

Assessing Land Use in Ireland: An Integrated Framework and Review of Indicators

Authors: Zachary Turk, Tracy Bradfield, Cathal Buckley, Emma Dillon and Thia Hennessy

Lead organisations: Cork University Business School, University College Cork and Teagasc



Assessing Land Use in Ireland: An Integrated Framework and Review of Indicators

Authors: Zachary Turk, Tracy Bradfield, Cathal Buckley, Emma Dillon and Thia Hennessy

Lead organisations: Cork University Business School, University College Cork and Teagasc

What did the research aim to address?

Through improved monitoring, land use policies can support national and EU goals, such as the European Green Deal, national energy and climate plans, and the Sustainable Development Goals. Therefore, the aims of this project included the development of a structured integrated framework for monitoring land use changes in Ireland, assessing their impact on production, environmental and wider socio-economic outcomes. The project outputs also include the identification of data collection gaps and recommendations for enhancing the availability and integration of land use monitoring data.

What did the research find?

A total of 36 priority indicators were selected and organised into a three-tier framework for Ireland. The framework provides comprehensive coverage while maintaining usability for policymakers. However, the study found that, while extensive data sources exist, critical gaps remain in land use monitoring, particularly regarding spatial resolution. The frequency of data collection and access to data for further analysis are also concerns. Many datasets are aggregated at the national or regional level, limiting our ability to track land use changes effectively. Some indicators, including those for biodiversity monitoring, are reported on at 6-year intervals, while others, such as soil quality metrics, lack regular updates. Data for some indicators, such as the Genuine Progress Indicator, are not currently collected, despite being beneficial in tracking the positive contributions and negative externalities associated with economic activity. We also found that monitoring of per- and polyfluoroalkyl substances could be improved given the increasing concerns about “forever chemicals”. In summary, existing data collection efforts are fragmented, originating from disparate sources rather than a unified system. Integrating disparate production, environmental and socio-economic data remains a challenge that is likely to require substantial investment to redress.

How can the research findings be used?

The findings emphasise the need for improved data governance, coordination and investment in long-term data collection. Establishing a centralised governing body responsible for coordinating the collection of land use data and their dissemination through an empowered data-sharing platform could enhance data collaboration across providers. Shifting from one-off reporting, in some cases, to sustained longitudinal studies would help track policy impacts over time. Increasing resources for localised data collection would improve granularity, while greater transparency in data methodologies and reporting would enhance accessibility and usability for policymakers. These improvements would support evidence-based decision-making, enabling Ireland to meet its climate, biodiversity and socio-economic targets while fostering resilience in land use planning.

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: Implementing regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

Knowledge: Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

Advocacy: Working with others to advocate for a clean, productive and well protected environment and for sustainable environmental practices.

Our Responsibilities Include:

Licensing

- > Large-scale industrial, waste and petrol storage activities;
- > Urban waste water discharges;
- > The contained use and controlled release of Genetically Modified Organisms;
- > Sources of ionising radiation;
- > Greenhouse gas emissions from industry and aviation through the EU Emissions Trading Scheme.

National Environmental Enforcement

- > Audit and inspection of EPA licensed facilities;
- > Drive the implementation of best practice in regulated activities and facilities;
- > Oversee local authority responsibilities for environmental protection;
- > Regulate the quality of public drinking water and enforce urban waste water discharge authorisations;
- > Assess and report on public and private drinking water quality;
- > Coordinate a network of public service organisations to support action against environmental crime;
- > Prosecute those who flout environmental law and damage the environment.

Waste Management and Chemicals in the Environment

- > Implement and enforce waste regulations including national enforcement issues;
- > Prepare and publish national waste statistics and the National Hazardous Waste Management Plan;
- > Develop and implement the National Waste Prevention Programme;
- > Implement and report on legislation on the control of chemicals in the environment.

Water Management

- > Engage with national and regional governance and operational structures to implement the Water Framework Directive;
- > Monitor, assess and report on the quality of rivers, lakes, transitional and coastal waters, bathing waters and groundwaters, and measurement of water levels and river flows.

Climate Science & Climate Change

- > Publish Ireland's greenhouse gas emission inventories and projections;

- > Provide the Secretariat to the Climate Change Advisory Council and support to the National Dialogue on Climate Action;
- > Support National, EU and UN Climate Science and Policy development activities.

Environmental Monitoring & Assessment

- > Design and implement national environmental monitoring systems: technology, data management, analysis and forecasting;
- > Produce the State of Ireland's Environment and Indicator Reports;
- > Monitor air quality and implement the EU Clean Air for Europe Directive, the Convention on Long Range Transboundary Air Pollution, and the National Emissions Ceiling Directive;
- > Oversee the implementation of the Environmental Noise Directive;
- > Assess the impact of proposed plans and programmes on the Irish environment.

Environmental Research and Development

- > Coordinate and fund national environmental research activity to identify pressures, inform policy and provide solutions;
- > Collaborate with national and EU environmental research activity.

Radiological Protection

- > Monitoring radiation levels and assess public exposure to ionising radiation and electromagnetic fields;
- > Assist in developing national plans for emergencies arising from nuclear accidents;
- > Monitor developments abroad relating to nuclear installations and radiological safety;
- > Provide, or oversee the provision of, specialist radiation protection services.

Guidance, Awareness Raising, and Accessible Information

- > Provide independent evidence-based reporting, advice and guidance to Government, industry and the public on environmental and radiological protection topics;
- > Promote the link between health and wellbeing, the economy and a clean environment;
- > Promote environmental awareness including supporting behaviours for resource efficiency and climate transition;
- > Promote radon testing in homes and workplaces and encourage remediation where necessary.

Partnership and Networking

- > Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

Management and Structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2021–2030

Assessing Land Use in Ireland: An Integrated Framework and Review of Indicators

(2023-NE-1202)

EPA Research Report

Independent scientific research funded by the Environmental Protection Agency

Prepared by

Cork University Business School, University College Cork and Teagasc



Authors:

Zachary Turk, Tracy Bradfield, Cathal Buckley, Emma Dillon and Thia Hennessy

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2021–2030. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Climate, Energy and the Environment. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to acknowledge the members of the project steering committee, namely David Dodd (Department of Climate, Energy and the Environment), Niamh Garvey (National Economic and Social Council), Mark Kearney (Department of Agriculture, Food and the Marine) and Fiona O'Rourke (Environmental Protection Agency). The authors would also like to acknowledge the support of the Research Project Manager on behalf of the EPA, namely Caroline Wynne.

We also thank the attendees of our presentation to the Agricultural Economics Society of Ireland (AESI) 2024 in Belfast on 25 June 2024 for their helpful comments and reactions.

DISCLAIMER

Although every effort has been made to ensure the accuracy of the material contained in this publication, complete accuracy cannot be guaranteed. The Environmental Protection Agency, the authors and the steering committee members do not accept any responsibility whatsoever for loss or damage occasioned, or claimed to have been occasioned, in part or in full, as a consequence of any person acting, or refraining from acting, as a result of a matter contained in this publication. Any opinions, findings or recommendations expressed in this report are those of the authors and do not reflect a position or recommendation of the EPA. All or part of this publication may be reproduced without further permission, provided the source is acknowledged.

This report is based on research carried out/data from March 2024 to February 2025. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2021–2030
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-383-6

April 2026

Price: Free

Online version

Project Partners

Dr Zachary Turk

Department of Economics
Cork University Business School
University College Cork
Áras na Laoi
Cork
T12 T656
Email: ZTurk@ucc.ie

Dr Tracy Bradfield

Department of Economics
Cork University Business School
University College Cork
Áras na Laoi
Cork
T12 T656
Email: Tracy.Bradfield@ucc.ie

Dr Cathal Buckley

Agricultural Economics and Farm Surveys
Department
Teagasc
Mellows Campus
Athenry
Co. Galway
H65 R718
Email: Cathal.Buckley@teagasc.ie

Dr Emma Dillon

Agricultural Economics and Farm Surveys
Department
Teagasc
Mellows Campus
Athenry
Co. Galway
H65 R718
Email: Emma.Dillon@teagasc.ie

Professor Thia Hennessy

College of Business and Law
University College Cork
O'Rahilly Building
Cork
T12 K8AF
Email: Thia.Hennessy@ucc.ie

Contents

Acknowledgements	ii
Disclaimer	ii
Project Partners	iii
List of Figures	vi
List of Tables	vii
Executive Summary	ix
1 Introduction	1
1.1 Layout of Report	2
2 Indicator Selection	3
2.1 Prospective Indicator Sources	3
2.2 Indicator Overview	15
2.3 Indicator Selection	23
3 Indicator Data Availability	33
3.1 Tier I Indicator – Genuine Progress Indicator	33
3.2 Tier II Indicators	35
3.3 Planetary Boundaries Contributions	37
3.4 Tier III Indicators	40
3.5 Summary of Data Availability	46
4 Discussion	51
4.1 Recommendations for Structural Change	54
4.2 Addressing Specific Indicator Shortcomings	55
5 Conclusion	57
References	58
Appendix 1 Exclusion of Some Promising Indicators	69
Abbreviations	71

List of Figures

Figure 2.1.	Ecological footprint and biocapacity estimates, Ireland	12
Figure 2.2.	Assessment framework tiers	24

List of Tables

Table 2.1.	SRC planetary boundaries	13
Table 2.2.	Models of assessment indicators	15
Table 2.3.	Domain-specific indices	22
Table 2.4.	Cross-domain indices	23
Table 2.5.	Suggested Tier II indicators	26
Table 2.6.	Suggested Tier III indicators	28
Table 3.1.	Status of data collection: Tiers I and II	47
Table 3.2.	Status of data collection: Tier III	48

Executive Summary

This report presents an assessment framework for monitoring land use changes in Ireland, focusing on the impact of such changes on production, environmental and socio-economic outcomes. The framework organises indicators into a three-tier system based on their frequency in existing datasets, linkages to land use and responsiveness to policy changes. The report also identifies current data collection levels, highlights shortfalls and recommends improving data availability and transitioning the framework from concept to implementation.

Background

Effective land use policy is essential for balancing competing demands while advancing national and EU goals, including those of the European Green Deal and national energy and climate plans, and the Sustainable Development Goals. However, substantial data collection and integration improvements are needed for effective monitoring. As a multifunctional resource, land supports agriculture, forestry, biodiversity, ecosystem services and socio-economic well-being. Ireland faces challenges in meeting its targets while managing competing land use demands.

To address these challenges, one of the recommendations from Phase 1 of the Land Use Evidence Review, conducted in 2023 and co-sponsored by the Department of Agriculture, Food and the Marine and the then Department of the Environment, Climate and Communications, is to develop an integrated land use assessment model to evaluate policy effectiveness. This framework should establish a baseline, track progress against key indicators and assess the impacts of policies on production, biodiversity and socio-economic outcomes and greenhouse gas emissions.

Indicator Selection and Categorisation

This report evaluates over 1000 potential indicators from international and national datasets. Thirty-six indicators were selected and organised into a three-tier

system. Land use data for each indicator were collected on the most granular scale permissible:

- Tier I overall status indicator: the Genuine Progress Indicator (GPI) provides a high-level assessment of outcomes in Ireland, capturing income along with public and ecosystem service values.
- Tier II domain summary indicators: these indicators measure socio-economic, production and environmental outcomes, along with climate change preparedness levels. They include subjective well-being, gross income per capita and ecological footprint relative to biocapacity indicators and a climate adaptation score. Also included are planetary boundary indicators for Ireland: emissions of carbon dioxide equivalents, the International Union for Conservation of Nature's Red List Index, net primary productivity, land cover share and chemical pollutant indicators.
- Tier III diagnostic indicators: these indicators comprise a set of recommendations for in-depth analysis when land use-driven outcomes deviate from targets. They cover air quality, biodiversity, climate change, production, socio-economic factors, soil quality and water quality monitoring.

Structuring indicators across tiers helps diagnose policy shortfalls while keeping the framework manageable and focused for users.

Data Availability

Significant challenges exist in relation to data availability and collection. The report highlights key gaps in monitoring land use impacts at a granular level:

- Low spatial resolution: many datasets are aggregated at the national or regional level, limiting their ability to capture localised land use changes.
- Infrequent data collection: critical indicators like biodiversity and soil quality lack regular updates.

- Missing critical indicators: GPI data are not currently collected, and data on per- and polyfluoroalkyl substance monitoring are underreported to the public.
- Limited integration of data: existing data stem from separate efforts rather than a unified effort.
- Barriers to cross-sectoral data integration: aligning agricultural, environmental and economic data remains challenging due to differences in methodologies, scale and reporting traditions. Combining data must also be balanced against issues with identification and General Data Protection Regulation protections.
- Ensuring granular data collection and availability: increase resources to enable increased sample sizes and more localised data gathering and reporting.
- Increasing transparency: improve the reporting of methodologies, databases and points of contact for statistics reported by national agencies.

Policy Implications and Recommendations

To improve land use monitoring and policy responsiveness, the report recommends the following:

- Strengthening data governance: establish a centralised data-sharing platform to integrate monitoring efforts across sectors, combined with centralised authority over data access.
- Investing in long-term data collection: shift from one-off reporting to sustained long-term data collection. This requires an institutional shift away from funding novel studies towards investment in long-term data collection.

Conclusion

Effective land use policy supports economic development, environmental protection and socio-economic well-being. This report outlines a tiered indicator framework for monitoring land use-driven outcomes and identifies key information gaps that must be addressed for full implementation. While progress has been made in aligning Ireland's land use policies with national and EU sustainability goals, further investment in data infrastructure and cross-sectoral collaboration is needed. Strengthening the evidence base will enhance Ireland's ability to meet climate, biodiversity and socio-economic targets while building long-term resilience.

1 Introduction

Land is a multifunctional resource that supports agriculture and forestry, sustains biodiversity, provides ecosystem services such as climate and water quality regulation, supports bioenergy production, and offers recreational and cultural opportunities. A well-managed landscape provides benefits that support human well-being while safeguarding our environment for future generations. To determine whether the lands of Ireland are, in fact, being managed well, we develop an assessment framework of indicators on land use following recommendations from Phase 1 of the Land Use Evidence Review (DAFM and DECC, 2023a). Gaining a better understanding of land use outcomes will help us understand how land use policy can be adapted to improve the state of the environment; resource availability; food, fibre and fuel production; and wider socio-economic outcomes.

To develop our assessment framework, we conduct a review of existing land use assessment indicators, including those explicitly mentioned in Phase 1 of the Land Use Evidence Review (DAFM and DECC, 2023a). During the process, we keep in mind our goal of understanding how land use policy can be adapted to improve the state of the environment; resource availability; food, fibre and fuel production; and broader socio-economic outcomes. We also keep a multidisciplinary perspective, as we intend the framework to encompass all land uses. While including biological, phenological, technical, social, political, economic and cultural indicators in our analysis, we acknowledge that some indicators will have a stronger relationship to land use than others. This work follows a recommendation from Phase 1 of the Land Use Evidence Review, which calls for “a more integrated model of Ireland’s land use. This would show the status of all aspects of Ireland’s land use: the social impacts, the economic impacts and the environmental system in which our society and economy operates” (DAFM and DECC, 2023a).

Developing an integrated model of land use and outcomes requires substantial planning. First, we must determine what indicators are necessary and informative – the objective of the first section of this review. Then, we want to determine whether the

recommended data are currently available, and, if not, what it would take to make them available – the purpose of the second section of this review. This progression reduces the tendency to let data availability define what is monitored, as we believe that what gets measured, gets managed. Finally, whether an integrated model can be brought into operation at this time must be determined, and, if not, what steps must be taken to make it operational.

To ensure that this review supports the development of our long-term outcome of interest – the development of an informative integrated model – we first discuss what such a model should accomplish. First, the model should identify the current state of outcomes influenced by land use. In doing so, a baseline, granular database, with which future comparisons will be made, needs to be available. Second, some idea of what desirable outcomes would look like should follow. This would then support identifying whether subsequent changes are an improvement on the past. We would also, preferably, want a model that allows scenario analyses of the impacts of land use changes once successive years of data are available. This would, for example, allow us to respond to questions such as how the profile of emissions of carbon dioxide equivalents (CO₂e) would change with a change in grazing patterns or the transition of land into or out of arable uses. We would want, however, to predict outcomes across several environmental, production and social metrics, which are sometimes more difficult to monitor. These include the capacity of the government and society to handle future issues related to global climate change – the building of system resilience.

With our goal in mind, this work’s first and second objectives are to review existing land use assessment frameworks developed at the international, European and country levels and then outline an integrated framework that provides a more all-encompassing assessment of land use. There is a broad range of existing models used to assess land use. Following a review of these models, we identify 36 indicators that could be prioritised to provide a comprehensive assessment of land from a multifunctional viewpoint.

It is also an attempt to account for both the direct and indirect impacts of land use, which is recommended by De Rosa (2018); in addition, a condensed list makes data collection more feasible. It is important to note that the integrated model can be applied universally. The third objective of this work is to identify gaps in data collection from an Irish perspective, to provide immediate impact for policymakers.

The reason for focusing on Ireland is that the country is currently behind on many of its environmental targets, such as its greenhouse gas emission reduction targets (EPA, 2024f). Currently, Ireland has the highest proportion of land allocated to agriculture in the EU, covering 69% of the total land area, primarily grassland, followed by forestry (11%), wetlands (7%) and settlements (2%) (CSO, 2023b). The extent of agricultural production, forest redevelopment, energy production (including energy crops, feedstock for anaerobic digestion and solar farms) and other land uses presents opportunities and challenges as Ireland and other nations work to meet their extensive environmental and socio-economic targets. These include commitments on climate change mitigation and adaptation, progress towards the Sustainable Development Goals (SDGs), and nature restoration and biodiversity preservation (DECC, 2022a,b; National Parks & Wildlife Service, 2024a).

Beyond the context of meeting national and international commitments, land use policy is a critical mechanism for enhancing environmental sustainability, ensuring resource availability, improving socio-economic performance and building resilience to future challenges. Effective land use policy is likely to require a strategic blend of regulatory adjustments, targeted investments and well-designed incentives that promote sustainable land management. These might include price-based mechanisms that encourage efficient land use in production while simultaneously

safeguarding land for conservation and ecosystem services. They might also include addressing rural economic development through land use strategies that provide employment opportunities, lead to the development of essential public goods and strengthen resilience against environmental and economic shock. Additionally, land use policies will be necessary for facilitating the transition to sustainable food systems and bioenergy development. Strengthening land use governance and investing in research-driven land management strategies will be essential in ensuring that land also remains a valuable and productive asset for future generations. However, such efforts will depend on the existence of sufficient data for monitoring the outcomes of land use policy on the rest of society. Reliable, high-resolution data are essential for evaluating the effectiveness of policies, identifying emerging challenges and refining strategies to ensure sustainable and equitable land use management. This report helps build that basis.

1.1 Layout of Report

The remainder of this report proceeds as follows. First, we describe our collection of indicators from existing assessment frameworks, important summary indicators and the approach taken for the collection of data on over 1000 indicators. Next, we discuss our dataset of indicators in terms of the information they suggest we include in our assessment model, how we organise and condense them, and the 36 priority indicators we identify as most important to include. With those indicators in hand, we then discuss data availability in Ireland – frequency, sources and scale of collection. Finally, we conclude with insights on transitioning from this review to a fully operational assessment model through improved data collection and coordination.

2 Indicator Selection

We expect that assessment of production should, at a minimum, include major land uses related to food, fibre and fuel production, e.g. agriculture and silviculture. Several ecosystem services are heavily dependent on land use through sources of recreational value, direct and indirect ecosystem services provision supporting society through water and air purification, and non-use values around the existence of nature such as biodiversity and carbon storage. Socio-economic impacts have traditionally been substantially more difficult to include in such models, so we pay particular attention to including socio-economic indicators. These involve, for example, tracking progress towards internationally recognised metrics such as the SDGs (United Nations, 2023). Finally, following on from the Stockholm Resilience Centre's (SRC) planetary boundaries framework (Richardson *et al.*, 2023) and modelling of the economy embedded in a stock-dependent biosphere (Dasgupta, 2021), we consider the monitoring of how changes in stocks of national and global importance impact the stability of Earth's systems. We also cannot imagine a model of land use-based outcomes without integrating data from surveys of the public. Surveys can capture statuses that are otherwise difficult to quantify, and understanding our attitudes and beliefs about agri-environmental and climate public goods will help us understand what to expect in the future.

2.1 Prospective Indicator Sources

We perform a literature review to understand what sort of assessment model would be appropriate for Ireland. To be efficient, we use expert recommendations by focusing our survey on existing lists of indicators and assessment frameworks proposed in Ireland and abroad. The focus on existing indicator sets allows us to capture the breadth of possibilities and the frequency with which key indicators are recommended. These span food, fibre and fuel production, and environmental and socio-economic concerns. Most indicator sets have an underlying goal or concern guiding their development, so including multiple indicator sets is important for capturing the breadth of the impacts we have in mind. We also include some

key individual indicators and shorter lists of indicators that are important as aggregate measures.

Generally, the indicator sets we find are developed from different perspectives and disciplines. This means that we encounter barriers in terms of differences in the terminology used and data requirements. Sometimes such barriers are even encountered for a single indicator set, when the compilation of that set is the result of a large number of diverse researchers' efforts. Nevertheless, we provide a comparison of indicators and, when possible, standardise the indicators. Subsequently, we can count the number of datasets that recommend the same indicator. We constrain our resulting dataset to indicator data that can feasibly be collected in Ireland, inform land use policy-driven outcomes and are frequently recommended by separate subject matter experts. To some degree, internationally comparable metrics have an advantage, particularly when they support Ireland in demonstrating that it is meeting international commitments. However, many such commitments require country-specific planning and measures of success, so we suggest that it is more important that the metrics selected best represent conditions "on the ground" in Ireland.

2.1.1 Frameworks of assessment indicators and best practices

In this section, we outline data sources in the form of indicator sets. These lists, developed by experts in their fields, tend to have specific focuses, e.g. the focus of the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD) on addressing biodiversity loss. Others, such as the SDGs, tend to include indicators covering multiple issues and are the result of work by a substantial number of researchers from different fields. Our sets of indicators include those from Phase 1 of the Land Use Evidence Review (DAFM and DECC, 2023a); the SDGs (United Nations, 2023); the Mapping and Assessment of Ecosystems and their Services (MAES) (Maes *et al.*, 2020) indicator set, following on from the Millennium Ecosystem Assessment (MEA) (Millennium Ecosystem Assessment, 2005); the Common

Agricultural Policy (CAP) Performance Monitoring and Evaluation Framework (PMEF) (European Commission, 2024b); the Adaptation Scorecard of the Climate Change Advisory Council (CCAC, 2024); and national biodiversity indicators. We also include smaller sets of indicators such as the Environmental Performance Index (EPI) (Block *et al.*, 2024), the Global Competitiveness Index (GCI) (Schwab and Zahidi, 2020), the Institute for Economics & Peace Global Peace Index (IEP-GPI) (Institute for Economics & Peace, 2024) and the Ecological Threat Report (ETR) (Institute for Economics & Peace, 2023).

To guide our review, we ask what progress in monitoring the food, fibre and fuel production, and environmental and socio-economic spheres in Ireland would entail. Subsequently, we ask what sets of indicators might identify whether areas of Ireland are making progress in critical areas in response to land use policies. Having considered these questions, we primarily group our discussion of indicator sets by theme. First, however, we provide a brief overview of the indicators recommended for further consideration in Phase 1 of the Land Use Evidence Review. This is followed by a review of major socio-economic, food, fibre and fuel production, and environmental indicator sets, with the final set being further subdivided due to the extent of land use impacts on the environment. We also review some additional sets of indicators that are more tangential to land use.

Phase 1 of the Land Use Evidence Review

Phase 1 of the Land Use Evidence Review led to the compilation of a list of proposed indicators, as summarised in Appendix A of *Land Use Review: Indicator Assessment* (DAFM and DECC, 2023b). The list includes 102 indicators that are subjectively ranked in terms of relevance (low, medium or high) to land use. The indicators are also denoted as being environmental, social or progress indicators. The environmental indicators category is widely defined such that it can include both measured and modelled outputs. It also includes indicators related to environmental–human linkages and human health. Social indicators are specifically about human institutions, society and quality of life, which are determined by factors other than environmental factors. Progress indicators report specifically on policy progression and implementation – and not

on whether policies are effective for their intended purpose. We have subdivided the Land Use Evidence Review indicators by following and retaining some aspects of the classification system used to subdivide the CAP indicators (European Commission, 2024b). The Department of Agriculture, Food and the Marine (DAFM) and the Department of Climate, Energy and the Environment (formerly the Department of the Environment, Climate and Communications (DECC)) also qualitatively assess their indicators in terms of feasibility and data availability.

We find that the Phase 1 indicator list comprises, in effect, substantially more than 102 indicators, as it includes lists of other indicators. One example is the entry for the Aichi Biodiversity Targets, which contains 162 indicators, and another example is the 8 headline Irish national biodiversity indicators, which comprise 71 sub-indicators. As such, the actual number of proposed indicators from Phase 1 of the Land Use Evidence Review is at least 300. Sources of the Phase 1 indicators are the European Environment Agency, the United Nations SDG programme, the National Parks & Wildlife Service (NPWS), the Irish Environmental Protection Agency (EPA), the International Union for Conservation of Nature (IUCN), BirdLife International and the National Biodiversity Data Centre (NBDC). These indicators were used to provide part of the overall evidence for the impacts and status of land use in Ireland (DAFM and DECC, 2023b). The authors note that the list of indicators is expected to be refined in future work – or other indicators are expected to be developed – as our review seeks to do. We take inclusion in the Phase 1 list as the first vote that a proposed indicator should be considered for inclusion in our assessment matrix. We initially include all such indicators regardless of whether they were assessed as having a low, medium or high level of relevance to land use. We assess relevance ourselves within the context of the wide scope of the impacts we would like to monitor.

