a government entity that may range from local to federal depending on the scale and sector of the project.

Table 1: EIA Procedure Breakdown (Environmental Impact Assessment Handbook, 2019)

Key Stages	Summary
Screening	Determining if the development requires an EIA.
Scoping	Identification of key most important impacts and alternative options to increase efficiency and effectiveness of the assessment.
Publicity & Consultation	Consultation with stakeholders, statuary bodies, NGOS, associations, clubs, and groups connected to the project. Ideally this is ongoing throughout the project.
Review & Evaluation of Ecosystem Services	Impact Prediction for chosen alternatives, report production, and reviews/amendments. Types of Assessments: cultural heritage impact, landscape and visual impact, ecological impact, geodiversity impact, soil assessment, outdoor access impact, and marine environment.
Decision Making	Alternative Selection via. Decision criteria.
Monitoring & Auditing	Analysing effectiveness of mitigation strategies.

Due to increasing public concern for environment starting in the 1960s, EIAs were introduced by the European Union (EU) Directive in the 1980s (Snow, 2021). Weston (2004) identifies the drivers for the creation of EIAs as societal trends in for environmental concern, scientific decision-making, and public participation. Although multiple decades have passed since their development, EIAs have not been significantly updated since their implementation, lead to gaps in the face of our current environmental challenges and technical innovation (Nita, 2019).

2.2. Role of EIAs in Scotland

The United Kingdom (UK) adopted the EU Directives on EIAs through the 1988 Town and Country Planning Regulations (Glasson, 1999). EIAs continue to be regulated through the Town and Country Planning Regulations and specific sectors policies (*Environmental Impact Assessment Handbook*, 2019). Now, around 800 EIAs are completed yearly throughout the UK (Jha-Thakur and Fischer, 2016). Smart *et al.* (2014) found that most participants from the planning field believe EIAs have the potential to influence decisions around wind farm developments in Scotland. While the study focused specifically on wind farms, it highlights the broader significance of EIAs underscoring the importance of EIAs to serve as meaningful resources for communities engaged in development decisions.

2.3. Policy perspective

Recent policy developments in the UK emphasize economic growth, with the Planning and Infrastructure Bill stating: “Sustained economic growth is the only route to delivering the improved prosperity our country needs and the higher living standards working people deserve” (*The Planning and Infrastructure Bill*, 2025). Scotland deviates from this commitment with its recent National Planning Framework 4, marking a shift towards a sustainability focused planning process (*NPF 4*, 2024). National Planning Framework 3 held economic growth as the priority, while NPF4 emphasizes rebalancing Scotland and has stricter requirements of implementing sustainable solutions (*About NPF 4*, 2025). The framework implements spatial assessment to allocate various areas for sustainability, liveability and productivity (*NPF 4*, 2024)

Through these strategies, Scotland is working to reach ambitious climate and biodiversity targets. The Scottish Government aims to halt biodiversity loss by 2030 and restore biodiversity by 2045 (*Biodiversity strategy to 2045*, 2022). Additionally, Scotland’s climate strategy includes reaching net zero emissions by 2045 (*Net Zero Strategy*, 2022). This is particularly urgent given the UK's status as having the least intact nature and ranking as the second-highest overall emitter of greenhouse gases in Europe (Barkham, 2022; Christenson, 2022). Achieving these targets will require robust planning and a strong role for EIAs to ensure development aligns with environmental and climate commitments, including the NPF4 which aligns with these goal (*National Planning Framework 4*, 2024).

Current studies around EIA continue to shape and suggest improvements for the effectiveness of assessments (Nita, 2019). However, over the past decades, there has been ongoing debate about the effectiveness of EIAs and whether they can keep pace with the growing complexity of societal changes and progress in scientific and technical insight (Bice and Fischer, 2020).

2.4. Critical Appraisal of EIAs

EIAs are widely recognized as important tools in planning decisions, yet their effectiveness remains contested (Arts *et al.*, 2012). This was supported by Jha-Thakur and Fischer's (2016) review of EIAs UK wide highlighting various weaknesses EIAs have failed to address throughout their lifetime. Failures in their effectiveness range from both inaccuracies in predictions and failure to engage impacted community members (Tenney and Gjerstad, 2006; Ferreiro *et al.*, 2013). EIAs are analysing deeply complex ecosystems composed of physical biotic, social, economic, cultural and intrinsic features resulting in uncertainties and emergent behaviours that create a complex system (Bodin, 2017; Fernando Martinez *et al.*, 2019). Through this literature review of current practices three aspects were isolated as limitations to see these complexities as weaknesses in EIAs: uncertainties and transparency, monitoring/evaluation, and

public participation. These limitations are consistent with Sinclair et al. (2022), a review by impact assessment professionals where twelve concepts were identified as keys to the future of IAs (Sinclair *et al.*, 2022).

2.4.1. Uncertainties and Complexities

Consistent with post-normal science, the unpredictability and complexities of socio-ecological systems will cause predictive methods to have a degree of uncertainty that should be considered throughout the life of the project (Bond *et al.*, 2015; Fernando Martinez *et al.*, 2019). Uncertainty may stem from various sources, such as data limitations, inadequate public participation, the absence of robust feedback loops, and increased unpredictability due to climate change (Rozema et al., 2012; Onyango, 2016; Alberts et al., 2020; Bice and Fischer, 2020).

Multiple studies highlight inadequate accounting and lack of transparency for uncertainty as a weakness in the current EIA process (Tenney and Gjerstad, 2006; Leung *et al.*, 2016). Cardenas and Halman (2016) found that uncertainty can arise at each of the stages of the EIA process. Moreover, climate-related uncertainties are often overlooked in EIA processes, which is a failure to adhere to the precautionary principle (Smart *et al.*, 2014). Tenney and Gjerstad (2006) reported that 29% of impact estimates were inaccurate and 43% of the documents failed to report uncertainty. Similarly, Leung *et al.* (2016) concluded the omission of uncertainty levels limits decisionmakers ability to make fully informed choices. Addressing uncertainty in a transparent and systematic manner is essential to enhance the reliability and effectiveness of the EIA process in guiding sustainable decision-making.

2.4.2. Public Participation

EIAs extend beyond environmental concerns to also address the social well-being and cultural impacts on populations and communities. These are considered through socio-economic parameters such as population and human health, material assets, and cultural and landscape heritage (*Environmental Impact Assessment Handbook*, 2019). Public participation is mandated in various stages of the EIA process.

However, considerable research has questioned the effectiveness of public participation requirements in practice. Nita et al. (2022) identified persistent gaps in the integration of socio-economic and human health aspects within both EIA procedures and their implementation. Similarly, Glasson (1999) pointed out two key weaknesses in the UK EIA process: insufficient attention to socio-economic impacts and unequal access among stakeholders, which hinders effective public participation. More recently, Jha-Thakur and Fischer (2016) argue that improvement has been made in this area due to legal obligations increasing scope for socio-economic impacts. However, given its importance, further enhancements are still needed.

Bodin (2017) finds that environmental governance needs collaboration to: “enhance the generation of knowledge, integrate insights from different knowledge systems, diffuse knowledge and best practices among actors”. Public participation can improve the efficacy of the overall EIA process in avoiding environmental destruction (O’Faircheallaigh, 2010). Hasan et al. (2018) emphasizes public participation contribution to validating data and findings.

Integrating social and environmental aspects is essential for meaningful sustainability assessments as environmental degradation is intrinsically linked to social well-being (Arushanyan *et al.*, 2017). Public participation, if done correctly, can alter power structure to better distribute the weight of decision-making. This is echoed in the Scottish context, where Thygesen and Agarwal (2014) finds that collaborative, deliberative approaches to EIAs mitigate the complexities of decision making around wind farms and are conducive to socially accepted solutions. Ultimately, integrating robust public participation into the EIA process not only incorporates procedural justice but also improves environmental outcomes (Smart *et al.*, 2014).

2.4.3. Monitoring and Evaluation

Within EIAs, when analysts propose a mitigation technique, they also suggest if and what type of monitoring measures are required (*Environmental Impact Assessment Handbook*, 2019). The monitoring measures ensure the impact of construction or operation doesn’t break a certain threshold or examine the effectiveness of the mitigation technique. The *Environmental Impact Assessment Handbook* (2019) states “monitoring can improve the future mitigation of similar developments”. However, reviews of the UK EIA process have consistently distinguished the monitoring stage as a weakness (Glasson, 1999; Jha-Thakur and Fischer, 2016). Jha-Thakur and Fischer (2016) discussed the potential of the 2014 EU directive to increase monitoring regulations. However, still in 2021, Glasson *et al.* (2021) highlights monitoring and auditing against predicted impacts is “the Achilles heel in the planning and assessment process”.

Jones and Fischer (2016) identify three primary barriers to effective monitoring and auditing in EIAs: the lack of appropriate legislation, implementation costs, and weak enforcement mechanisms. Additionally, Soria-Lara *et al.*, (2020) reports that existing monitoring practices suffer from poor accuracy and limitations in information. In Scotland, Zwart *et al.* (2015) found that monitoring data is often underutilized, highlighting the potential for contribution to broader learning or adaptive management strategies.

There is broad consensus regarding the persistent weakness within the EIA process. However, Onyango and Gazzola (2024) discuss the stagnation in EIA legislation in the United Kingdom and advocate for a fundamental framework shift. Caro-Gonzalez *et al.* (2023) observe that while there is a growing paradigm

shift pushing EIAs to address greater complexity, current legislation still lacks the holistic perspective necessary to drive this transition.

2.5. Systems Thinking

Given the identified weaknesses of the EIA process, this research proposes systems thinking as a strategy to promote a more holistic approach and address these shortcomings (Onat *et al.*, 2017; Kubiak *et al.*, 2025). Systems science originated in the 1950s and has since evolved to bridge various disciplines in tackling complex, time-sensitive challenges, such as those posed by sustainability (Hieronymi, 2013). Initially developed to foster interdisciplinary collaboration, systems thinking provides a framework for understanding and predicting the behaviour of interconnected systems (Verrier *et al.*, 2022). This multidisciplinary perspective integrates social, environmental, economic, and governance dimensions, allowing for a deeper exploration of the interactions and feedback loops between them (Hassan *et al.*, 2025).

Porter and Córdoba (2009) categorize systems thinking into three broad approaches: functionalist, interpretative, and complex adaptive. The latter, complex adaptive systems, are particularly relevant to large-scale environmental systems, which are often characterized by nonlinearity, feedback, and emergent behaviours. Complex adaptive systems originally designed for socio-economic problems, will be applied in this context to provide complexity aware approaches to EIAs (Levin, 1998).

Systems thinking promotes a shift toward more integrated and dynamic forms of analysis that can mitigate many of the critiques discussed (Ehrlich, 2022). Verrier *et al.* (2022) highlights systems thinking approaches reduce risk and uncertainty, particularly in the face of complex socio-ecological challenges. Another strength system's thinking lies is its participatory foundations through illuminating the linkage between the environmental and social systems often missed in EIAs (Nita *et al.,* 2022; Scolozzi *et al.*, 2025). As Voulvoulis *et al.* (2017) notes, systems thinking demands interdisciplinarity to foster mutual learning and innovative problem-solving. Drawing on diverse social perspectives not only improves knowledge generation but also allows decision-makers to account for values, trust, and attitudes in the evaluation process (Verrier *et al.*, 2022). Additionally, systems thinking encourages robustness through continuous feedback, reflection, and adaptation through iterative evaluation (Porter and Córdoba, 2009). Nieminen and Hyytinen (2015) further argue that the overlap of social embeddedness and effective monitoring processes for successful systems integration.

There is existing work applying systems thinking to related fields, such as Life Cycle Assessment (LCA), where it has been used to integrate complex variables and reveal causal relationships (Onat *et al.*, 2017; McAvoy *et al.*, 2021). Similarly, Fernando Martinez *et al.*, (2019) explored the application of network analysis, closely related to systems thinking, in the context of EIAs. Ehrlich (2022) focused on how

systems thinking can fill the gap of collective impacts absence in cumulative impact assessments due to the current siloed practice. Although, in Scotland, there has been an emphasis on ecosystem-based approaches that incorporate elements of systems thinking, there remains a notable gap in the literature of evaluating general EIA practices through a systems thinking lens (Wawrzyczek *et al.*, 2018a). This work will be done within the context of Scotland's hydrological systems.

2.6. Hydrology Context

Hydrology plays a crucial role in shaping Scotland's landscape, with peatlands covering approximately 20% of Scotland (Lorne, 2024). Peatlands provide a wide range of ecosystem services such as water purification, carbon storage, biodiversity, cultural services, and more (Wawrzyczek *et al.*, 2018). However, the delivery of these services depends on the peatlands maintaining water saturation, underscoring their significant hydrological connections. Alterations to groundwater can create a cascade of negative effects, ultimately degrading the peatland ecosystem (Wawrzyczek *et al.*, 2018). Patel *et al.* (2025) note the interconnection of peatlands with their communities due both to their economic opportunity and conservation for ecosystem services.

Along with the rest of world, Scotland has been experiencing changes in average annual rainfall and changes to water temperature (Adaptation Scotland, 2025). Communities are dependent on the water quality and flood adaptation of rivers and lochs for both economic and health and safety reasons (Gilvear *et al.*, 2002). The health of the hydrologic systems of both peatland and rivers/lochs is integral to reaching biodiversity targets. Scotland has committed 250 million to rewet 250,000 hectares of peatland by 2032, protecting these ecosystems aligns with Scotland's policy goals.

Badr *et al.* (2004) notes that there are multiple deficiencies in the water impact assessment practice, highlighting the need for more robust and integrated hydrological analysis within EIA processes. Jorat *et al.* (2024) identifies how renewable energy development has increased pressure on vital peatland habitats and discussed failures of mitigation techniques. Pan *et al.* (2018) highlights the complex relationship between water impact and urban land use. Finally, hydropower has the potential to alter downstream ecosystems including fish populations which communities rely on for economic reasons (Sample *et al.*, 2015). The planning sector holds responsibility to accurately analyse the impacts of developments to the systems communities depend on.

There is a large amount of existing work on the intersection of systems thinking and water resource management (Mashaly and Fernald, 2020). Reed and Barbrook-Johnson (2022) highlight complex systems thinking as a tool to ingrate transdisciplinary knowledge, monitoring, and stakeholder engagement to peatland management. For these reasons, it was decided to focus on the hydrological impacts during this analysis.

This study will use a framework synthesis approach to examine Scottish EIA practices in the context of hydrological systems. By applying a systems thinking perspective, the findings identify strengths, gaps and opportunities for improving EIA processes through more adaptive, integrated, and holistic approaches.

3. Methodology

A framework synthesis approach was used to identify and select an appropriate systems thinking framework. This framework was then applied to evaluate three EIA case studies, assessing the extent to which systems thinking themes are incorporated. The analysis highlighted both the strengths and the gaps within these case studies, which was used to identify opportunities for operationalizing systems thinking within EIA practice. Additionally, a workshop was completed with the help of the Association of Environmental Clerks and Works and NatureScot with the purpose of getting feedback from professionals working on EIAs in Scotland. The workshop aimed to assess the value of implementing the key findings and to identify potential barriers, in order to prioritise next steps for EIA practice.

3.1. Methodology Literature Review

Evidence synthesis is a group of methodologies that analyse an area of work, concept, theories through a systematic process (Macura *et al.*, 2019). An offshoot of framework analysis, developed in 1994, framework synthesis is a form of evidence synthesis well suited for policy analysis (Dixon-Woods, 2011). Framework synthesis adds more structure to an evidence synthesis as it breaks down the process to selecting an *a priori* framework which is then utilized as a basis to evaluate an existing body of work against (Carroll *et al.*, 2013).

More specifically, it's structure allows for researchers to work within time limitations, applicable for this study (Brunton *et al.*, 2020). This is due to the theme identification occurring *a priori* or through the initial framework (Dixon-Woods, 2011). However, it is not limited to the *a priori* themes and incorporates a second stage of *de novo* or themes that emerge during analysis (Dixon-Woods, 2011; Watkins and Collins, 2025). Therefore, the analysis allows both deductive and inductive coding (Watkins and Collins, 2025). The benefit being it can address a specific question while allowing space for emerging issues (Dixon-Woods, 2011). Framework synthesis has a transparent and pragmatic structure, where other methods rely more on conceptual interpretation (Carroll *et al.*, 2013). Because of this, framework synthesis falls on the realist side of evidence synthesis, typically fit for questions that are relatively developed in order to find an *a priori* framework (Brunton *et al.*, 2020).