Socio-economic indicators: SDGs and the Human Development Index

The United Nations SDGs (United Nations, 2023, 2024) comprise a collection of targets and corresponding indicators of progress, grouped into 17 overarching goals. Adopted in 2015 by United Nations Member States including Ireland, they

are intended to encourage progress towards both social and environmental targets, recognising the interconnectedness between the welfare of people and that of the environment. The SDGs supersede the Millennium Development Goals and include an expansion of objectives, to better encompass issues in both advanced and developing countries. For example, in reference to education, SDG 4 now focuses on “quality education” rather than on achieving universal primary school educational levels as in the Millennium Development Goals. This SDG includes 10 targets and 12 proposed indicators to track progress towards achieving SDG 4, including primary school attainment and developing the necessary infrastructure to pursue that attainment.

In total, the SDGs include 249 proposed indicators that are unevenly representative. The interconnectedness between SDGs is also noted. Consequently, there are overlaps in the policy requirements for and effectiveness of progress towards SDGs. For example, it would be difficult to argue that SDG 13 – climate action – can be pursued independently of SDG 7 – affordable and clean energy. We also note the relevance of SDG 14 – life below water – given the importance of Ireland’s offshore environment. We suggest that Ireland’s blue water areas be included alongside land uses, as harvesting in the marine environment can be a substitute for production on land.

Unfortunately, the monitoring of progress towards the SDGs – as with most indicators – will require monitoring at local levels to provide meaningful information about land use policy impacts. This means pursuing the collection of substantially more disaggregated data than is done for national metrics. The implementation of SDG monitoring, going from the United Nations proposal to national implementation to monitoring on local scales, has been limited to date. Despite the lack of data collection infrastructure and other criticisms of the SDGs, however, they still represent a substantial advance towards identifying the needs of society and tracking progress towards meeting these needs. Notably, as Ireland is required to pursue the SDGs, tracking progress towards SDGs related to land use would support wider government monitoring goals.

An advantage of the breadth of the SDGs is that agencies tasked with specific mandates can pursue

monitoring that matches those mandates. The SDGs provide salient recommendations of which indicators to develop. In terms of an overall assessment matrix, however, the breadth of the SDGs may present a problem, as there are more goals and a larger information burden than may be practical to deal with. Therefore, the development of summary measures that, for example, focus on specific SDG indicators that are thought to be correlated with other indicators have been proposed. The Human Development Index (HDI) is one such summary indicator used for international comparisons (United Nations Development Programme, 2024a). The HDI traditionally focused on three dimensions: long and healthy lives, knowledge, and standards of living. The HDI then reports the geometric mean of the three dimensions after standardisation such that all estimates fall within an interval of 0 to 1. Recently, the HDI also underwent a “planetary pressures” adjustment based on carbon dioxide (CO₂) emissions and a material footprint measure is used to weight the HDI by a rough estimate of sustainability.

In addition to the HDI and the planetary pressures-adjusted HDI, the United Nations Development Programme has also reported an inequality-adjusted HDI. Rather than weighting by additional metrics, the inequality-adjusted HDI is reweighted based on inequality within the dimensions of the composite HDI (United Nations Development Programme, 2024b). Inequality weightings are also influenced by an inequality aversion parameter following Atkinson (1970), which is a common approach to integrating inequality considerations into public policy. At the national level, Ireland ranks seventh across the three versions of the HDI (based on 2022 data, most recent year). Incorporating HDI measures into an assessment tool would need to occur on a refined geographical scale as with the other indicators identified in this report.

As an alternative, the SDG Index (Sachs *et al.*, 2024) selects a subset of SDG indicators – 125 in the 2024 Sustainable Development Report – then develops an index score on a scale of 0–100, indicating attainment of their related targets. To date, the SDG Index has been estimated at national levels. Year-over-year comparisons have been cautioned against, however, as the SDG Index continues to develop and a few different indicators are included each year. The SDG Index, like many composite

indices, does not include a notion of what trade-offs between progress in one indicator and regression in another would imply. That is, progress in indicators is not weighted by their marginal values to society – an admittedly difficult prospect to address.

Food, fibre and fuel production: CAP and Central Statistics Office EPI

The European Commission's CAP programme recognises the need for review and assessment. For the 2014–2022 period, CAP monitoring took the form of the Common Monitoring and Evaluation Framework (CMEF), updated to the PMEF for 2023–2027 (European Commission, 2024b). Some CAP indicators are specifically tailored to the monitoring of programme implementation, while others are intended to monitor general societal changes that are thought to be linked to the CAP. In addition to the CMEF and the PMEF, a set of “context indicators” for tracking more general economic and environmental factors, with a purpose along the same lines as our review's, have been proposed. The CAP context indicators are divided into socio-economic, wider agricultural sector and environmental impact indicators.

As with other sets of indicators, the PMEF and CAP context indicators have a specific focus – to avoid falling short of CAP objectives (OECD, 2021; European Commission, 2024a). Therefore, as progress is made towards CAP goals, the indicators selected may be refined over successive periods. However, a comparison of CAP 2023–2027 with CAP 2014–2022 indicates an expansion of monitoring rather than a replacement. At present, CAP monitoring is based on 44 result indicators and 47 context indicators (91 in total). CAP results indicators are primarily focused on tracking CAP expenditure and the uptake of CAP programmes – direct impacts of the CAP. Like the SDGs, Ireland is a party to the CAP and actively implements agricultural policies with CAP results in mind.

The Irish Central Statistics Office (CSO) EPI (CSO, 2023b) is also included in this section, as it has a strong focus on land use in its 70 environmental performance indicators across 10 categories; however, five of these are global context indicators and several are EU-wide status indicators without equivalent local

metrics. Consequently, 49 Ireland-specific indicators are also included.

Environment as a service: MEA to MAES

One perspective on how to include environmental concerns in assessments is through monitoring changes – often in terms of value – in what are referred to as “ecosystem services”. As implied, these are values placed on definable segments of the environment based on the value of the services they provide to humanity. One example is in terms of air and water purification – waste processing – but ecosystem services are substantially more varied across the provisioning of natural resources, regulating the climate and other Earth systems, supporting biological processes, and providing recreational and cultural benefits based in the experiences we have in nature. The concept of ecosystem service values originated in the 1970s (Gómez-Baggethun *et al.*, 2010). However, the concept has gained substantial traction only over the last two decades, following the MEA (Millennium Ecosystem Assessment, 2005), which outlined how to identify and define ecosystem services and subsequently how to include their values in public policy.

Ecosystem service values are, however, easier to define and measure in principle than in practice, as they are context specific. They tend to be based on not just the ecosystem service they provide, but also who benefits from this service. As such, two sites can produce different levels of value even if they provide a similar service because they are situated in communities that are different. Ecosystem services also often have public goods attributes such as being difficult to make exclusive, further complicating the measurement of their value in practice. Therefore, the approach to measuring ecosystem service values – even deciding on which service values to measure – requires tailoring. We can find several proposals on which ecosystem services are most important to measure. Layke *et al.* (2012) provide a review of the first substantial effort to list and classify ecosystem service options. Their accompanying database (no longer publicly available) included over 600 ecosystem service value estimates – a number that has no doubt grown substantially since.

Parker *et al.* (2016) provide another early effort at mapping which ecosystem services are relevant and where they occur. However, the MAES indicator set (Maes *et al.*, 2020) provides a more tractable middle ground. This indicator set represents ecosystem services that are likely to apply to much of Ireland without being tailored to specific sites. Changes in values at specific sites would then indicate improvement or degradation of the state of nature and how it is valued in related localities. However, the MEA also cautions that linkages between changes in ecosystem services and human well-being are often indirect and not well understood. So, it remains an open question as to the benefit of monitoring specific ecosystem service values versus other approaches to monitoring the environment more directly.

In our review, MAES-recommended indicators are used to include the ecosystem service value perspective. One way in which MAES indicators are subdivided is into habitats, defined as urban, agroecosystems, forests, inland wetlands, heathlands and shrubs, sparsely vegetated lands, rivers and lakes, and marine areas. Indicators can be further divided into those monitoring pressures – causes of change – and conditions as the status of ecosystems providing services (202 total indicators). While ecosystem service values are an increasingly important part of policy development, the number of MAES indicators subdivided by habitat is not indicative. A habitat can produce several smaller streams of value that can be subdivided because the processes involved are well understood. In woodlands, for example, carbon sequestration can be broken down into measurable processes such as above-ground biomass accumulation, below-ground root growth and soil organic carbon changes, each of which can be estimated separately and linked to management practices. Alternatively, the processing in a habitat producing value might be less well understood, but the net effect still measurable. In peatlands, carbon storage is a function of complex interactions between waterlogged conditions, plant litter accumulation and anaerobic microbial activity; these are difficult to quantify yet the net carbon balance can be estimated.

Rather than measure the environment in terms of the services it provides, the next section discusses the measurement of changes in the status of biodiversity directly.

Biodiversity: CBD Aichi Biodiversity Targets, Ireland's national biodiversity action plan and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

The CBD provides guidance on monitoring the status of biodiversity related to the Aichi Biodiversity Targets (Secretariat of the Convention on Biological Diversity, 2016). The 162 indicators are grouped into 20 targets, which are then grouped into 5 strategic goals. Of the 162 indicators, 159 are potentially relevant to changes in the status of biodiversity within Ireland, while the remainder relate to nations becoming signatories to international accords. While the Aichi Biodiversity Targets have been in part superseded, they form the basis of a substantial share of biodiversity policy and are substantial in breadth. Recently, they have been revised into 4 goals and 23 targets, in the Kunming–Montreal Global Biodiversity Framework. The list of indicators in the new set is more constrained, with a number identified as being for monitoring progress towards more than one target – which gives rise to the question of why they are separate targets. Consequently, we follow Phase 1 of the Land Use Evidence Review and other sources by continuing to focus on the wider set of Aichi Biodiversity Targets.

We also note linkages between the Aichi Biodiversity Targets and the SDGs. The CBD identifies these linkages (Secretariat of the Convention on Biological Diversity, 2016) in addition to SDGs that are specifically targeted at the state of nature such as SDGs 13–15. These linkages suggest at least one pathway through which land use policy can impact socio-economic outcomes, as the status of biodiversity tends to be directly impacted by land use. In particular, we note the multifaceted relationship between ecosystem services in the Aichi Biodiversity Targets and the SDGs, with SDG indicators on life on land and water being frequently related to the Aichi Biodiversity Targets.

To operationalise progress towards CBD targets, countries are required to submit and periodically revise national biodiversity action plans (NBAPs). Ireland submitted its most recent plan, its fourth NBAP, in February 2024 for the 2023–2030 period (National Parks & Wildlife Service, 2024a). As opposed to strategic goals, the NBAP has five overarching objectives (seven in the third NBAP). These objectives are composed of several monitored outcomes,

which are further related to target–indicator pairs. As opposed to the streamlining in the Kunming–Montreal Global Biodiversity Framework, Ireland recommends an expansive set of indicators, as do many countries, to allow more refined allocation of monitoring to responsible ministries.

A substantial share of the target–indicator pairs within the fourth NBAP are concerned with setting up policy frameworks, improving existing policies and building monitoring mechanisms to ensure progress towards meeting biodiversity targets. A smaller share is focused on specific biodiversity targets. The fourth NBAP is a planning document that includes information on which parties are responsible for each item, rather than a set of assessment indicators. Its target–indicator pairs are also often binary, e.g. indicating whether a framework has been developed, rather than linking land use changes to biodiversity outcomes. We instead focus on the CBD target indicators in our framework, which will ultimately indicate whether Ireland’s planning efforts have been successful.

Additionally, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) offers a separate set of 71 indicators grouped into themes such as direct and indirect drivers of biodiversity change, ecosystem functions and human well-being (IPBES, 2019). These indicators largely contribute to the identification of which indicators are important, reinforcing the Aichi Biodiversity Target-based indicator list, rather than introducing entirely new metrics. Both CBD and IPBES indicator sets will also support future NBAP efforts, as they align with the general monitoring requirements of the EU’s Nature Restoration Law (Regulation (EU) 2024/1991, Article 20; EU, 2024b), which will come into effect in September 2026.

Climate: Ireland’s Climate Change Assessment, the Intergovernmental Panel on Climate Change, and risk and resilience

In general, indicators around global climate change are divided based on whether they relate to adaptation or mitigation. In most datasets thus far, some form of greenhouse gas emissions monitoring is recommended, as global climate change threatens systematic negative impacts. The monitoring of mitigation is a comparatively easy task relative to adaptation, however, as CO₂e emissions have a

uniform impact regardless of where they are emitted. Adaptation is location specific – relative to the needs of areas facing different threats. In the case of Ireland, national guidance is issued through Ireland’s Climate Change Assessment (ICCA) as part of the Climate Action Plan (EPA, 2023a) and supported by the Climate Ireland Adaptation Network, which is currently examining advancements in climate adaptation at a national level.

The ICCA (volume three) notes that “monitoring and evaluation of adaptation are limited as the focus is primarily on progress in implementation” (EPA, 2023b). Therefore, while both the Intergovernmental Panel on Climate Change (IPCC) and ICCA make specific reference to knowledge gaps around land use related to mitigating global climate change impacts, guidance on monitoring is limited (EPA, 2023b; IPCC, 2023). It is also unclear how progress in adaptation is linked to progress in implementation if the former has not been sufficiently monitored. Fortunately, monitoring adaptation – and underlying risk – is a subject of increasing interest in pursuit of efficient management practices, leading to the development of several metrics. These might be grouped into measures of risk due to global climate change – in particular increases in extreme weather events – and measures of adaptation, readiness and resilience.

The Sendai Framework for Disaster Risk Reduction (SFDRR), adopted in 2015, is a global policy framework aimed at reducing disaster risk and enhancing resilience following the Hyogo Framework for Action (United Nations, 2015). The SFDRR has four priority areas – understanding disaster risk, strengthening disaster risk governance, investing in risk reduction for resilience and enhancing disaster preparedness, where the latter includes better rebuilding following incidents. The framework also includes seven targets related to indicators of disaster risk reduction. They include disaster-related mortality and the number of people impacted, measures of economic loss and infrastructure damage, national strategies and international cooperation progress, and availability of disaster risk information and early warning systems.

The Environmental Vulnerability Index (EVI) was also developed to assess the vulnerability of ecosystems to natural and anthropogenic pressures, particularly in small island nations (Kaly *et al.*, 2004). The index uses

50 indicators across categories such as environmental hazards, resilience and exposure to assess a country's capacity to deal with disasters and change (the EVI ranked Ireland as highly vulnerable to flooding and pollution from agriculture). As the EVI includes 50 indicators, it is a potentially data-intensive index to update. Additionally, many indicators are invariant to land use, e.g. measures of general climate and disaster probabilities, and so would not, as an index, be particularly useful for our purposes. The indicators that do vary with land use, however, are added to our overall dataset.

Other EVI-acronym indices – such as the Economic and Environmental Vulnerability Index and the Economic Vulnerability Index – are focused on the least developed countries, and, as such, are less applicable to Ireland (Guillaumont *et al.*, 2021). These are of a class of multidimensional vulnerability indices, which include economic, social and environmental indicators – as our intended assessment framework will – but to assess vulnerability to various forms of economic and environmental shocks. The indices generally include indicators of vulnerability and resilience on systems in place to respond to shocks. In other applications, such as the United Nations Multidimensional Vulnerability Index (UN-MVI), the division is between exposure and volatility indicators, which are further subdivided into economic, social and environmental groups (Guillaumont *et al.*, 2021). In total, the UN-MVI recommends 13 each of vulnerability and resilience indicators. Vulnerability indicators monitor exposure to several different types of shocks but are generally invariant to domestic land use policy. Resilience indicators include some that can be supported through land use changes, such as ensuring the adequacy of cropland, tree cover, diversification of the economy, and sufficient household incomes to support savings and asset accumulation.

The Index for Risk Management (INFORM) attempts to monitor the level of risk due to humanitarian crises and disasters sufficiently large to overwhelm national response capabilities, potentially requiring international intervention (DRMKC, 2024). INFORM uses several indicators grouped into hazards and exposure, vulnerability, and lack of coping capacity. The INFORM framework has also evolved into four separate versions – Risk, Warning, Severity, and Climate Change. In the context of this section, INFORM Climate Change is most relevant while we include

INFORM indicators from all versions in our dataset. As in other risk datasets, INFORM Climate Change has indicators for a range of different disaster probabilities for which Ireland performs well – except for flood risk – and consequently receives a “very low” climate change risk rating (one of the best ratings). INFORM Climate Change then provides predictions of future levels of risk for different climate change scenarios where Ireland again receives a “very low” risk rating (Poljanšek *et al.*, 2022). However, the national ranking does not inform whether some areas of Ireland would benefit from building resilience, as the INFORM framework sets a high bar – the need for international intervention – as the metric of interest.

An alternative approach to building a composite index out of several indicators is to survey relevant agencies and key industry representatives on climate change adaptation status. This follows from the European Commission's EU Adaptation Strategy (European Commission, 2021b) and efforts at developing an adaptation preparedness scoreboard (European Commission, 2018). The CCAC has subsequently released four iterations of Ireland's Adaptation Scorecard to monitor progress towards the National Adaptation Framework of 2018 (CCAC, 2024). The Adaptation Scorecard measures changes in resilience in terms of governance and resourcing, risk and adaptation management, and policy implementation and mainstreaming across several sectors of government and the environment. The questionnaire was administered to departments responsible for adaptation plans and local government related to the implementation of the National Adaptation Framework as a national-level survey. The CCAC then converts the largely qualitative survey responses into an assessment of progress and ranks the government entities surveyed.

Additional indicator sets: EPI, the GCI, the IEP-GPI and the ETR

Several smaller sets of indicators that are intended to convey specific perspectives also warrant consideration. In this section, we discuss a few of these sets, many of which were proposed for comparison with the SDGs in the *World Happiness Report 2020* (Helliwell *et al.*, 2020). EPI, like the HDI, is a composite index spanning several indicators (Block *et al.*, 2024). Its focus is on environmental

performance and it was developed in response to the difficult-to-manage breadth of information in the MEA. In its most recent form, EPI is based on 58 indicators grouped into 11 issue categories, further grouped based on three policy objectives: ecosystem vitality, environmental health and climate change mitigation. These indicators describe progress in relation to several, possibly competing, issues. As the development of the EPI involved combining substantially different datasets and issues into a composite index, EPI developers have qualitatively weighted these indicators. In the most recent year for which data are available, Ireland ranked 16th at the national level in terms of its EPI score but almost certainly has substantial variability within the country, driven in part by land use differences.

The GCI is another composite measure that is based on several indicators (Schwab and Zahidi, 2020). The GCI focuses on monitoring metrics associated with long-run economic growth and labour markets and so provides a markedly different perspective. The GCI includes 64 indicators, grouped into 18 concepts (as well as 11 priorities) and further grouped into 4 areas of action. The GCI indicators have been criticised for lacking environmental monitoring beyond indicators on the green energy transition. However, when included in a larger dataset of indicators that already includes environmental concerns, this is less relevant. Many GCI indicators – 25 of 64 – are also based on survey questions primarily focused on public perceptions, so the cost of collection is smaller than most. This also implies that the data may not be readily available but can be readily collected.

The IEP-GPI is yet another composite of indicators and is focused on the “peacefulness” of society (Institute for Economics & Peace, 2024). The general basis for including peacefulness is that it is a precondition for well-being and development. The IEP-GPI is based on 23 indicators grouped into 3 categories. The indicators are also grouped by whether they are focused on external conflicts and relations (9 indicators) or internal conflict (14 indicators). However, of the 14 internal indicators, only 6 are likely to vary within Ireland. Others, such as national arms sales, provide no useful identifying variation. The six IEP-GPI indicators relevant to this study relate to violence in society, incarceration rates and scale of internal security force deployments, though it is unlikely that these indicators are sufficiently impacted by land use policies outside,

perhaps, populated areas. In a source related to the IEP-GPI, the ETR attempts to forecast peacefulness based on environmental pressures on society (Institute for Economics & Peace, 2023). The ETR suggests seven measures be used to develop four indicators – natural disaster displacement, demographic pressures, food insecurity and water risk.

2.1.2 Summary indicators

An alternative to using the frameworks of several indicators – or indices based on them – is to select summary indicators that attempt to convey similar information, but rather than reporting piecemeal they convey the net effect of a system. An advantage of this method is a reduced number of metrics to consider, although this would be at the expense of concealing details about how the relevant system is changing. Despite that shortfall, summary indicators are pervasive. Likewise, it is worth considering whether summary indicators can contribute to our assessment framework. In this section, we discuss indicators on output and environmental impacts, and on whether critical planetary boundaries are being surpassed.

Gross domestic product, gross national income, gross national product and the Genuine Progress Indicator

National output measures are widely known and referenced in policy decisions and, as such, are worth consideration. Three commonly used indicators – usually placed in per capita terms – are gross domestic product (GDP), gross national income (GNI) and gross national product (GNP). GDP, the most frequently used metric in most countries, measures the total market value of all goods and services produced within a country’s borders regardless of whether the income is earned by domestic or foreign entities. GNI instead measures the total income of a country’s residents and businesses earned both domestically and abroad. As such, it excludes domestic income from non-residents and is a particularly important measure when large but financially isolated business entities operate within a country. GNP is like GNI but also includes factor incomes received and paid abroad. In practice, in Ireland, GNI and GNP tend to be nearly identical, while GDP is substantially inflated due to the presence of unintegrated multinational corporations whose profits

flow abroad. Consequently, GNI is the normal basis for measuring economic output in Ireland.

Used on their own, summary magnitude indicators of economic performance such as GDP, GNI and GNP face several criticisms. Primarily, these criticisms focus on the inability of the indicators to capture the broader dimensions of welfare, as they do not account for income inequality, the value of public services and goods, or externalities from production. As we would notionally use such an indicator alongside other metrics, we might still avail of the information they provide by choosing appropriate companion metrics following the recommendations of Stiglitz *et al.* (2010). These might include using measures such as subjective well-being (SWB), some accounting of non-market goods and measures of future prospects such as wealth.

Alternatively, one might modify a growth metric to account for its shortcomings. This is, however, difficult in practice. At the household level, equally distributed equivalent (EDE) income has been proposed as an inequality-adjusted measure – the as-if level of household income when including inequality effects. While first proposed by Atkinson in 1970, it has only recently begun to be considered in policy applications due to improved data availability. Calculating the value of public goods and services requires a substantially greater information burden – particularly when disaggregated – and careful methodological development, but has recently shown promise (Gethin, 2023). As poorer households may rely more heavily on public goods – and rural households receive a greater benefit from natural capital – these may be important adjustments to consider.

Naturally, in the context of land use policy, summary measures of economic activity also overlook the long-term environmental and social impacts of land use. For example, an expansion of agricultural production might boost GNI but may lead to soil degradation, biodiversity loss or increased greenhouse gas emissions, impacting GNI and several other factors later. Consequently, measures such as the Genuine Progress Indicator (GPI) have been developed to adjust for non-market goods and services, including changes in the value of natural capital stocks (Kubiszewski *et al.*, 2013). The costs and value of implementing a GNI-based GPI indicator at the subnational level in Ireland are currently unknown.

We also consider implementing GNI separately from such considerations, which are instead measured through metrics such as the ecological footprint and SWB discussed next. There is also some advantage to keeping GNI separate from wider socio-economic and environmental indicators in terms of diagnostic ability.

Ecological Footprint and Biocapacity Accounts

To date, the Ecological Footprint and Biocapacity Accounts (EFBA) are produced at the national level by York University's Ecological Footprint Initiative and the Global Footprint Network (Dworatzek *et al.*, 2024). EFBA provide a pair of measures that, when contrasted, estimate the amount of biocapacity in reserve or, more often, the amount of overshoot. With the necessary data, these measures could be estimated on any geographical scale and adapted to our needs. Generally, these measures are useful for estimating the ecological footprint in terms of the area of land and water required to produce food and materials, the surface area of cities and infrastructure, and forest area required to sequester our greenhouse gas emissions. That is, an ecological footprint measures the demand placed on resources, including net imports, by the population of an area. By using land area, all inputs are placed in the same units. Biocapacity is, in contrast, a supply-side measure of the capacity within the same geographical area to satisfy demand for renewable resources and ecosystem services – an estimate of natural carrying capacity. An overshoot suggests that an area is not self-sufficient and either consumes unsustainably within the local area or imports to satisfy demand and consequently draws on the biocapacity of other areas.

Land uses in the ecological footprint and biocapacity calculations include agricultural land (crops and grazing), forests in terms of production and carbon sequestration, built areas and fishing grounds. Demand and supply are then adjusted to global equalised hectares by contrasting an area's biological productivity as well as an intertemporal adjustment. National-scale estimates of Ireland's overshoot in terms of consumption versus biocapacity since 1969 are reported in Figure 2.1. An interesting observation is that, had Ireland retained the same biocapacity that it had in the 1960s or even as late as the end of the 1980s, it would have excess environmental reserves today. However, due to

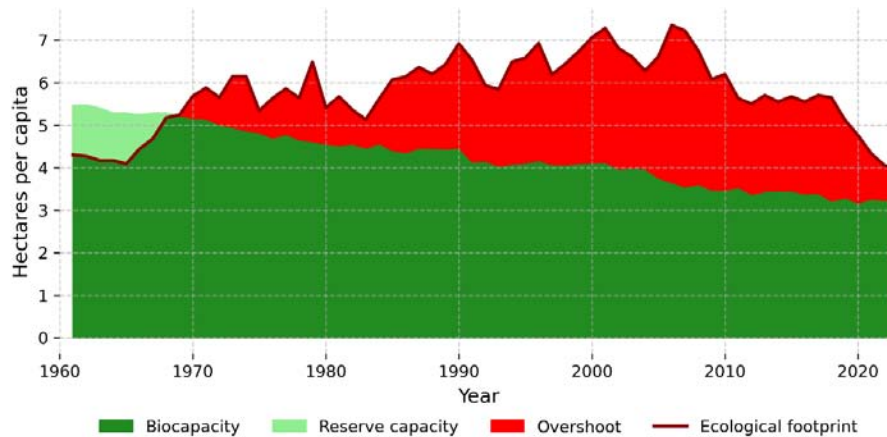


Figure 2.1. Ecological footprint and biocapacity estimates, Ireland. Based on data in Dworatzek *et al.* (2024).

declining biocapacity from a substantially raised ecological footprint for much of the last 50 years, Ireland continues to overshoot biocapacity. That is, the environmental stock of Ireland is substantially degraded such that Ireland still overshoots biocapacity despite a declining per capita ecological footprint.

Ecological footprint and biocapacity estimates are net effect estimates of land productivity and demand. When disaggregated to local areas, biocapacity changes would include changes in the productivity of land, while changes in the ecological footprint include changes in both food and material consumption, but also changes in energy usage. However, footprint and biocapacity metrics are less informative for diagnostic purposes, as they do not link to specific actions. Instead, they provide a statistic on biosphere health – a foundation for economic activities (Dasgupta, 2021) where continued overshooting of capacity may eventually lead to substantial losses in economic potential (Groom and Turk, 2021).

SWB

Recognising the limited scope of income and consumption metrics, the use of an alternative metric referred to as SWB has been proposed. Rooted in psychology (Diener, 1984), the SWB metric has continued to develop and has found support as an alternative or complementary measure to income measures (Sen, 1995; Diener *et al.*, 2015). For example, Ireland has shown an interest in including SWB in a framework for the wider assessment of

socio-economic indicators known as the Well-Being Framework (Department of the Taoiseach, 2024) and in the CSO's Well-being Information Hub (CSO, 2024), where the additional indicators listed are also included in our dataset for consideration. SWB is a survey-based measure that intends to capture self-evaluation of respondents' quality of life in terms of happiness and life satisfaction. As such, it provides insight into how people perceive their quality of life beyond income. Data on SWB as a single metric can be simple to collect, as is currently done for the CSO's Survey on Income and Living Conditions (SILC), and follow-up questions could be included to explore the sources of differences in aggregate SWB ratings. Finland consistently scores highly in happiness indices and Finnish people experience a deep appreciation for nature, which may justify a survey that connects SWB with land use in Ireland. In addition, as access to housing is a pressing issue in Ireland that impacts well-being and land use, detailed questions on this topic could be included.

Alternative metrics to SWB tend to emphasise different aspects of well-being. The Capability Approach instead focuses on the capacity to achieve goals and a quality of life that respondents value (Sen, 1999). This framework focuses on people's abilities to achieve certain "functionings", such as being healthy, educated or socially connected. As such, the Capability Approach also allows diagnostic analysis of the causes of lower self-reported scores. However, for Ireland, the developing economy-focused Capability Approach may be less fitting than SWB in its common

forms. Additionally, applying the Capability Approach to quantify people’s well-being may require more complex data about people’s opportunities.

SRC planetary boundaries

The SRC, also discussed in *Land Use Evidence Review: Phase 1 Synthesis Report* (DAFM and DECC, 2023a), suggests that nine planetary boundaries are critical thresholds for Earth’s systems (Richardson et al., 2023). Planetary boundaries are intended to indicate limits on how the natural environment can be strained without risking substantial change – perhaps rapidly – from historically humanity-friendly conditions. The concept is that exceeding any of several planetary boundaries could lead to a breakdown in the ability of the planet’s environment to self-regulate – to maintain the current steady state. Due to the interconnectedness of Earth’s systems, exceeding any of the planetary boundaries identified could impact several of them. Consequently, ensuring that no planetary boundary is exceeded is an important prerequisite for long-term production, socio-economic and environmental stability, and progress.

The SRC suggests monitoring the nine planetary boundaries impacting the stability of Earth’s systems and their resilience to future challenges, as in Table 2.1. Each boundary represents a distinct yet interrelated aspect of the planet’s systems, and, as such, crossing multiple boundaries makes it more likely that the remaining boundaries will also be crossed, as the resilience of Earth’s systems will be reduced.

However, we must consider whether the planetary boundaries suggested are appropriately planetary in nature and whether policy in Ireland supports remaining within these boundaries. Ireland’s ample, frequent rainfall ensures water availability and flows (EPA, 2021b), and domestic water availability in Ireland does not impact the global picture. Through adherence to the Montreal Protocol, Ireland, like many countries, is also not a contributor to stratospheric ozone depletion. Additionally, the primary cause of ocean acidification and atmospheric radiative forcing is an increase in atmospheric CO₂ concentrations, double counting the impact of greenhouse gases. As a separate issue, atmospheric aerosol loading is a substantial concern, which historically was partially

Table 2.1. SRC planetary boundaries

Planetary boundary	SRC control variable/proposed indicator	Status
Climate change	Atmospheric CO ₂ concentration	Red
	Total anthropogenic radiative forcing at the top of the atmosphere	
Change in biosphere integrity	Genetic diversity – extinction rate	Red
	Functional integrity measured as energy available to ecosystems	
Stratospheric ozone depletion	Stratospheric ozone concentration	Green
Ocean acidification	Carbonate ion concentration global surface ocean saturation state with respect to aragonite	Green
Biogeochemical flows: phosphate and nitrogen cycles	Phosphate flows from freshwater systems into the ocean from fertilisers via erodible soils	Red
	Nitrogen industrial and intentional fixation	
Land system change	Area of forested land as the percentage of original forest cover and area of forested land as the percentage of potential forest	Red
Freshwater change	Human-induced disturbance of blue water flow	Red
	Human-induced disturbance of water available to plants as a percentage of land area with deviations from preindustrial variability	
Atmospheric aerosol loading	Interhemispheric difference in aerosol optical depth	Green
Novel entities	Percentage of synthetic chemicals released to the environment without adequate safety testing	Red

Status indicates whether the SRC assesses global consumption of the environment as being within planetary boundaries (green) or exceeding planetary boundaries (red).

Source: Based on data reported in Richardson et al. (2023).

driven by land use policies.¹ However, at present, the burning of most crop residues and other land use practices that negatively affect air quality are banned in Ireland. However, the issue of atmospheric aerosol loading remains substantial in Ireland – particularly in colder months – as a result of residential heating decisions, namely the burning of solid fuel such as peat, coal and wood, rather than land use.

Notably, the SRC planetary boundaries do not include planetary boundaries focused on civil society. While other sets of indicators, such as the GCI, have been criticised for not including the environment, the converse criticism is rarely made – i.e. that indicators lack a sufficient socio-economic dimension, e.g. some minimum sufficiency criteria to maintain Earth's population. Consequently, the SRC planetary boundaries are not a sufficient set of metrics for our uses but rather provide a set of necessary conditions. Additionally, including the planetary boundaries allows consideration of the environment as a set of environmental stocks in which society can invest. These investments in maintaining or growing the planet's resources then return a higher planetary tolerance for production activities. Each planetary boundary is directly affected by land use decisions as direct products of land use. Rather than planetary levels, however, the domestic use of planetary boundaries would take the form of changes in net contributions to the primary drivers of exceeding each planetary boundary.

Other planetary boundary metrics also require reconsideration. The use of genetic diversity measured as extinctions per million species per year, as suggested by the SRC, is particularly problematic, as it monitors biodiversity loss too late – after irreversible extinctions have occurred. Focusing on extinctions overlooks opportunities to intervene and preserve genetic diversity. Rather, proactive alternatives that track the degradation of ecosystems and populations are more fitting. The SRC's metrics for biosphere functional integrity as net primary production (NPP) and human appropriation of NPP (HANPP) are more fitting to Ireland's needs. The NPP metric provides a measure of ecosystem functionality, reflecting the

impact of human activities on the rate at which plants convert energy into biomass as the foundation for all terrestrial food webs. By examining HANPP as a share of NPP, we can assess the impact of human activity on ecosystem health and biodiversity. NPP can also be measured as a growth rate or referenced to an estimated best-case scenario. Importantly, it can be monitored via remote sensing, reducing the administrative burden of nationwide monitoring.

It is also uncertain what the best approach to the monitoring of novel entities at the subnational level would be. Most concerning at present are per- and polyfluoroalkyl substances (PFAS), which are increasingly regulated at the national level, e.g. via the Stockholm Convention on Persistent Organic Pollutants (POPs) and the European POPs Regulation. However, before the dangers of PFAS were understood, their use became widespread in many applications, and, as a result, they have subsequently been detected in soils, surface water and groundwater. Therefore, the use of PFAS still warrants careful monitoring, particularly in relation to the use of potentially PFAS-containing biosolids in agriculture.

2.1.3 Summary of indicator sources

Through our selection of indicators, we attempt to capture a broad range of production, environmental and socio-economic factors that are influenced by land use. We have done so by drawing from important sources of indicators from different fields related to land use. Some indicator sources, such as the CAP and IPBES indicators, are directly relevant and important to include, while others, such as the GCI, help inform whether land use can be linked to the concerns on which these indicators are focused. In Table 2.2, we summarise our indicator sources, both existing sets of indicators and key summary metrics. In doing so, we touch on many concerns also expressed in Ireland's recent State of the Environment Report (EPA, 2024i) while linking to wider socio-economic issues. In the next section, we discuss key takeaways from our indicator dataset and discuss our methodology for choosing a substantially smaller subset on which to base our assessment framework.

¹ Atmospheric aerosol loading can normally be measured via remote sensing (Zhang *et al.*, 2021), but this can be challenging in Ireland due to the extent of cloud cover and natural aerosols.

Table 2.2. Models of assessment indicators

Category	Number of indicators	Reference
Models of indicator sets		
Phase 1 of the Land Use Evidence Review	300+	DAFM and DECC (2023b)
SDGs	249	United Nations (2023, 2024)
HDI	5–7	United Nations Development Programme (2024a)
CAP	91	European Commission (2024b)
CSO-EPI	70	CSO (2023b)
MAES	202	Maes <i>et al.</i> (2020)
CBD Aichi Biodiversity Targets	162	Secretariat of the Convention on Biological Diversity (2016)
Ireland's NBAP	50+	National Parks & Wildlife Service (2024a)
IPBES	71	IPBES (2019)
ICCA	Varies	EPA (2023a)
SFDRR	7	United Nations (2015)
EVI	50	Kaly <i>et al.</i> (2004)
INFORM	Varies	DRMKC (2024)
EPI	58	Block <i>et al.</i> (2024)
GCI	64	Schwab and Zahidi (2020)
IEP-GPI	23	Institute for Economics & Peace (2024)
ETR	4	Institute for Economics & Peace (2023)
SRC planetary boundaries	7 of 13	Richardson <i>et al.</i> (2023)
Summary indicators		
GPI	1	Kubiszewski <i>et al.</i> (2013)
Modified GNI	1	Timoney (2023)
EFBA	1	Dworatzek <i>et al.</i> (2024)
SWB	1	Diener (1984); Diener <i>et al.</i> (2015)
CCAC Adaptation Scorecard	1	CCAC (2024)

2.2 Indicator Overview

To select from the well over 1000 indicators proposed across the datasets identified, several refinement steps are carried out. We begin by stripping units of measure (e.g. total, share, percentage) and perspectives (e.g. total, background levels, changes). This is because the focus of our assessment indicators is on changes over time, in addition to improving dataset comparability. Then, we combine indicators that appear to have the same meaning but are worded differently. We do this by sorting and manually combining indicators based on their similarity. Often, this involves checking explanatory notes from source datasets to ensure that we have understood their meaning – and whether differences in wording are intentional or natural variations.

The next step then involves discerning whether each indicator applies to Ireland. This entails evaluating whether the indicator in question is likely to exhibit

variation when measured at different locations across Ireland. Indicators that do not demonstrate “informative variance” – meaning that they do not vary in a way that provides useful information related to land use, land use change and forestry (LULUCF) in Ireland – are filtered out. This process improves the relevance of the dataset for our intended use, as it enables us to focus on indicators that may offer meaningful insights. However, at this stage, we make no presumptions on causality and rather have chosen informative variance as a sufficient condition to retain a proposed indicator. We also make initial assessments on whether we expect each indicator to vary, even slightly, with an outcome of interest – those related to environmental, resource availability, food, fibre and fuel production, or wider socio-economic changes. We then further combine the remaining, still substantial, number of indicators when they have been used in subsets for specific purposes, while retaining notes on their former uses. For example, different datasets have called for

the monitoring of specific subsets of species, such as birds, on the IUCN Red List. This approach allows for the development of a streamlined and more flexible dataset. Finally, a text normalisation process and then “fuzzy matching” are used to arrive at similarly grouped clusters of indicators. This step helps identify indicators that are conceptually similar, so that we can decide whether to combine indicators. Combining indicators is performed manually. At no point is the indicator selection and filtering process outsourced to an algorithm.

2.2.1 Land use and cover

This research seeks to understand how land use policy can be adapted to improve several outcomes. Critical to this is an understanding of how to measure LULUCF. If land use does not change in response to land use policy yet we observe changes in environmental and socio-economic outcomes, then that policy must be influencing society by other avenues, which is unlikely to be the intention of the land use policy. In this section, we explore the different ways of monitoring LULUCF that emerged from the indicator sets we have assessed.

Indicators of LULUCF represent the physical and functional characteristics of a landscape. Some distinctions are clear and well covered by DAFM and DECC (2023b). The “CORINE Land Cover 2018” dataset is the most recent release of Copernicus European land cover maps for Ireland (EPA, 2018a; Büttner *et al.*, 2021) and it estimates at a resolution of a 25-hectare scale. Land is classified under 44 groups, including artificial surfaces, agriculture, forests and seminatural areas, wetlands and water – both inland and near-shore (Büttner *et al.*, 2021). The Europe-wide Coordination of Information on the Environment (CORINE) initiative provides international comparability. However, the breadth of the initiative and historically slow rate of land cover change has meant that it would be costly to continually release CORINE dataset iterations and therefore they have been released at 6-year intervals, with the next iteration, due to be published in 2026, being the final in the current series. The low frequency of release limits the ability of CORINE datasets to inform our understanding of linkages between changes in land cover and more frequently observed socio-economic conditions. However, the next iteration, CORINE

Land Cover Plus (CLCPlus), will be collected at 3-year intervals by the Copernicus Programme and at a resolution of down to 10 metres (European Environment Agency, 2024). At present, detailed land use and cover mapping by remote sensing, supported by a robust classification framework, must play a critical role in LULUCF management, an effort that is under way.

The distinction between land cover and land use made in Phase 1 of the Land Use Evidence Review is also important. DAFM and DECC (2023b) recommend the use of European Abstraction Grid for Land Information Exchange (EAGLE) Land Use Attributes, which, like CORINE datasets, can be aggregated at different levels. At the top, these are separated into primary, secondary and tertiary production levels, as well as into infrastructure, residential and other uses – not otherwise labelled natural areas (Arnold *et al.*, 2023). As noted in the Land Use Evidence Review (DAFM and DECC, 2023a), most of Ireland’s land would be placed in primary production – containing agriculture and silviculture – followed by other uses such as wetlands and waterbodies. However, it is unclear whether EAGLE land use mapping would be sufficient at level 3 or finer scales to tie land use to socio-economic changes. Each indicator set suggests that we monitor the subdivisions of land use or land cover to different degrees of precision. However, in practice, these decisions should be influenced by our objectives. Whether we monitor crop subdivisions on a finer scale should instead be based on whether we can monitor corresponding farmer decisions and socio-economic outcomes on the same scale, e.g. whether monitoring subdivisions within cereal crops improves our ability to predict changes in environmental and socio-economic outcomes. In contrast to the land use disaggregation possible through EAGLE mapping, we note that national input–output tables, which could be used to link land use to socio-economic outcomes through economic activity, are currently available only on comparatively highly aggregated scales, with some preliminary work on a more regional scale ongoing as part of Phase 2 of the Land Use Evidence Review.

EAGLE Land Use Attributes also capture other important themes observed in our dataset, namely both the importance of the condition of land and its protection status. However, it is difficult to make a distinction between the condition of land as a component of LULUCF versus the condition of

land being classified as an indicator of production, environment or socio-economic outcomes. For example, one can imagine that the productivity and ecosystem service values derived from land are closely related to the conditions of that land.

We also find that at least 20 different representations of the protected status of land are used by the various indicator sets identified. Some are focused on a type of land cover but others are entirely general, including indicator sets that track the area, share or number of protected areas, e.g. the area of protected forests. Other indicator sets suggest monitoring protection in terms of specific national requirements, such as requirements set out by Natura 2000 or the Ramsar Convention on Wetlands, or through specific certification programmes, such as those for forests of the Forest Stewardship Council and the Programme for the Endorsement of Forest Certification. We also observe different recommendations on the extent to which monitoring should be focused on specific protected statuses. For instance, we might attempt to monitor marine habitat protection in general or focus on key biodiversity areas of marine habitats. Other indicators suggest that the point of reference should also be considered. For example, we observe the scale of protected human lands suggested as a metric, as these areas contain crops and dwellings and have done so for perhaps centuries. An implied point of reference is to protect these areas from modernisation – to preserve traditional ways of life – rather than to, say, return land to a natural state, which would have greater environmental benefits.

In addition to formal conservation statuses, we also find indicators of informal protection statuses. For example, in terms of agricultural lands, some indicator sets suggest monitoring the levels of organic, sustainable, conservation or high-nature-value agriculture in operation. Analogously, we find some indicators that suggest monitoring whether fisheries are sustainably operated but without specific instructions on the framework that should be used for such monitoring.

We also find indicators that suggest employing metrics on the connectivity between habitats. For example, the MAES, Irish national biodiversity and Aichi Biodiversity Target indicator sets and subsequently Phase 1 of the Land Use Evidence Review suggest monitoring landscape fragmentation. One suggestion from our

data sources on how to operationalise monitoring landscape fragmentation is through the use of a landscape mosaic index based on the similarity of land cover and on clustering by land cover type within a geographical area (Riitters *et al.*, 2009). This approach is not without issues, however. For example, it is invariant to the landscape type or protected species of interest, and, because different species have different land requirements, the impact of land fragmentation will differ depending on their ability to traverse inhospitable land cover. It is uncertain how to overcome this obstacle. Another issue is that Ireland does not have a functional habitat map, at least not one that includes condition assessments of different habitats. It is hoped that national habitat mapping work can progress as a component of national land use mapping efforts as well as under nature restoration plan monitoring.

We also find indicators that suggest monitoring the rate of land take – the transformation of other habitat types to human-intensive uses – namely in the SDG, Aichi Biodiversity Target and MAES indicator sets, and subsequently in Phase 1 of the Land Use Evidence Review. This should again be monitored for different habitat types and have a strong geospatial dimension, but it is unclear how to assign weightings to land take losses from different habitat types. That is, it is unclear how we should value the prevention of land take from forests in exchange for greater land take from inland wetlands or vice versa. One might suggest that a biodiversity net gain requirement similar to that introduced in the UK in the Environment Act 2021 (Schedule 14) could address this issue (Government of the UK, 2021). This requirement mandates that new development must achieve a 10% increase in biodiversity units – a metric from the UK Department for Environment, Food and Rural Affairs (CIEEM Ireland Policy Group, 2024). However, such a requirement presumes that biodiversity loss is the main issue in all areas of the country. Yet, some areas with greater current levels of biodiversity are also facing particularly acute housing crises. Therefore, a biodiversity net gain requirement itself might redirect efforts away from other pressing issues, suggesting that additional research is needed in habitat condition mapping.

Other proposals include monitoring the extent of agricultural areas around inland wetlands and waterways due to the impact of run-off from

agriculture. Another proposal is to focus on gaps in the protection of designated habitats rather than on the extent of already protected habitats themselves. This would suggest that, in general, Ireland has made substantial progress in protecting at-risk areas and so we should focus on remaining shortfalls – whether the case or not. Some indicator sets also recommend focusing on financial flows – particularly related to the CAP – such as the amount of money offered to farmers and other land users to enact biodiversity conservation efforts.

It is also important to note that several metrics are related to urban and densely populated areas. These include the imperviousness of city landscapes, density in terms of building footprints, the availability of green spaces including greenbelt designations, and how urban spaces connect to other types of land cover such as whether national parks and green spaces are available near urban areas. We also observe a converse suggestion – in addition to monitoring land take, we could monitor the level of land recycling and densification, that is, the return of previously used land to new anthropocentric uses rather than using it to further urban sprawl.

In the end, we find it difficult to decide on which metrics should represent LULUCF in our assessment model. Metrics should include changes in land use and land cover but also notions of the quality of that cover and the productivity of land uses, whether monetised or in other units.

2.2.2 Food, fibre and fuel production, environmental and socio-economic indicators

To a greater extent than with LULUCF indicators, the food, fibre and fuel production, environmental and socio-economic indicator lists provide many options. Due to the focus on linking land use policies to outcomes, many of the indicators from our dataset have a socio-economic focus through the inclusion of, for example, the SDG, GCI, IEP-GPI and ETR indicator sets. These sets include several indicators tied to land use, such as through infrastructure and urban sprawl or through governance and regulation, fitting with Phase 1 of the Land Use Evidence Review's progress classification. The diversity of socio-economic metrics also reflects the complexity of monitoring social problems such as through the

SDGs. Many are more directly a result of income or consumption potential through income, disposable income and employment opportunities, which are also related to land use policy. In terms of commercial impacts, we find recommendations to use financial soundness indicators, though this most likely applies only to firms for which land is a substantial input to production.

Some alternative indicators and indicators for which it is perhaps easier to collect data are also recommended, such as measures of the share of the population living below national poverty lines, as recommended in the SDGs. We also see recommendations such as tracking GDP or income loss due to disasters, climate change or other drivers of ecosystem damage. Recommendations to monitor domestic commodity prices and volumes instead suggest taking a supply-side perspective. In each of these cases, we must consider applicability to Ireland in the present.

Yet another suggestion is to monitor the ability of communities to continue to use traditional knowledge and practices to earn livelihoods – a suggestion based on the Aichi Biodiversity Targets. This would put the perspective on traditional ways of life being the preferred way of life for our modern population. This gives rise to an important question on whether socio-economic metrics can be chosen where the population itself determines what success means, i.e. allowing each community to decide what success means rather than relying on SDG-focused and other socio-economic-focused metrics. This adds additional weight to the recommendation to use something like SWB metrics collected via surveys.

It is difficult to decide where to draw the line in such a study. We find potentially important socio-economic indicators, such as the levels of homelessness, serious crime and the prison population, but question whether these indicators are sufficiently linked to land use policies. If we monitor both changes in income and changes in outcomes such as these, i.e. outcomes that are most likely income driven, we must be careful not to double count the impact of social changes. We also find recommendations to track age structure, mortality and general causes of mortality, and the general health of the population, as well as recommendations to monitor public and private investments. Far more

indicators are recommended than can be cost-effectively monitored.

On the environmental side, we find recommendations to track engagement with biodiversity, global climate change and other issues. One recommended way of tracking these is to monitor keyword searches around biodiversity in print and online media. However, it is unclear whether this would serve as a sufficient statistic for estimating changes related to land use policy. However, this might fit with the related recommendation of using a biodiversity barometer – a survey-based approach to monitoring commercial and public engagement with and knowledge about biodiversity. Some recommendations extend to monitoring engagement and teaching about the environment and biodiversity in schools and membership of biodiversity-related organisations. Different forms of public engagement with the environment, such as engagement with biodiversity issues, are noted across indicator sets. These are to some degree non-price-based alternatives to measuring the value that the population places on the environment. As another form of monitoring how the population engages with the environment, some sources recommend tracking how much time and money the public spends on visiting natural areas and on environmental tourism.

After socio-economic indicators, biodiversity-relevant indicators are the second most frequently recommended – due to the inclusion of the Aichi Biodiversity Targets, IPBES and national biodiversity indicators – and these are quite varied in focus. However, many indicator sets include suggestions related to the IUCN Red List and more generally focus on the abundance of species or their status, which, naturally, are habitat specific. Some recommended indicators are related to the density of species of concern in a habitat. The monitoring of the quality of habitats is also frequently recommended in addition to or rather than focusing on species. At first glance, this might appear to reduce the information burden; however, to know whether the quality of a habitat has improved, we must know what it should look like, i.e. what a healthy habitat entails for the species in an area. Interestingly, we find that monitoring the status of birds is recommended more often than monitoring most other categories of animals. We also find general status indicators such as whether the ecological status of a habitat is in good, moderate or poor

condition, the use of which, again, would require a firm understanding of what the baseline should be as well as what current conditions are.

We also find the converse of positive biodiversity metrics. One recommendation is to track the ecological net footprint of the population in each area. Other recommendations are to monitor the rate of extinction, the number of extinctions prevented and the mortality of key species. In addition, instead of measuring the extent of areas under conservation plans and protection, some recommendations suggest using metrics that consider what has already been lost, such as the increase in the number of habitats that require protection or the size of the area lost via land take. Similarly, we also find recommendations on the use of metrics that focus on the prevalence of or growth in invasive species rather than the preservation of native species.

In relation to marine environments, we frequently find recommendations on monitoring whether fish species are being sustainably managed. In fact, it is in relation to fisheries that we primarily find the term “stock” being used – other than in a couple of references to forests – despite it being applicable to a variety of environmental and biodiversity settings. Monitoring the presence of contaminants in biota, dissolved oxygen levels, sound pollution and sea floor litter, as well as plastic litter in the sea and on beaches, is also recommended.

Several other indicators relate to waste creation, disposal and treatment – in general terms as well as in relation to solid and sewage wastes. Clearly, responsible waste creation and management have a critical impact on the environment, which may be observed in terms of the value of ecosystem services that nature can provide to us, the value we place on improvements in the status of nature, and the extent to which our scarce land resources must be allocated to waste management. We might also monitor the scale of the impacts from our income and consumption choices on the environment through material footprint measures such as those developed by the Ecological Footprint Initiative. In terms of global climate change, the analogous measure would instead focus on the carbon intensity of our income or consumption. However, the latter would potentially double count these impacts if we monitor emissions both during production and during consumption – with differences being driven by net imports, which an increasing

number of experts suggest should also be monitored and carbon border adjustments tied to them.

Several indicators also relate specifically to soil, water or air quality, as this directly impacts human and environmental health and is often substantially influenced by land use. The monitoring of emissions to soil, water and air can be taken as quite general, for example the monitoring of CO₂e emissions, covering the emissions of several greenhouse gases, as recommended by CSO-EPI, the SDGs, the CAP monitoring programme and EPI, and, subsequently, Phase 1 of the Land Use Evidence Review. Other indicators, including the SDGs, SRC planetary boundaries and EPI, explicitly single out CO₂ emissions. Some notion of greenhouse gas-related emissions should be included in our assessment matrix.