Framework synthesis is beneficial when working with large amounts of data as it manages complexity well (Brunton *et al.*, 2020). It's structure encourages ease of communication to audience through a clear

and consumable process (Brunton *et al.*, 2020). Additionally, Flemming *et al.* (2019) discusses the integration of qualitative and quantitative evidence bolstering the results. The methodology has typically been practiced in healthcare and psychology sectors (Brunton *et al.*, 2020). However, it has more recently been used in environmental policy considerations such as nano-material and flood risk (Belluco *et al.*, 2018; Watkins and Collins, 2025).

There has been a general movement within evidence synthesis methods to better incorporate stakeholder opinions for increased validity of reviews and quality of output (Harris *et al.*, 2016; Pullin *et al.*, 2018). Brunton *et al.* (2020) highlights a limitation of framework synthesis is the lack of stakeholder engagement within the review design and interpretation of results. To mitigate this limitation, stakeholder engagement was employed at the mapping and interpretation stage of framework synthesis through a workshop.

Framework synthesis was chosen as the methodology over other evidence synthesis due to its increased structure, which allows for time constraints through *a priori* framework themes and the combination of inductive and deductive coding (Flemming *et al.*, 2019). Additionally, the researcher selected framework synthesis for its ease of communication to an audience of mixed backgrounds in hopes of benefits for policy implications (Brunton *et al.*, 2020).

3.2. Methods

Framework synthesis has six phases: Familiarization, Framework Selection, Indexing, Charting, Mapping, and Interpretation demonstrated in Figure 1 below (Macura *et al.*, 2019; Brunton *et al.*, 2020).

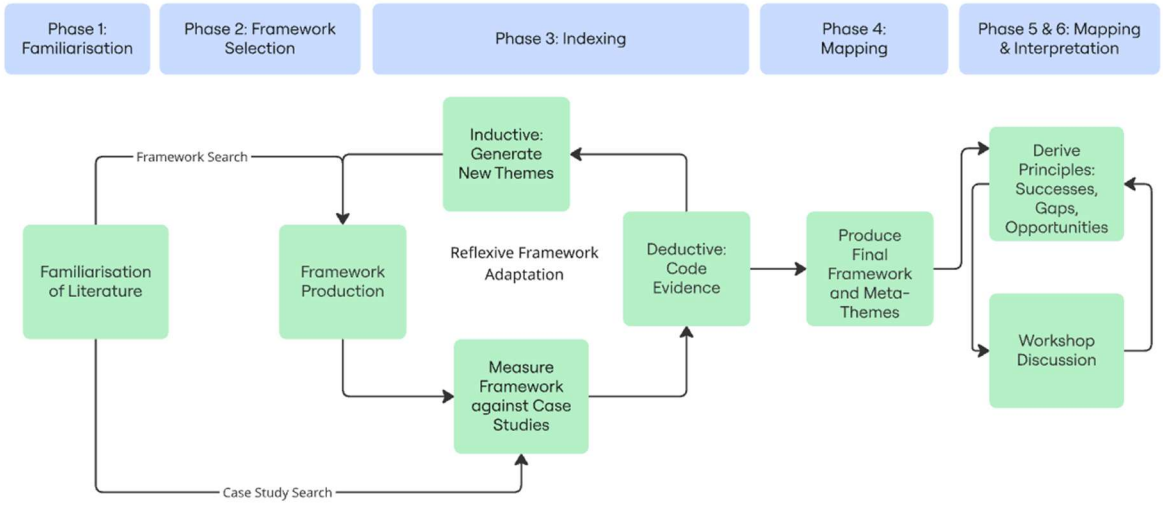

Figure 1: Visual Graphic of Methodology Process

3.2.1. Phase 1: Familiarization

The first stage is familiarization which was completed through the literature review for this study. It included researching both the existing policy of EIAs in Scotland, critiques of EIAs, systems thinking applicability, and the hydrologic systems in Scotland.

3.2.2. Phase 2: Framework Selection

Framework selection can be completed in two ways for framework synthesis. The first is created through thematic coding of foundational studies of the subject, the second is selecting a good enough existing framework or a best-fit framework (Macura *et al.*, 2019). This research utilized the best fit framework selection due to time constraints and the plethora of existing systems thinking frameworks (Carroll *et al.*, 2013). To test the extent of which EIAs consider systems thinking, an evidence synthesis of existing systems thinking frameworks was completed. To collect these frameworks the search strings in Table 2 were utilized to cast a wide search of systems thinking frameworks. However, the studies were required to be related to sustainability. There was no limitation on the year of study as systems thinking is a relatively recent area of work. The search was done in the Scopus database.

3.2.2.1. Inclusion and Exclusion Criteria

The search resulted in 427 existing studies. The process of screening is demonstrated in Table 2. Following a PRISMA process, this project protocol was decided prior to the screening process to remove research bias (Page *et al.*, 2021). The initial screening was focused just on the abstract and excluded any studies that clearly didn't seem to include a system thinking framework in the context of sustainability. The secondary screening included reviewing the framework. They were removed if they didn't consider the crossover of social and environmental systems, were not applicable to EIAs due to specificity, or failed to have a framework. Any remaining frameworks were reviewed for methodological quality. The final 14 frameworks that were found to be applicable to the study were decided through a criterion based on the familiarization phase. The frameworks must include uncertainty, social aspects, monitoring, and system thinking characteristics. The selection process was based on rating all the frameworks based on these criteria as demonstrated in Appendix A.

Table 2: Project Protocol

Database	Scopus	Studies
Search String	(TITLE-ABS-KEY("systems thinking") AND TITLE-ABS-KEY("framework" OR "tenets") AND TITLE-ABS-KEY("sustainability")) AND (LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"MULT") OR LIMIT-TO (SUBJAREA,"EART") OR LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"ENER"))	423 collected on May 31st 2025
Initial Screening (Just Abstracts)	Must include systems thinking Implies a framework is produced or edited within the study	167 excluded 256 remain
Secondary Screening (Framework Search)	External Validity (applicability to research question) Remove any studies with no framework Remove any studies that is unlikely to apply to socio-ecological problems Remove frameworks that are specific to the case study	242 excluded 14 remain
Final Inclusion (Methodology)	Internal Validity (methodology quality assessment) Remove poor quality studies	0 removed due to quality
Framework Selection	Based off the criteria in Appendix A	2 studies selected

Two frameworks were selected: a study from (Rossing *et al.*, 2021) and a study from (Davidson and Venning, 2011). The initial format of the frameworks is available in Appendix B. Although originally planned to select one framework, the combination of the two frameworks complement each other's strengths and weaknesses. Rossing *et al.* (2021), was chosen due to its alignment with the three main critiques illuminated during the familiarisation phase. It discusses systems thinking through the intersection of complex adaptive systems theory, social learning, and monitoring. This framework will be referred to as the conceptual framework. It was originally built to consider co-innovation in the context of sustainable agriculture. This gap in applicability was mitigated through the addition of the Davidson and Venning (2011) framework. The framework is grounded in an interpretive approach to systems thinking in the context of decision making for sustainable development. It highlights adaptive management through feedback loops and the incorporation of community consultation. This framework will be referred to as the procedural framework as it incorporates systems thinking into impact assessments through a thorough step by step process.

The frameworks were edited slightly due to scope of the project, consistent with the method (Brunton *et al.*, 2020). No changes were made to the conceptual framework prior to analysis. The procedural framework included a process section focused on efficiency and effectiveness of methodologies, inclusion of various scenarios, and use of appropriate models (Davidson and Venning, 2011). This section was excluded from the themes as it is more focused on the characteristics of the specific methodologies used within EIAs. As this is not the focus of this study, this section was found to be out of scope. Inform decision making was also removed as the role the EIAs play in the decision is not discussed in the EIAs. The identify hazards and systematically identify hazards steps have been combined due to their similarity. Likewise, the uncertainty and evaluate the certainties, uncertainties, and probabilities steps were merged due to similarity. Table 3 lists the themes from the two frameworks together creating an *a priori* framework for this analysis.

Table 3: A priori Systems Thinking Framework

Conceptual Framework Meta- Themes	Conceptual Framework Themes	Definition	Procedural Framework Themes
Monitoring and Evaluation	Accountability	Monitoring for the purpose of ensuring the obligatory regulations or criteria	Adopt a holistic perspective
	Learning	Monitoring for the purpose of learning weather mitigation tactics are effective	Have adequate scope Clear vision of sustainability and goals that define visions Links visions and goals to indicators and assessment criteria
	Reflexivity	Monitoring for the purpose of inputting data into future EIAs	Anticipate man-made and natural risks through a consultation process
Social Learning	Network of Actors	Receiving input from those who are impacted or can contribute to knowledge generation	Best available information Integrate the knowledge and understanding from all relevant disciplines to provide society with the tools to review the sustainability and the risks of proposed policies and plans
	Needs Identification	Identify needs of the various actors	Identify the consequences by systematically cataloguing hazards Develop criteria for what is meant by "safe enough" or sustainable Identify all judgements, assumptions and uncertainties in data and interpretations
	Perceptions of Others	Creating a space for actors to learn from others and encourage collaboration	Input should be drawn from broad representation of key grass roots, professional, technical and social groups, including youth, women and indigenous people – to ensure recognition of diverse and changing values
Complex Adaptive Systems	Hierarchal Systems	Subsystems nest within larger systems, function independently and as a larger whole	Incorporation of economic, social and environmental outcomes Vulnerability concerns and implications
	Causal Relationships	Interactions between various sectors of the Impact Assessment	Evaluate the certainties, uncertainties and the probabilities involved in the calculations of the vulnerability and of the exposure Compare with criteria to assess the need for further action Determine options to control, mitigate and adapt to the risk
	Emergent Behaviour	Unexpected or unpredictable outcomes of a complex system	Promote and guide monitoring systems to collect, assimilate and archive data relevant to the determination of sustainability and risk, now and in the future Communicate the results to those who need to know
	Adaptive Management	Approaching a system with learning, flexibility, and responsiveness	Need to be adaptive and responsive to change and enable collective learning and feedback to decision-making

3.2.3. Phase 3: Indexing

The indexing phase includes case study selection and assesses the studies against the *a priori* framework. This methodology deviates from the standard process of a second evidence synthesis to find primary studies as the analysis is on EIAs (Brunton *et al.,* 2020). Due to the size and complexity of EIAs documents, only three case studies of various developments were selected from different locations in Scotland.

3.2.3.1. Case Study Selection

Due to the size and complexity of EIAs documents, only three case studies of diverse developments were selected from various locations in Scotland. This was due to the time constraints of the study. It was decided to have each case study be a different type of development to increase the reach of the study. The included case studies development types are hydropower, wind farm, and mixed-use development. Selection criterion for the EIAs was decided prior to the search. The case studies must have been decided after 2018 but prior to 2022 to avoid any current contentious developments. Additionally, it was required the projects must have been decided and consented. The case studies need to have analysis of the water environment/hydrological impact at construction and operational levels scoped in. Additionally, at least one of the case studies needed to include peatland impacts to represent Scotland's vulnerable hydrological system. Based on these criteria, three case studies were selected, two involving peatlands. The researcher redacted specific information on the case study as the purpose of this research is to analyse EIA practices in Scotland rather than specific case studies. The developers were contacted and informed about the research. The EIAs were accessible as they are publicly available.

3.2.3.2. Analysis Boundary

To ensure that systems thinking was properly evaluated, the entire EIA report was analysed. However, the figure and appendices files were excluded. Due to the size of the document, although the whole report was reviewed, a boundary around the hydrology system was drawn for coding. The geology and hydrology, ecology, and fish impact sections were analysed in-depth focusing on the procedure as well. Other sections such as, the landscape and visual, socio-economic, air quality, noise, etc, were reviewed for interconnections with the hydrological system specifically. The policy section was excluded as the goal is to focus on the procedure of EIAs, therefore, policies outside of the ones constructing EIAs can't be critiqued. The EIAs were analysed both deductively and inductively, one of the benefits of the framework synthesis.

3.2.3.3. Deductive Coding

Qualitative analysis was completed using MaxQDA (Gizzi and Rädiker, 2021). The first stage of coding focused on highlighting any clear themes from the *a priori* framework. Text was coded when representative of a theme. Through deductive coding, the researcher ensured the analysis did not force the data to fit as this must be avoided to encourage analytical value (Flemming *et al.*, 2019). Through the coding process, there was a clear lack of project specific context and goal setting, causing these steps to be removed from the procedural framework.

3.2.3.4. Inductive Coding

A second phase of analysis utilized inductive coding to generate themes for areas of the EIA that do not fit with in the *a priori* framework. Table 4 list the new themes. Due to the prevalence of uncertainty, through inductive coding, uncertainty was proposed as a meta-theme to incorporate systems thinking into EIAs. This was due to its importance in informing decision makers and its clear variation between EIAs in current practices. In addition, some complex adaptive systems characteristics terms were added: cumulative impacts, irreversibility, and temporal consideration. The new procedural sections added define uncertainty in the design at the time of assessment and clearly state residual effects upon completion of mitigation techniques.

Table 4: Inductive Coding Themes

Conceptual Meta-Themes	Conceptual Themes	Definition
Complex Adaptive Systems	Cumulative Impact	Combined effects of multiple developments or various impacts within one development
	Temporal Consideration	Considering delays, accumulation, and nonlinear relationships in socio-ecological systems
	Irreversibility	Impacts that last indefinitely due to crossing a threshold which ultimately changes a system
Uncertainty	Uncertainty in Data	Lack of applicable data or uncertainty based on variation in data
	Uncertainty in Design	Unknowns regarding the development's design or construction
	Confidence levels	Confidence level of the mitigation tactics to work and the residual effects
Social Learning	Social Data Input	Including information learned from consulting the public
	Public Input	Specifically receiving insight from public entities
Monitoring & Feedback	Monitoring Data Input	Including monitoring data within an impact assessment

Gaps of the framework themes were highlighted with the hope of finding opportunities to incorporate the conceptual themes that were gaps. Throughout this process codes that represent a missing conceptual code were also added, i.e. opportunity codes. These were utilized to represent opportunities in the charting section. Opportunity codes were coded in based on the researcher's knowledge and experience with the subject in areas that were determined to have an absence of a systems thinking component.

3.2.4. Phase 4: Charting

Following Brunton *et al.* (2020), the charting phase analyses the relationships between the themes derived from the data. The researcher chose to analyse the relationship between the procedural framework and the conceptual framework to produce a final framework. The relationships were assessed based on code relation tables produced through MaxQDA. A table was produced to count the number of intersections, direct overlap of codes, between the various procedural themes and conceptual themes. A second table was produced to count the number of times each procedural theme and conceptual theme was within three paragraphs of each other. These are available in Appendix C. The researcher would often have an idea of these relationships based on the qualitative review, however, utilized the quantitative data to confirm the overlap. Consideration was given to both which procedural themes had the most overlap for each conceptual theme and which conceptual theme had the highest number of overlaps for each procedural step. The gaps were limited in the number of codes. In this case, certain case studies outperformed the others in a certain main theme, therefore they were zeroed in on to determine relationships between the conceptual and procedural themes. Based on the results of the charting phase a final framework was created. The intention of the framework is to exemplify how systems thinking fits into the impact assessment procedure. The final framework is pictured in Table 5.

Table 5: Final Framework of Systems Thinking in Impact Assessment Procedure

Procedural Themes	Conceptual Meta-Themes	Conceptual Themes
Anticipate man-made and natural risks through a consultation process	Complex Adaptive Systems	Hierarchical Systems
		Network of actors
	Social Learning	Needs Identification
		Public Input
Best available information	Complex Adaptive Systems	Cumulative Impacts
	Uncertainty	Uncertainty in Data
	Monitoring and Feedback	Mointoring data input
Identify unknowns in design process	Complex Adaptive Systems	Adaptive Management
	Uncertainty	Uncertainty in Design
Integrate the knowledge and understanding from all relevant disciplines to provide society with the tools to review the sustainability and the risks of proposed policies and plans	Social Learning	Social Data Input
		Needs Identification
		Perception of others
Identify the consequences by systematically cataloguing hazards	Complex Adaptive Systems	Temporal Consideration
		Emergent Behaviour
		Causal Relationships
Develop criteria for what is meant by "safe enough" or sustainable	Complex Adaptive Systems	Irreversibility
Identify all judgements, assumptions and uncertainties in data and interpretations	Complex Adaptive Systems	Emergent Behaviour
	Uncertainty	Uncertainty in Data
	Monitoring and Feedback	Mointoring data input
Input should be drawn from broad representation of key grass roots, professional, technical and social groups, including youth, women and indigenous people – to ensure recognition of diverse and changing values	Social Learning	Social Data Input
		Needs Identification
		Perception of others
Incorporation of economic, social and environmental outcomes	Complex Adaptive Systems	Hierarchical Systems
		Causal Relationships
		Temporal Consideration
Vulnerability concerns and implications	Complex Adaptive Systems	Cumulative Impacts
		Temporal Consideration
Evaluate the certainties, uncertainties and the probabilities involved in the calculations of the vulnerability and of the exposure	Complex Adaptive Systems	Temporal Consideration
		Emergent Behavior
	Uncertainty	Confidence Level
Compare with criteria to assess the need for further action		
Determine options to control, mitigate and adapt to the risk	Complex Adaptive Systems	Temporal Consideration
		Causal Relationships
		Irreversibility
	Uncertainty	Emergent Behavior
		Confidence Level
	Monitoring and Feedback	Monitoring Data input
		Accountability
		Reflexivity
Residual effects	Complex Adaptive Systems	Temporal Consideration
		Causal Relationships
Promote and guide monitoring systems to collect, assimilate and archive data relevant to the determination of sustainability and risk, now and in the future	Complex Adaptive Systems	Irreversibility
	Monitoring and Feedback	Accountability
		Learning
		Reflexivity
Communicate the results to those who need to know	Complex Adaptive Systems	Causal Relationships
Need to be adaptive and responsive to change and enable collective learning and feedback to decision-making	Complex Adaptive Systems	Adaptive Management
	Social Learning	Public Input
		Perception of others
	Monitoring and Feedback	Learning
		Reflexivity

3.2.5. Phase 5 and 6: Mapping and Interpretation

Mapping and interpretation phase extrapolates the results to communicate to policy makers and those in the industry. Following a similar strategy to Watkins and Collins (2025), the themes were mapped into strength, gap, or opportunity. The mapping was based on the qualitative understanding of the EIAs and backed up through the quantitative data. The quantitative data was the observed number of times each theme was coded in each case study. However, it was decided not to be a specific cut-off number because there was so much variation in the length and number of sections and therefore number of codes of the EIAs. Additionally, there was another level of complexity due to some themes being a strength in one case study but a gap in others. It was determined that if two of the three were identified as successes the theme would be allocated to strengths and vice versa for gaps. Opportunities were determined by the number of opportunity codes created that highlighted areas within the EIA where conceptual systems thinking themes could have been applied but were not.

Once the mapping of strengths, gaps, and opportunities was complete, the researcher utilized the workshop to further interpret the results. Utilizing Haddaway *et al.* (2017), the researcher considered the purpose and goal of the workshop in order to most effectively design the workshop structure. The goals include provide context, endorse the review, and share the review to others.

3.2.5.1. Identification and Invitation of Stakeholders

The stakeholder group included a range of professionals involved in EIAs. The participants were invited through the partnered organisations. Additionally, the workshop was marketed through Scotland EIA conference.

3.2.5.2. Initial Engagement

The structure of the workshop allowed for 30 minutes to present to the audience on the purpose, methodology, and results of the study. The purpose of this presentation was to ensure the audience members were fully informed (Haddaway *et al.,* 2017).

3.2.5.3. Documenting Stakeholder Inputs

The workshop utilized a program called Slido to receive feedback on the results of the framework synthesis. Appendix E lists the questions asked to participants during the workshop. The attendees totalled around 22 while 12 participated in the question portion of the workshop. The attendees who did not participate felt they did not have enough experience in EIAs to effectively add to the questions.

3.2.6. Methodological Limitations

In regard to the final framework production, the MaxQDA program also had limitations. The code relation tables were set to be within three paragraphs. However, there was concern for error as the program had issues with acknowledging tables. This issue was mitigated by prioritizing the intersection code relation table, representing codes that directly overlap with minimal error. These tables are available in Appendix C.

Additionally, a couple of relationships were not confirmed by the data but based on researcher's perceptions. These were due to the themes lacking data because they were gaps and low occurrences. Alternatively, this was due to the lack of data on the two procedural steps added during the inductive coding phase. An additional column is provided in the framework table in Appendix D to demonstrate which analysis or whether the researcher's opinion determined the connection.

The analysis was restricted to three case studies due to time constraints. Therefore, there is likely to be more variation throughout the current procedures of EIAs in Scotland. Additionally, there was only one researcher who completed the coding process based on the project type, therefore there is less ability to check for biases (Pullin *et al.*, 2018).

4. Results

The mapping and interpretation results are split by strengths, gaps, and opportunities. The themes were broken down between the four meta themes: complex adaptive systems, uncertainty, social learning, and monitoring and feedback.

4.1. EIA's strengths in systems thinking

The strengths listed in Table 6 were selected based on the occurrence and quality of the theme in at least two of the three case studies. The key strengths include requiring accountability monitoring, consulting a network of actors for needs identification, reporting data and design uncertainty, and incorporating causal relationships.

Table 6: EIA's Strengths in Systems Thinking, the numbers represent the quality occurrences of each theme per case study

Conceptual Meta-Themes	Conceptual Themes	Mixed-Use Development	Wind Farm	Hydro Scheme
		Case Study 1	**Case Study 2**	**Case Study 3**
Complex Adaptive Systems	Cumulative Impact	2	6	8
	Causal Relationships	12	53	39
	Temporal Impacts	2	7	12
Uncertainty	Design Uncertainties	5	1	14
	Uncertainty of Data	12	8	21
Social Learning	Network of Actors	7	4	8
	Needs Identification	6	5	8
Monitoring and Feedback	Accountability	6	9	10

4.2. EIA's Gaps in systems thinking

The conceptual themes, listed in Table 7, that were gaps found to be limited in high quality occurrences within two of the three case studies. The complex adaptive systems gaps are adaptive management, emergent behaviour, hierarchal systems, and irreversibility. The uncertainty gaps were acknowledging uncertainty in the results. Although case study 3 did include confidence levels, this was an exception as the other two case studies did not. The social learning gaps were sharing perception of others, utilizing social data, and including public participation. However, case study 2 was an exception, due to its higher number of codes within the social learning meta-theme. Finally, within monitoring and feedback, learning and reflexivity were both concluded as gaps. Cumulative impact, within the complex adaptive systems meta-theme, did not fall into either category due to its strong occurrence, however seeming to lack quality of assessment.

Table 7: EIA's Gaps in Systems Thinking, the numbers represent the quality occurrences of each theme per case study

Conceptual Meta Themes	Conceptual Themes	Mixed-Use Development	Wind Farm	Hydro Scheme
		Case Study 1	Case Study 2	Case Study 3
Complex Adaptive Systems	Emergent Behaviour	1	4	9
	Adaptive Management	0	7	2
	Hierarchal Systems	0	1	2
	Temporal Consideration	2	2	4
	Irreversibility	6	2	3
Uncertainties	Uncertainty in Results	2	1	14
Social Learning	Perceptions of others	1	3	1
	Social Data Input	1	5	2
	Public Input	1	2	1
Monitoring and Feedback	Learning	2	4	1
	Reflexivity	1	2	3

4.3. EIA's opportunities in systems thinking

Table 8 lists the opportunities based on the number of codes for each opportunity code. The analysis of the areas of opportunities includes considering CAS characteristics in impact assessment, reporting uncertainty, improving confidence through monitoring and feedback, integrating a social feedback loop, and fostering an adaptive management mindset.

Table 8: EIA's Opportunities in Systems Thinking, the numbers represent the quality occurrences of each theme per case study

Conceptual Meta-Themes	Conceptual Themes	Opportunities	Mixed-Use Development	Wind Farm	Hydro Scheme
			Case Study 1	Case Study 2	Case Study 3
Complex Adaptive Systems	Irreversibility, Temporal Consideration, Emergent Behaviour, Cumulative Impact	Enhancing consideration of CAS characteristics	17	17	14
Uncertainty	Uncertainty in Results	Acknowledge uncertainty	13	11	8
Social Learning	Public Input, Perceptions of Others, Social Data Input, Hierarchal Systems	Integrate social feedback loop	6	3	7
Monitoring and Feedback	Monitoring Data Input, Learning, Reflexivity	Strengthening confidence through reflexive monitoring and feedback	8	13	17
Mixed	Adaptive Management	Fostering an adaptive management mindset	9	8	5

4.4. Workshop Discussion Results

The workshop utilized the Slido program to collect data from the workshop. The first four questions collectively aimed to assess the current EIA landscape and identify which proposed opportunities are already in practice, where gaps remain, and which opportunities should be prioritized for implementation.

Question 1: Which of these opportunities do you see already successfully implemented in the EIA procedure?

The first question focused on which opportunities were already seen in the current EIA space. Figure 2 shows the number of votes for each opportunity. Opportunity 2, acknowledging uncertainty, received 15 votes highlighting that is often used already in EIAs.

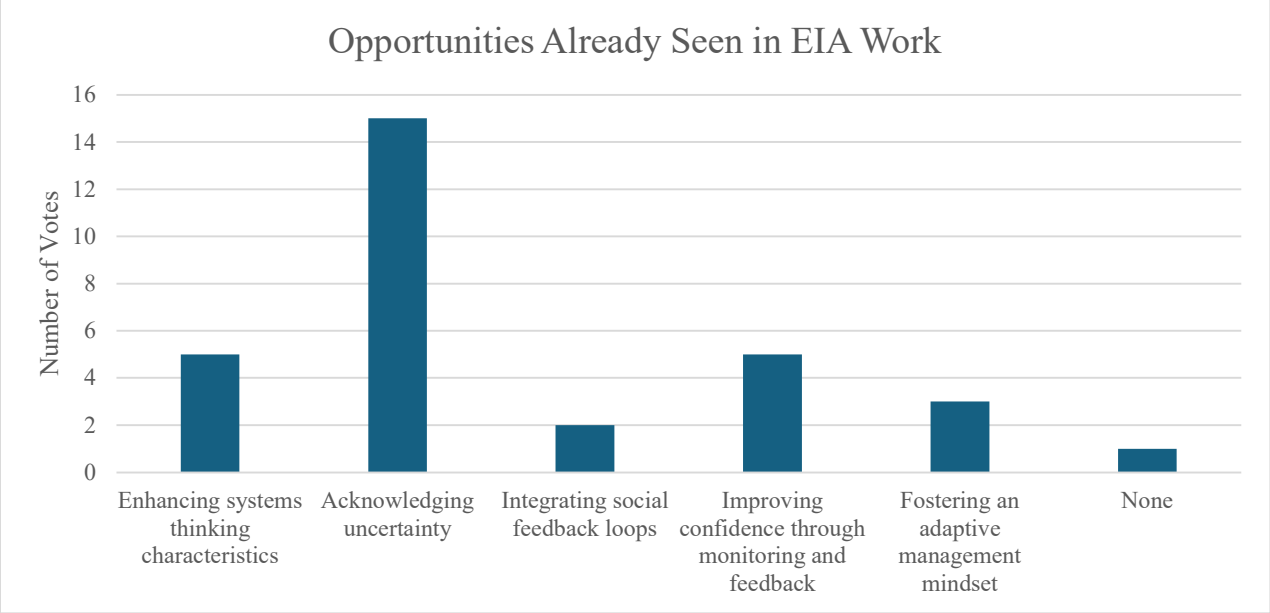

Figure 2: Opportunities already seen in EIA work

Question 2: When addressing uncertainty in EIAs, is there anything you currently do that is not included in the research findings?

The second question explored how uncertainty is currently addressed within EIAs to ensure that no relevant ideas were overlooked in this research. The participants identified several additional opportunities not covered in the main findings of this study: the use of a worst-case scenario program and reviewing mitigation tactics.

Participants also discussed challenges in how uncertainty is managed in the current EIA process. One key issue raised was inconsistency between chapters, which aligned with the findings from the framework synthesis analysis. Additionally, multiple participants observed that uncertainty can sometimes be a tactic used by developers to reduce accountability. By stating a confidence level rather than certainty,

developers may frame potential impacts within a range, thereby diminishing their responsibility for specific outcomes.

Question 3: Which of these factors do you think create more inefficiencies in the process than benefits?

Due to the already length nature of the EIA process, the aim of the proposed opportunities is to not significantly increase procedural demands. Accordingly, the third question examined whether the opportunities introduced any unnecessary inefficiencies, as this was considered a key indicator of their potential for successful implementation. Overall, all opportunities performed relatively well in this regard per Figure 3: Opportunities ranked based on their likelihood to create more inefficiencies in the process than benefitsFigure 3. However, acknowledging uncertainty and integrating social feedback loops were identified as having the most potential for increase inefficiencies.

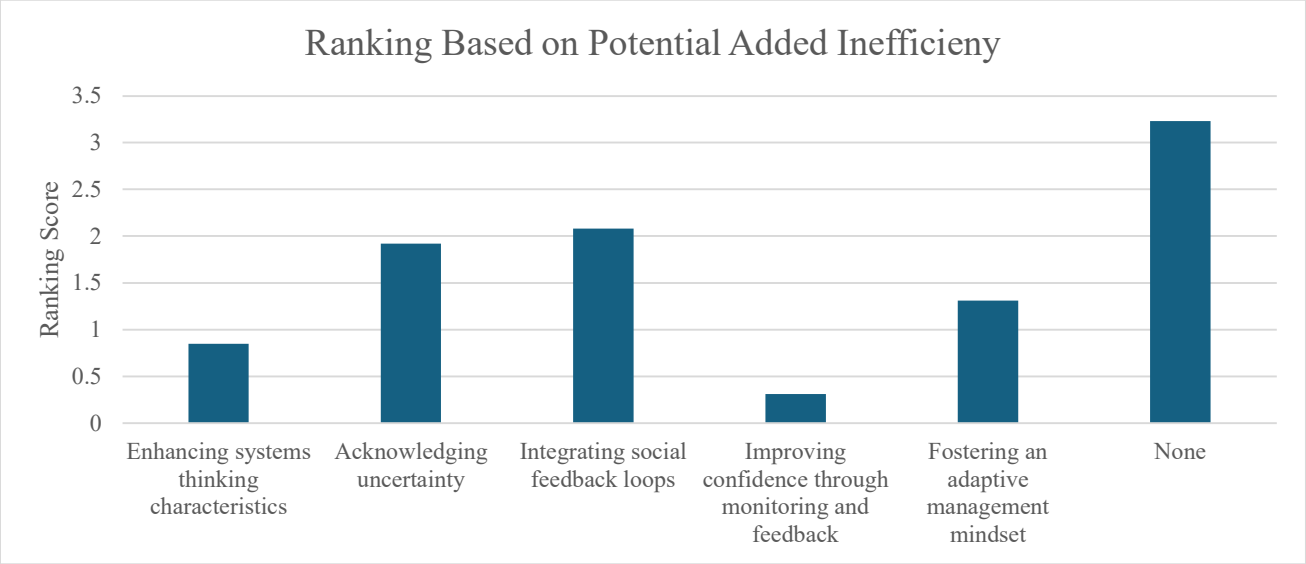

Figure 3: Opportunities ranked based on their likelihood to create more inefficiencies in the process than benefits

Question 4: Which of these opportunities do you consider most important?

Question 4 identified which opportunity the participants believe to be the most vital to implement. As shown in Figure 4, the opportunities ranked highest for most important to incorporate were improving confidence through monitoring and feedback and fostering an adaptive management mindset.