However, monitoring emissions related to ozone creation and ozone layer depletion, volatile organic compound emissions, sulfur dioxide emissions and levels of particulate matter of $\leq 2.5\mu\text{m}$ (PM_{2.5}) and $\leq 10\mu\text{m}$ (PM₁₀) has also been recommended. Many of these air pollutants are referenced specifically in the context of urban and heavily populated areas and relate to damage to human health. These are known to have quantifiable impacts on quality of life and so their impacts can be monetised, if necessary, through the “value of a statistical life” concept (Keller *et al.*, 2021), quality of life and mortality impacts, and estimates of marginal damage values (EnvEcon, 2015). The complexity of air pollutants has also led to the recommendation of using an air quality index (AQI) metric that measures the levels of several pollutants.

Similarly, the impacts of water quality can be assessed via several alternative metrics. Some of these involve monitoring ammonium, phosphate, nitrate, total nitrogen and total phosphorus levels in addition to pesticide levels and biochemical oxygen demand. These pollutants enter water primarily as a result of agricultural run-off, with negative effects on Ireland’s water quality. As for air quality, a water quality index (WQI) has been recommended because of the number of pollutants and potential complexity of their interactions. Some sources suggest binary tracking, such as through identifying the number or length of waterways that meet a minimum threshold in terms of ecological status. Under Ireland’s current climate conditions, however, water exploitation, net withdrawal

and water stress-type metrics may not be worth including, as it would further crowd metrics on more pressing issues.

Another set of metrics focuses on measuring soil conditions and changes in soil quality. Some recommended metrics relate to the retention in the soil of phosphorus, nitrogen and other chemicals directly related to agriculture. Other recommended metrics relate more to the inalienable qualities of soil. However, metrics on soil organic matter (SOM) and erosion rate stand out, as changes in these metrics have wide-reaching consequences, including in relation to mitigating climate change and impacting water quality. The EU Soil Monitoring Law, introduced in December 2025 (European Commission, 2026), will strengthen soil reporting requirements.

The SDGs, CAP monitoring programme and the CSO-EPI, and subsequently Phase 1 of the Land Use Evidence Review, also include metrics on energy and infrastructure. A couple of the indicators identified relate to energy demand and consumption, but most consider whether energy is being produced via renewables or clean fuel. Transport infrastructure recommendations also include metrics on both transport demand and share of green infrastructure in transport.

Several metrics relevant to food, fibre and fuel production also remain after we consider indicators that are mostly uniform across the country. Some indicators include those that consider changes in yields and biomass volumes. However, a change in yield on a plot of land presumes that the crop has remained the same and so indicators that look at changes in profitability per acre and the solvency of land-based operations might be more effective. However, total production volumes within stable uses and key outputs such as cereals still warrant consideration. The carbon intensity of land uses from IPBES and the value of ecosystem services from the SDGs per unit of land or land use also seem to be promising. A stock that one might also monitor is changes in estimates of the carbon storage of land.

We also find recommendations to track the level of inputs in relation to land uses, particularly in agriculture, and, equivalently, fishing efforts in relation to capital expenditure in the marine environment. The tracking of fertiliser inputs has been recommended by the CAP and MAES indicator sets, as well as the

tracking of a larger set of inputs, including pesticide use, size of the labour force and more generally farming intensity, and the level of investments to improve forest productivity. Instead of inputs, the MAES indicator set also suggests alternatives such as changes in the level of forest fires, defoliation and dead wood in forests. These indicators are increasingly recognised for their ecological relevance. Notably, standing and lying dead wood are among the indicators that Member States may monitor under nature restoration plan requirements for forest ecosystems. The CAP indicator set additionally recommends monitoring the level of energy use in primary industries, including agriculture. Other suggestions include monitoring noise pollution levels from, for example, roads and other forms of infrastructure. Additionally, in disaster-prone areas, estimating the potential value of the damage or loss of any building or infrastructure would be useful in informing an understanding of whether land use and other global climate adaptation measures can be expected to provide a net-positive return.

Metrics on regulation focus on governments establishing the legal, fiscal and physical infrastructure necessary to implement land use, conservation and social policies. As such, indicators suggested in our dataset include those on government spending in relation to goals and local governments' adoption or implementation of strategies. National-scale involvement in, for example, EU programmes does not in itself provide useful intra-national information, but establishing whether the programmes have been implemented by local authorities does, e.g. whether local authorities have biodiversity action plans in operation. Conversely, highly granular and diverse tracking metrics can introduce challenges with regard to effective implementation. Regulatory metrics suggested also include monitoring the stringency or effectiveness of environmental protection programmes and the absence of harmful subsidies or other harmful support for agriculture and fisheries. Due to the inclusion of CAP monitoring indicators, we find several indicators on implementation, in terms of farmers and rural areas supported by the CAP. However, in relation to other outcomes, metrics on CAP support might be grouped among similar, non-exclusive metrics. Another type of regulatory metric relates to the form of regulation used, e.g. whether ecosystem-based approaches, environmental taxes

and subsidies or CAP and trade programmes are used versus command-and-control regulation. Monitoring the type and evolution of such regulatory tools can be informative, as incentive-based programmes, e.g. grants for adopting environmentally beneficial practices in agriculture, have shown success in reducing emissions. However, it is unclear whether this is a productive avenue to monitor, as the outcomes of regulation are the important dimension. Assessing the stringency of environmental protection and reducing harmful subsidies in agriculture and fisheries are also key priorities, but, again, may be difficult to assess. Finally, we find recommendations to monitor the level of integration policy; however, monitoring the level of integration policy is somewhat difficult to quantify. That is, some form of metric is required to ensure that diverse policies impacting food, fibre and fuel production, socio-economic conditions, and the environment are coordinated and not enacting contradictory mechanisms.

The Aichi Biodiversity Targets and Phase 1 of the Land Use Evidence Review also suggest monitoring ecosystem resilience. However, a specific metric with which to achieve this is difficult to define. Yet, an ecosystem resilience metric would be particularly forward-looking, as it would help predict whether ecosystems will be impacted to a greater or lesser extent by global climate change. This is an area where perhaps expert-based survey work would be most effective. We also note further recommendations to use surveys, which would need to be on a refined geographical scale. Surveys are likely to play an important role in improving understanding of specific land uses, such as in agriculture and forestry; to increase understanding of the public's engagement with and valuation of nature; and to improve the monitoring of somewhat difficult-to-quantify aspects of socio-economic well-being. Surveys, out of necessity, form the basis of important metrics such as SWB, which summarises the net effect of many other factors.

Finally, in addition to SWB, we note several other promising summary metrics, such as the GNI, the GPI and the EFBA, as well as quasi-summary indices such as the HDI. When the overall status of production, society or the environment is the metric of interest, these summary metrics might be better fit for purpose than a diverse set of indicators or data-intensive composite indices. Next, we consider other instances when such indices might also be fit for purpose.

2.2.3 Indices as indicators

Within the dataset of suggested indicators are several indices intended to summarise sometimes complex data into manageable metrics. In addition to the risk of not conveying which factors are driving an index's change, however, summarising data also implies that more data must be collected. As such, the use of indices in our assessment framework is worth considering with caution.

In the context of monitoring production, socio-economic and environmental changes – a wide spectrum of outcomes – it is essential to distinguish between two broad types of indices. First, there are subject-specific indices that focus entirely on one domain. These indices aggregate data from a single field, such as agricultural productivity, economic income levels or environmental health, to offer focused insight. Data collection is then limited to a well-defined subject area and might be sufficiently designed and managed by one subject matter expert.

Second, there are cross-domain or composite indices requiring the integration of information from multiple subject areas. These indices aim to provide a more holistic view of progress through data obtained from various domains, perhaps linking

economic, environmental and social outcomes. The data collection for these indices is more complex and likely to require some sort of harmonisation and methodological consistency in design, yet allows for field-specific approaches. Additionally, the aggregation process often eliminates native units of measure, such as hectares of land use or tonnes of CO₂ for emissions, further hindering meaningful interpretation. As such, we recommend these indices instead be treated – as they have in Chapter 3 of this report – as separate indicators.

In either case – field-specific or cross-domain indices – there tends to be some flexibility in what may be included in an index. Indices, particularly cross-domain ones, tend to evolve as methodologies improve, additional data become available or priorities shift. This means that the set of indicators included in an index may change from year to year, leading to challenges in direct year-over-year comparisons. However, this adaptability can also be advantageous, as an index can be tailored to Ireland's unique conditions while remaining recognisable – but not equivalent – to international variants. In Table 2.3, domain-specific indices, i.e. those requiring information from within a specific field, are listed; cross-domain indices are listed in Table 2.4.

Table 2.3. Domain-specific indices

Domain	Index
Air quality	AQI on particulate matter (PM _{2.5} and PM ₁₀)
Biodiversity	Biodiversity Habitat Index Biodiversity intactness index
Species conservation	IUCN Red List Index
Species population trends	Living Planet Index
Conservation	Protected Area Connectedness Index
Fisheries	Spawning stock biomass or biomass index of commercially exploited species
Species conservation	Species Protection Index Species Status Information Index
Biodiversity	Wild Bird Index
Biodiversity monitoring	Wildlife Picture Index
Landscape structure	Landscape Fragmentation Index
Vegetation cover	Mountain Green Cover Index
Protected area management	Protected Areas Representativeness Index
Wetlands conservation	Wetland Extent Trends Index
Governance	Corruption Perceptions Index
Political systems	Egalitarian Democracy Index
Economic stability	Financial Soundness Indicators
Cultural, linguistic diversity	Index of Linguistic Diversity and Language Endangerment Index
Water use	Water Exploitation Index

Table 2.4. Cross-domain indices

Domain	Index
Environmental, chemical pollutants	AQI on smog, acid rain and ozone contributors
Climate, biodiversity	Climatic Impact Index for birds
Agriculture, biodiversity	Farmland Birds Index
Environmental, biodiversity	Global Ecosystem Restoration Index
Marine, environmental, biodiversity	Ocean Health Index
Agriculture, environmental sustainability	Sustainable Nitrogen Management Index
Land use, agriculture, biodiversity	Connectivity of Semi-Natural Elements (Agroecosystems) Index
Climate, socio-economic vulnerability	Global Climate Risk Index
Social well-being, economic development	Better Life Index
Public awareness, biodiversity	Biodiversity Barometer
Agriculture, sustainability, food security	Food Loss Index and Food Waste Index
Food security, environmental sustainability	Proteus Food Security Index
Agriculture, government policy	Agriculture Orientation Index for government expenditures
Marine pollution, environmental health	Index of Coastal Eutrophication and floating plastic debris density
Water quality, biodiversity	WQI for biodiversity

The critique of composite indices does not necessarily apply to summary indicators. Some indicators, such as SWB, measure the net effect across drivers of well-being as a standalone metric – a single, comprehensive measure without combining diverse metrics. Others, such as the GNI or GPI, aggregate components measured in common units (e.g. euros). While summary indicators may rely on diverse data sources in some cases, integration is also supported through more consistent methodologies and a perspective that comparisons are expected (e.g. euros with euros). As a result, while summary indicators have their own limitations, including an inherent loss of detail, they differ fundamentally from indices that merge disparate data types into a single score.

Summary and domain-specific indices will appear as is in the policy recommendations section of this report, while components of cross-domain indices will instead appear as needed. The purpose of this distinction is to ensure that the complexity – and eventually cost – involved with the use of indices is not inadvertently concealed.

2.3 Indicator Selection

We must understand how land use contributes to production, socio-economic and environmental concerns. The quantitative comparison of different metrics has, however, been described as a “Herculean task” (Baumgärtner *et al.*, 2015). Even when the

scope and units of measure are the same, differences in methodologies between, say, ecosystem service valuations lead to doubts about their comparability (Boyd and Banzhaf, 2007). Ignoring methodological differences, others have aggregated indicators by placing them on a common scale and then applying a weighting methodology. Unfortunately, weighting tends to be entirely subjective, as weightings are influenced by the experts selected to provide them and consensus is often unachievable (Sachs *et al.*, 2024), sometimes resulting in the application of equal weightings, which is itself a judgment call (OECD and Joint Research Centre, 2008).

As a result of substantial issues with combining metrics, credible efforts to inform policy based on analyses of multifaceted issues often report panels of indicators without quantitative guidance on their comparison. Alternatively, one may rely on metrics that are already aggregated measures themselves, e.g. the GNI, EFBA and SWB. Meanwhile, aggregated metrics hinder the identification of pathways through which land use changes impact results.

Consequently, we suggest a multi-tiered approach – an assessment framework on multiple scales. At the top, i.e. Tier I, a summary, perhaps composite, metric summarises net change across all domains. Then, following as Tier II, headline indicators summarising production, socio-economic and environmental spheres indicate general progress in a salient and simplified way. Below this, headline indicators,

important domain indices, summary indicators and indicators based on our expert “vote” approach and literature reviews make up Tier III. Tier III is intended to support diagnostic analysis of the lack of outcome responsiveness to land use policy changes. The three-tier concept is summarised in Figure 2.2.

Additionally, there is some question as to whether other progress indicators measured in terms of growth or progress are relevant when planetary boundaries are already being exceeded. If operating within planetary boundaries is in fact critical, the stability of the natural environment will eventually become a constraint on other measures of success, including general well-being. Our approach is to add planetary boundary metrics relevant to Ireland to the Tier II level. When planetary boundaries become more clearly binding, this may require re-evaluation – perhaps the placement of planetary boundaries at the Tier I level or above all other indicators.

2.3.1 Tier I: composite summary indicator

The Tier I indicator aims to provide a comprehensive summary measure of progress towards sustainable development. Unlike the more detailed, domain-specific Tier II indicators, the proposed Tier I indicator would summarise progress across all fields. Such a summary metric could present challenges regarding methodological coherence and data comparability. One option is to develop a tailored GPI that would contain an economic measure along the lines of GNI

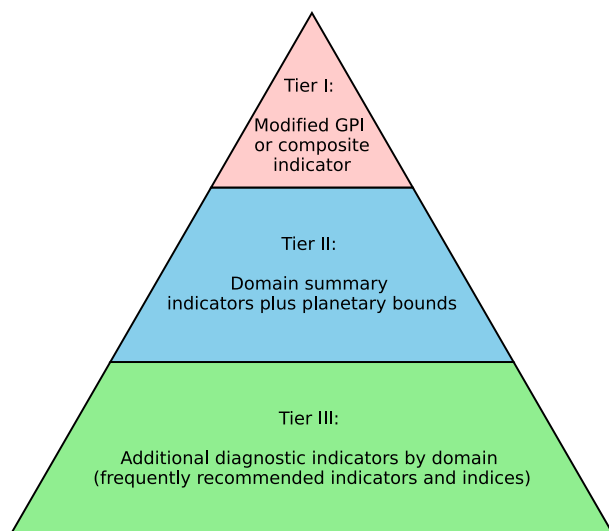


Figure 2.2. Assessment framework tiers.

plus account for environmental degradation and social externalities. Another option is to develop a composite index based on the Tier II indicators to follow, which would aggregate those into a unified score without directly monetising non-market goods and externality components. Both approaches are discussed in this section.

The GPI is becoming a more widely used alternative to GDP, offering a more holistic measure of economic welfare by accounting for environmental degradation, social inequality and non-market services, such as household labour and volunteer work (Barrington-Leigh and Escande, 2018). The GPI adjusts for negative externalities (e.g. pollution, resource depletion and income inequality), which are typically ignored in GDP calculations (Kubiszewski *et al.*, 2013; Berik, 2020). In the Irish context, a tailored GPI could integrate Ireland-specific factors, such as biodiversity loss, land use change and carbon emissions, while also adjusting for social costs linked to economic inequality and health disparities.

The GPI adjusts traditional economic measures by accounting for both the positive contributions and the negative externalities associated with economic activity. The GPI begins with personal consumption expenditure – a core component of GDP – but applies adjustments to reflect income inequality, environmental degradation and non-market services, such as household labour and volunteer work. This adjustment process requires the monetisation of various environmental and social factors that are typically excluded from conventional economic metrics. For instance, the costs of pollution, carbon emissions, biodiversity loss and resource depletion are subtracted from economic output, while positive externalities, such as the value of ecosystem services and social welfare, are added. The basic GPI formulation would include a measure of preferably inequality-adjusted incomes, combined with the value of non-market socio-economic and environmental (ecosystem services) benefits and costs, adaptation and mitigation costs and changes in the value of capital, including natural capital.

There are some clear advantages to the use of a modified GPI in Ireland. The GPI encapsulates a wide range of economic, social and environmental variables, which aligns with our interest in a

comprehensive measurement of progress. While we suggest that the GPI be modified to fit conditions in Ireland, versions of the GPI have resulted from an established methodological framework, allowing for more straightforward implementation and international comparability. However, the use of a modified GPI also comes with some challenges. First, while the GPI methodology has been established, tailoring it to the Irish context may require significant data collection – and assumptions, particularly for non-market services and the monetisation of environmental and social externalities. The data burden could be high, especially for measurements of biodiversity loss and the value of ecosystem services on a disaggregated scale. While stated and revealed preference methodologies can be used, they tend to be costly and time intensive to estimate and maintain.

An alternative to using the GPI would be to construct a composite index using the Tier II indicators to be discussed. This approach would result in a standardised score represented on a common scale, e.g. 0–1 or 0–100, to summarise progress across different dimensions. The composite index could be structured to ensure that each of the major domains – socio-economic, environmental and production – are captured without necessarily making trade-offs explicit between these dimensions.

However, the central challenge lies in determining the weightings to assign to each indicator. Without explicit guidance on how to value the trade-offs between domains, e.g. economic growth versus environmental preservation, there is an inherent subjectivity in assigning these weightings. Even applying equal weighting constitutes a value judgment and should not be viewed as a neutral default. However, such subjectivity also presents an opportunity if the weighting method is transparent – it can help users visualise the trade-offs involved and facilitate discussion. Engaging stakeholders in this process may then enhance legitimacy and clarify how different priorities influence overall assessments.

This approach also has additional advantages and disadvantages. As the composite index would be built directly from the Tier II indicators, it would ensure consistency between mid- and high-level reporting. This could streamline data collection efforts and reduce the burden of introducing a separate metric. By normalising the indicators on a standard scale,

the composite index also offers a straightforward, interpretable score, making it easier to communicate Ireland's sustainability progress. However, while normalisation allows for comparison across scales, it does not reveal the underlying values associated with these trade-offs. Moreover, building a composite index from the Tier II indicators does not increase the amount of information available from Tier II indicators, as it contains the same information.

Ultimately, the decision on which of these two approaches to take would most likely need to be based on feasibility. The GPI offers a more theoretically robust approach to assessing national welfare but carries a potentially large additional information burden, while the composite index offers a more streamlined option but only summarises the proposed Tier II indicators rather than adding more information to the decision-maker's toolset.

2.3.2 *Tier II: domain summary indicators*

The Tier II indicators supplement Tier I indicators by still providing relatively high-level summary metrics on the socio-economic, production and environment domains while also providing metrics on resilience to future challenges and planetary boundary monitoring. While less detailed than the follow-on Tier III indicators, Tier II metrics serve as crucial intermediaries, synthesising broader trends to inform policy adjustments and guide diagnostic work. The suggested Tier II indicators are reported in Table 2.5.

Each domain indicator allows for a comprehensive assessment of national well-being, resource use and environmental sustainability from different perspectives. The inclusion of SWB captures the non-economic dimensions of welfare, reflecting the growing focus on holistic development in Ireland. A survey-based SWB indicator in particular captures a population's perceived quality of life, incorporating metrics on economic and non-economic progress across the SDG indicators and in relation to mental health, social cohesion and personal satisfaction.

In the production domain, the gross income or product per capita indicator highlights the potential for wealth generation and spending power. As a local equivalent to GNI, it stands out as a measure of national economic output and of the geospatial distribution of consumption potential across Ireland. Ideally, this

Table 2.5. Suggested Tier II indicators

Indicator type	Indicator	Standard unit
Domain summary indicators		
Socio-economic	SWB	Score (0–10)
Production	Gross income or gross product per capita (GNI, GNP equivalents)	€/capita
Environment	Ecological footprint relative to biocapacity	Hectares/capita
Resilience and preparation	CCAC Adaptation Scorecard-based index	Score (0–12) – adjustable
Planetary boundary indicators		
Climate change and ocean acidification	CO ₂ e emissions	Tonnes/year
Biosphere integrity: genetic diversity	IUCN Red List (replacement for extinction rate)	Index (0–1) on species survival
Biosphere integrity: functional integrity	Net primary product or Biodiversity Habitat Index	Carbon (g/m ²) or intactness (0–100%)
Biogeochemical flows	Surface water and groundwater NO ₃ and P concentrations	mg/L
Land system change	Land cover shares relative to target (expanded from forested land)	Hectares/total
Novel entities	PFAS levels in surface water and groundwater, particularly drinking water (most pressing novel entity issue)	ng/L

This list does not include indicators from the SRC system for stratospheric ozone depletion or freshwater change, as these are not pressing issues in Ireland, nor does it include indicators on aerosol optical depth, as this is primarily caused by decisions not related to land use in Ireland. Land system divisions following EU summary classifications: urban, agroecosystems, forest, inland wetlands, heathlands and shrub, sparsely vegetated lands.

would be used on an inequality-adjusted basis, such as in EDE income, ensuring that economic growth is evaluated in conjunction with equity considerations. Its inclusion in the Tier II framework allows for the assessment of economic development without disconnecting the framework from social equity or environmental concerns.

The use of an ecological footprint relative to biocapacity would help elucidate whether Ireland’s resource use is damaging long-term capacities and provide information on progress towards sustainable consumption goals. This indicator assesses the extent to which Ireland’s resource consumption and waste generation exceed the regenerative capacity of its ecosystems and as such directly links to concepts like environmental carrying capacity and resource overshoot. Tracking this balance is essential for ensuring that national consumption remains within sustainable limits, aligning with SDG 12 (responsible consumption and production).

The complexity of adaptation to global climate change presents substantial methodological challenges, while building resilience is increasingly important. This domain might best rely on a survey-based climate adaptation index through building on the CCAC

Adaptation Scorecard. Such a composite indicator would evaluate Ireland’s preparedness for climate-related risks through a survey at disaggregated levels of government and with the results used to build an index. Such local government self-reporting would notionally focus on infrastructure resilience, policy frameworks and adaptive capacity. Such a measure of our preparation and ability to respond to climate-related disruptions, in particular extreme weather events, is directly aligned with SDG 13 (climate action).

Additionally, a series of indicators relevant to Ireland from the planetary boundaries framework, including measures on CO₂e emissions, biosphere integrity and chemical releases, are suggested to provide information on whether we are operating within critical limits as a precursor to sustainable development. In terms of climate change and ocean acidification, total contributions to CO₂e emissions are clearly the most important metric to monitor. A CO₂e emissions indicator is used to track Ireland’s greenhouse gas emissions across sectors, with emissions being converted into CO₂e to allow an integrated assessment of all major contributors to climate change, including methane (CH₄). This tracking is critical to ensuring

compliance with both national climate targets and international commitments under the Paris Agreement.

In terms of genetic diversity as a component of biosphere integrity, a metric based on the IUCN Red List or Living Planet Index would perhaps be the best option. The shift from a global extinction metric to localised species data allows for more targeted biodiversity conservation efforts under Ireland's NBAP and aligns with the Aichi Biodiversity Targets. In terms of functional integrity, the NPP metric is a popular and important indicator reflecting ecosystem functionality and resilience. We also posit, as an alternative, the Biodiversity Habitat Index (BHI), but this is associated with a greater information burden, as it contrasts the current state of the environment in each location with our objective, or how the environment should be. In general, NPP is the preferred metric due to the greater capacity to use remote sensing for data collection and, overall, the substantially lower information burden.

Chemical flows into the environment take many forms and are directly related to land use policies in Ireland. Nitrogen and phosphorus levels in both surface water and groundwater indicate the level of nutrient loading from agricultural run-off and urban waste, which can lead to eutrophication and threaten drinking water quality. Waterborne levels of nitrogen and phosphorus are indicators of particular relevance to CAP monitoring, Ireland's EPI and several SDGs and Aichi Biodiversity Targets.

Novel entities, in particular PFAS levels in surface water and groundwater, are of increasing concern, as they are persistent bio-accumulative pollutants that can lead to several harmful effects on people and the environment. As the most pressing and well-known novel entity in the planetary boundaries sense, PFAS are worth monitoring.

The planetary boundaries framework also specifically mentions land use in the context of forest cover. For our purposes, we expand considerations of land cover to include measures of land cover shares relative to target levels and to include a wide range of land cover types. In forests, the composition level might also be more granular, e.g. minimally coniferous versus deciduous composition, due to disparities in biodiversity and other benefits. Urban green spaces and wetlands also stand out as important land uses benefiting society as well as nature. Land cover itself will obviously vary across conditions in Ireland and

so would best be measured against targets to ensure balanced land system management. This would, of course, interact with the other planetary boundary and domain indicators. Instead, this is a measure of implementation of land use policy.

If indicators suggest less than expected levels of progress, one may want to review additional information or pursue further research. As such, it is recommended that the Tier II indicators be supported by select diagnostic indicators under the following Tier III level.

2.3.3 Tier III: diagnostic indicators

Tier III of the assessment framework is intended to provide granular diagnostic data relating to the impacts of land use change. The selection of these indicators is primarily informed by their inclusion in existing recommendations as expert "votes" on their relevance as well as further literature review. The indicators discussed in this section and reported in Table 2.6 are divided into sub-domains. These include additional indicators on environmental, production and socio-economic outcomes. In addition, the environmental domain is subdivided into air quality, biodiversity, climate change, soil and water indicators. This division is intended to support an understanding of the substantial number of environmental impacts occurring from land use policy changes. Environmental outcomes impact production and socio-economic outcomes as well and so feature prominently in indicator sets such as the SDGs.