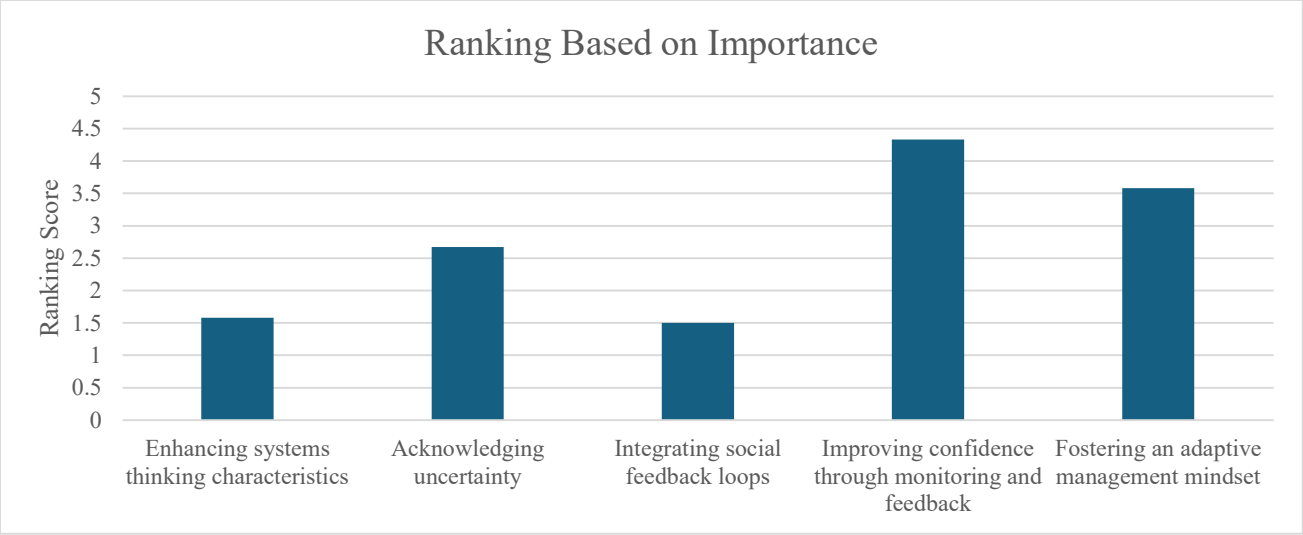

Figure 4: Opportunities ranked based on Importance of Implementation

5. Discussion

This analysis examined Environmental Impact Assessment (EIA) procedures in Scotland through a systems thinking lens to evaluate the extent to which current practices incorporate holistic principles for predicting and managing environmental impacts. The findings highlighted strengths, gaps, and opportunities in the EIA process based on observations of key systems thinking themes. This discussion reflects on the strengths and gaps of the EIA procedure and how they built the five opportunities highlighted in the results.

5.1. Opportunity 1: Enhancing Consideration of CAS Characteristics

Through this analysis, it becomes evident that hydrological systems function as complex adaptive systems (CAS), a conclusion supported by Giacomoni and Berglund (2015) and Zischg (2018). This recognition raises an important question: how can EIA processes adapt to account for this complexity and better predict the impacts driven by development?

5.1.1. CAS Characteristics from an Ecosystem Perspective

A notable strength across all three case studies was the recognition of causal relationships between interconnected ecological vulnerabilities. This was demonstrated by frequent cross-referencing between sections of the EIAs, reflecting an understanding of feedback and feedforward mechanisms. For example, the assessments noted how peatland changes can affect groundwater-dependent species, how construction noise may influence both aquatic and terrestrial species, and how lowering river water flow impacts the whole ecosystem.

Several critical gaps emerged regarding the incorporation of complex adaptive system characteristics. Although cumulative impacts were included in all three case studies, they typically lacked depth. The analysis always concluded there were no cumulative impacts due to either no adjacent developments or assuming no hydrological or ecological connection. This is consistent with findings by Wawrzyczek *et al.* (2018b). Also collective impacts, impacts within one development impacting the same vulnerability (Ehrlich, 2022), were largely unacknowledged.

Moreover, the EIAs stated the methodology incorporated consideration of reversibility, duration, and frequency of impacts. However, there was little substantive analysis, particularly when considering reversibility. These determinations are often reduced to distinction between construction and operational impacts. The EIAs typically highlight the risk, incorporate any potential mitigation tactics, and then assume the construction impacts were temporary. However, Gilmour *et al.* (2022) discusses the ability for construction to lower the water table, and alter groundwater flow which can negatively impact peatlands. Wawrzyczek *et al.*, (2018a) has highlighted that construction impacts on water table are not linear, and therefore require a longer timeframe than the EIA. Chen *et al.* (2009) found that there were long-term impacts due to large infrastructure construction in water quality for nearby rivers. These temporal considerations were largely absent in the EIAs as the construction impacts assuming reversibility seemed to lack long-term and delayed relationships.

Finally, two of the three case studies showed limited recognition of emergent behaviour, a core concept in complex adaptive systems. Emergent behaviour occurs when multiple system changes occur simultaneously, leading to unpredictable results (Felzer and Sahagian, 2014). Zischg (2018) notes the difficulties of isolating cause and effects of hydrological alterations due to multiple ecological and social shifts unfolding simultaneously. For example, the river flow and water temperature are likely to change and impact the nutrient and biological cycles of rivers, but exactly how is difficult to forecast (Felzer and Sahagian, 2014). In contrast, case study 3 was the only EIA to identify these complexities, noting the assessment was complex due to many variables therefore accurate predictions are impossible. Furthermore, they stated the rate and pattern of change are not clear in reference to river water temperature in UK. Such statements reflect an awareness of uncertainty and system complexity. However, the lack of similar considerations in the other two case studies indicates an overall weakness in acknowledging the unpredictable and emergent nature of ecosystem responses within EIA processes. The absence of these CAS characteristics demonstrates flaws in the predictive capability of EIAs.

5.1.2. CAS Characteristics from a Socio-Ecological Perspective

While causal relationships were recognized as a strength, these interactions were largely confined to the ecological processes. There was minimal evidence of feedforward or feedback loops that connected the

social and ecological systems, in other words, a lack of interlinkage between multiple systems or hierarchical systems. The main sections analysing social aspects were landscape and visual, cultural heritage, and socio-economic impact. However, these were typically addressed in isolation from hydrological analyses. For example, case studies 2 and 3 did not reference the connection of the geology and hydrology sections to any of the social impacts. Case study 1 omitted socio-economic impacts completely, though it acknowledged the changes in the hydrology would impact the landscape visually, which in turn can affect land users, suggesting a partial recognition of the interdependence between society and the environment.

There was a clear gap in connecting the social to the ecological through the absence of feedback loops of environmental impacts, such as carbon emissions and biodiversity degradations affect to the human population long term. This is consistent with findings by Smart *et al.* (2014) arguing that EIAs are ineffective in predicting climate change impacts. Patel *et al.* (2025) discusses the importance of social feedback when looking at peatland management. The study cites a climate change–peatland degradation reinforcing feedback loop: as peatland degrades, it releases greenhouse gases that exacerbate climate change, which in turn accelerates the degradation of peatland ecosystems, ultimately leading to socio-economic impacts. The only exception to missing this feedback loop is case study 2 including a carbon balance analysis. The analysis found that the peatland restoration scheme will results in the carbon to be beneficial outweighing the habitat loss and construction carbon emissions after 1.9 years. However, peatland restoration is complex and a long-term solution with the possibility of increasing release of methane and nitrous oxide if done incorrectly (Patel *et al.*, 2025)). Additionally, the other two case studies did not include this analysis.

Regardless of the inclusion of carbon balance analysis there are multiple ways social and ecological systems interact that are overlooked within EIAs. The United Nations Department of Economic and Social Affairs (UNDESA) support the interconnection stating the economic and social development and maintaining the integrity of the natural environment depends on the health of water systems (GWP, 2017). Pan *et al.* (2018) discusses the deep integration of water and land resource systems within economic and social domains, underscoring that sustainable development must maintain balance among social, economic, and environmental subsystems, which can’t be analysed in isolation.

The omissions of these interlinkages indicate a broader issue: the limited application of systems thinking across sub-systems and hierarchical levels within EIA processes. Integrating ecological and social impact pathways through feedbacks and feedforwards would strengthen the predictive capacity of EIAs and enhance their value for planning (Cardenas and Halman, 2016).

The opportunity of considering CAS characteristics is important as both peatland and floodplains fall into this category. As Zischg (2018) describes, floodplains exemplify complex adaptive systems due to their dynamic interactions, co-evolution, and emergent behaviours. Similarly, Patel *et al.* (2025) discusses the current state of peatland management as siloed between the technocratic, ecological, and socio-economic despite clear benefits of a holistic, systems-based approach.

The gaps in complex adaptive system themes around complex relationships and interconnections limits the effectiveness of both the impact assessments and the broader decision-making process (Porter and Córdoba, 2009). CAS characteristics allow the EIA to be complexity aware (Rossing *et al.*, 2021), and acknowledging these complex intricacies supports more comprehensive understanding of the potential impacts (Fernando Martinez *et al.*, 2019). Incorporating complex adaptive systems strengthens decision-making by enhancing integration, responsiveness, and resilience (Davidson and Venning, 2011).

5.1.3. Workshop identified Implementation Insights

The most frequently mentioned barrier to implementing systems thinking was a limited understanding of the concept among practitioners. This is coupled with another barrier mentioned, the reliance on existing templates and established EIA procedures. Additionally, some questioned whether systems thinking would fit within the existing legal framework governing EIAs, suggesting that further research is needed to explore this compatibility. These challenges reflect the broader resistance to change within the EIA practice that has been consistent with existing literature (Onyango and Gazzola, 2024). As one participant implied, it is difficult to alter processes that have been "set in stone" for so long. It was suggested by participants; implementation would be dependent on targeted training and capacity-building initiatives along with systematic change, similar conclusions to work done by Ehrlich (2022).

5.2. Opportunity 2: Acknowledging Uncertainty

Complex adaptive systems are coupled with uncertainty due to emergent behaviour, non-linear impacts, and thresholds of reversibility (Braithwaite *et al.*, 2018). Additionally, increased ecological and social change, leave more unknowns in the rates and patterns of hydrological systems (Felzer and Sahagian, 2014; Bice and Fischer, 2020). Multiple procedural themes were focused on uncertainty. While reporting design and data uncertainty was a strength, there was a weakness in reporting confidence levels of the resulting mitigation tactics and impacts. This is flawed, as acknowledging uncertainty in data should logically extend to uncertainty in the outcomes. Previous research has also documented inconsistencies in EIA predictions, reinforcing the need to transparently report confidence levels (Tenney and Gjerstad, 2006).

Uncertainty related to development design was generally well articulated through the case studies. However, the success of reporting these uncertainties depends on the feedback loop of adaptive management when the design details are clarified. Reiterating that EIAs are not complete after decisions, but should be dynamic tools that evolve throughout the process (Glasson *et al.*, 2021).

Research around the uncertainties of the mitigation tactics of peatland restoration highlight variation in success (Patel *et al.*, 2025). The process sometimes leads to emissions and rewetting can drive short-term negative impacts such as water quality degradation and agricultural viability (Patel *et al.*, 2025). Also, the changes in hydrological rates and patterns due to climate change increase uncertainty around water quality and flood risk (Zischg, 2018). Jorat *et al.* (2024) discusses the lack of research around construction impacts such as cut and fill roads long term for hydrological connectivity. These studies demonstrate the criticality of reporting uncertainty in results and mitigation tactics in EIAs. The omission of uncertainty reporting not only undermines the scientific integrity of EIAs but also impairs decision-making. Tenney and Gjerstad (2006) argue that withholding uncertainty imposes on the decision makers ability to assess the impacts.

Although uncertainty in results was concluded to be a weakness, case study 3 was an exception, utilizing confidence levels for both the mitigation tactics and the impacts. Typically, confidence levels were determined based of “data limitations”, “uncertainty in operating regime”, and “lack of scientific evidence”. However, the other two case studies did not include confidence levels. Given the complexity of socio-ecological systems and frequent limitations in available data, the integration of confidence levels into impact predictions is both appropriate and necessary.

Within the workshop discussion, acknowledging uncertainty emerged as the most established practice within existing EIA procedures. Participants widely recognized that uncertainty is already addressed in EIAs, indicating that this opportunity is comparatively mature. Participants highlighted additional methods for managing uncertainty that were not fully captured in the research framework, most notably the use of worst-case scenario approaches such as the *Maximum Design Envelope*. This tool enables conservative impact assessments when design details are incomplete by identifying maximum potential impacts. However, responses also revealed that current practices vary in quality and consistency, with uncertainty sometimes being applied unevenly across assessment chapters.

By explicitly communicating confidence levels in the results, EIAs can provide meaningful guidance for the decision makers to best understand the risks. Incorporation of a post-normal science mindset to acknowledge the uncertainties and therefore the limitations of traditional scientific approaches is necessary to further EIA process (Bond *et al.*, 2015). The findings suggest a paradigm shift from viewing

uncertainty as an obstacle to encourage its incorporation for more robust assessments and informed decisions (Saltelli *et al.*, 2023).

Uncertainty in complex systems can be partially mitigated through mechanisms such as social learning and monitoring-based feedback that enhance adaptive capacity and support more resilient environmental governance (Cardenas and Halman, 2016). Saltelli *et al.* (2023) argues through a critical post-normal science lens, transdisciplinary strategies are necessary to recognize and mitigate the uncertainties.

5.2.1. Workshop Identified Implementation Insights

Participants identified several barriers to more transparently addressing uncertainty in EIAs. Culture around EIAs were a factor, one participant felt that developers or legal teams might perceive explicitly acknowledging uncertainty as sign of weakness. Contradicting the previous opinion, another participant discussed how uncertainty can be a tool for developers. This contradiction highlights the need of further research in this area. Another challenge mentioned was the additional time and cost required to assess and communicate uncertainty. Additionally, there is an increased complexity introduced to the assessment and a lack of clarity around how this uncertainty can change with design changes. One participant cautioned that overcompensating for uncertainty could itself become a barrier due to unnecessary conservatism.

To overcome this, participants suggested the need for a structured process to identify and score uncertainty across different EIA topics consistent with a call for guidance from Leung *et al.* (2016). This guidance should be supported by clear links between uncertainty and monitoring and feedback mechanisms.

5.3. Opportunity 3: Integrate the Social Feedback Loop

The analysis highlights strengths in consultation with stakeholders, however, there was a critical gap in including public voices in the procedure. Social learning is essential to breakdown the siloes of the environmental impacts and social impacts (Warren and McFadyen, 2010). A systems thinking mindset requires inclusive processes that embeds the public perspectives into EIAs (Nieminen and Hyytinen, 2015).

Two of the three case studies failed to include public representation. Proving to be a gap in the Davidson and Venning (2011) framework which includes a procedural theme encouraging incorporation of a wide variety of perspectives for youth, women, and indigenous peoples through inclusion of grass roots and social groups. In contrast, case study 2 had a great example of including a community liaison group to create a mechanism for public perception at multiple steps of the EIA and feedback into the design process. However, grey literature (uncited to prevent identification of the case study) surrounding the

same development revealed ongoing public dissatisfaction, suggesting the participatory process may have been insufficient, non-inclusive, or ineffectively executed.

Properly embedding social learning into EIA practices enhances systems thinking by integrating local knowledge, values, and lived experiences, which are essential for predicting the broader socio-ecological impacts of development (Ehrlich, 2022). Additionally, public involvement has been shown to further the EIA accuracies in reducing uncertainty (Cardenas and Halman, 2016). In Scotland, Gilmour *et al.* (2022) highlights public engagement as a strategy to better mitigate construction-related impacts on peatland. Patel *et al.* (2025) further emphasizes that the economic realities of rural communities must be considered in the analysis for long-term success in peatland restoration. Additionally, findings by Smart *et al.* (2014) support the benefits of the developer and community relationship to improve the quality of a project and reduce conflict. Similarly, Sinclair *et al.* (2015) argue that effective public participation must be deliberative and continuous, beginning at the earliest stages of the EIA process and maintained throughout.

A further limitation observed in the EIAs was a lack of "perception of others" or mutual learning through understanding one another's values. Public perception and trust inherently interact with environmental interventions (Sala *et al.*, 2013). An effective deliberation process can create an opportunity for social learning of others perspectives alongside of the assessment (Sala *et al.*, 2013). For example, Scolozzi *et al.* (2025) found that through communication with the public, their motivation to support the flood risk management measures grew. This study suggests prioritizing shared vision over control, therefore creating space for stakeholders to shape decisions. Additionally, Warren and McFadyen (2010) found community ownership proved to increase social acceptance when comparing wind farms in Scotland. Such an approach fosters a sense of agency and shared responsibility, ultimately leading to more socially robust and widely accepted environmental outcomes (Ferreiro *et al.*, 2013; Scolozzi *et al.*, 2025).

Incorporating the social system through feedback loops is also vital to complex adaptive systems as discussed prior. Additionally, the increased accuracy and potential to improve implementation through community ownership highlight the significance of the EIA process to enhance the social feedback loop.

5.3.1. Workshop Identified Implementation Insights

Social feedback loop was identified by the workshop participants as the opportunity that has the highest potential to add procedural inefficiencies. The participants suggest successful social participation is dependent on finding the "right people" to involve and ensuring clarity regarding roles, responsibilities and time of participation consistent with findings by Fonseca and Fitzpatrick (2024). Another primary challenge identified by participants to implementing social learning is the willingness of the developers to engage openly and adapt based on new insights. Participants emphasized that meaningful engagement

requires substantial time and coordination, which can deter developers as they are operating under tight project deadlines.

Social feedback success in dependent on developer buy-in, this will likely need to be enforced through legislation or a shift in development culture. To successfully implement this feedback loop, a structured plan must be put in place at the beginning of the project depending on the needs of the project (O'Faircheallaigh, 2010). The EIA space is working towards this as the International Society of Environmental Professionals (ISEP) is releasing a framework for Social Impact Assessments that has the potential to improve clarity with the potential to inform a more structured process (Howard *et al*., 2025).

5.4. Opportunity 4: Improving confidence through Monitoring and Feedback

The analysis revealed a strength among EIAs in monitoring accountability, focused on ensuring baseline criteria is not crossed for a significant timeframe. Alternatively, the analysis concluded gaps in both learning and reflexivity of monitoring. Learning utilizes monitoring as a tool to test the effectiveness of mitigation. Reflexivity highlights the value of evidence-based learning to improve future EIA predictions. This gap is consistent with current findings (Glasson *et al.*, 2021). Effective monitoring is crucial to encouraging long-term sustainable outcomes for the developments subject to EIAs (Soria-Lara *et al.*, 2020).

The accountability monitoring was also often limited for the construction time, limiting the monitoring to a short-term scope. Therefore, neglecting the non-linear impacts to ecosystems that emerge post-construction (Wawrzyczek *et al.*, 2018a). Impacts and mitigation practices with limited existing research would also benefit from extended operation monitoring to reduce uncertainties around the impacts long term. For example, case study 3, addresses emergent behaviour and hydrological system complexities. However, the assessment fails to use monitoring as a tool for to better understand these uncertainties. This represents a missed opportunity, as Patel *et al.* (2025) highlights the uncertainties around peatland restoration can be mitigated through monitoring.

Monitoring and auditing are essential not only for verifying the accuracy of EIA predictions but also for improving project management and facilitating evidence-based learning for future developments (Glasson *et al.*, 2021). Within the workshop, participants also emphasized the tactic of reviewing mitigation measures. One way of improving this process is through these monitoring and feedback mechanisms. In the context of complex adaptive systems, such as peatland and hydrological environments, monitoring is a tool to mitigate uncertainty and enhance decision-making through feedback loops (Cardenas and Halman, 2016).

Pinto *et al.* (2019) analyses the 24 criteria put forward to the International Association for Impact Assessment (IAIA). Their findings emphasized the crucial role of stakeholder engagement in effective monitoring and auditing practices. EIA should evolve into an adaptive process that continues throughout the project lifecycle, particularly as a strategy to manage decision-making under uncertainty (Glasson *et al*., 2021).

5.4.1. Workshop Identified Implementation Insights

Monitoring and feedback were ranked the lowest in potential to add inefficiencies to the EIA procedure. This suggests the opportunity may be viewed as potentially able to improve the procedural efficiency (Glasson *et al.*, 2021).

Several practical and institutional barriers were identified for monitoring and feedback. These included limited funding and time, inconsistency of data collecting and sharing, and a lack of regulatory requirements or enforcement mechanisms. Additionally, concerns about project confidentiality and developer resistance due to perceived risk exposure would hinder implementation. Participants also noted the necessity of clear guidance on how monitoring should be conducted and reported. These barriers have been discussed in existing literature (Glasson *et al.*, 2021; OEP, 2023). The barriers suggest successful implementation would require multiple intervention points including enforcement mechanisms, funding for labour and time, and effective shared database.

5.5. Opportunity 5: Foster an Adaptive Management Mindset

The analysis revealed adaptive management as a final, yet critical opportunity for strengthening the effectiveness of EIAs. EIAs are intended to be an iterative process recycling through certain steps when additional information or project changes occur (*Environmental Impact Assessment Handbook*, 2019). However, adaptive management was determined to be a gap through the analysis. Adaptive management has been utilized in sustainable development settings where dynamics are variable or unknown to reach climate and biodiversity goals (McAfee *et al.*, 2006). Adaptive management offers a participative and learning perspective to deal with uncertainties around changes in design and mitigation tactics through integration of risk monitoring and management (Viegas *et al.*, 2013).

Adaptive systems management is a strategy to address the complex socio-ecological systems creating feedback loops through social learning and monitoring (Armitage *et al.*, 2009). In doing so, it responds directly to the gaps identified across the case studies, aligning with calls from existing literature for a more holistic process. This underscores the central premise of adaptive management; the intersection of learning, collaboration, and iterative feedback (Armitage *et al.*, 2009). Viegas *et al.* (2013) concurs that adaptive management can improve the weaknesses of EIAs current practices.

Bond *et al.* (2015) advocates for adaptive management as a response to the "post-normal" context where EIAs now operate, in which complexity and unpredictability make traditional forecasting inadequate. Porter and Córdoba (2009) argue complex adaptive systems require continual monitoring to adjust and adapt as needed to remain effective. Sala *et al.* (2013) propose effective governance around the overlap of nature and society requires mechanisms such as monitoring and reporting, adaptive management, and societal learning.

Moreover, the social feedback loop embedded into adaptive management ensures the evolving needs and perspectives of communities inform the project (Lee *et al.*, 2020). In the socio-hydrological domain, Scolozzi *et al.* (2025) emphasize the combination of quantitative scientific factors and qualitative social perceptions creates more robust management strategies. Through the hybrid approach of adaptive management leveraging both monitoring feedback and social learning, EIAs could transform from static, predictive exercises into dynamic, reflexive tools.

5.5.1. Workshop Identified Implementation Insights

The challenge facing implementing an adaptive management mindset relates both to institutional culture and inflexible planning conditions. Participants indicated that many practitioners are not familiar with adaptive management principles, and that the approach runs counter to the status quo of the linear EIA procedure. The open-ended and iterative nature of adaptive management is viewed as more complex and uncertain, discouraging adoption. Furthermore, the lack of enforcement mechanisms and rigidity of planning conditions again prove to be a barrier of implementation. These challenges emphasize the incorporation of these opportunities is dependent on systematic change.

To successfully implement, the participants seemed to highlight the need for adaptive management to be perceived as contributing to the EIA process, adjustments in regulations and increased enforcement, and finally willingness to change.

5.6. Current Policy Implications

There has been a call for integration in the EIA procedure by the International Association for Impact Assessment (IAIA) (Vanclay, 2014). Although, this integration is supported by many in the field as well as this research, translating into practice remains a significant challenge (Ehrlich, 2022).

However, in the current Scottish policy landscape, there are legislative changes currently proposed that reflect a growing recognition of the need for adaptation within the EIA process. The Natural Environment (Scotland) Bill, recently introduced but not yet passed, proposes giving the Scottish Government new powers to create and revise EIA legislation (Natural Environment Scotland Bill, 2025). The new National Planning Framework 4 and related policy reforms present opportunities for the adaptation of EIAs to

better suit the needs of Scotland. There is potential for a transition to Environmental Outcome Reports in England which may apply to Scotland (EOR, 2023). The intention is to replace EIAs with a system focused on the outcomes and likely requiring monitoring and feedback. Environmental Outcome Reports (EORs) are based on the Levelling-up and Regeneration Act 2023, however further legislation and clear guidance is being developed (EOR, 2023). These changes have the potential to provide a vessel for implementing the proposed opportunities.

5.7. Implementation Barriers

Although the systems thinking opportunities offer a promising path toward more resilient and responsive EIAs, it also introduces complexity. If not carefully managed, this complexity risks slowing down the EIA process, placing additional strain on already overstretched agencies. Workshop participants generally agreed that none of the proposed opportunities would be excessively burdensome to process efficiency. However, acknowledging uncertainty and integrating social feedback loops were perceived as having the greatest potential to introduce inefficiencies, reflecting concerns about added complexity in an already lengthy process. A clearer understanding of these barriers and their potential points of inefficiency can support more targeted interventions, thereby reducing the risk of encumbering the EIA process.

The key barriers reflected from the workshop range from operational issues, such as resource limitations and lack of guidelines, to systematic issues, including institutional inertia, cultural resistance to change, and the reliance on developer buy-in. Many of the operational barriers highlighted by participants align with concerns already identified in the EIA literature. For example, past studies suggest that monitoring and feedback systems are less a matter of policy than of resourcing and require a centralized database and enforcement mechanisms, aligning with the results in the workshop (OEP, 2023; Patel *et al.*, 2025). Reinforcing the significance of resource constraints, Wawrzyczek *et al.* (2018a) found long-term monitoring and data organization require financial and logistical burdens putting pressure on the already tight local authority budget. Additionally, O'Faircheallaigh's (2010) work regarding public participation emphasizes the necessity of structure and guidance through well-established, inclusive techniques. The study demonstrates that guidance can ensure that social input is meaningful, actionable and aligned with project needs as advised by the workshop participants.

While many of the barriers were focused on resource issues or guidance needs, some opportunities, however, call for deeper systematic change, such as fostering an adaptive management mindset or embedding systems thinking. These shifts challenge the current procedural and institutional norms of EIAs, demanding both cultural and legislative adaption. Onyango and Gazzola (2024) explore the application of change-making approaches in EIAs and highlight that shifting the current status quo will require further research and evidence-based approaches to produce broader procedural reform.

While participants saw value in each proposed opportunity, successful implementation will depend on building capacity, clarifying regulatory needs, clear guidance documents, and fostering a culture of learning and adaptation within the EIA practice.

5.8. Next Steps

Given these constraints, the successful adoption of systems thinking opportunities must be approached with nuance and balance. Implementation is not merely a policy challenge but requires multiple intervention points. To avoid overwhelming practitioners and diluting focus, intervention points should be strategically identified to ensure the change is both feasible and effective. Decisions surrounding these policy changes should be handled with care and informed by transdisciplinary collaboration and guidance (Snow, 2021).

The workshop participants prioritized opportunities that strengthen learning and adaptability over those focused solely on analysis. Improving confidence through monitoring and feedback, alongside fostering an adaptive management mindset, were ranked as the most critical opportunities to implement. This indicates a strong preference for EIAs that function as iterative, learning-oriented processes rather than static, one-off assessments, positioning these opportunities as the highest priority for future implementation.

5.9. Further Research

Despite its prevalence, uncertainty management was also identified as problematic. Participants raised concerns that uncertainty can be strategically used by developers to reduce accountability by framing impacts probabilistically rather than definitively. Further research focusing on avoiding this negative impact could be necessary before moving forward with implementation. Additionally, workshop participants raised concerns about the extent to which systems thinking can be effectively integrated within existing legal frameworks. Addressing this barrier through further research may help clarify and support the practical implementation of systems thinking in EIA processes.

Smart *et al.* (2014) has identified bias and unequal distribution of opinions around wind farm developments in Scotland. Looking forward, there is the potential for EIAs to be a mechanism in Scotland for decentralizing decision-making while implementing more effective projects (Wawrzyczek *et al.*, 2018a). Further studies should also explore which intervention points can encourage public participation in Scotland that enhances resilience and responsiveness.

Given the emphasis on transforming EIAs into processes that learn over time, further research is needed to strengthen post-monitoring and post-approval feedback mechanisms. Assessing the implementation of a centralized data system that supports long-term learning and accountability would enable more effective

feedback loops within EIA practice. Research evaluating post-approval feedback mechanisms would also help assess the responsiveness of impact assessments to design changes following development approval. Specifically in this context, adaptive management represents a potential approach to addressing current gaps in feedback and learning and should be centred in further investigation.

6. Conclusion

The planning sector has a responsibility to balance social, environmental, and economic aspects, a task becoming increasingly challenging as ecological and social changes intensify. EIAs are a critical tool in addressing these issues, but must evolve to keep pace with advances in technical insights and growing recognition of the limitations of traditional approaches (Bice and Fischer, 2020).

The research concluded that EIAs often overlook the interconnections and uncertainties inherent in complex socio-ecological systems. Through a systems thinking framework, this study analysed the strengths, gaps, and opportunities to better incorporate these complexities. While strengths were found in baseline accountability monitoring and consultation processes, key gaps emerged around uncertainty considerations, long-term reflexive feedback, inclusive social learning, and adaptive management. The analysis highlights several key opportunities to incorporate these aspects: enhancing consideration of CAS characteristics, reporting confidence levels, integrating a social feedback loop, improving confidence through monitoring and feedback, and fostering an adaptive management mindset. This analysis researched the current EIA practices, particularly in hydrological contexts.

In summary, the research highlights that the future of EIAs in Scotland needs to adapt to better take on the intense challenges ahead. Adaptive management presents a promising path forward through integration of monitoring, social learning, and feedback to address uncertainty and complexity. However, implementation remains challenging due to resource limitations, status quo mindset, and clear guidance. Therefore, its implementation must be strategic, well-supported, and targeted. Due to the complexities around implementation, further research should be completed to determine the most effective leverage points. This analysis encourages embedding systems thinking into EIA practice to improve long-term effectiveness, equity and resilience of environmental decision making during these uncertain times of increased social and ecological change.

7. References

About National Planning Framework 4 (2025) *David Dodds Associates Ltd*. Available at: https://www.daviddoddsassociates.com/articles-updates/about-national-planning-framework-4 (Accessed: June 29, 2025).

Armitage, D.R. *et al.* (2009) "Adaptive co-management for social–ecological complexity," *Frontiers in Ecology and the Environment*, 7(2), pp. 95–102. Available at: https://doi.org/10.1890/070089.

Arnold, R.D. and Wade, J.P. (2015) "A Definition of Systems Thinking: A Systems Approach," *Procedia Computer Science*, 44, pp. 669–678. Available at: https://doi.org/10.1016/j.procs.2015.03.050.

Arts, J. *et al.* (2012) "The effectiveness of eia as an instrument for environmental governance: reflecting on 25 years of eia practice in the netherlands and the uk," *Journal of Environmental Assessment Policy and Management*, 14(04), p. 1250025. Available at: https://doi.org/10.1142/S1464333212500251.

Arushanyan, Y., Ekener, E. and Moberg, Å. (2017) "Sustainability assessment framework for scenarios – SAFS," *Environmental Impact Assessment Review*, 63, pp. 23–34. Available at: https://doi.org/10.1016/j.eiar.2016.11.001.

Badr, E.-S., Cashmore, M. and Cobb, D. (2004) "The consideration of impacts upon the aquatic environment in environmental impact statements in England and Wales," *Journal of Environmental Assessment Policy and Management*, 06, pp. 19–49. Available at: https://doi.org/10.1142/S1464333204001572.

Barkham, P. (2022) "Britain ranks bottom in Europe for nature connectedness," *The Guardian*, 23 June. Available at: https://www.theguardian.com/environment/2022/jun/23/britain-ranks-bottom-in-europe-for-nature-connectiveness (Accessed: June 29, 2025).

Belluco, S. *et al.* (2018) "State of art of nanotechnology applications in the meat chain: A qualitative synthesis," *Critical Reviews in Food Science and Nutrition*, 58(7), pp. 1084–1096. Available at: https://doi.org/10.1080/10408398.2016.1237468.

Bice, S. and and Fischer, T.B. (2020) "Impact assessment for the 21st century – what future?," *Impact Assessment and Project Appraisal*, 38(2), pp. 89–93. Available at: https://doi.org/10.1080/14615517.2020.1731202.

Biodiversity strategy to 2045 (2022) *Scottish Government*. Available at: https://www.gov.scot/publications/scottish-biodiversity-strategy-2045-tackling-nature-emergency-scotland/ (Accessed: March 25, 2025).