Air quality is a critical aspect of environmental health with direct links to land use practices. In addition to CO₂e in Tier II, a few specific indicators stand out: the monitoring of ammonia (NH₃), CH₄ and potentially the use of an AQI. NH₃ is a key pollutant primarily associated with agricultural activities, particularly the use of fertilisers and emissions from livestock operations. As land use transitions occur – particularly involving intensified agricultural production – increased NH₃ emissions tend to degrade air quality through the formation of secondary particulate matter; this has respiratory health impacts as well as contributing to atmospheric aerosol loading. CH₄ is a potent greenhouse gas in the short term, significantly contributing to climate change and also being closely linked to land use involving livestock and the drainage of organic soils. CH₄ also affects air quality indirectly

Table 2.6. Suggested Tier III indicators

Domain	Indicator	Standard unit	Relevance
Air	Air NH ₃	mg/m ³	Linked to agricultural emissions and land use transitions
	Air CH ₄	ppm	Tied to livestock emissions and land use changes
	AQI	Index (0–500)	Measures air quality across multiple pollutants; critical for assessing human health impacts of urban and rural air pollution
Biodiversity	Species richness	Number of species	Impacts of land use and waste management on biodiversity
	Macroinvertebrate index on rivers	Bio-score	Indicator of river ecosystem health and pollution impacts
	IUCN Red List status – disaggregated	Threatened species count	Changes in conservation status of threatened species; critical for monitoring extinction risk
	Biodiversity intactness index	Score (0–100)	Measure of abundance of native species in an area relative to what a pristine ecosystem of the same type would have
Climate change	Carbon intensity of land use	CO ₂ e/ha/year	Measures carbon emissions from land use practices; critical for climate mitigation
	Government preparedness for climate change (survey based)	Index	Measures perceptions of readiness for climate-related extreme weather events
	National Adaptation Framework implementation	Percentage of planned actions implemented	Tracks the progress and types of climate adaptation strategies across sectors
Production	Agricultural yield (per hectare)	kg/ha	Measures land productivity in agriculture; linked to sustainable land management
	Timber production (forestry)	m ³ /year	Tracks sustainable forest management and the economic benefits of timber production
	Urban land productivity (e.g. real estate and services)	€/m ² or jobs created	Measures economic productivity of urban land, reflecting land use for residential, commercial and service activities
	Industrial land productivity	€/m ² or jobs created	Tracks the productivity of industrial land, including manufacturing, energy production and logistics
	Wetland ecosystem services	€/m ²	Measures the value provided by wetlands, including flood control, water filtration and carbon sequestration
	Grassland productivity	kg/ha	Tracks productivity of grasslands, particularly for livestock grazing or biodiversity conservation
	Recreational land use (parks, conservation areas)	€/year or visits/year	Measures the recreational, cultural or conservation value of land designated for public use or biodiversity protection
Socio-economic	Discretionary income	€	Measures household financial flexibility; linked to cost of living and local economic conditions
	Employment in agriculture, forestry and other sectors	Percentage of population employed in these sectors	Measures labour market shifts across the country due to land use transitions, capturing both urban and rural dynamics
	Access to services and infrastructure	Percentage of population with access	Assesses the population's access to services (health, education, transport) impacted by land use changes
Soil	Soil health (organic matter levels)	Percentage organic content	Sustainability of land use practices; critical for long-term productivity
	Soil erosion rate	Tonnes/ha/year	Linked to the sustainability of agricultural and forestry practices

Table 2.6. Continued

Domain	Indicator	Standard unit	Relevance
Water	Wastewater treatment efficiency	Percentage of wastewater treated	Impact on water quality and nearby ecosystems
	WQI	Index (0–100)	Aggregates water quality parameters; critical for assessing impacts of land use on water ecosystems
	Surface Water Ecological Status Index	Bio-score (Q-value)	Indicator of surface water ecological status

by contributing to the formation of ground-level ozone, negatively impacting health and leading to a substantial number of premature deaths each year as well as reducing crop productivity. By tracking these air pollutants, policymakers can assess the effectiveness of agricultural regulations aimed at reducing emissions, such as improved manure management practices, the adoption of more sustainable fertiliser applications and other reduction strategies. Additionally, such tracking enables targeted interventions to mitigate pollution in agricultural hotspots.

An AQI provides another means to measure air quality by aggregating the concentrations of multiple pollutants, including particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide, ozone and sulfur dioxide. These pollutants, generated by transport, industrial activity, burning waste and energy production, have direct impacts on both human health and environmental quality. The AQI is potentially important for assessing the cumulative impacts of various land use activities on air quality, including in urban and suburban areas where biomass is still used as a heat source by many households. By using an AQI, emissions can still be monitored while not reducing the focus on CO₂e, including NH₃ and CH₄ emissions, which are, at present, a greater concern due to general reductions in AQI-based pollutants. Monitoring air quality is linked to progress on SDG 3 (good health and well-being) by ensuring healthy environments, SDG 11 (sustainable cities and communities) and Aichi Biodiversity Target 8 (on reducing pollution and minimising the negative impacts of agricultural pollutants).

Water quality indicators are crucial for understanding other avenues through which emissions from land use enter the rest of the environment. A WQI can, like an AQI, be used as an aggregate measure across secondary concerns beyond NH₃ and phosphorus (Tier II indicators) to include pH, dissolved oxygen, clarity, sedimentation, *Escherichia coli* and biological

indicators, complementing existing monitoring under the Water Framework Directive (EPA, 2021b). These indicators are closely tied to SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production) and Aichi Biodiversity Target 8 (on minimising pollution impacts on ecosystems) and support Ireland's commitments under the NBAP.

Key biodiversity indicators are intended to monitor species levels and quality of habitats. These include an indicator that monitors species richness relative to expected levels – a measure of the number of species within a given ecosystem versus a locally calibrated biodiversity target, which itself warrants careful consideration. This indicator would support an understanding of the ecological impacts resulting from habitat loss and fragmentation, especially in regions undergoing agricultural or urban expansion. A macroinvertebrate index would perform a similar function as a bio-indicator of river and aquatic ecosystem health, particularly of health impacts due to changes in agricultural run-off and waste management practices. Disaggregating the IUCN Red List status by habitat and/or species group would provide additional context on which species are at risk of extinction and help tailor biosphere integrity-related interventions. A biodiversity intactness index (BII) would additionally help assess the suitability of habitats based on the abundance of species relative to an undisturbed ecosystem. This indicator is particularly relevant for assessing the impacts of land use change on ecosystem functionality in agricultural, forested and urban areas. These indicators are directly relevant to Aichi Biodiversity Target 6 (sustainable management of aquatic resources), SDGs 14 and 15 (life below water and on land, respectively) and Aichi Biodiversity Target 12 (which calls for preventing species extinctions) and would support Ireland's NBAP.

In terms of the socio-economic dimension, land use has broader effects on household income through employment and access to services. Modified

(potentially EDE-adjusted) household income is included in Tier II as a fundamental measure of economic well-being, but it does not reflect issues around changes in the cost of living or consequently households' capacities to save and invest for the future. If resources become scarcer, we expect prices to rise and, consequently, households will have less capacity to save, highlighting the importance of maintaining and growing the productive capacity of different land uses. As such, income net of expenses (saving potential) is an important metric. Additionally, monitoring employment in agriculture, forestry and other land use-intensive sectors captures some of the impacts of land use transitions and how reliant the economic system is on land use.

Land use changes can also significantly impact access to essential services through the geographical distribution of the population and level of infrastructure development – which is traditionally low in rural areas. Monitoring the population's access to infrastructure – particularly net-zero emissions infrastructure – also provides information on one of the drivers of urbanisation. This metric also captures one of the drivers of SWB outcomes, which the public sector can address well. The proposed socio-economic metrics directly relate to SDG 1 (no poverty), SDG 8 (decent work and economic growth), SDG 11 (sustainable cities and communities) and Aichi Biodiversity Target 7 (which emphasises the importance of sustainable agricultural and forestry practices) and contribute to Ireland's CAP monitoring.

Production indicators help monitor the financial drivers underlying some land use decisions plus the non-market value of land cover types that are sometimes overlooked. Expanding the scope beyond agriculture and silviculture to include urban, industrial and natural land-based financial flows supports a more comprehensive understanding of how different land uses contribute to productivity through providing complementary services. Clearly, per hectare agricultural yield is an important measure of productivity that is relevant to SDG 2 (zero hunger), as it indicates the ability to feed a growing population, and it is also related to SDG 12 (responsible consumption and production) and Aichi Biodiversity Target 7. Forestry is gradually returning to the status of a critical sector in land use – including through agroforestry – as a means of medium-term carbon sequestration plus timber production, an important measure of

the economic value derived from forests. Metrics on timber production align with SDG 15 (life on land), which emphasises the importance of the protection and sustainable management of forests for combating deforestation, and Aichi Biodiversity Target 7, which aims to ensure that forests contribute to the economy while maintaining their ecological integrity.

Considerations of land use productivity also extend to urban land and relate to ensuring that when land is lost from other habitats to urban uses it is used efficiently. The urban land productivity indicator measures the output from land used for residential, commercial and service purposes, reflecting the economic value generated by cities and urban centres, and is related to SDG 11 (sustainable cities and communities). By tracking the productivity of urban land, policymakers can assess the effectiveness of land use policies in promoting sustainable urban development while minimising environmental impacts. Land designated for industrial use also serves a vital role in economic output, resulting in a recommendation for a comparable industrial land productivity measure. As industrial estates can take up substantial tracts of land and often require access to water and waste removal means, ensuring that industrial space is not wasted can be an important function of land use policy, and is related to SDG 9 (industry, innovation, and infrastructure), which focuses on building resilient infrastructure and promoting sustainable industrialisation.

Complementary to human uses of land, wetlands provide critical ecosystem services, including water filtration, flood control, carbon sequestration and biodiversity support. Wetland ecosystem services are, unfortunately, sensitive to not just wetland-focused policy but also all land use policies, as wetland health depends on moderating the flow of pollutants into wetland systems, to keep these flows at sustainable levels. Ensuring the maintenance or growth of wetland ecosystem services in terms of value or other metrics supports SDG 6 (clean water and sanitation) and SDG 15 (life on land), as wetlands play a role in maintaining water quality, and aligns with Aichi Biodiversity Target 14, as wetlands contribute to the health and resilience of other ecosystems. Grasslands – often used for livestock grazing and a major share of land use in Ireland – also contribute to both agricultural productivity and ecosystem health. The grassland productivity indicator measures the

output of grasslands, particularly in relation to livestock yield, while considering the ecological value of these areas for biodiversity conservation and as means of soil carbon storage.

Land areas designated for recreation, conservation and public use also have a vital role in supporting human health and well-being while conserving biodiversity and contributing to climate change mitigation as carbon sinks. The recreational land use indicator measures the economic and environmental value of parks, conservation areas and other public lands used for recreational purposes, but most directly through their use value as public access to nature.

Soil health is also a fundamental component of sustainable land use, influencing both agricultural productivity and environmental quality. As such, healthy soils have received increasing attention across the EU, including in the EU Soil Strategy for 2030 and Soil Monitoring Law, enacted in December 2025, which requires Member States to monitor and assess soil health (European Commission, 2021a, 2026). Healthy soils provide essential ecosystem services, including water regulation, nutrient cycling and carbon sequestration, all of which are critical for maintaining productive landscapes and resilient ecosystems. Monitoring soil health is therefore crucial for ensuring the long-term viability of agriculture. SOM levels are an important indicator of soil health, reflecting the ability of the soil to support plant growth, store nutrients and retain water. SOM also contributes to the formation of stable soil structure, enhancing water infiltration, reducing erosion and supporting microbial activity, and is an indicator of carbon sequestration levels. Soil erosion is also a major challenge in both agricultural and forest areas and can reduce the availability of fertile topsoil and productivity. Erosion also contributes to sedimentation in waterways, exacerbating water quality issues. While not the only issues impacting soil, SOM and erosion levels are related to other candidate metrics, including levels of compaction and rates of nutrient leaching. So, a soil quality index, along the same lines as the AQI and WQI, could be considered. This index might include measures on nutrient balances, salinity, soil compaction and pH levels relative to targets, although it should first be considered whether this would add sufficient, actionable information about soil health to make it worth reducing the focus on other metrics. The interaction between soil health and water quality also

underscores the importance of integrated management and coordination, as soil sedimentation upstream impacts water quality throughout a catchment.

Finally, climate change poses one of the most significant threats to environmental and socio-economic stability, and land use plays a critical role in both contributing to and mitigating this threat. As such, effective climate change monitoring requires tracking both emissions from land-based activities and adaptation efforts to prepare for the potentially increasing frequency and severity of climate-related events. The following diagnostic indicators are intended to provide additional context on Ireland's contributions to greenhouse gas emissions and readiness.

Carbon intensity per hectare ($\text{CO}_2\text{e/ha}$) as a metric would help tie emissions to land use, in particular in agriculture and forestry, where the intensity of land use directly influences the volume of emissions through, for example, livestock concentrations, fertilisation rates and energy use. As such, tracking carbon intensity helps identify specific practices that generate disproportionately elevated levels of emissions, aligned with SDG 13 (climate action), and would support Ireland's efforts to meet its national climate and Paris Agreement commitments.

As adaptation is highly context specific, it is unfortunately more difficult to construct a sufficient quantitative metric to measure it. While Tier II contains a CCAC Adaptation Scorecard-based index based on responses from government agencies on a granular scale, a complementary survey could be administered to the public. A key aspect of climate resilience is understood to be the capacity of governments at various levels to prepare for and respond to climate-related hazards such as floods, heatwaves and droughts. To assess whether the scale of preparation is believed to be sufficient, a survey-based indicator on perceptions of government preparedness for climate change-driven extreme weather events is appropriate. Such an indicator would also be useful for assessing gaps between perceived and actual readiness. Additionally, measuring Ireland's progress in implementing national climate action plans has itself emerged as an important metric related to tracking the implementation of the National Adaptation Framework (DECC, 2024) and net-zero commitments.

The Tier III diagnostic indicators are intended to support the use of Tier I and II indicators and to provide a means to pursue corrective land use policies. By linking these indicators to domestic and international frameworks, such as the SDGs and biodiversity targets, this framework also suggests

their importance in a wider context. These diagnostic indicators are essential for enabling policymakers to refine and adapt land use strategies in response to evolving production, environmental and socio-economic conditions.

3 Indicator Data Availability

In this section, we begin with some general findings on the status of relevant data in Ireland. Then, the status of collection and dissemination of data on the recommended Tier I–III indicators are discussed in order.

3.1 Tier I Indicator – Genuine Progress Indicator

There has been a history of trying unsuccessfully to legislate on the collection and reporting of a GPI in Ireland (Houses of the Oireachtas, 2017, 2020). We can, however, assess the collection of data relevant to constructing the GPI:

$$GPI = GNI_{\varepsilon}^* + NMP + NCC \quad (3.1)$$

where GNI_{ε}^* is Ireland’s modified GNI, which is then inequality adjusted; NMP is the value in terms of services provided from non-market and public goods, both natural and built; and NCC is the change in the net value of natural and built capital, inclusive of adaptation and resilience expenditure and other investments. This assessment process then involves monetising various environmental and social factors that are often omitted from conventional economic measures.

While there are alternative ways to adjust GNI to account for inequality concerns, use of the Atkinson index has a strong theoretical basis (Atkinson, 1970). It is also generally intuitive – an adjustment to reflect losses in societal welfare due to unequal income distribution – emphasising how inequality diminishes the benefits across much of society that should be received from economic output. The adjustment is based on multiplying Ireland’s preferred measure of income, GNI^* , by the ratio of EDE income (y_{ε}) to mean income (\bar{y}), $\frac{y_{\varepsilon}}{\bar{y}}$, where:

$$y_{\varepsilon} = \begin{cases} \frac{1}{N} \sum_{i=1}^N \frac{y_i^{1-\varepsilon}}{1-\varepsilon}, & \varepsilon \neq 1, \varepsilon \geq 0 \\ \frac{1}{N} \sum_{i=1}^N \ln(y_i), & \varepsilon = 1 \end{cases} \quad (3.2)$$

based on incomes, y_i , and societal elasticity of marginal utility of consumption, ε . This gives the proportion of the mean income that society would consider equally valuable if all incomes were distributed equally, given society’s level of inequality aversion.² Data on traditional income and GNI-equivalent indicators, e.g. household-scale earnings, are collected across Ireland (CSO, 2023a). These would then be adjusted for transfer payments to households. Conducting an inequality adjustment following Atkinson (1970) and Sen (1976), however, would require a similarly granular measure of the elasticity of marginal utility of consumption, ε , which has yet to occur. Yet, it is entirely reasonable that ε could differ across Ireland, which would be more accurate than using a national average estimate from Evans (2005) or Turk (2024). Turk (2024) offers a method to estimate ε at disaggregated levels.

NMP captures in part what might be referred to as the “hidden scaffolding” of society – a wide variety of untraded goods and services on which the economy and society depend. In socio-economic terms, this includes the values of unpaid household labour and community volunteer work, but also the direct and indirect value received from living in a well-functioning society. NMP also includes the net of costs resulting from a developed society, such as the cost of crime and unemployment and more mundane issues such as lost value from commuting times. NMP also includes value from other public service flows, e.g. from public health and education. In terms of the environment, NMP potentially includes the value of an expansive number of sources of ecosystem services, which are reduced in response to destructive activities. These include regulating services related to air, climate, disease and pests, pollination, erosion, water flow rates, water purification and water treatment.³ Environmental detractors from NMP include any additional losses in value not attributed to differences in the value of ecosystem services, including losses in existence values due to environmental

2 Nationally, this is generally close to and above 1 in Ireland, e.g. 1.00 or 1.47, depending on the point of reference in Evans’ marginal versus average tax-based approach (Evans, 2005), and 1.08 based on the rate of inequality growth in Turk (2024). A value close to 1 means that the distribution of income does not significantly diminish perceived societal welfare.

3 For a list of example studies on regulating and cultural services from the environment, see Table 2 in Drupp *et al.* (2024).

degradation – in part an environmental parallel to the value received from a well-functioning society.

Net capital change, *NCC*, includes changes in the value of both natural and built capital rather than flows. This includes the value of renewable and non-renewable natural resources (mineral deposits, tree stands, stocks of species, soils, climate), built capital (both private and public) and potential human capital and productivity as a less physical form of built capital.⁴ Consequently, overconsumption today of renewable forms of net capital reduces their value in the future, as does inefficient transformation of non-renewable net capital into built capital. Net capital changes, particularly in terms of natural capital, may involve changes in the value of long-lived – even perpetual – resources and so will be sensitive to the application of appropriate social discounting methods. Current national recommendations in Ireland use the Ramsey rule-based “social rate of time preference” approach (Ramsey, 1928; O’Callaghan and Prior, 2018; Department of Public Expenditure and Reform, 2019).⁵ This basis has the social discount rate determined as, $SDR = \mu + \varepsilon\bar{g}$, based on the pure rate of time preference, μ , previously noted elasticity of marginal utility of consumption, ε , and mean growth rate in consumption per capita, \bar{g} . Long-term societal perspectives on the future, inequality and growth potential may differ across Ireland and consequently also impact the value of *NCC*, even for similarly long-lived resources. *NCC* will also be sensitive to whether we value natural capital at market rates or on an explicitly environmental basis (Weikard and Zhu, 2005; Hoel and Sterner, 2007), which can substantially change – generally uplift – the value of natural capital (Baumgärtner *et al.*, 2015; Drupp *et al.*, 2024).

The recording of the consumption of non-market goods and services consistently at the household level is, at present, non-existent in Ireland. However, following initiatives to establish and then expand the System of Environmental Economic Accounting framework by the EU under Regulation (EU) No 691/2011 (European Commission, 2022c), the CSO has established an Ecosystem Accounts Division (EAD) for the purposes of monitoring the extent, condition and service

flows of ecosystems in Ireland. Regulation (EU) No 691/2011 specifies which ecosystem accounts must be monitored with reporting on a 3-yearly basis. Requirements include monitoring the extent of ecosystem types at a high level of typology (level one), the condition of ecosystems (nine variables) and the service flows from ecosystems (seven services). The EU mandates the collection of the same data from each Member State for comparability and so some variables will monitor more pressing issues in Ireland than others.

The CSO EAD’s baseline assessments (due to be available in 2026) will contain information on the extent and condition of physical units relevant to environmental components of *NCC* and *NMP*. This might also build on work by the EPA on measuring the extent of some natural capital in Ireland, but not valuing this natural capital (Stout *et al.*, 2023); advice on natural capital accounting in Ireland (Ní Dhúill and Sheehy, 2024); the NPWS’s ecosystem services mapping project (Parker *et al.*, 2016) and partial valuation frameworks such as those proposed by Norton *et al.* (2016); and the more developed national capital accounting framework used in the UK (Office for National Statistics, 2024). The CSO EAD’s current mandate, however, does not include the transformation of services into monetary value terms. If the CSO EAD later follows United Nations and EU guidelines (United Nations *et al.*, 2014; Vysna *et al.*, 2021), a highly disaggregated accounting of ecosystem services in terms of value will result and could potentially be recreated based on historical data on ecosystem service flows. Estimates of non-market and public service flows might also be arrived at by survey-based methods at the household level. Estimating these flows would require the extensive collection of data on respondents’ use of such services and their interaction with the environment, both directly and via their consumption choices. It would also require information on the value of substitutes – the opportunity costs of respondents’ choices – or other valuation methods to ensure information is comparable in financial terms. However, these estimates are no closer to being available at this time than comprehensive System of

4 The changes in the value of intellectual property could, notionally, be included but would suffer from the same issues as GDP/capita experience due to the large – and largely unintegrated – international business presence in Ireland.

5 Current guidelines at the national level are to apply a 4% social discount rate based on the social rate of time preference approach, declining to 1.5% over the very long term (>275 years) for long-lived considerations.

Environmental Economic Accounting estimates. It is also unlikely that reliable estimates of natural capital will be obtained from household surveys alone due to the complexity of measuring natural capital and its value over time.

We also note that the level of spending tied to adaptation and resilience is potentially considerable and monitoring this could be a means of including the costs of global climate change in measures of welfare. These costs would include spending under the Climate Action and Low Carbon Development (Amendment) Act 2021 (Government of Ireland, 2021), €3.15 billion of spending under the Future Ireland Fund and Infrastructure, spending under the Climate and Nature Fund Act 2024 (Government of Ireland, 2024a) and substantial transitions costs of €1–3 billion per year (Casey and Carroll, 2023). The alternative to these expenditures is large reductions in income earning potential, in the value of the *NMP* and *NCC* components of equation 3.1, and in investments. These have conservatively been estimated to amount to a reduction of €2 billion per year by 2050 (de Bruin *et al.*, 2024) – as this estimate does not include the value of ecosystem services.

Estimates of net changes in the built capital stock of Ireland are, in comparison, at least nationally available – estimated annually as a component of national accounting (CSO, 2024f) following standard accounting practices. These estimates are available for a number of years in their aggregate form, and it may be possible to estimate disaggregated historical values. It is unclear, however, whether reliable, comparable estimates of human capital exist. However, this might also build on work in the area (Kavanagh and Doyle, 2007; World Bank and Government of Ireland, 2021).

Overall, we find that Ireland is substantially unprepared to implement monitoring of a sufficient number of GPI components on a sufficiently granular scale to arrive at productive estimates. This is unlikely to remain the case, however, as there is substantial interest in both Ireland and the EU in establishing relevant monitoring frameworks. However, putting estimates into financial terms will also require a concerted research effort, even once the extent of ecosystem service flows and natural capital values have been estimated in their natural units. As such, it is unclear when functional and meaningful GPI estimates will exist, as these research

efforts have yet to be established and would take some time to complete.

3.2 Tier II Indicators

In comparison to GPI, Ireland's collection of data on the domain summary Tier II indicators is proceeding well. The CSO, as the country's primary statistical agency, collects and makes available some of the data on our indicators of interest. Data are primarily available through the CSO's data portal (CSO, 2024c), dedicated reports, Ireland's open data repository (Government of Ireland, 2024b) and international repositories such as those managed by Eurostat (<https://ec.europa.eu/eurostat>).

3.2.1 Subjective well-being

SWB has been of increasing interest globally, including in Ireland (Department of the Taoiseach, 2023, 2024; OECD, 2024). Compared with some measures, the measurement of well-being is more open to interpretation and innovation, as it is a concept for which a fixed definition and methodology have yet to be established (O'Rafferty, 2020). Rather, inter- and intra-temporal comparability is sought. As a component of statistics on living conditions, the EU regulates the collection of metrics on well-being (Regulation (EC) No 1177/2003; EU, 2003). Consequently, the CSO included modules on well-being in the 2013 and 2018 SILC (Wall, 2013; O'Brien, 2018). It also collected limited data on SWB annually from 2021 to 2023 (most recent data), by including questions on the respondent's perceived standard of health (CSO, 2024k). The CSO's SWB reporting is at the national level; however, reported sample sizes include 4191 households and 10,199 individuals who participated in the 2023 SILC (CSO, 2024j), and this suggests that county-level or more granular reporting on SWB and other SILC-based metrics is feasible and that the data required for such reporting already exist in internal CSO datasets. In 2021–2023, the Irish Government published an annual report titled *Understanding Life in Ireland: The Well-being Framework 2023* (Department of the Taoiseach, 2023). This framework consists of 11 dimensions of a sustainable quality of life, which were developed from 35 indicators. In 2023, the government committed to a review of the framework approximately 4 years later (Department of the Taoiseach, 2023).

The report includes a detailed methodology, and how performance is measured can be summarised as follows: a 100% improvement in an indicator over circa 5 years and/or Ireland being the best performing country constitutes a result of 1; a result of 0 means that there has been no change in performance over the last 5 years and/or that Ireland's score is the same as the average; and a result of -1 means that there was 100% deterioration in the indicator over circa 5 years and/or that Ireland is the worst performing country (Department of the Taoiseach, 2023).

3.2.2 *Income or product per capita*

The closest equivalent to per capita national statistics such as the GNI is likely household equivalised income. This is an income measure that is often adjusted by household size and considered in disposable or net rather than gross terms. The CSO, like statistical agencies in most countries, has collected such statistics for several years as key metrics for informing national policy decision-making, e.g. data collected via the CSO's SILC since 2010 (CSO, 2024j). However, the most granular level of publicly available data is regional. Additionally, tracking farm household income separately from general household income may provide important insights into the specific economic challenges and opportunities faced by agricultural households and could serve as a valuable stand-alone indicator.