Bodin, Ö. (2017) "Collaborative environmental governance: Achieving collective action in social-ecological systems," *Science*, 357(6352), p. eaan1114. Available at: https://doi.org/10.1126/science.aan1114.

Bond, A. *et al.* (2015) "Managing uncertainty, ambiguity and ignorance in impact assessment by embedding evolutionary resilience, participatory modelling and adaptive management," *JOURNAL OF ENVIRONMENTAL MANAGEMENT*, 151, pp. 97–104. Available at: https://doi.org/10.1016/j.jenvman.2014.12.030.

Braithwaite, J. *et al.* (2018) "When complexity science meets implementation science: a theoretical and empirical analysis of systems change," *BMC Medicine*, 16(1), p. 63. Available at: https://doi.org/10.1186/s12916-018-1057-z.

Brunton, G., Oliver, S. and Thomas, J. (2020) "Innovations in framework synthesis as a systematic review method," *Research Synthesis Methods*, 11(3), pp. 316–330. Available at: https://doi.org/10.1002/jrsm.1399.

Cardenas, I.C. and Halman, J.I.M. (2016) "Coping with uncertainty in environmental impact assessments: Open techniques," *Environmental Impact Assessment Review*, 60, pp. 24–39. Available at: https://doi.org/10.1016/j.eiar.2016.02.006.

Caro-Gonzalez, A.L. *et al.* (2023) "From procedural to transformative: A review of the evolution of effectiveness in EIA," *ENVIRONMENTAL IMPACT ASSESSMENT REVIEW*, 103, p. 107256. Available at: https://doi.org/10.1016/j.eiar.2023.107256.

Carroll, C. *et al.* (2013) "'Best fit' framework synthesis: refining the method," *BMC Medical Research Methodology*, 13(1), p. 37. Available at: https://doi.org/10.1186/1471-2288-13-37.

Chen, Y. *et al.* (2009) "Effects of Highway Construction on Stream Water Quality and Macroinvertebrate Condition in a Mid-Atlantic Highlands Watershed, USA," *Journal of environmental quality*, 38, pp. 1672–82. Available at: https://doi.org/10.2134/jeq2008.0423.

Christenson, A. (2022) *Greenhouse gas emissions and other environment measures, UK and European countries: 2020*. Office for National Statistics.

"Climate change trends and projections" (2025) *Adaptation Scotland*. Available at: https://adaptation.scot/scotland-and-climate-change/climate-change-trends-and-projections/ (Accessed: August 5, 2025).

Davidson, K.M. and Venning, J. (2011) "Sustainability decision-making frameworks and the application of systems thinking: An urban context," *Local Environment*, 16(3), pp. 213–228. Available at: https://doi.org/10.1080/13549839.2011.565464.

Dixon-Woods, M. (2011) "Using framework-based synthesis for conducting reviews of qualitative studies," *BMC Medicine*, 9(1), p. 39. Available at: https://doi.org/10.1186/1741-7015-9-39.

Ehrlich, A. (2022) "Collective impacts: using systems thinking in project-level assessment," *Impact Assessment and Project Appraisal*, 40(2), pp. 129–145. Available at: https://doi.org/10.1080/14615517.2021.1996901.

Environmental Impact Assessment Handbook (2019). Scottish Natural Heritage, Historic Environment Scotland. Available at: https://web.archive.org/web/20220901050635/https://www.nature.scot/sites/default/files/2018-05/Publication%202018%20-%20Environmental%20Impact%20Assessment%20Handbook%20V5.pdf (Accessed: March 22, 2025).

Felzer, B and Sahagian, D. (2014) “Climate impacts on regional ecosystem services in the United States from CMIP3-based multimodel comparisons,” *Climate Research*, 61(2), pp. 133–155. Available at: https://doi.org/10.3354/cr01249.

Felzer, Benjamin and Sahagian, D. (2014) “Climate impacts on regional ecosystem services in the United States from CMIP3-based multimodel comparisons,” *CLIMATE RESEARCH*, 61(2), pp. 133–155. Available at: https://doi.org/10.3354/cr01249.

Fernando Martinez, L., Toro, J. and Leon, C.J. (2019) “A complex network approach to environmental impact assessment,” *IMPACT ASSESSMENT AND PROJECT APPRAISAL*, 37(5), pp. 407–420. Available at: https://doi.org/10.1080/14615517.2018.1552442.

Ferreiro, M. de F., Goncalves, M.E. and Costa, A. (2013) “Conflicting values and public decision: The Foz Coa case,” *ECOLOGICAL ECONOMICS*, 86, pp. 129–135. Available at: https://doi.org/10.1016/j.ecolecon.2012.10.006.

Flemming, K. *et al.* (2019) “Qualitative evidence synthesis for complex interventions and guideline development: clarification of the purpose, designs and relevant methods,” *BMJ Global Health*, 4(Suppl 1). Available at: https://doi.org/10.1136/bmjgh-2018-000882.

Fonseca, A. and Fitzpatrick, P. (2024) “The Long and Winding Road to Meaningful Public Participation in Impact Assessment,” in, pp. 99–120. Available at: https://doi.org/10.4324/9781003388227-9.

Giacomoni, M.H. and Berglund, E.Z. (2015) “Complex Adaptive Modeling Framework for Evaluating Adaptive Demand Management for Urban Water Resources Sustainability,” *Journal of Water Resources Planning and Management*, 141(11), p. 04015024. Available at: https://doi.org/10.1061/(ASCE)WR.1943-5452.0000543.

Gilmour, D. *et al.* (2022) *Effectiveness of construction mitigation measures to avoid or minimise impact to groundwater dependent wetlands and to peat hydrology*. Center of Expertise for Waters.

Gilvear, D.J., Heal, K.V. and Stephen, A. (2002) “Hydrology and the ecological quality of Scottish river ecosystems,” *Science of The Total Environment*, 294(1), pp. 131–159. Available at: https://doi.org/10.1016/S0048-9697(02)00060-8.

Gizzi, M.C. and Rädiker, S. (2021) *The Practice of Qualitative Data Analysis: Research Examples Using MAXQDA*. BoD – Books on Demand.

Glasson, J. (1999) “The First 10 years of the UK EIA System: Strengths, Weaknesses, Opportunities and Threats,” *Planning Practice & Research*, 14(3), pp. 363–375. Available at: https://doi.org/10.1080/02697459915652.

Glasson, J. *et al.* (2021) “Monitoring and auditing the local socio-economic and environmental impacts of the early stage construction of Hinkley Point C Nuclear Power Station, UK,” *Impact Assessment and Project Appraisal*, 39(2), pp. 84–95. Available at: https://doi.org/10.1080/14615517.2020.1838237.

Haddaway, N.R. *et al.* (2017) “A framework for stakeholder engagement during systematic reviews and maps in environmental management,” *Environmental Evidence*, 6(1), p. 11. Available at: https://doi.org/10.1186/s13750-017-0089-8.

Harris, J. *et al.* (2016) “How stakeholder participation can contribute to systematic reviews of complex interventions,” *J Epidemiol Community Health*, 70(2), pp. 207–214. Available at: https://doi.org/10.1136/jech-2015-205701.

Hasan, M.A., Nahiduzzaman, K.M. and Aldosary, A.S. (2018) “Public participation in EIA: A comparative study of the projects run by government and non-governmental organizations,” *Environmental Impact Assessment Review*, 72, pp. 12–24. Available at: https://doi.org/10.1016/j.eiar.2018.05.001.

Hassan, R., Di Martino, M. and Daher, B. (2025) “Quantifying sustainability and resilience in food systems: a systematic analysis for evaluating the convergence of current methodologies and metrics,” *Frontiers in Sustainable Food Systems*, 9. Available at: https://doi.org/10.3389/fsufs.2025.1479691.

Hieronymi, A. (2013) “Understanding Systems Science: A Visual and Integrative Approach,” *Systems Research and Behavioral Science*, 30(5), pp. 580–595. Available at: https://doi.org/10.1002/sres.2215.

Housing to 2040 (2021) *Scottish Government*. Available at: https://www.gov.scot/publications/housing-2040-2/ (Accessed: August 5, 2025).

Jha-Thakur, U. and Fischer, T.B. (2016) “25years of the UK EIA System: Strengths, weaknesses, opportunities and threats,” *Environmental Impact Assessment Review*, 61, pp. 19–26. Available at: https://doi.org/10.1016/j.eiar.2016.06.005.

Jones, R. and Fischer, T. (2016) “EIA Follow-Up in the UK — A 2015 Update,” *Journal of Environmental Assessment Policy and Management*, 18, p. 1650006. Available at: https://doi.org/10.1142/S146433321650006X.

Jorat, M.E. *et al.* (2024) “Future Carbon-Neutral Societies: Minimising Construction Impact on Groundwater-Dependent Wetlands and Peatlands,” *Sustainability*, 16(17), p. 7713. Available at: https://doi.org/10.3390/su16177713.

Kubiak, S.M. *et al.* (2025) “Evaluating Disability Inclusivity in Accreditation Standards for Exercise Science-Related Programs: A Scoping Review,” *Journal of Strength and Conditioning Research*, 39(3), pp. e506–e515. Available at: https://doi.org/10.1519/JSC.0000000000005016.

Lawless, C., Howard, R. and Smyth, E. (2025) *ISEP*, *Placing people at the heart of Environmental Impact Assessment: ISEP launches new guide on Social Impact Assessment*. Available at: https://www.isepglobal.org/resources/blogs/2025/october/isep-launches-new-guide-on-social-impact-assessment/ (Accessed: January 12, 2026).

Lee, S.Y., Díaz-Puente, J.M. and Vidueira, P. (2020) “Enhancing Rural Innovation and Sustainability Through Impact Assessment: A Review of Methods and Tools,” *Sustainability*, 12(16), p. 6559. Available at: https://doi.org/10.3390/su12166559.

Leung, W. *et al.* (2016) “Disparate perceptions about uncertainty consideration and disclosure practices in environmental assessment and opportunities for improvement,” *Environmental Impact Assessment Review*, 57, pp. 89–100. Available at: https://doi.org/10.1016/j.eiar.2015.11.001.

Macura, B. *et al.* (2019) “Systematic reviews of qualitative evidence for environmental policy and management: an overview of different methodological options,” *Environmental Evidence*, 8(1), p. 24. Available at: https://doi.org/10.1186/s13750-019-0168-0.

Mariani, L. *et al.* (2022) “Achieving Sustainable Development Goals Through Collaborative Innovation: Evidence from Four European Initiatives,” *Journal of Business Ethics*, 180(4), pp. 1075–1095. Available at: https://doi.org/10.1007/s10551-022-05193-z.

McAfee, B.J., Malouin, C. and Fletcher, N. (2006) “Achieving forest biodiversity outcomes across scales, jurisdictions and sectors with cycles of adaptive management integrated through criteria and indicators,” *FORESTRY CHRONICLE*, 82(3), pp. 321–334. Available at: https://doi.org/10.5558/tfc82321-3.

McAvoy, S. *et al.* (2021) “Combining Life Cycle Assessment and System Dynamics to improve impact assessment: A systematic review,” *Journal of Cleaner Production*, 315, p. 128060. Available at: https://doi.org/10.1016/j.jclepro.2021.128060.

National Planning Framework 4 (2024). Available at: https://www.gov.scot/publications/national-planning-framework-4/ (Accessed: March 16, 2025).

Net Zero Strategy (2022) *GOV.UK*. Available at: https://www.gov.uk/government/publications/net-zero-strategy (Accessed: March 25, 2025).

Nieminen, M. and Hyytinen, K. (2015) “Future-oriented impact assessment: Supporting strategic decision-making in complex socio-technical environments,” *Evaluation*, 21(4), pp. 448–461. Available at: https://doi.org/10.1177/1356389015606540.

Nita, A. (2019) “Empowering impact assessments knowledge and international research collaboration - A bibliometric analysis of Environmental Impact Assessment Review journal,” *Environmental Impact Assessment Review*, 78, p. 106283. Available at: https://doi.org/10.1016/j.eiar.2019.106283.

Nita, A., Fineran, S. and Rozylowicz, L. (2022) “Researchers’ perspective on the main strengths and weaknesses of Environmental Impact Assessment (EIA) procedures,” *ENVIRONMENTAL IMPACT ASSESSMENT REVIEW*, 92, p. 106690. Available at: https://doi.org/10.1016/j.eiar.2021.106690.

O’Faircheallaigh, C. (2010) “Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making,” *Environmental Impact Assessment Review*, 30(1), pp. 19–27. Available at: https://doi.org/10.1016/j.eiar.2009.05.001.

Onat, N.C. *et al.* (2017) “Systems thinking for life cycle sustainability assessment: A review of recent developments, applications, and future perspectives,” *Sustainability (Switzerland)*, 9(5). Available at: https://doi.org/10.3390/su9050706.

Onyango, V. and and Gazzola, P. (2024) “Change-making in Environmental Impact Assessment (EIA): piloting changeology approach using England as a case study,” *Impact Assessment and Project Appraisal*, 42(3), pp. 251–266. Available at: https://doi.org/10.1080/14615517.2024.2345492.

Page, M.J. *et al.* (2021) “The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.” Available at: https://doi.org/10.1136/bmj.n71.

Pan, H. *et al.* (2018) “Sociohydrology modeling for complex urban environments in support of integrated land and water resource management practices,” *LAND DEGRADATION & DEVELOPMENT*, 29(10), pp. 3639–3652. Available at: https://doi.org/10.1002/ldr.3106.

Patel, N. *et al.* (2025) “Towards Resilient Peatlands: Integrating Ecosystem-Based Strategies, Policy Frameworks, and Management Approaches for Sustainable Transformation,” *SUSTAINABILITY*, 17(8), p. 3419. Available at: https://doi.org/10.3390/su17083419.

Pinto, E. *et al.* (2019) “Distilling and applying criteria for best practice EIA follow-up,” *Journal of Environmental Assessment Policy and Management*, 21(2). Available at: https://doi.org/10.1142/S146433321950008X.

Porter, T. and Córdoba, J.-R. (2009) “Three Views of Systems Theories and their Implications for Sustainability Education,” *Journal of Management Education*, 33, pp. 323–347. Available at: https://doi.org/10.1177/1052562908323192.

Pullin, A.S. *et al.* (2018) *Guidelines and Standards for Evidence Synthesis in Environmental Management*. (Collaboration for Environmental Evidence).

Reed, M.S. and Barbrook-Johnson, P. (2022) “Complex systems methods for impact evaluation: lessons from the evaluation of an environmental boundary organisation,” *Mires and Peat*, 28(34), pp. 1–14. Available at: https://doi.org/10.19189/MaP.2022.OMB.569.

Rossing, W.A.H. *et al.* (2021) “Crafting actionable knowledge on ecological intensification: Lessons from co-innovation approaches in Uruguay and Europe,” *Agricultural Systems*, 190. Available at: https://doi.org/10.1016/j.agsy.2021.103103.

Rossing, Walter A.H. *et al.* (2021) “Crafting actionable knowledge on ecological intensification: Lessons from co-innovation approaches in Uruguay and Europe,” *Agricultural Systems*, 190, p. 103103. Available at: https://doi.org/10.1016/j.agsy.2021.103103.

Sala, S., Farioli, F. and Zamagni, A. (2013) “Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1,” *The International Journal of Life Cycle Assessment*, 18(9), pp. 1653–1672. Available at: https://doi.org/10.1007/s11367-012-0508-6.

Saltelli, A. *et al.* (2023) “Impact assessment culture in the European Union. Time for something new?,” *ENVIRONMENTAL SCIENCE & POLICY*, 142, pp. 99–111. Available at: https://doi.org/10.1016/j.envsci.2023.02.005.

Sample, J.E. *et al.* (2015) “Scotland′s hydropower: Current capacity, future potential and the possible impacts of climate change,” *Renewable and Sustainable Energy Reviews*, 52, pp. 111–122. Available at: https://doi.org/10.1016/j.rser.2015.07.071.

Scolozzi, R., Scolobig, A. and Borga, M. (2025) “Public Support for Flood Risk Management: Insights from an Italian Alpine Survey Using Systems Thinking,” *Geographies*, 5(1), p. 3. Available at: https://doi.org/10.3390/geographies5010003.

Scottish energy strategy (2017) *Scottish Government*. Available at: https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/ (Accessed: August 5, 2025).

Sinclair, A.J., Doelle, M. and Gibson, R.B. (2022) "Next generation impact assessment: Exploring the key components," *Impact Assessment and Project Appraisal*, 40(1), pp. 3–19. Available at: https://doi.org/10.1080/14615517.2021.1945891.

Sinclair, P. *et al.* (2015) "Stakeholder engagement within the sustainability assessment of bioenergy: Case studies in heat, power and perennial and annual crops from the UK," *Biomass and Bioenergy*, 73, pp. 11–22. Available at: https://doi.org/10.1016/j.biombioe.2014.11.017.

Smart, D.E., Stojanovic, T.A. and Warren, C.R. (2014) "Is EIA part of the wind power planning problem?," *Environmental Impact Assessment Review*, 49, pp. 13–23. Available at: https://doi.org/10.1016/j.eiar.2014.05.004.

Snow, A. (2021) "The environments of environmental impact assessment: Transforming neoliberal environmental governance from within," *ENVIRONMENT AND PLANNING E-NATURE AND SPACE*, 4(4), pp. 1462–1486. Available at: https://doi.org/10.1177/2514848620958370.

Soria-Lara, J.A. *et al.* (2020) "Revealing EIA process-related barriers in transport projects: The cases of Italy, Portugal, and Spain," *Environmental Impact Assessment Review*, 83, p. 106402. Available at: https://doi.org/10.1016/j.eiar.2020.106402.

Tenney, A., Kværner ,Jens and and Gjerstad, K.I. (2006) "Uncertainty in environmental impact assessment predictions: the need for better communication and more transparency," *Impact Assessment and Project Appraisal*, 24(1), pp. 45–56. Available at: https://doi.org/10.3152/147154606781765345.

The Planning and Infrastructure Bill (2025) *GOV.UK*. Available at: https://www.gov.uk/government/publications/the-planning-and-infrastructure-bill (Accessed: June 29, 2025).

Thygesen, J. and Agarwal, A. (2014) "Key criteria for sustainable wind energy planning—lessons from an institutional perspective on the impact assessment literature," *Renewable and Sustainable Energy Reviews*, 39, pp. 1012–1023. Available at: https://doi.org/10.1016/j.rser.2014.07.173.

Vanclay, F. (2014) "Integration and focus from the perspective of social impact assessment: a response to Morrison-Saunders et al.," *Impact Assessment and Project Appraisal*, 32(1), pp. 11–13. Available at: https://doi.org/10.1080/14615517.2013.872851.

Verrier, B. *et al.* (2022) "Beyond the social license to operate: Whole system approaches for a socially responsible mining industry," *Energy Research and Social Science*, 83. Available at: https://doi.org/10.1016/j.erss.2021.102343.

Viegas, C.V. *et al.* (2013) "A review of environmental monitoring and auditing in the context of risk: unveiling the extent of a confused relationship," *Journal of Cleaner Production*, 47, pp. 165–173. Available at: https://doi.org/10.1016/j.jclepro.2012.12.041.

View of the implementation of environmental assessment regimes in England. (2023). Office for Environmental Protection.

Voulvoulis, N., Arpon, K.D. and Giakoumis, T. (2017) "The EU Water Framework Directive: From great expectations to problems with implementation," *Science of the Total Environment*, 575, pp. 358–366. Available at: https://doi.org/10.1016/j.scitotenv.2016.09.228.

Warren, C.R. and McFadyen, M. (2010) "Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland," *Land Use Policy*, 27(2), pp. 204–213. Available at: https://doi.org/10.1016/j.landusepol.2008.12.010.

Watkins, S. and Collins, A. (2025) "From community engagement to community inclusion for socially and procedurally just flood risk governance," *Journal of Flood Risk Management*, 18(1), p. e13042. Available at: https://doi.org/10.1111/jfr3.13042.

Wawrzyczek, J. *et al.* (2018a) "The ecosystem approach in ecological impact assessment: Lessons learned from windfarm developments on peatlands in Scotland," *Environmental Impact Assessment Review*, 72, pp. 157–165. Available at: https://doi.org/10.1016/j.eiar.2018.05.011.

Wawrzyczek, J. *et al.* (2018b) "The ecosystem approach in ecological impact assessment: Lessons learned from windfarm developments on peatlands in Scotland," *Environmental Impact Assessment Review*, 72, pp. 157–165. Available at: https://doi.org/10.1016/j.eiar.2018.05.011.

Weston, J. (2004) "EIA in a risk society," *Journal of Environmental Planning and Management*, 47(2), pp. 313–325. Available at: https://doi.org/10.1080/0964056042000209058.

Wichaisri, S. and Sopadang, A. (2018) "Trends and Future Directions in Sustainable Development," *Sustainable Development*, 26(1), pp. 1–17. Available at: https://doi.org/10.1002/sd.1687.

Zischg, A.P. (2018) "Floodplains and Complex Adaptive Systems—Perspectives on Connecting the Dots in Flood Risk Assessment with Coupled Component Models," *Systems*, 6(2), p. 9. Available at: https://doi.org/10.3390/systems6020009.

Zwart, M.C. *et al.* (2015) "Using environmental impact assessment and post-construction monitoring data to inform wind energy developments," *Ecosphere*, 6(2), p. art26. Available at: https://doi.org/10.1890/ES14-00331.1.

8. Appendices

    8.1. Appendix A – Framework Selection Criteria

    8.2. Appendix B – Foundational Frameworks

    8.3. Appendix C – Code Relations Tables

    8.4. Appendix D – Proposed Framework with Explanation

    8.5. Appendix E – Workshop Discussion Questions

Appendix A

Framework Selection Criteria

Author	Framework Name	Systems thinking	New or Edited framework	Uncertainty	Complexity	Stakeholder	Monitoring/F	Clear Themes	Applicability to	Methodology	Sector	Year	Link	Citations
Abu-Bakar (Meadows 2017)	Components of Systems Thinking	5	Lists out the key componenets of systems thinking based on the Meadows 2017 book also incorporates collaboration ecosystem, stakholder theory, and strategic management	1	3	5	3	5	3	literature review, conceptual analysis, extensive review of CE roadmaps, theoretical framework development	Circular Economy	2024	Developing a Strategic Methodology for Circular E	2
Bataleblu	Resilient Sustainability Assessment Framework	5	combining UMDO (uncertainty-based multidisciplinary design optimization) and model-based systems engineering (MBSE) and TSoS (the systems of systems) nature	5	4	3	4	3	3	driving power and dependencies using matrix impact cross-reference multiplication methodology	sustainability reporting and assessment	2024	Resilient Sustainability Assessment Framework fr	0
Casarejos	Conceptual Diagram for Modeling and Framing SE Systems	5	critical analysis and synthesis of key issues trends and themes	2	4	4	4	3	3	Bibliographic Research to Produce the Conceptual Framework	Sustainability Science	2020	Casting Long-Term and Regenerative Perspectives	8
Chen	Dynamic Management Framework for PPPs with SEA	4	Framework generated through the methods of systems thinking, system dynamics, and Managing for Results (MFRs)	0	0	3	5	4	5	Case Study DSPIR was applied to framework to test	Environmental Assessment	2011	Integrated dynamic policy management methodol	16
Gittins	Leverage Point Framework (Meadows, 1999)	5	Existing LP framework applied to River Health	0	3	3	5	5	3	Using a systems thinking framework to identify areas to leverage	River Restoration	2025	A Leverage Points Framework To Manage Changes	1
Grupper	SES frameworks and thinking	4	SES framework with complementary social science processes and complex adaptive systems. Modelled off McGinnis and Ostrom 2014	3	5	5	5	5	4	applying SES framework to e-flow efforts case study	Environmental Flow	2025	Identifying and Approaching Barriers to Environme	0
Gu	Diagram of the Relationship of Framework to others	4	Integrating hueristic framework with Gunderson's adaptive cycle. Process analysis to connect with hierarchal pieces. Combining geodesign themes with ecological systemsthinking.	5	5	4	4	4	3	Systematically identify influential articles, find themes, mix with ecological systems thinking to create a framework	GeoDesign	2018	Geodesign Processes and Ecological Systems Thi	29
Kay	Self-Organizing Holarchic Open Systems	4	dependent on complex systems thinking and post-normal science	4	5	2	5	3	3	Methodology unclear, introducing SOHO systems and frameworks	Post-Normal Science	1999	https://www.sciencedirect.com/science/article/p	358
Kennedy	Learning Framework of 5 move for leverage systems thinkng concepts	5	New framework based on systems thinking	1	5	1	5	5	3	Framework development for a systems approach to sustainability management education with systems tihnking theory	Systems thinking Education	2025	Teaching a Systems Approach to Address the Sust	0
Missimer	Social Portion of the Framework for Strategic Sustainable Development	4	Conceptual modelling to produce the framework edits. Editting the Framework for Strategic Sustainable Development	4	5	4	5	4	4	Design research, literature review then propose (conceptual modelling) and test a solution	Sustainable development	2017	A strategic approach to social sustainability – Part	207
Plummer	Sustainable Livelihoods framework	3	developed from literature on ecological resilience, livelihoods, and consensus building	4	5	5	5	4	4	analyzing the literature to create an evaluative framework	Sustainable Resource Use / Adaptive co-management	2007	A resilience-based framework for evaluating adapt	402
Rossing	three domains of co-innocation	4	co-innovation based in complex adaptive systems perspective, social learning setting, nad dynamic monitoring and evaluation, adapted from existing work	4	5	5	5	5	5	tested framework combined from multiple studies through case studies in cluding in-depth interviews	Co-innovation, case studies were ecological intensification	2021	Crafting actionable knowledge on ecological inter	40
Tacchi	framework for evaluating commincation for development	4	Think its from Lennie and Tacchi 2013	5	5	5	5	5	4	Book chapter, introduce frameowrk and trends/debates in development evaluation	Communication for Development	2014	A Participatory Framework for Researching and Ev	14
Davidson	decision-making framework underpinned by systems thinking	5	an Interpretive approach to systems thinking	4	5	4	5	5	5	an Interpretive approach to systems thinking, then applied to analyze various methodologies	Impact Assessment	2011	https://www.tandfonline.com/doi/pdf/10.1080/13549839.2011.565464?utm_source=scopus&getft_integrator=scopus	37

Appendix B

Foundational Frameworks

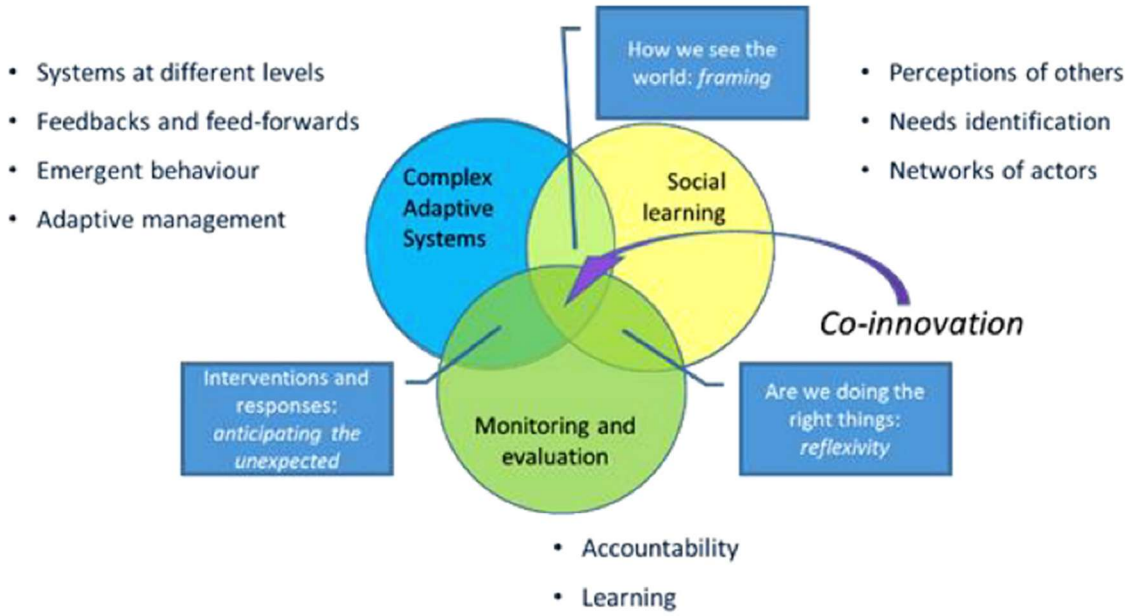

Fig. 2. Three domains of co-innovation, with keywords per domain and results emerging at their overlap. Adapted from Rossing et al. (2010), Dogliotti et al. (2014a) and Albicette et al. (2017).

Table 2. A decision-making framework underpinned by systems thinking.

Framework elements	Examples of criteria applied within reviewed frameworks applicable for this key characteristic
Context or environment	Adopt a holistic perspective
	Have adequate scope
Goals and objectives	Clear vision of sustainability and goals that define that vision
	Links visions and goals to indicators and assessment criteria
Inputs: Data and/or information	Best available information
	Anticipate man-made and natural risks through a consultation process
	Integrate the knowledge and understanding from all relevant disciplines to provide society with the tools to review the sustainability and the risks of proposed policies and plans
	Identify the consequences by systematically cataloguing hazards
	Identify hazards
	Develop criteria for what is meant by "safe enough" or sustainable
	Identify all judgements, assumptions and uncertainties in data and interpretations
	Input should be drawn from broad representation of key grass roots, professional, technical and social groups, including youth, women and indigenous people – to ensure recognition of diverse and changing values
Processes	Efficiency concerns and implications
	Effectiveness
	Determine concerns by using risk assessment techniques for various scenarios
	Undertake calculations with appropriate models
	Quantify the potential losses
Outputs: Actions	Incorporation of economic, social and environmental outcomes
Evaluation, reporting and feedback	Vulnerability concerns and implications
	Uncertainties
	Evaluate the certainties, uncertainties and the probabilities involved in the calculations of the vulnerability and of the exposure
	Compare with criteria to assess the need for further action
	Determine options to control, mitigate and adapt to the risk
	Promote and guide monitoring systems to collect, assimilate and archive data relevant to the determination of sustainability and risk, now and in the future
	Communicate the results to those who need to know
	Need to be adaptive and responsive to change and enable collective learning and feedback to decision-making
	Inform decision-making

Sources: Millennium Ecosystem Assessment (2005), Euroscience Council and IUGG Bureau (2002), Ismail-Zadek (2004) and Hardi and Zdan (1997).