3.2.3 *Ecological Footprint and Biocapacity Accounts*

Data for the purpose of constructing EFBA are not domestically collected in Ireland. The data available in Ireland are based on national estimates, which are part of a global database based on assumptions about the productivity of land types and consumption on the national scale (Dworatzek *et al.*, 2024). Consequently, consumption and biocapacity data, on the necessary per capita and per hectare scales, do not exist at a granular level at this time. Matching the existing EFBA methodology (Lin *et al.*, 2018) would involve granular, at least annually updated, estimates of yield and equivalence factors across major land types. To match international estimates, these estimates would be on

factors for infrastructure, forests, inland fishing, marine fishing, grazing and croplands. However, factors could instead be chosen to match Ireland's mix of land cover. These factors could then be used to estimate the relative productivity of different land types for use in biocapacity accounting. In time, with a fully developed land use map linked to land parcel data and revenues, such an approach could be undertaken. Similarly, the ecological footprint of society would need to be estimated on a similar granular scale and consistently updated. In existing national EFBA, the footprint component is based on a consumption and land use matrix, relating consumption to different land use/cover types (Global Footprint Network, n.d.). Many of these data could conceivably be collected in the SILC, the Household Budget Survey, if sample sizes were substantially larger (CSO, 2024g), or as a separate endeavour. Additionally, sectoral input-output tables (CSO, 2023d) could be used to account for the carbon footprint and other impacts of industry – and should also be updated over time. In short, a dedicated effort involving geospatial analysis and additional survey work will be needed to arrive at a land use-relevant EFBA methodology. However, such an endeavour may yield significant results for policy development in Ireland, as a disaggregated EFBA metric would be highly informative in relation to the impacts of land use.

3.2.4 *Climate Change Advisory Council Adaptation Scorecard-based index*

A CCAC Adaptation Scorecard-based index would follow from the national-scale work of the CCAC, which is now in its fourth iteration (CCAC, 2024). However, such a means of assessment would need to be redeveloped. It would need to be primarily quantitative in nature rather than qualitative, as the assessment would need to be conducted on a substantially larger scale to provide results that are meaningful relative to land use.⁶ The assessment would then need to be conducted with departments, agencies and county- and city-level management to ensure sufficiently granular data collection. This would clearly require substantial planning – and the funding to support it – to upscale capacity relative to current endeavours.

⁶ Improving the clarity of how the assessment is being conducted by making it quantitative in nature would also fit with recommendations from the most recent adaptation scorecard workshop (CCAC, 2023).

3.3 Planetary Boundaries Contributions

The EPA has made a significant effort to make data more publicly available, including data relevant to Ireland's planetary boundaries contributions. This has included making substantial amounts of data available via the EPA's GeoPortal (EPA, 2024c), the EPA's research data archive (EPA, 2024k) and datasets on the open data repository (Government of Ireland, 2024b). This information has enabled the EPA to conduct highly relevant and informative environment-focused reporting (EPA, 2024i). This has also been supported by other efforts, including community- and volunteer-based collective efforts in the context of biodiversity monitoring. Consequently, in some cases, substantial amounts of data are available, but additional processing and management are needed to make these data comparable in terms of land use. In this section, we review data availability tied to recommendations on monitoring SRC planetary boundaries.

3.3.1 Greenhouse gas emissions (carbon dioxide equivalents)

The EPA has previously undertaken comprehensive geospatial modelling of greenhouse gas and other emissions of interest (Nielsen *et al.*, 2020). However, most public reporting on greenhouse gas emissions is on the national scale, divided by major sources. While county-level greenhouse gas inventories have been compiled recently as part of compiling baseline emissions inventories in support of climate action plans (Meath County Council, 2023; Waterford City & County Council, 2023), most counties have not made these data available. The frequency of reporting has recently changed to quarterly (EPA, 2024k), on a seasonally adjusted basis. The data themselves are divided into the sectors of agriculture, buildings, electricity generation, industry, transport and other. Estimates are given in CO₂e terms based on global warming potential. Estimates have been available on the national scale since 1990 (EPA, 2024h) and are projected to 2050 (EPA, 2024f). Both types of estimates are based on modelling the emissions impacts of several processes, including several focused on land use and agriculture (Duffy *et al.*, 2024; EPA, 2024g; Styles *et al.*, 2024). Consequently, regional or more granular estimates could be derived if

the parameters of the EPA's models were known on a more granular scale. This information is not available at present, however, and deriving more granular estimates may require substantially more data on differences in the determinants of emissions across the country.

3.3.2 IUCN Red List

The IUCN Red List database includes 1680 entries for Ireland, as it includes species found in Irish waters and migratory species that pass through Ireland. Consequently, the monitoring of species abundance and diversity must rely on the domestic share of IUCN Red List monitoring. The baselines for assessment have been developed by the NPWS in the form of regional red list reports (National Parks & Wildlife Service, 2020). These are updated at 6-year intervals, as required by the Habitats Directive, and focus on specific groups of species. These efforts are complemented by several species- or habitat-specific surveys and the NPWS's Irish Wildlife Manuals, which are published on a comparable timescale (National Parks & Wildlife Service, 2024b).

Other efforts have also been undertaken to assess the status of Ireland's wildlife. These have often also focused on specific groups of species. BirdWatch Ireland conducts primarily volunteer-based data collection activities on an annual basis. These include the Countryside Bird Survey (since 1998) on breeding countryside birds during breeding season (BirdWatch Ireland, 2024a); the Irish Wetland Bird Survey (since 1994), which involves visiting the same wetlands year-over-year (BirdWatch Ireland, 2024b); and the Garden Bird Survey, which has been run over winters since 1989. The NBDC also operates several targeted monitoring programmes (National Biodiversity Data Centre, 2024c). These include the Irish Butterfly Monitoring Scheme (since 2008), the Bumblebee Monitoring Scheme (since 2012), the new Flower-Insect Timed Count (since 2017), Dragonfly Ireland (since 2019), the Rare Plant Monitoring programme (since 2017), several more targeted surveys (e.g. on urban foxes, Irish hedgehogs) and a few marine biodiversity surveys (National Biodiversity Data Centre, 2024a). As these surveys are heavily based on citizen science, with data collection primarily being conducted by volunteers, there are challenges in ensuring that the data collected are representative.

Our takeaway is that substantial amounts of data have been collected that can bridge the gap between the intention behind the IUCN Red List and implementation on a subnational scale. However, the 6-year interval of collection of data from some sources reduces our ability to link the data to other outcomes. In other cases, citizen science-based data will require specialised processing to account for the probability of observation (selection) bias and ensure they meet statistical standards.

3.3.3 *Net primary production and the Biodiversity Habitat Index*

Monitoring NPP measures, in short, the net change in carbon biomass over time. NPP is sometimes discussed in terms of HANPP. The NPP and HANPP metrics, then, indicate two different trends. NPP is directly related to carbon storage, regardless of whether landscape changes benefit biodiversity. In comparison, HANPP indicates how much of NPP goes to human uses and conversely what remains to support biodiversity and the stability of the environment. However, when NPP is also subdivided by land use type, it becomes more informative about biodiversity as well – when, say, the NPP of agriculture is counted separately from the NPP of wetlands. Ideally, NPP and HANPP would both be measured. Estimation methods for each also follow distinct paths. HANPP can be arrived at by careful accounting of land use, e.g. monitoring the productivity of agriculture, including livestock, silviculture and other land uses. NPP is then modelled using assumptions on how observed outputs and often changes in land cover relate to carbon retention in the environment. Through land use and population densities, carbon retention and extraction via human appropriation are then used to map HANPP and NPP estimates, sometimes on a global scale (Imhoff *et al.*, 2004; Ma *et al.*, 2012; Mayer *et al.*, 2021). Estimates of NPP and HANPP can be extrapolated back in time (Kohlheb and Krausmann, 2009), attributed to specific components of the global food system (Roux *et al.*, 2022) or attributed to trade flows (Liang *et al.*, 2023) on such a basis. As another approach, estimates have been made on an increasingly granular scale using satellite imagery on the basis of solar energy absorption and similar assumptions on production and the functionality

of ecosystem services (Imhoff *et al.*, 2004; National Aeronautics and Space Administration, 2023).

The use of remote sensing suggests that granular, comparatively low-cost estimates of NPP and HANPP can be derived. However, estimates are heavily reliant on their calibration to real-world conditions. When the parameters representing conditions fundamentally change, e.g. reductions in the soil's ability to store carbon as the climate warms (Rodrigues *et al.*, 2023), estimates based on prior calibrations will become inaccurate. Consequently, substantial fieldwork is required – both initially across Ireland and periodically to update findings – to support the granular estimation of NPP and HANPP based on remote sensing. This sort of verification and linkage to remote-sensing information has already been started, e.g. by the EPA (RePEAT Project, n.d.; Saunders *et al.*, 2022; AI2Peat, 2025), and work has also begun on long-term soil carbon sequestration by Teagasc (Fenton *et al.*, 2024; Teagasc, n.d.) in addition to traditional soil mapping (Teagasc, Environmental Protection Agency and Cranfield University, n.d.). Additionally, using satellite-based sensing will limit NPP reporting to the frequency of collection and analysis. However, this will also be true for change in LULUCF, which we would want to tie to outcomes. In conclusion, indicative estimates of NPP and HANPP exist for Ireland, but estimates of a quality and granularity sufficient to base policy on do not exist at present, and a concerted research effort will be required to gather and update such estimates over time.

The BHI instead measures the suitability of a habitat relative to expectations. The use of this index would require determining what habitat should exist at each location, followed by determining the extent to which each location matches that expectation. The first requirement has yet to be met, and this is a necessary precursor to the second requirement, as habitats grouped under summary labels such as “wetlands” are far from homogeneous.

3.3.4 *Surface water and groundwater nitrate and/or phosphorus concentrations*

The main issue impacting water quality in Ireland – like much of the EU – is excess concentrations of nitrogen and phosphorus, primarily from agriculture,

entering waterways (EPA, 2024i).⁷ Consequently, and in response to Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for community action in the field of water policy (EU, 2000), Ireland has undertaken substantial efforts to monitor the status of its waters and begin remediation efforts. These efforts have been further supported recently by the Water Action Plan 2024 (Department of Housing, Local Government and Heritage, 2024).

Measurement of water quality in Ireland is well under way – the result of an expanding effort that started in the 1970s. However, while efforts to monitor water quality are substantial, they face challenges. In Ireland, the measurement of water quality occurs at sites in 4829 waterbodies (across rivers, lakes, estuaries, coastal water and groundwater), a subset of the approximately 84,000 km of waterways, 12,000 lakes and expansive coastline of Ireland (Feeley *et al.*, 2020). Consequently, data on water quality in Ireland reflect only a subsample of waterbodies, albeit a substantial one. In addition to the EPA's GeoPortal, research data repository and contributions to open data, the EPA publishes substantial data via Catchments.ie (EPA, 2024b). However, data from the GeoPortal are perhaps the most accessible. Groundwater quality data include sufficient information for nitrogen and phosphorus concentration monitoring as well as for the monitoring of several other pollutants.

However, catchment monitoring also necessitates converting information into geographical scales that are comparable with land use. Additionally, as pollutants are carried from one area to another, careful consideration of where pollutants enter waterways is also required when attributing pollutants to land use. This suggests that additional research is needed to determine the scale on which the positioning of monitoring stations would allow such attribution, i.e. the identification of where pollutants have entered Ireland's waterways in response to land use.

In conclusion, there is a history of promising data collection, but it is unclear whether data are being collected in a way that informs understanding of land use on a granular scale.⁸

3.3.5 *Land cover shares relative to targets*

As noted, Ireland has made substantial progress in LULUCF classification as part of the European CORINE land cover programme (EPA, 2018a; Büttner *et al.*, 2021). That effort, released in 6-year intervals (most recently based on 2018 data with the analysis completed in 2022), is based on highly granular, primarily satellite-based imagery, supported by substantial secondary data sources on land use and land cover. However, the frequency of data collection is a limitation in comparison with more frequently collected socio-economic and production data.

Another limitation is difficulty in coming to some agreement on what land cover should look like – what land cover targets should be on a granular scale. Ireland has multiple, sometimes competing, interests relevant to LULUCF. The Habitats Directive (EU, 1992) and Natura 2000 protection efforts (European Environment Agency, 2023) have resulted in substantial planning studies and efforts as well as restoration efforts such as the Nature Restoration Law (Regulation (EU) 2024/1991) and Bord na Móna's large-scale peatland restoration programme (Bord na Móna, 2024). Some of these efforts may conflict with afforestation targets (DAFM, 2023) and local and regional development efforts to address socio-economic issues such as Ireland's housing crisis. Some programmes, such as the CAP, have been adjusted in recent years to place a larger focus on environmental protection and conservation (European Commission, 2022a). However, to determine whether land use policy is positively affecting land cover shares, granular, multi-stakeholder-agreed land cover targets are needed. If these exist, they are not publicly available. It is likely that a concerted government effort will be needed to arrive at such targets.

7 See Chapter 8 of Ireland's State of the Environment Report 2024 (EPA, 2024k).

8 In a complementary approach, the EPA established in late 2022 the National Agricultural Inspection Programme to inspect agricultural sources of excess run-off into waterways (EPA, 2024l). This involves reporting on point source operations and subsequently inspections by the EPA, with a substantial number of inspected operations being fined to date. This sort of programme does not directly support identification; however, an indicator that monitors changes in the share of operations that excessively pollute in response to changes in policy is another potential Irish context-specific indicator.

3.3.6 PFAS levels in surface water and groundwater, particularly drinking water

Recently, the European Chemicals Agency proposed restricting a substantial number (>10,000) of PFAS under the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (European Chemicals Agency, 2023) in addition to a limited number of existing restrictions. As a signatory to the Stockholm Convention on Persistent Organic Pollutants, Ireland also has obligations to reduce or eliminate three PFAS substances: perfluorooctane sulfonate, perfluorooctanoic acid and perfluorohexane sulfonic acid (United Nations Environment Programme, 2023).

PFAS can find their way into the environment and subsequently into our food system by other less deliberate means than their production and application. Potential sources of PFAS include fire training sites, where PFAS-containing foams are regularly used during training, industrial sites that use PFAS, landfill sites and urban wastewater treatment plants. Consequently, exposure tied to land use can also occur through the application of biosolids from wastewater treatment plants in agriculture. As these chemicals can accumulate in waste and are difficult to remove, monitoring has been focused on preventing substantial flows into treatment facilities rather than any sort of attempt to remove them from biosolids as part of the National Wastewater Sludge Management Plan (Uisce Éireann, 2016); however, the results of monitoring are not publicly available. Additional monitoring requirements have recently been adopted by the EU, e.g. through the recast Urban Wastewater Treatment Directive (EU, 2024a) and the Drinking Water Directive (EU, 2020), with monitoring requirements in the latter starting next year. Ireland's POP National Implementation Plan further notes the limited monitoring of POPs in Ireland's soils, including the three PFAS covered by the convention (EPA, 2018b). However, the EPA has reportedly included major PFAS in surface water monitoring since 2019 as part of Ireland's obligations under the Water Framework Directive. Summary information has been published at the national level in terms of the number of sites exceeding guidelines (EPA, 2022). When water chemical status data including PFAS measurements have been collected at surface water monitoring sites under the Water Framework

Directive, they are included in water monitoring data by Catchments.ie and accessible via the EPA's GeoPortal (EPA, 2024c). The 3-year frequency of reporting leads to some delay in establishing the level of PFAS in surface waters. Proposals have also been made to expand the current level of PFAS monitoring, which will improve monitoring (European Commission, 2022b) but may also reduce comparability with past data. Some one-off studies have also measured the presence of, exposure to and exposure pathways for PFAS. These included studies monitoring PFAS and brominated flame retardants at select fire training sites (EPA, 2021a), landfill leachate sampling studies (Harrad *et al.*, 2020a; EPA, 2021c), and studies of human exposure and pathways (Harrad *et al.*, 2020b) and measures of the levels of PFAS in common wastes (Harrad *et al.*, 2023). Moreover, ongoing research, due to be published in 2027, aims to identify potential sources and pathways of PFAS in the Irish environment (EPA, n.d.). In terms of PFAS levels in groundwater, the EPA has started to monitor levels at 6-year intervals following EU guidelines (EPA, 2023c). To date, publicly available data include the results of 197 measurements in 2020 of 618 total borehole measurements. In conclusion, while soil-monitoring efforts in Ireland are reportedly increasing, and the EU Soil Monitoring Law requires the implementation of solutions for managing contaminated soils (European Commission, 2026), existing data sources, e.g. under the European POPs Regulation and through the Land Use/Cover Area Frame Survey (often referred to as LUCAS) (Fernandez-Ugalde *et al.*, 2022), focus on other select pollutants and provide limited coverage of PFAS. Some PFAS-contaminated sites, such as at airports and fire training facilities, have been reported under Ireland's Article 13 submission to the European Chemicals Agency (2023, 2024), in line with obligations under the Stockholm Convention. However, recent reviews of Irish soil research (McNamara *et al.*, 2022) highlight persistent gaps and a bias towards agricultural soils and conventional parameters like pH and nitrogen. As a result, there remains insufficient granular and routine data to assess whether PFAS pose a broader concern in Irish soils or how they might relate to land use patterns.

3.4 Tier III Indicators

As previously noted, following Tier II summary indicator monitoring, shortfalls in progress towards

production, socio-economic or environmental goals may be identified. Our assessment framework would then recommend the use of Tier III diagnostic indicators to identify causes of shortfalls in making progress. We outline the status of data collection and availability relevant to our recommended Tier III indicators in this section. Data sources for these indicators are sometimes related to Tier II data sources but in most cases independent data collection is required. This results in additional validation of conditions, as the summary and diagnostic indicator result from separate sources.

3.4.1 Air pollution

As noted in the Tier II indicators section (see section 3.2), the Government of Ireland has an annual reporting requirement on several greenhouse gas emissions, recently revised to quarterly reporting (EPA, 2024d), in the form of CO₂e, with disaggregated estimates following annually. This includes reporting on CH₄ emissions, which account for the second largest greenhouse gas contribution to global warming from Ireland (EPA, 2024e). This is due to livestock in agriculture being the largest source of CH₄ emissions and the basis of a substantial share of economic activity in the country.

The IPCC provides guidance on the estimation of greenhouse gas emissions, with a preference for the use of parameters estimated on a granular scale and frequently updated to capture changes in technology and interactions between factors. The general method for arriving at CH₄ emissions is based on attribution to specific economic activities, particularly related to livestock, agriculture and land use. This would, for example, be based on a CH₄ emissions estimate per head of livestock – a multiplier. In the absence of more granular data, national estimates are generally applied to arrive at estimates. A more expansive version of this methodology is then used to arrive at national estimates in Ireland's National Inventory Submissions (e.g. EPA, 2024g), and past and future estimates are available in *Ireland's Greenhouse Gas Emissions*

Projections 2023–2050 (EPA, 2024f). The capacity to estimate these emissions on a granular scale will then depend on the availability of production data and developing and updating appropriate emissions intensity factors to account for regional variances. This would continue recent efforts to arrive at revised emissions factors commissioned by the EPA (O'Brien and Shalloo, 2019) and on mapping greenhouse gas emissions at a detailed level (Nielsen *et al.*, 2020).

Agricultural activity is also the primary source of NH₃ emissions in Ireland. Rather than contributing to global warming, NH₃ is an air and water pollutant with negative impacts on environmental and human health. Because of the widespread negative impacts of NH₃ emissions – as well as indicating inefficient production methods – efforts to decrease them have received substantial attention. This has resulted in the inclusion of NH₃ in the ceilings set out in Directive (EU) 2016/2284, the National Emissions Ceilings Directive (EU, 2016), and estimates on how to best reduce emissions (Buckley *et al.*, 2020) and revisions of estimates of emissions intensity factors (Owusu-Twum *et al.*, 2024). Estimates of NH₃ emissions are also supported by recent mapping efforts (see, for example, Nielsen *et al.*, 2020), and are similarly constrained by the availability of production data and disaggregated emissions intensity factors.

We might model the outcome of several air pollutants of lesser concern as a composite AQI. National ambient air quality monitoring sites have expanded substantially in recent years, to 115 sites that monitor air quality frequently throughout the day.^{9,10} The data collected are sufficient to arrive at air quality estimates across the landscape in the form of an AQI (EPA, 2024a). As with some other estimates, e.g. water quality, there is some concern over ensuring attribution – that is, that pollution is properly attributed to sources. Deciding on which scale of AQI-relevant data to use to best to arrive at an estimate also requires some thought – that is, whether annual or seasonal means are preferable to estimates that report peak values or periods of worse or better air quality.

9 In 2016, Directive (EU) 2016/2284 further increased the reporting requirements for a few critical air pollutants, including NH₃ (EU, 2016), leading to the design of a national monitoring framework in Ireland (Kelleghan *et al.*, 2021). However, this directive involves monitoring the impact of air pollution on nature, with a focus on sensitive sites (Kelleghan *et al.*, 2021).

10 Ambient air monitoring may eventually include NH₃ under a revised Cleaner Air for Europe Directive (EPA, 2024a).

3.4.2 Biodiversity

Tier II indicators on planetary boundaries include two dimensions on biosphere integrity – genetic diversity and functional integrity. Tier III indicators instead focus on collecting substantial information on the species in environments. These would then be reported in diverse ways – generally as indices – where the underlying data on specific species identified would be retained. These data could then support further diagnostic work based on the sensitivity of species to specific issues.

Using the BII would require the most in-depth knowledge on biodiversity, as it measures the suitability of an area based on the average abundance of a substantial and diverse set of organisms relative to what we expect to be present in the area (Scholes and Biggs, 2005). That is, it is a measure of species abundance relative to a baseline expectation. This has been estimated globally based on geospatial analysis (Phillips *et al.*, 2021) tied to estimates of species responsiveness to changes in habitats (Hudson *et al.*, 2014). However, making the BII an operational component of policy on a granular scale would require local-scale knowledge sufficient to establish baselines for several species and careful monitoring over time.

Complementary or alternative indicators have less stringent data requirements. The species richness indicator provides a count of the number of species in an area without linking to a habitat baseline.¹¹ Substantial amounts of data have been collected on species observations in recent years following the NBDC's development of a citizen's science portal. This allows members of the public to report sightings of species throughout Ireland – over 1.3 million records have been added to date – which can be accessed via the NBDC data portal (National Biodiversity Data Centre, 2024b). However, as with other sources of volunteer data collection, careful study is required to account for the probability of sightings. A more rigorous, complementary approach would be to expand the NPWS's environmental inventory or survey work (National Parks & Wildlife Service, n.d.), as linkages to land use change will require consistent,

repeated measurement on the same scale and timeline as land use change is observed.

We note that substantial work on monitoring the abundance of species in waterways has been undertaken by Inland Fisheries Ireland under Directive 2000/60/EC, the Water Framework Directive (EU, 2000). This has resulted in rivers, lakes and transitional waterways being surveyed annually since 2008 (Inland Fisheries Ireland, 2024b) in addition to Inland Fisheries Ireland's focused reporting, for example through its fish counter reports (e.g. Inland Fisheries Ireland, 2024a). A suggested indicator is a macroinvertebrate index that would perform a similar function to a bio-indicator of river and aquatic ecosystem health and would be influenced by land management through agricultural run-off and waste management practices.

Finally, as noted in the discussion of using the IUCN Red List as a planetary boundary indicator (see section 3.3.2), substantial subsets of species data have been collected in Ireland through citizen science initiatives of the NBDC. Whether these subsets are sufficiently indicative of environmental pressures due to land use change – or whether other disaggregate subsets should instead be monitored – warrants further consideration. Disaggregation of the IUCN Red List is also linked to the updates of the NPWS's red list reports at 6-year intervals and additional one-off environmental survey work, which may need to be upscaled.

3.4.3 Climate change

Ireland recognises the importance of land use in mitigating global climate change, as some land uses are substantial sources of or sinks for greenhouse gases (EPA, 2024d). Differences in greenhouse gas emissions due to different land uses has resulted in the EPA modelling separately the emissions from agriculture, buildings, electricity generation, industry, transport and other uses (EPA, 2024j). Within these broad categories, emissions estimates are arrived at by modelling specific emissions-generating processes, e.g. the impact of manure management practices on CH₄ emissions. Emissions projections also include

¹¹ The Living Planet Index is a frequently noted alternative to monitoring species richness. This is a generally more observable subset, with a focus on counting only vertebrate species. This is a possibility worth considering if environmental surveying budgets are particularly constrained.

LULUCF changes (EPA, 2024f). As in the case of CO₂e estimates, the additional capacity required to disaggregate national-scale estimates by land use type into granular estimates is at present uncertain. However, work is under way at Teagasc via the National Agricultural Soil Carbon Observatory (data not publicly available) and efforts are under way to improve the management of carbon budgets through Ireland joining the EU's Integrated Carbon Observation System research consortium.

In addition to monitoring statistics relevant to mitigation, we also recommend adaptation-related monitoring. Tier II indicators include an expansion of the CCAC Adaptation Scorecard to capture the government's own perception of adaptation. To complement this, an expansion of current public survey efforts may be in order. For example, the CSO's SILC could include questions on the public's perception of national preparedness for climate change and extreme weather events. This would ostensibly capture otherwise unknown shortfalls in adaptation efforts.

Reporting on climate change adaptation plan implementation would also support identifying shortfalls in preparedness. The National Adaptation Framework (DECC, 2024) includes monitoring by local authorities in addition to national departments and agencies, and so, when implemented, the necessary data will ostensibly be collected.

3.4.4 Production

Data on agricultural yield per hectare are collected by Teagasc on an annual basis as part of its EU Farm Accountancy Data Network membership requirements (European Commission, 2024c), with analyses published in National Farm Survey Reports (Teagasc, 2024b) and Harvest Reports (e.g. Teagasc, 2024a). These data are made publicly available at the national level with historical farm-level data being available by request.¹²

DAFM publishes national-level data on forestry production in cubic metres on an annual basis as well as substantial, detailed statistics on the type of production (also aggregated to national statistics) and the mapping of Ireland's forests (DAFM, 2024).

The CSO conducts the Roundwood Removals Survey to compile statistics on removals of roundwood and roundwood biomass from privately owned forests in Ireland (CSO, 2023c); these statistics are also publicly available only as national-level statistics, but data come from respondents across Ireland.

It can be complex to measure urban land productivity, and proxy variables may be required. For example, the CSO reported quarterly 2018 and 2019 data on employment rates in urban areas and it collects annual income and poverty rate data as part of the annual SILC (CSO, 2020). Another approach is to measure the share of urban land that is used efficiently via remote sensing. This would entail estimating the current composition of land use in urban areas versus benchmark land use or similar measures (O'Driscoll *et al.*, 2023). This would allow estimates of the effects of urban land use on people to be considered on a similar scale to that used for nature by the BHI, and this would, therefore, support reporting under the EU's Nature Restoration Law (Regulation (EU) 2024/1991) around avoiding net losses in urban green spaces when it comes into effect in 2026. An alternative approach that would require less information would be to estimate the ratio of used and occupied area to total area, although what is considered well-used land, e.g. green spaces, would need to be decided on.

The CSO also collects quarterly data on employment by sector, including industrial sectors that may represent industrial land productivity. Assessing the incomes of households in urban areas is also an option. A measure of production, or economic output, that is a direct result of the use of industrial land would be more informative, but these data are not currently being collected. It might entail, for example, comparing the economic output of industrial land with the total consumption of natural resources – land plus ecosystem services – or, as a starting point, area of land used.

The value of wetland ecosystem services is likely to be substantial across Ireland's more than 13,500 wetland sites (Wetland Surveys Ireland, 2024). Wetlands provide substantial value through their provisioning, regulating, supporting and cultural services. They both absorb and store water – purifying it, providing a source to draw from and mitigating

¹² As of January 2026, 2010–2017 farm-level data can be requested from the Irish Social Science Data Archive (ISSDA, 2026).

flooding. They also provide recreation and tourism opportunities, a habitat for biodiversity and can be either a source of carbon emissions or a highly effective means of long-term storage, when effectively managed. Despite the extensive value that wetlands most likely provide, estimates on their value are limited, and a substantial research effort would be required to fully quantify and monitor this value.¹³

Grasslands serve a vital role in Ireland's food production, accounting for the largest share of agricultural land. Measuring their productivity is then of substantial importance to other agricultural operations as well as socio-economic outcomes related to food and the cost of living. Consequently, indicators of grassland productivity should be included in an assessment framework alongside other agricultural yields. Monitoring of grass productivity, however, is complicated by grazing throughout the season and so requires intensive monitoring. Teagasc collects detailed productivity data via the enrolment of producers into its PastureBase Ireland programme for the purpose of improving farm advisory services and subsequent farm management (Teagasc, 2021). Details of this substantial sample of grassland users are not publicly available. For the purposes of monitoring grassland productivity, arriving at an agreement to use granular summary data would perhaps be the most expedient and efficient course of action. Alternatively, the CSO has produced summary national estimates of grassland production from 2000 to 2022 (CSO, 2024e), which are partially based on data provided to the CSO by Teagasc.

Recreational land use in Ireland is also a substantial source of value to the public, including by reducing healthcare costs via illness prevention (Grilli *et al.*, 2020), and a source of income from overseas tourism (Department of Rural and Community Development, 2022). Fáilte Ireland surveys national attractions on an annual basis and from those surveys it can determine the number of people who visit natural attractions, visitor gardens, heritage sites, etc. (Fáilte Ireland, 2024a). Such data are attraction specific.¹⁴ Coillte also collects data on the numbers of visitors to its forests (Coillte, 2021); the CSO EAD collects data on the number of overnight stays in accommodation that

may be attributed to visits to ecosystems in support of ecosystem accounts reporting (Regulation (EU) No 691/2011; EU, 2011); and the CSO has conducted one-off survey work on visits to nature areas (CSO, 2021).

As with other indicators, production indicators would perhaps be best fit for purpose if they use the same units, e.g. euros of benefit per hectare. However, some land uses are non-interchangeable, e.g. the extent to which wetlands and industrial areas can or should be transformed. As such, these benefits should at a minimum not be considered comparable between land uses, even if the same units of measure are used. We would, rather, treat land cover shares, measured as the extent of land cover, separately as a planetary boundary indicator in our list of Tier II indicators, and then we include more detailed and varied indicators of land use in our set of Tier III indicators that assess the productivity of land uses.

3.4.5 Socio-economic

Data on discretionary income are collected annually by the CSO, as it is considered an important indicator of whether households are becoming better or worse off (CSO, 2024h). These CSO data have been publicly available on the county scale since 1999 (CSO, 2024b). From 2022 onwards, estimates have been based on employee tax, Department of Social Protection demographic and CSO Business Register data, which are matched before being anonymised (CSO, 2024d), offering promise that data will be reported on a more granular basis in the future.

Employment from land use activities can be assessed from CSO labour force survey data, which have calculated "agriculture, forestry and fishing" employment on a quarterly basis since 1998, with an improvement in methodology in mid-2017 (CSO, 2024i). These data are reported as an aggregate category based on a survey (12,863 valid responses in the first quarter of 2024), where respondents are asked to indicate their industrial sector of main employment and as such it is unclear whether further disaggregation of the data is possible.

¹³ Frequently cited estimates on wetland values in Ireland come from a single source that often notes the insufficiency of available data on which to arrive at estimates (Bullock *et al.*, 2008).

¹⁴ A dashboard of these data is available via Fáilte Ireland (2024b).

In 2019, the CSO published a comprehensive report on the distance people travel to services such as schools, hospitals, garda stations, libraries and public transport options. This involved matching the coordinates of dwellings enumerated in the 2016 census, the coordinates of destination points for a set of everyday services and the road network from the then Ordnance Survey Ireland (CSO, 2019a). The census is conducted every 5 years (CSO, 2024a) and so presumably access to services can be updated via this method at 5-yearly intervals. Other data, such as data on travel times to work, have been collected through other regional quality-of-life surveys (e.g. CSO, 2019b). Satisfaction with access to services and infrastructure could also be directly surveyed, building on the National Transport Authority's annual survey work (e.g. National Transport Authority, 2024), to encompass satisfaction with access to all services and infrastructure influenced by land use constraints.

3.4.6 Soil

As a component of accurately estimating NPP, changes in soil carbon stocks across Ireland must be accurately estimated. If NPP is implemented within the Tier II indicators, then soil carbon estimates must be collected. If, instead, the BHI is implemented due to weaker collection requirements, SOM estimation should proceed at intervals matching LULUCF data collection. Soil health monitoring has recently been mandated by the EU's Soil Monitoring Law, enacted in December 2025 (Council of the European Union, 2025; European Commission, 2026), allowing flexibility in how Member States measure soil health.

The results of work under way by Geological Survey Ireland and Teagasc based on soil samples from the Tellus Project, which involved the national mapping of Ireland's soils (Geological Survey Ireland, 2024a), have been used to identify soil carbon content. Teagasc also operates the National Agricultural Soil Carbon Observatory, though any data collected from their 28 research sites are not publicly available, and methodological advancements will be supported by Ireland's involvement in the Integrated Carbon Observation System over time. National mapping (Geological Survey Ireland and Teagasc, 2024) and an in-depth study of farm soil content as an avenue for carbon sequestration (Geological Survey Ireland, 2024b) also potentially support this measure through

providing a baseline on soil organic content, which would require some sort of programme for updating information on when land use or climatic changes are expected to change SOM content. Importantly, as the EU mandates the collection of data on soil carbon content in some ecosystems (croplands and grasslands), the CSO EAD has a reporting requirement of 3-year intervals (Regulation (EU) No 691/2011; EU, 2011), with baseline estimates expected in 2026.

Soil erosion is a product of soil composition, topology, climate and land cover, among other factors, and is of particular concern for sustained agricultural productivity as well as the health of waterways. Concerns have grown in the EU in recent years, as a substantial share of agricultural lands are susceptible to erosion under current land management practices. This has included modelling course-scale erosion rates (Eurostat, 2020; Joint Research Centre – European Soil Data Centre, 2024). Similar, model-based estimates have previously been derived within Ireland (Kiely *et al.*, 2014). Ground-based soil erosion estimates are not directly reported in Ireland and are, for example, reported as total suspended solids at water monitoring stations. However, disaggregated data on turbidity as well as water content are available as surrogate data for total suspended solids. These data would conceivably need to be linked to land use through a similar attribution scheme to that proposed for other waterborne pollutants and then equated to erosion rates.

3.4.7 Water

As noted in section 2.3.2, nitrates and phosphorus concentrations in surface water and groundwater are included in the planetary boundaries component of the Tier II indicators. In this section, we explore two additional recommended indicators: WQI and wastewater treatment efficiency.

The EPA currently categorises river quality based on a "Q-value", which classifies rivers into high, good, moderate, poor or bad ecological status (EPA, 2020). The collection of water quality data in Ireland presents a substantial challenge due to the breadth of waterways. River water quality monitoring involves site visits for collection, with around 1500 of 2365 waterways being assessed in 2022/2023 plus 224 lakes in 2021–2023 and several estuary and

coastal sites assessed for levels of key pollutants. The EPA assesses what activities impact water quality by quantifying the sources of nitrates and phosphorus on the conditions and activities within the catchment. Approximately 140 datasets are utilised and they include activity-related information, such as population size, numbers and locations of septic tanks, the level of treatment from wastewater treatment plants, animal numbers and excretion rates, soil types, forestry, and industrial and other activities (EPA, 2025). Therefore, multiple land uses are considered.

Wastewater treatment and release is a distinct issue from agriculture- and industry-based effluents – even if we were to focus on land use-based pollution, inclusion of data on the location of wastewater releases would be important for separating the impact of these flows from other issues. The EPA publishes data on wastewater treatment and releases into the environment (EPA, 2017).¹⁵ However, it is clear from reporting (EPA, 2024m) that Ireland continues to be substantially out of compliance with the EU's Urban Wastewater Treatment Directive (Council Directive 91/271/EEC; EU, 1991).

3.5 Summary of Data Availability

In Tables 3.1 and 3.2, we summarise the availability of data for our identified indicators. We find that, in some cases, the relevant data for supporting our suggested indicators are currently collected. The CSO and EPA are frequent sources of information, supported by a patchwork of organisations, including the NBDC, BirdWatch Ireland, Teagasc, Coastwatch, the Marine Institute, Geological Service Ireland, the Irish Meteorological Service and the CCAC. The amalgamation of data from these providers, which have different mandates and resource availability, can hinder clear communication of the status of production, socio-economic and environmental outcomes. The difficulty with regard to which sources of data are identified – let alone granular statistics on those measures – suggests that improvements in data centralisation and availability would support monitoring outcomes. The lack of an accessible, centralised and harmonised database most likely hinders effective decision-making, monitoring of progress and policy evaluation.

We also note that in some cases national agencies report estimates on important topics without the underlying information or methodology being easily accessible. Statistics should be accompanied by links to sufficient and preferably raw data to allow replication of the results and detailed methodological descriptions sufficient to support replication. We also find that sufficient information is often not reported to allow for contacting the creators of statistics within Ireland's agencies, but, rather, generic contact details for those without responsibility for the data. Details of the methodology used are generally more often available from the CSO than from the other organisations/agencies. However, vital information is often not directly connected to the statistics being reported in graphics or tables, e.g. the source of a graphic is reported as "CSO Ireland" rather than being linked to the underlying data and information on the collection of those data.

Additionally, in many cases, we find suggestions that the data of interest are already being collected, but, perhaps due to concerns over small sample sizes, are only being reported on the national scale. This is resulting in a dearth of sufficiently granular information to link to land use policy – or local decision-making in general. That is, data are sometimes in an inadequate state not because of collection but rather because of insufficiently granular dissemination.

Other data of interest, such as EFBA, NPP and BHI data, should be based on disaggregated Irish estimates rather than globally calibrated, remote-sensing-based estimates. This would require substantial initial fieldwork and a framework for updating estimates over time in response to land use change or other sources of change such as global climate change.

Efforts would also need to be made to revise and expand the CCAC's scorecard framework to efficiently and quantitatively assess adaptation efforts at all levels of administration across Ireland. A complementary effort would instead survey the public's perceptions of preparedness. There is also a nascent effort to conduct natural capital accounting across the EU, including Ireland. To bring this accounting to a sufficient standard to form an informative part of our recommended framework would initially require

¹⁵ These data are perhaps outdated – circa 2010 or 2017 – depending on the accuracy of the published metadata.

Table 3.1. Status of data collection: Tiers I and II

Indicator	Scale	Frequency	Agency/entity	Barrier
GPI ^a	–	–	Some components available from CSO, EPA and NPWS	Lack of legal mandate
SWB ^b	National	Annually	CSO	Insufficient sample size – risks re-identification
Gross income or gross product per capita (GNI, GNP equivalents) ^c	Regional	Annually	CSO	Insufficient sample size – risks re-identification
Ecological footprint relative to biocapacity ^d	National	Annually	Ecological Footprint Initiative and Global Footprint Network	No domestic capacity – relies on global datasets with coarse assumptions
CCAC Adaptation Scorecard-based index ^e	National	Annually	CCAC	Further development of survey methodology needed
CO ₂ e emissions ^f	National	Quarterly (formerly annually)	EPA	Increased emissions modelling capacity needed
IUCN Red List (replacement for extinction rate) ^g	Disaggregated	6 yearly or more frequently	NPWS, NBDC and BirdWatch Ireland (partially citizen science based)	Limited talent pool of ecological consultants to support measurement
NPP or BHI ^h	–	–	Some supporting methodologies in development by Teagasc and EPA	Insufficient domestic capacity – relies on global datasets with coarse assumptions
Surface water and groundwater nitrogen and phosphorus ⁱ	Site based	Varied, often one or more times per year	EPA	Additional research on attribution to sources needed
Land cover shares relative to target ^j	–	–	Coverage known, but targets require coordination between several groups	Multi-stakeholder agreement on land cover targets needed
PFAS levels in surface water and groundwater ^k	Site based	Varied for surface water, 6 yearly for groundwater	Increasing monitoring since 2020, plus some prior one-off studies	Transparency on PFAS records and increased frequency of monitoring needed

GPI is an overall indicator, grey-shaded indicators are domain summary indicators, and the remaining indicators are planetary boundary indicators.

^aNorton *et al.* (2016); Parker *et al.* (2016); Stout *et al.* (2023); CSO (2024f); Ní Dhúill and Sheehy (2024).

^bWall (2013); O'Brien (2018); Department of the Taoiseach (2023, 2024); CSO (2024j,k).

^cCSO (2024j).

^dDworatzek *et al.* (2024).

^eCCAC (2024).

^fNielsen *et al.* (2020); EPA (2024f,g,h,j).

^gNational Parks & Wildlife Service (2020); National Biodiversity Data Centre (2024b).

^hSaunders *et al.* (2022); Fenton *et al.* (2024); Teagasc, Environmental Protection Agency and Cranfield University (n.d.).

ⁱHannigan and Kelly-Quinn (2016); EPA (2024b).

^jTailte Éireann and Environmental Protection Agency (2023).

^kUisce Éireann (2016); EPA (2022, 2023b, n.d.).

–, missing data.

a large-scale effort, followed by the development of another monitoring and updating framework.

3.5.1 Feasibility scenario analyses used at present

A key element of effective land use policy is assessing whether current land use patterns align with the

environmental, economic and socio-economic needs of today and the future. In Ireland, land use plays a critical role in addressing climate goals, biodiversity conservation, food security and rural economic stability. Land use efficiency is essential for ensuring the viability of key sectors, including agriculture, forestry and renewable energy production. Socio-economic challenges, such as improving incomes

Table 3.2. Status of data collection: Tier III

Indicator	Scale	Frequency	Agency/entity	Barrier
Air				
Air NH ₃ ^a	National	Annually	EPA and Teagasc	Increased production modelling capacities needed
Air CH ₄ ^b	National	Annually (quarterly as part of CO ₂ e)	EPA and Teagasc	Increased production modelling capacity needed
AQI ^c	115 sites	Continuously	EPA	Additional research on attribution to sources needed
Biodiversity				
Species richness ^d	Sightings	Continuously	NBDC via citizen science continuous entries	Development of statistical methods to address selection bias needed
Macroinvertebrate index on rivers ^e	Site-based (~4500) surveys but limited and focused on ecological status of water, not on biodiversity	Varied, often one or more times per year	EPA, related work by Inland Fisheries Ireland	Additional data collection on species to measure biodiversity needed
IUCN Red List status – disaggregated ^f	Mixed	6 yearly or more frequently	NPWS (habitat- or species-based infrequent reports) and NBDC (citizen science-based species reporting)	Limited talent pool of ecological consultants to support measurement
BI ^g	–	–	One-time global estimates (not domestically produced)	No domestic capacity nor repeated global estimates
Climate change				
Carbon intensity of land use ^h	National	Quarterly	EPA	Increased emissions modelling capacity needed
Climate Adaptation Action Plan implementation ⁱ	Local government	Annually (not yet available)	Department of Climate, Energy and the Environment	Expansion of work that is in development needed
Government preparedness for climate change (survey based) ^j	–	–	Could be appended to existing CSO survey efforts	Requires methodological development and perhaps a reporting requirement
Production				
Agricultural yield (per hectare) ^k	Farm level	Annually	Teagasc	Insufficient sample size – risks re-identification
Timber production (forestry) ^l	National	Annually	DAFM	Insufficient sample size – risks re-identification
Urban employment as a proxy for urban land productivity ^m	Household	Quarterly	CSO	Insufficient sample size – risks re-identification
Industrial land productivity ⁿ	Household	Quarterly	CSO	Requires methodological development
Wetland ecosystem services ^o	–	–	Extent of wetlands measured; ecosystem services mostly unquantified	Requires substantial upscaling of research capacity
Grassland productivity ^p	Farms	Ongoing	Teagasc	Confidential data that would risk re-identification
Recreational land use (parks, conservation areas) ^q	Individual	Ongoing	Fáilte Ireland, Coillte and CSO	Expansion of collection to more locations needed

Table 3.2. Continued

Indicator	Scale	Frequency	Agency/entity	Barrier
Socio-economic attributes				
Discretionary income ^f	Household	Annually	CSO	Held as confidential, possibly sufficient
Employment in agriculture, forestry and other sectors ^g	Household	Quarterly	CSO	Insufficient sample size – risks re-identification
Access to services and infrastructure ^h	Household	5 yearly	CSO	Infrequent and limited in current collection scope
Water				
Soil health (organic matter levels) ^u	National requirement, likely supported by detailed mapping	Not yet – 3 yearly starting in 2026	Preliminary mapping is under way; CSO EAD reporting to start in 2026	Requires repeated mapping and an update mechanism
Soil erosion rate ^v	Site based (~2000)	Varied – one or more times per year	Some modelling completed; EPA measures indirectly as disaggregated estimates in water quality surveys	Additional research on attribution to sources needed
Soil				
Wastewater treatment efficiency ^w	Discharge point based	Annually (licensing)	EPA	Likely to be sufficient
WQI ^x	Site based (~2000)	Varied – one or more times per year	EPA	Additional research on attribution to sources needed
Surface water ecological status Q-value	Site based (~4500)	Varied – often one or more times per year	Surface water ecological status Q-value	Likely to be sufficient

Indicators are grouped based on their connection to air, biodiversity, climate change, production, socio-economic attributes, water and soil, respectively.

^aNielsen *et al.* (2020); Owusu-Twum *et al.* (2024).

^bO'Brien and Shalloo (2019); Nielsen *et al.* (2020); EPA (2024e,g,j).

^cEPA (2024a).

^dNational Biodiversity Data Centre (2024b); National Parks & Wildlife Service (n.d.).

^eEPA (2020, 2024n); Inland Fisheries Ireland (2024a,b).

^fNational Parks & Wildlife Service (2020).

^gHudson *et al.* (2014); Phillips *et al.* (2021).

^hEPA (2024d,f,k).

ⁱAs an expansion of CCAC (2024).

^jNo current capacity, but could conceptually be attached to existing CSO collections, such as CSO (2024k).

^kTeagasc (2024a,b).

^lCSO (2023c); DAFM (2024).

^mCSO (2020).

ⁿCSO (2020, 2024i); O'Driscoll *et al.* (2023).

^oWetland Surveys Ireland (2024).

^pTeagasc (2021).

^qCoillte (2021); Department of Rural and Community Development (2022).

^rCSO (2024b,d).

^sCSO (2024h).

^tCSO (2019a,b, 2024a); National Transport Authority (2024).

^uEU (2011); Geological Survey Ireland (2024a,b); Geological Survey Ireland and Teagasc (2024).

^vKiely *et al.* (2014); Eurostat (2020); EPA (2024n); Joint Research Centre – European Soil Data Centre (2024).

^wEPA (2017, 2024n).

^xEPA (2024c).

–, missing data.

and quality of life, also require a strategic approach to land use planning, particularly in rural areas. Both production and socio-economic outcomes depend heavily on a stable environmental base, and, conversely, the state of nature depends on how we manage it. However, the existing distribution of land across agriculture, forestry, wetlands and other areas does not necessarily reflect the ideal distribution for making progress towards Ireland's many competing objectives. The Land Use Evidence Review highlighted the need for greater alignment between practice and targets, and we have identified a streamlined set of indicators for efficient monitoring and the current state of data collection for those indicators.

With indicators in hand, ideally the next step would be to use them in scenario analyses – projecting how different land use strategies may influence environmental, economic and socio-economic outcomes. However, our case study in this section finds that data collection and availability in Ireland is insufficient (as summarised in Tables 3.1 and 3.2). Additionally, sufficient data availability would need to be followed by the application of advanced modelling techniques to arrive at projections under different scenarios that can be considered reliable.

Discussions with land use modellers have underscored that, while scenario planning is entirely feasible, it demands significant financial investment and labour-intensive research efforts. Replication of the Natural Environment Valuation tool (Land, Environment, Economics and Policy Institute, 2019), for example, could form the basis of a forward-looking model. In its present form, application of the tool involves an interdisciplinary team of 10 researchers and it would need to be expanded further to include a wider set of indicators as we have proposed.¹⁶ As another example, the SeQUEsTER project (Styles *et al.*, 2024), with a team of six researchers, modelled land use impacts on greenhouse gas emissions and removals in Ireland. Some capacity is already under development in Ireland for studying land use's contribution towards carbon budgets (McGuire *et al.*, 2020; Daly *et al.*, 2024). Modelling based on these efforts should also inform Phase 2 of the Land Use Evidence Review. Given the data constraints and investment in staff and resources required to conduct meaningful scenario analyses, this report highlights that such needs must be addressed before meaningful projections can be made. The importance of building institutional capacity to support land use forecasting cannot be overstated, as it remains a crucial gap in Ireland's current land use planning framework, in addition to insufficient data collection.

¹⁶ Number of researchers based on interviews with Natural Environment Valuation tool team members.

4 Discussion

Our integrated assessment framework focuses on selecting insightful indicators to capture land use impacts across production, socio-economic and environmental domains. These indicators provide an overview of overall status while identifying specific issues. The framework is a starting point for developing a detailed “shopping list” of data requirements, unconstrained by current data availability. Rather than allowing existing data to bias the selection of indicators, we first identified the metrics most relevant for providing meaningful insights into land use changes. However, practical challenges, such as data accessibility and collection costs, remain critical considerations. Advances in technology, such as remote sensing, data analytics and artificial intelligence, may enhance the feasibility and affordability of data collection. However, moving towards implementation should include comparing alternatives in terms of costs versus information substitutability.

Notably, many proposed indicators overlap with existing collection needs, presenting opportunities for government agencies such as the CSO, NPWS and EPA to collaborate on data collection to meet diverse stakeholder needs efficiently. However, when we contrast the proposed framework with current data availability, we find that critical gaps exist. In some cases, potential substitutes may exist for data that are limited, and using such substitutes would enable the use of a least-cost approach without substantially compromising the integrity of the assessment. Many indicators were reviewed but ultimately excluded from the integrated framework to ensure a minimal yet sufficient selection that balances insight with practicality and cost. The chosen indicators aim to effectively estimate conditions on the ground without imposing unnecessary financial burdens. Some indicators, such as the Living Planet Index, Aerosol Optical Depth indicator and marine-related metrics, were excluded later in the assessment despite their potential relevance to pressing issues. These were deemed insufficiently connected to land use or likely to yield limited returns relative to the research investment required. Further details on the rationale for these exclusions are provided in Appendix 1.

In developing our assessment framework, we evaluated the adequacy of current land use and land cover data collection efforts. Our approach began by envisaging an assessment system free from the constraints of existing data limitations and collection costs, allowing us to construct a framework that reflects true information needs. CORINE datasets have provided a valuable means of assessing LULUCF to date within the EU. However, its 6-year reporting intervals contrast with the more frequent annual or quarterly updates typical for social, environmental and industrial data, limiting its applicability for timely decision-making. However, with the end of CORINE land cover data collection approaching, its replacement, CLCPlus, should provide improvements in both frequency – increasing to a 3-year interval – and the resolution of subsequent mapping. Recent land cover mapping detail has already advanced substantially as in the national land cover map produced based on 2018 CORINE data collection combined with other data sources and improved methodologies (Tailte Éireann and Environmental Protection Agency, 2023). Additional advancements are being piloted in Phase 2 of the Land Use Evidence Review.

Advancements in remote sensing, including the integration of electro-optical satellite imagery with machine learning-supported classification, aerial collection and perhaps light detection and ranging scanning – increasingly available as a paid service from Tailte Éireann (2026) – also offer promising avenues for updating LULUCF datasets. Such geospatial innovations now enable the mapping of crop types, facilitating higher-resolution land use monitoring as in the most recent land cover mapping (Tailte Éireann and Environmental Protection Agency, 2023). In Ireland, the work of Geological Survey Ireland and cross-agency collaboration in relation to GeoHive and Tailte Éireann datasets further support the integration of diverse LULUCF data sources. However, current capacities fall short of meeting the specific information needs of this framework. Key to linking land use changes to outcomes will be efforts to reduce the reliance on less periodic measurements. Future geographic information system expansion,

including higher-frequency imagery analysis or another framework for updating, will be critical in closing key gaps in land use and cover monitoring.