Appendix C

Code Relationship Tables

Complex Adaptive Systems Meta-Theme Relationship to the Procedural Themes based on Intersection	assuming reversibility	lack of feedback loop (+) (+)	Assumption of linear relationships	Ignoring thresholds	Cumulative Impacts	Temporal Considerations	Emergent Behaviour (+) (+)	Feed-Forwards (+)	Hierarchal Systems (+)	Irreversibility	Adaptive Management	Non-Linear (+)
Anticipate man-made and natural risks through a consultation process	0	0	0	0	0	0	0	0	0	0	0	0
Inputs	0	0	0	0	0	0	0	0	0	0	0	0
Inputs > Best available information	0	0	0	0	0	0	0	0	0	0	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	0	0	0	0	0	0	1	0	0	0	0
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	0	0	0	0	0	0	0	0	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	0	0	0	0	0	0	0	0	0	1	0	0
Inputs > identify all judgement, assumptions and uncertainties in data	0	0	0	1	0	0	2	0	0	0	0	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	0	0	0	0	0	0	0	0	0	1	0
Output Actions	0	0	0	0	0	0	0	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0	0	0	1	0	0	0	1
Evaluation Report and Feedback	0	0	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	0	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0	0	0	0	0	0	0	1
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	0	0	0	0	0	0	0	0
Uncertainties (+) > Design Uncertainty	0	1	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	0	0	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	1	0	1	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	0	1	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	0	0	0	0	0	0	0	0	0	7	0

Complex Adaptive Systems Meta-Theme Relationship to the Procedural Themes based on Proximity with in 3 paragraphs	assuming reversibility	lack of feedback loop (+) (+)	Assumption of linear relationships	Ignoring thresholds	Cumulative Impacts	Temporal Considerations	Emergent Behaviour (+) (+)	Feed-Forwards (+)	Hierarchal Systems (+)	Irreversibility	Adaptive Management	Non-Linear (+)
Anticipate man-made and natural risks through a consultation process	13	11	4	4	5	7	4	2	0	4	6	2
Inputs	0	0	0	0	0	0	0	0	0	0	0	0
Inputs > Best available information	24	20	12	10	24	18	16	20	3	11	12	10
Inputs > Integrate knowledge and understanding from relevant disciplines	19	11	8	4	21	15	12	13	4	4	9	9
Inputs > Identify the consequences by systematically cataloguing hazards (+)	9	14	4	5	11	16	16	17	4	6	4	10
Inputs > Develop criteria for what is meant by safe enough or sustainable	18	14	6	6	11	14	6	9	0	6	3	4
Inputs > identify all judgement, assumptions and uncertainties in data	35	37	18	18	22	25	28	24	5	19	10	13
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	12	9	3	5	12	7	7	9	3	2	9	3
Output Actions	0	0	0	0	0	0	0	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	4	0	2	0	3	2	0	2	0	0	5	2
Evaluation Report and Feedback	0	0	0	0	0	0	0	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	12	13	4	0	3	5	8	7	0	6	4	2
Evaluation Report and Feedback > Vulnerability concerns and implication	13	5	6	5	12	8	7	4	0	5	7	7
Evaluation Report and Feedback > Uncertainties (+)	4	10	0	2	5	17	18	13	3	14	0	10
Uncertainties (+) > Design Uncertainty	2	10	0	2	0	0	2	5	0	2	2	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	15	21	7	3	16	18	16	15	4	10	7	14
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	23	30	14	11	19	22	25	23	6	15	9	16
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	43	30	15	13	21	21	12	12	3	14	15	5
Evaluation Report and Feedback > Communicate the results to those who need to know	5	8	4	0	3	3	2	2	0	4	2	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	22	25	9	5	10	20	12	11	0	9	21	7

Uncertainty Meta-Theme Relationship to the Procedural Themes based on Intersection	missing uncertainty of data	missing uncertainty in results	Uncertainty in Data	Design Uncertainty	Confidence Levels
Anticipate man-made and natural risks through a consultation process	0	0	0	0	0
Inputs	0	0	0	0	0
Inputs > Best available information	0	0	6	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	0	0	1	0
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	2	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	0	0	1	0	1
Inputs > identify all judgement, assumptions and uncertainties in data	1	1	41	3	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	0	0	0	0
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	1	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	17
Uncertainties (+) > Design Uncertainty	0	0	3	15	1
Evaluation Report and Feedback > Compare with criteria to assess need for further action	0	4	0	0	0
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	0	1	1	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	0	0	0	0	0
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	0	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	0	0	0	0

Uncertainty Meta-Theme Relationship to the Procedural Themes based on Intersection	missing uncertainty of data	missing uncertainty in results	Uncertainty in Data	Design Uncertainty	Confidence Levels
Anticipate man-made and natural risks through a consultation process	5	7	10	4	3
Inputs	0	0	0	0	0
Inputs > Best available information	13	28	40	8	10
Inputs > Integrate knowledge and understanding from relevant disciplines	7	22	20	4	8
Inputs > Identify the consequences by systematically cataloguing hazards (+)	9	19	32	6	17
Inputs > Develop criteria for what is meant by safe enough or sustainable	9	19	26	7	9
Inputs > identify all judgement, assumptions and uncertainties in data	17	41	78	32	24
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	11	22	14	3	2
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	5	4	2	2
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	16	13	4	4
Evaluation Report and Feedback > Vulnerability concerns and implication	4	18	24	8	5
Evaluation Report and Feedback > Uncertainties (+)	0	5	24	5	30
Uncertainties (+) > Design Uncertainty	0	9	24	29	7
Evaluation Report and Feedback > Compare with criteria to assess need for further action	5	21	30	4	15
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	9	35	41	12	15
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	22	44	34	8	4
Evaluation Report and Feedback > Communicate the results to those who need to know	0	14	11	4	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	13	24	22	3	5

Uncertainty Meta-Theme Relationship to the Procedural Themes based on Intersection for Case Study 3	missing uncertainty of data	missing uncertainty in results	Uncertainty in Data	Design Uncertainty	Confidence Levels
Anticipate man-made and natural risks through a consultation process	0	0	0	0	0
Inputs	0	0	0	0	0
Inputs > Best available information	0	0	2	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	0	0	1	0
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	0	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	0	0	0	0	1
Inputs > identify all judgement, assumptions and uncertainties in data	1	1	21	1	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	0	0	0	0
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	0	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	14
Uncertainties (+) > Design Uncertainty	0	0	2	10	1
Evaluation Report and Feedback > Compare with criteria to assess need for further action	0	0	0	0	0
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	0	1	0	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	0	0	0	0	0
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	0	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	0	0	0	0

Social Learning Meta-Themes Relationship to the Procedural Themes based on Intersection	Missing Public Input	Data Input	Networks of Actors (+)	Needs Identification	Perceptions of others
Anticipate man-made and natural risks through a consultation process	5	0	8	9	0
Inputs	0	0	0	0	0
Inputs > Best available information	0	0	0	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	1	0	1	1
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	0	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	0	0	0	0	0
Inputs > identify all judgement, assumptions and uncertainties in data	0	0	0	0	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	6	3	3	3
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	0	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	0
Uncertainties (+) > Design Uncertainty	1	0	2	1	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	0	0	0	0	0
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	0	0	0	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	0	0	0	0	0
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	1	1
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	1	0	0	2

Social Learning Meta-Themes Relationship to the Procedural Themes based on Proximity with in 3 paragraphs	Missing public input	Data Input	Networks of Actors (+)	Needs Identification	Perceptions of others
Anticipate man-made and natural risks through a consultation process	8	3	12	13	0
Inputs	0	0	0	0	0
Inputs > Best available information	5	15	17	16	8
Inputs > Integrate knowledge and understanding from relevant disciplines	5	11	12	13	7
Inputs > Identify the consequences by systematically cataloguing hazards (+)	4	7	2	4	6
Inputs > Develop criteria for what is meant by safe enough or sustainable	6	3	9	8	0
Inputs > identify all judgement, assumptions and uncertainties in data	18	10	23	23	11
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	2	16	17	16	12
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	5	4	4	2
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	7	4	10	8	3
Evaluation Report and Feedback > Vulnerability concerns and implication	2	5	7	11	7
Evaluation Report and Feedback > Uncertainties (+)	7	2	5	6	0
Uncertainties (+) > Design Uncertainty	4	0	11	9	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	5	2	8	6	5
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	8	8	17	20	8
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	16	18	20	23	11
Evaluation Report and Feedback > Communicate the results to those who need to know	2	0	6	5	4
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	5	10	16	17	14

Social Learning Meta-Themes Relationship to the Procedural Themes based on Intersection based on Case Study 2	Missing Public Input	Data Input	Networks of Actors (+)	Needs Identification	Perceptions of others
Anticipate man-made and natural risks through a consultation process	0	0	1	2	0
Inputs	0	0	0	0	0
Inputs > Best available information	0	0	0	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	1	0	1	1
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	0	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	0	0	0	0	0
Inputs > identify all judgement, assumptions and uncertainties in data	0	0	0	0	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	3	1	2	2
Output Actions	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0
Evaluation Report and Feedback	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	0	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	0
Uncertainties (+) > Design Uncertainty	0	0	0	0	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	0	0	0	0	0
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	0	0	0	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	0	0	0	0	0
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	0	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	1	0	0	2

Monitoring and Feedback Meta-Theme Relationship to the Procedural Themes based on Intersection	Missing Learning	No Monitoring Data Input	No Reflexivity	Learning	Reflexivity	Accountability
Anticipate man-made and natural risks through a consultation process	0	0	0	0	0	0
Inputs	0	0	0	0	0	0
Inputs > Best available information	0	4	0	0	0	0
Inputs > Integrate knowledge and understanding from relevant disciplines	0	0	0	0	0	0
Inputs > Identify the consequences by systematically cataloguing hazards (+)	0	0	0	0	0	0
Inputs > Develop criteria for what is meant by safe enough or sustainable	3	0	0	0	0	5
Inputs > identify all judgement, assumptions and uncertainties in data	0	0	1	0	0	0
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	0	0	0	0	0	0
Output Actions	0	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	0	0	0	0	0	0
Evaluation Report and Feedback	0	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	0	0	0	0	0	0
Evaluation Report and Feedback > Vulnerability concerns and implication	0	0	0	0	0	0
Evaluation Report and Feedback > Uncertainties (+)	0	0	0	0	0	0
Uncertainties (+) > Design Uncertainty	0	0	0	0	0	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	1	0	0	0	0	1
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	0	0	1	0	0	0
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	14	0	1	6	1	23
Evaluation Report and Feedback > Communicate the results to those who need to know	0	0	0	0	0	0
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	0	0	0	2	5	1

Monitoring and Feedback Meta-Theme Relationship to the Procedural Themes based on Proximity of 3 Paragraphs	Missing Learning	No Monitoring Data Input	No Reflexivity	Learning	Reflexivity	Accountability
Anticipate man-made and natural risks through a consultation process	8	2	16	3	4	14
Inputs	0	0	0	0	0	0
Inputs > Best available information	21	12	41	7	5	22
Inputs > Integrate knowledge and understanding from relevant disciplines	18	8	26	7	4	18
Inputs > Identify the consequences by systematically cataloguing hazards (+)	8	5	30	6	10	13
Inputs > Develop criteria for what is meant by safe enough or sustainable	12	2	23	4	7	18
Inputs > identify all judgement, assumptions and uncertainties in data	23	10	59	11	14	30
Inputs > Input should be drawn from broad representation of key grass roots, professional, technical and social groups	13	7	16	8	4	17
Output Actions	0	0	0	0	0	0
Output Actions > Incorporation of economic, social, and environmental outcomes	2	4	4	0	0	0
Evaluation Report and Feedback	0	0	0	0	0	0
Evaluation Report and Feedback > Residual effects post mitigation	10	4	13	6	2	9
Evaluation Report and Feedback > Vulnerability concerns and implication	2	6	19	4	2	8
Evaluation Report and Feedback > Uncertainties (+)	4	5	21	2	9	2
Uncertainties (+) > Design Uncertainty	0	0	4	0	0	0
Evaluation Report and Feedback > Compare with criteria to assess need for further action	13	4	24	8	9	14
Evaluation Report and Feedback > Determine options to control, mitigate and adapt to risk	23	8	44	8	14	29
Evaluation Report and Feedback > Promote and guide monitoring systems to collect, assimilate and archive data determing sustainability and risk	32	7	45	20	12	47
Evaluation Report and Feedback > Communicate the results to those who need to know	5	0	6	5	0	5
Evaluation Report and Feedback > Adaptive responsive to enable feed back to decisionmaking	14	8	28	14	13	23

Appendix D

Proposed Framework with Explanation

Procedural Themes	Conceptual Meta-Themes	Conceptual Themes	Confirmation
Anticipate man-made and natural risks through a consultation process	Complex Adaptive Systems	Hierarchical Systems	confirmed by intersection data, missing social learning
	Social Learning	Network of actors Needs Identification Public Input	confirmed by case study 2 example, limited to social learning as the focus is consultation process
Best available information	Complex Adaptive Systems	Cumulative Impacts	proximity analysis, also had researcher qualitative decision as the most important
	Uncertainty	Uncertainty in Data	confirmed by intersection data
	Monitoring and Feedback	Mointoring data input	confirmed by intersection data
Identify unknowns in design process	Complex Adaptive Systems	Adaptive Management	determined by researcher, as this is a new procedure theme
	Uncertainty	Uncertainty in Design	confirmed by intersection data
Integrate the knowledge and understanding from all relevant disciplines to provide society with the tools to review the sustainability and the risks of proposed policies and plans	Social Learning	Social Data Input Needs Identification Perception of others	confirmed by case study 2 example, limited to social learning as the focus is multidisciplinary
Identify the consequences by systematically cataloguing hazards	Complex Adaptive Systems	Temporal Consideration Emergent Behaviour Causal Relationships	confirmed by the proximity analysis, looking at the highest theme for this specific step
Develop criteria for what is meant by “safe enough” or sustainable	Complex Adaptive Systems	Irreversibility	confirmed by intersecting analysis
Identify all judgements, assumptions and uncertainties in data and interpretations	Complex Adaptive Systems	Emergent Behaviour	intersecting analysis (highest intersection for this theme)
	Uncertainty	Uncertainty in Data	confirmed by intersection data
	Monitoring and Feedback	Mointoring data input	confirmed by intersection data
Input should be drawn from broad representation of key grass roots, professional, technical and social groups, including youth, women and indigenous people – to ensure recognition of diverse and changing values	Social Learning	Social Data Input Needs Identification Perception of others	confirmed by case study 2 example and intersection to determine most significant, limited to social learning as the focus as focus is social representation
Incorporation of economic, social and environmental outcomes	Complex Adaptive Systems	Hierarchical Systems Causal Relationships Temporal Consideration	cascading and temporal effects confirmed by intersection analysis, hierarchical systems, not confirmed by data, but included by researcher
Vulnerability concerns and implications	Complex Adaptive Systems	Cumulative Impacts Temporal Consideration	confirmed by proximity data confirmed by intersection data
Evaluate the certainties, uncertainties and the probabilities involved in the calculations of the vulnerability and of the exposure	Complex Adaptive Systems	Temporal Consideration Emergent Behavior	confirmed by proximity data
	Uncertainty	Confidence Level	confirmed by intersection data
Compare with criteria to assess the need for further action			
Determine options to control, mitigate and adapt to the risk	Complex Adaptive Systems	Temporal Consideration Causal Relationships Irreversibility Emergent Behavior	confirmed by proximity (highest for this theme) and intersecting analysis (only intersection for this theme)
	Uncertainty	Confidence Level	confirmed by intersection data for case study 3
	Monitoring and Feedback	Monitoring Data input Accountability Reflexivity	monitoring data input confirmed by intersection, accountability and reflexivity confirmed by proximity analysis
Residual effects	Complex Adaptive Systems	Temporal Consideration	confirmed by (lack of feedback loops)
		Causal Relationships	confirmed by (assuming reversibility) oppportunity to check this
Promote and guide monitoring systems to collect, assimilate and archive data relevant to the determination of sustainability and risk, now and in the future	Complex Adaptive Systems	Irreversibility	confirmed by proximity data
	Monitoring and Feedback	Accountability Learning Reflexivity	confirmed by intersection data
Communicate the results to those who need to know	Complex Adaptive Systems	Causal Relationships	confirmed by proximity data
Need to be adaptive and responsive to change and enable collective learning and feedback to decision-making	Complex Adaptive Systems	Adaptive Management	confirmed by intersection data
	Social Learning	Public Input Perception of others	confirmed by Case study intersection data
	Monitoring and Feedback	Learning Reflexivity	confirmed by proximity data and researcher opinon

Appendix E

Workshop Discussion Questions

A. Which of these opportunities do you see already successfully implemented in the EIA procedure?
   1. Enhancing Systems Thinking Characteristics
   2. Acknowledging Uncertainty
   3. Integrating Social Feedback Loops
   4. Improving Confidence through Monitoring and Feedback
   5. Fostering an Adaptive Management Mindset

B. When addressing uncertainty in EIAs, is there anything you currently do that is not included in the research findings?
   Open Question

C. Which of these do you find will just add to inefficiencies in the process that outweigh the potential benefits?
   1. Enhancing Systems Thinking Characteristics
   2. Acknowledging Uncertainty
   3. Integrating Social Feedback Loops
   4. Improving Confidence through Monitoring and Feedback
   5. Fostering an Adaptive Management Mindset

D. Which of these opportunities do you consider most important?
   1. Enhancing Systems Thinking Characteristics
   2. Acknowledging Uncertainty
   3. Integrating Social Feedback Loops
   4. Improving Confidence through Monitoring and Feedback
   5. Fostering an Adaptive Management Mindset

E. What do you think is the implementation barrier to Opportunity 1, enhancing systems thinking characteristics?
   Open Question

F. What do you think is the implementation barrier to Opportunity 2, acknowledging uncertainty?
   Open Question

G. What do you think is the implementation barrier to Opportunity 3, integrating social feedback loops?
   Open Question

H. What do you think is the implementation barrier to Opportunity 4, improving confidence through monitoring and feedback?
   Open Question

I. What do you think is the implementation barrier to Opportunity 5, fostering an adaptive management mindset?
   Open Question