It is important to note that the relationships between land use changes and the proposed indicators are often indirect and may take extended periods to manifest. Consequently, monitoring changes in these indicators should be understood as indicative of policy influence rather than causal proof of outcomes. Direct and indirect policy effects further complicate attribution, making it difficult to isolate land use changes without dedicated causal inference-based studies. Broader social and environmental policies may also influence land use indirectly, reinforcing the need to interpret relationships between indicators as correlational rather than causal. Given these complexities, we have chosen indicators that appear most promising for identifying outcome changes due to land use shifts. However, when the magnitude of expenditure on a land use policy or project is particularly large, i.e. when the stakes are high, we would instead suggest incorporating specialised assessment, as establishing causal connections requires focused research.

Another consideration is the asymmetry of gains and losses in interpreting indicator changes. Drawing from prospect theory (Kahneman and Tversky, 1979), we recognise that losses are often perceived as more significant than equivalent gains. This complicates the process of weighting indicators, as applying equal weighting to gains and losses would not reflect the subjective value that society might place on different outcomes. For example, tensions between conservation efforts and productive land uses highlight how certain losses may be considered more severe than corresponding gains. Moreover, the current framework will not fully capture societal preferences regarding opposition or support for specific land use policies or related outcomes. In a more optimised framework, public sentiment would influence subjective weightings, prioritising indicators aligned with public concerns and policy priorities.

Additionally, it is essential to remember that marginal changes in many indicators can generate substantial public value. Incremental improvements or declines in these indicators, rather than long-term attainment of targets, are often the focus of public interest and policy action. Like economic growth or inflation rates, these indicators should be continuously monitored in their

marginal change or growth forms to provide insights into the effectiveness of land use policies and their impacts on societal and environmental outcomes.

Our case study reveals that some relevant data supporting the suggested indicators are already being collected in Ireland. Key sources include the CSO and EPA, supplemented by contributions from organisations such as the NBDC, BirdWatch Ireland, Teagasc, Geological Survey Ireland and the CCAC. However, the fragmented nature of these data sources – each with differing mandates and resource capacities – creates obstacles to understanding production, socio-economic and environmental outcomes as a whole. The challenges in identifying these sources and accessing sufficiently granular data highlight the urgent need for improved data centralisation and accessibility. The absence of a harmonised, accessible database hinders effective decision-making, progress monitoring and policy evaluation, underscoring the importance of streamlining data systems. A central land data hub would combine the data collection efforts of many government agencies, such as those involved in the Land Use Evidence Review, and the CSO may be a suitable administrative host given its role as the national statistics office. For the collection of some data, contractual obligations may need to be put in place.

During the course of our review, we find that a substantial amount of relevant information has been collected by separate groups in Ireland. However, the availability and accessibility of those data are often constrained – frequently condensed into publicly available national statistics without a clear path being provided to more granular data access. National agencies in Ireland frequently report estimates on critical topics, but providing detailed sources of underlying information and methodologies would benefit end users. At a minimum, statistics should include links to sufficient data to enable replication of analyses, aligning with modern research standards for transparency and replicability. However, we find that agencies rarely provide adequate contact information for data creators, relying instead on generic points of contact with no clear responsibility for the data. While the CSO generally offers accessible methodological details, this information can sometimes be disconnected from the statistics themselves. For instance, graphics or tables may simply cite “CSO

Ireland” as a source without any links to the underlying data being provided or the collection process being explained. Greater integration of methodologies with reported data would significantly enhance usability and reliability and support the government’s goal of increasing the use of open data in line with the Open Data Strategy (Department of Public Expenditure, NDP Delivery and Reform, 2023).

In several instances, we find that relevant data are being collected, but, most likely due to concerns over small sample sizes, are only reported on the national scale. This has led to data that are insufficiently granular to link to land use policy changes or inform local decision-making. The issue often lies not in data collection itself but in the limited dissemination of more detailed estimates. As an opposing consideration, care must be taken to ensure that combining datasets does not lead to the re-identification of individuals. Such precautions must be in keeping with protections under the General Data Protection Regulation (GDPR). Ensuring that privacy concerns do not become an unnecessary barrier to data utility will require a balance between accessibility and responsible data governance.

In other cases – particularly in environmental reporting – substantial one-off collection efforts have been undertaken, sometimes at highly granular scales. These efforts have often provided novel snapshots of conditions in Ireland to address specific questions or concerns. However, incorporating such research into an assessment model requires transitioning to a recurring collection and reporting framework. Achieving this would benefit from an institutional shift towards funding long-term monitoring networks rather than favouring innovative but one-off collections.

Significant knowledge gaps also persist, as summarised in Tables 3.1 and 3.2. Addressing some, such as the development of GPI, would require developing a new research agenda. Similarly, the EFBA, NPP and BHI indicators need to be derived from disaggregated, Ireland-specific estimates rather than globally calibrated remote-sensing-based metrics. Achieving this will require extensive initial fieldwork and a framework for updating estimates to account for land use changes and other factors, such as global climate change.

Beyond specific gaps, data collection efforts are often fragmented across separate initiatives.

Were these efforts to be combined under a dedicated initiative, they could yield more actionable information. However, in many cases, data collection is still in its infancy. The inadequacy of data collection is well documented, with concerns underscored by initiatives like the commissioning of the Land Use Evidence Review. Implementation should address these gaps by estimating the costs of collecting missing data and exploring indicator substitutability to balance cost-effectiveness with quality. Advances in technology, such as remote sensors for the collection of NPP data, data analytics and artificial intelligence, have the potential to significantly enhance the feasibility and affordability of data collection compared with past efforts.

Revising and expanding small-scale efforts, such as the CCAC’s scorecard framework, will be necessary for transforming them into more efficient, quantitative assessments. A complementary approach could include surveying public perceptions of preparedness, which is not currently done but could be integrated into existing surveys. Additionally, the nascent effort towards natural capital accounting across the EU, including in Ireland, shows promise but will require significant initial investment. Establishing robust standards and a framework for ongoing monitoring and updates would necessitate a large-scale coordinated effort.

Another challenge lies in the natural scale of data, which is often incompatible with the needs of land use assessment. For instance, water data are organised by catchment and sub-catchment, complicating their integration with other datasets. The attribution of pollutants is further complicated by their movement across the landscape via air or water, making it difficult to identify their points of origin. Additionally, the pace of change in land use practices and outcomes will remain an issue. Substantial lag times in land use change may not align with practical policy cycles, and expectations of rapid change must be tempered to match physiological limitations.

Finally, data collection in Ireland is often driven by legal requirements, typically following the enactment of legislation that responds to changes in EU mandates. As a result, substantial delays have occurred between legislative changes and data availability. In some cases, such as with the GPI, legislative efforts to mandate data collection have failed to be adopted

(Houses of the Oireachtas, 2017, 2020). Ideally, a more streamlined process could be established for transitioning from concept to collection more efficiently. However, any such revision must continue prioritising concerns regarding data ownership, security and trust, while ensuring compliance with GDPR standards.

4.1 Recommendations for Structural Change

Targeted structural reforms are recommended at multiple levels to address impediments to implementation. This section outlines targeted and actionable recommendations for institutional reforms, policymakers, agencies and researchers, and they are, therefore, considered the next priority steps for assessing land use in Ireland. The recommendations are structured hierarchically. First, institutional reforms that would impact all levels are recommended, followed by recommendations for policymakers, agency-level implementation and, finally, researchers.

4.1.1 Recommendations for institutional change

Institutional-level recommendations refer to broad, system-wide reforms. These recommendations focus on addressing foundational constraints such as fragmented collection and reporting and, in general, on improving coordination. Recommendations are explicitly in terms of the assessment framework but may also support other research endeavours as good practices:

- Shift from one-off reporting to longitudinal monitoring, with data being available via a central land use hub. Funding models should prioritise consistent, repeated data collection over novel one-time studies.
- Place a greater focus on maximising transparency and enabling open access within GDPR and other protection requirements.
- Nominate a national land use monitoring authority. A dedicated agency or interdepartmental body, arising from the Land Use Evidence Review Committee, could coordinate land use and outcome data collection and collation. Its mandate should include ensuring inter-agency coordination in relation to ensuring data sufficiency and collection efficiency.
- Develop a centralised data repository hosted by the CSO, potentially. A national, publicly accessible database should consolidate multiple agencies' land use and outcome data. The nominated authority should control access policies, ensuring maximum transparency within GDPR constraints.
- Establish a shared vision of land use policy goals, which would need to be decided on by a national land use monitoring authority. A multi-stakeholder agreement should define target land use shares on granular scales, ensuring coordinated land use governance across sectors and jurisdictions. Progress towards implementing this recommendation will hopefully be evident in Phase 2 of the Land Use Evidence Review.

4.1.2 Recommendations for policymakers

Policymakers mandate collection requirements and funding availability. As such, the following actions would help policymakers enable movement towards a functional assessment framework:

- Ensure that the regular collection of recommended indicators is mandated on sufficiently granular scales. Some, such as the GPI, may require separate legislative efforts.
- Consider whether a legislative basis is needed to build national capacity for data collection. Some indicators, such as EFBA and NPP metrics, lack a mandate to build domestic capabilities. Others related to existing biodiversity monitoring will require expansion of current capacities to enable more frequent monitoring. It is unclear whether such expansions would require a legislative basis but one is emerging through the EU's Nature Restoration Law and Member State requirements to develop nature restoration plans. Increased biodiversity monitoring will also require increasing the number of specialist ecological conservation consultants on which reporting relies. Developing the specific workforce may also require a policy intervention.
- As an alternative to national collection, consider whether county- and community-level data collection mandates and citizen science initiatives (e.g. by the NBDC) might better inform local policy decisions. However, data should also be centrally

stored and accessible nationally to ensure broad accessibility.

- Ensure legislative support for data sharing. Introduce legal provisions that push for transparency and data availability to the public within the constraints of GDPR and proprietary concerns.

4.1.3 Recommendations for agencies

Government and non-governmental agencies are responsible for implementing policies, collecting data and ensuring efficient reporting systems. These recommendations aim to improve the operational capacity of agencies in terms of land use and related outcomes monitoring:

- Ensure statistical transparency. Each statistic or graphic on which decision-making might be based should be directly linked to its supporting data and a description of its derivation. This could occur through more widespread implementation of the Irish Statistical System Code of Practice and European Statistics Code of Practice (CSO, 2013; European Statistical System Committee, 2017). Contact information for responsible parties should be specific, allowing for immediate follow-up on methodology, updates and clarifications.
- Increase the granularity of data collection and availability. Move from broad national- and regional-level statistics to local-level reporting. Within the confines of existing collection requirements, consider whether fewer statistics collected with larger sample sizes might better inform decision-making through the availability of more granular data. Ensure that data are then reported to the extent that GDPR restrictions allow on an area-by-area basis. This could be monitored by the suggested national land use monitoring authority.
- Enhance institutional capacity for complex indicator development such as GPI estimation, domestic development and calibration of existing international estimates, as well as the attribution of point sources of pollution based on data perhaps already collected.

4.1.4 Recommendations for researchers

Researchers play a key role in developing methodologies, addressing data gaps and developing tools that improve the quality, relevance and appropriateness of land use and outcome data. However, researchers must work within the institutional frameworks in place and as such are limited in the actions they can take. However, some recommendations emerge:

- Advance methods for measuring currently untracked indicators. Focus research efforts on indicators that lack domestic or granular measurement.
- Conduct cost-benefit analyses of alternative data collection methods. Evaluate whether citizen science initiatives, private sector partnerships and/or appending new indicator collection to existing efforts might be more efficient than developing entirely new collection efforts.
- Expand forecasting and scenario modelling. While greenhouse gas emission models are well established, similar predictive tools should continue to be expanded to include socio-economic and production outcomes linked to land use changes.
- Enhance engagement with local governments and other stakeholders. Strengthening collaboration between researchers, policymakers, local communities and industry ensures that research outputs are grounded in practical realities and directly inform decision-making.

4.2 Addressing Specific Indicator Shortcomings

The effective assessment of land use change and its corresponding impacts most likely requires prioritising some improvements over others, and four different approaches on how to prioritise emerge depending on how we value shortcomings:

1. Prioritising an overarching measure of welfare, making incremental improvements by focusing on “low-hanging fruit”, ensuring a basic level of diagnostic capacity for each Tier III focus, and ensuring that land use and land cover monitoring is itself sufficient warrant consideration.

2. Updating land use and land cover data on a 6-year cycle – soon to be a 3-year cycle under CLCPlus – and a time lag between data collection and publication do not match well with the more frequent and timely monitoring of environmental, production and socio-economic outcomes. This limits both our capacity to understand the linkages between land use and outcomes and our ability to respond to challenges in a timely manner. This recommendation is foundational because, without timely land use data, the ability to link land use changes to outcomes is limited.¹⁷
3. Alternatively, prioritising GPI as our Tier I indicator has benefits beyond land use policy, as it would support shifting the focus of economic policy from GNI towards this more holistic measure of welfare. While GPI is conceptually appealing, its measurement is challenging, as this requires collecting and integrating data on economic, environmental and social factors. As such, efforts to mandate collection are likely needed but are yet to be successful.
4. Focusing on the most incremental of improvements – the low-hanging fruit – has some financial advantage. This involves choosing to improve collection based on the least cost and consequently would most likely focus on bolstering existing collection and reporting. For example, additional data collection by the CSO on the determinants of SWB is a relatively cost-effective means of summarising the net effect of many factors. It may also be cost-effective to survey experts on ecosystem resilience and government departments on national climate change preparedness. As another alternative, ensuring minimal indicator coverage provides some practical, immediate benefits. This could be guided by ensuring that each Tier III level group has at least one functional indicator. However, some risk would remain in that single indicators

for each group would miss important changes in Ireland and, additionally, would not provide an overall picture of welfare. Yet, this approach would provide a basic level of diagnostic capacity and be informative on where monitoring is insufficient.

Among the four proposed approaches presented above, we suggest that ensuring frequent land use and land cover monitoring is the highest priority, as it underpins all other indicators. We would recommend, as a default position, focusing on incremental improvements in data collection in the near term, while laying the groundwork for more comprehensive collection over time.

Our suggested prioritisation of specific indicator collection improvements is as follows:

- Improve land use and land cover monitoring frequency.
- Focus on incremental improvements (low-hanging fruit) through improving collection, attribution and data availability for existing indicators, as outlined in Tables 3.1 and 3.2, e.g. cost-effective expert surveys and extension of SWB surveys.
- Ensure that every Tier III group has at least one functional indicator.
- Develop long-term domestic capacities to monitor GPI, EFBA, NPP and other insufficient indicators.
- Expand predictive modelling capacity once sufficient data collection exists to form a basis for it.

Despite clear challenges, the framework is not far from reaching full functionality. However, achieving this will require structural changes, coordinated planning and resource expansion. Even if pursued incrementally, substantial progress could be made within the decade. However, full-scale implementation, including predictive scenario modelling, will require sustained progress.

¹⁷ Within a specific targeted indicator, e.g. on forestry, analyses could also be based on forest mapping rather than full land use mapping. However, the capacity to conduct an assessment on how forests interact with other land uses would be lost and therefore this is a second-best option.

5 Conclusion

Through this review, we have identified a set of 36 indicators that we organise into a three-tier framework to monitor the impact of land use policy changes on environmental, socio-economic and production outcomes. These indicators track the productivity and sustainability of land use-intensive production sectors and the creation of ecosystem services; socio-economic outcomes related to general well-being and influenced by land use; ecosystem and biodiversity impacts and capacities; and long-term sustainability (adaptation and planning for future challenges). We then assessed the status of relevant data collection. The two processes were kept separate – identifying indicators, then identifying their feasibility at present in our Irish case study – to avoid having data availability guide indicator selection. The framework balances our capacity to draw actionable insights about land use impacts against the feasibility of implementation.

Our case study in Ireland reveals both strengths and challenges in the current data landscape. Some of the data required to estimate the recommended indicators are already being collected. In some instances, significant revisions to existing efforts will be necessary to align data collection with the proposed framework, while in other cases no relevant data collection activity is currently in place. This highlights a critical gap in moving from conceptual design to practical implementation. Particularly concerning is the fact no data appear to be collected for certain indicators in Ireland, underscoring the urgent need for coordinated efforts to build capacity.

Looking forward, cost-effective and adaptable monitoring approaches will be critical. As new data become available, advances in research on shadow prices and marginal benefits can be made, and, as policy priorities shift, the framework should be refined, expanded or revised accordingly. Flexibility is particularly crucial given future uncertainties surrounding global climate change and its implications for land use. To ensure the effective monitoring of land use changes, we also recommend the nomination of an organisation or entity with a clear mandate to coordinate data collection and analysis. This body would need to integrate data from separate agencies and influence future collection to address gaps. However, the fragmented nature of Ireland's current data collection system presents significant challenges to creating such capacity.

In conclusion, developing a minimally sufficient set of indicators that balances comprehensiveness with practicality is essential for monitoring the impacts of land use change effectively. This review details one approach to creating a framework for assessing the socio-economic, environmental and production outcomes resulting from land use policy adjustments. While the current capacity to implement such a framework in Ireland may be limited, this work sets the stage for a substantially greater effort. Establishing a robust, adaptable monitoring system may require a coordinated effort, national investments and perhaps ongoing refinement to ensure that land use policies are both sustainable and responsive to future challenges.

References

- AI2Peat, 2025. AI2Peat – All-Ireland, AI-enhanced Peatland Monitoring Platform. Available online: <https://ai2peat.ie/> (accessed 30 April 2025).
- Arnold, S., Kosztra, B., Banko, G., Milenov, P., Smith, G., Hazeu, G., Bock, M., Caetano, M., Perger, C. and Mancosu, E., 2023. *Explanatory Documentation of the EAGLE Concept Version 3.2*. EIONET Action Group Land Monitoring in Europe (EAGLE), European Environment Agency, Copenhagen, Denmark.
- Atkinson, A.B., 1970. On the measurement of inequality. *Journal of Economic Theory*, 2(3): 244–263.
- Barrington-Leigh, C. and Escande, A., 2018. Measuring progress and well-being: a comparative review of indicators. *Social Indicators Research*, 135(3): 893–925.
- Baumgärtner, S., Klein, A.M., Thiel, D. and Winkler, K., 2015. Ramsey discounting of ecosystem services. *Environmental & Resource Economics*, 61(2): 273–296.
- Berik, G., 2020. Measuring what matters and guiding policy: an evaluation of the Genuine Progress Indicator. *International Labour Review*, 159(1): 71–94.
- BirdWatch Ireland, 2024a. Countryside Bird Survey: monitoring Ireland's breeding countryside birds. Available online: <https://birdwatchireland.ie/our-work/surveys-research/research-surveys/countryside-bird-survey/> (accessed 20 February 2025).
- BirdWatch Ireland, 2024b. Irish Wetland Bird Survey: monitoring wintering waterbirds in Ireland. Available online: <https://birdwatchireland.ie/our-work/surveys-research/research-surveys/irish-wetland-bird-survey/> (accessed 20 February 2025).
- Block, S., Emerson, J.W., Esty, D.C., de Sherbinin, A., Wendling, Z.A., Kurczynski, K., Lin, F., Xu, C., Wu, N., Harwood, J. et al., 2024. *Environmental Performance Index 2024*. Yale Center for Environmental Law & Policy, Yale University, New Haven, Connecticut, USA.
- Bord na Móna, 2024. *Enhanced Decommissioning, Rehabilitation and Restoration Scheme (EDRRS): Annual Monitoring and Verification Report EDRRS Year 2 (April 2022 to March 2023)*. Available online: https://www.bnmpcas.ie/wp-content/uploads/sites/18/2024/08/Annual-Monitoring-Report_2023_Final_Redacted.pdf (accessed 14 January 2026).
- Boyd, J. and Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63(2): 616–626.
- Buckley, C., Krol, D., Lanigan, G., Donnellan, T., Spink, J., Hanrahan, K., Boland, A., Forrestal, P., Humphreys, J., Murphy, P. et al., 2020. *An Analysis of the Cost of the Abatement of Ammonia Emissions in Irish Agriculture to 2030*. Teagasc, Oak Park, Carlow, Ireland.
- Bullock, C., Kretsch, C. and Candon, E., 2008. *The Economic and Social Aspects of Biodiversity: Benefits and Costs of Biodiversity in Ireland*. Department of the Environment, Heritage and Local Government, Government of Ireland, Dublin, Ireland.
- Büttner, G., Kosztra, B., Maucha, G., Pataki, R., Kleeschulte, S., Hazeu, G., Vittek, M., Schröder, C. and Littkopf, A., 2021. *Copernicus Land Monitoring Service – CORINE Land Cover User Manual*. Copernicus Land Monitoring Service, European Environment Agency, Copenhagen, Denmark.
- Casey, E. and Carroll, K., 2023. *What Climate Change Means for Ireland's Public Finances*. Irish Fiscal Advisory Council, Dublin, Ireland.
- CCAC (Climate Change Advisory Council), 2023. *Final Report: Adaptation Scorecard Workshop*. CCAC, Dublin, Ireland.
- CCAC (Climate Change Advisory Council), 2024. *Fourth Climate Change Adaptation Scorecard Report*. CCAC, Dublin, Ireland.
- CIEEM Ireland Policy Group, 2024. *Biodiversity Net Gain in Ireland*. Chartered Institute of Ecology and Environmental Management, Ampfield, UK.
- Coillte, 2021. Visitor numbers triple to Coillte's local forests during Covid lockdown. Available online: <https://www.coillte.ie/visitor-numbers-triple-to-coilltes-local-forests-during-coivd-lockdown/> (accessed 20 February 2025).
- Council of the European Union, 2025. Soil Monitoring Law: Council reaches deal with Parliament. Available online: <https://www.consilium.europa.eu/en/press/press-releases/2025/04/10/soil-monitoring-law-council-reaches-deal-with-parliament/> (accessed 14 January 2026).
- CSO (Central Statistics Office), 2013. Irish Statistical System Code of Practice (ISSCOP). Available online: <https://www.isscop.ie/> (accessed 25 April 2025).

- CSO (Central Statistics Office), 2019a. Measuring distance to everyday services in Ireland: background and methodology. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-mdsi/measuringdistancetoeverydayservicesinireland/backgroundandmethodology/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2019b. Regional SDGs Ireland 2017. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-rsdgi/regionalSDGsireland2017/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2020. Urban and rural life in Ireland: URA19 – persons age 15 years and over in employment. Available online: <https://data.cso.ie/table/URA19> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2021. Household environmental behaviours – visits to nature areas quarter 3 2021. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-hebna/householdenvironmentalbehaviours-visitsstonatureareasquarter32021/> (accessed 27 April 2025).
- CSO (Central Statistics Office), 2023a. DEA08 – annual earnings. Available online: <https://data.cso.ie/table/DEA08> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2023b. Environmental indicators Ireland 2023. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-eii/environmentalindicatorsireland2023/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2023c. Roundwood Removals Survey. Available online: <https://www.cso.ie/en/methods/tn/roundwoodremovalssurvey/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2023d. Supply and use tables for Ireland 2020. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-sau/supplyandusetablesforireland2020/input-outputtables/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024a. Census. Available online: <https://www.cso.ie/en/census/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024b. County incomes and regional GDP archive 2021. Available online: <https://www.cso.ie/en/statistics/nationalaccounts/countyincomesandregionalGDP/countyincomesandregionalGDParchive2021/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024c. CSO's PxStat Open Data Platform. Available online: <https://data.cso.ie/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024d. Distribution of earnings by gender and county 2023: background notes. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-dea/distributionofearningsbygenderandcounty2023/backgroundnotes/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024e. Ecosystem accounts – grasslands and croplands 2000–2022. Available online: <https://www.cso.ie/en/releasesandpublications/fp/fp-eagac/ecosystemaccountsgrasslandsandcroplands2000-2022/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024f. Estimates of the capital stock of fixed assets. Available online: <https://www.cso.ie/en/statistics/nationalaccounts/estimatesofthecapitalstockoffixedassets/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024g. Household Budget Survey 2022–2023. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-hbs/householdbudgetsurvey2022-2023/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024h. Institutional sector accounts non-financial and financial – annual. Available online: <https://www.cso.ie/en/statistics/nationalaccounts/institutionalsectoraccountsnon-financialandfinancial-annual/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024i. Labour Force Survey. Available online: <https://www.cso.ie/en/methods/labourmarket/labourforcesurvey/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024j. Survey on Income and Living Conditions (SILC) 2023: background notes. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-silc/surveyonincomeandlivingconditionssilc2023/backgroundnotes/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024k. Survey on Income and Living Conditions (SILC): methods – social conditions. Available online: <https://www.cso.ie/en/methods/socialconditions/silc/> (accessed 20 February 2025).
- CSO (Central Statistics Office), 2024l. Well-being Information Hub. Available online: <https://www.cso.ie/en/releasesandpublications/hubs/p-wbhub/well-beinginformationhub/> (accessed 20 February 2025).
- DAFM (Department of Agriculture, Food and the Marine), 2023. *Ireland's Forest Strategy 2023–2030*. Government of Ireland, Dublin, Ireland.

- DAFM (Department of Agriculture, Food and the Marine), 2024. Forest statistics and mapping. Available online: <https://www.gov.ie/en/collection/15b56-forest-statistics-and-mapping/> (accessed 20 February 2025).
- DAFM and DECC (Department of Agriculture, Food and the Marine, and Department of the Environment, Climate and Communications), 2023a. *Land Use Evidence Review: Phase 1 Synthesis Report*. Government of Ireland, Dublin, Ireland. Available online: <https://assets.gov.ie/static/documents/land-use-evidence-review-synthesis-report.pdf> (accessed 14 January 2026).
- DAFM and DECC (Department of Agriculture, Food and the Marine, and Department of the Environment, Climate and Communications), 2023b. *Land Use Review Phase 1: Indicator Assessment*. Government of Ireland, Dublin, Ireland. Available online: <https://assets.gov.ie/static/documents/land-use-evidence-review-synthesis-report.pdf> (accessed 28 January 2026).
- Daly, H., Aryanpur, V., Suleimenov, B. and Deane, P., 2024. *Pathways for Ireland's Energy System to 2050: Modelling Analysis to Support the Climate Change Advisory Council on the Second Carbon Budget Programme*. Energy Policy and Modelling Group, University College Cork for the Climate Change Advisory Council. Available online: <https://www.climatecouncil.ie/media/CBWG%20Report%20TIMES-Ireland%20Model.pdf> (accessed 14 January 2026).
- Dasgupta, P., 2021. *The Economics of Biodiversity: The Dasgupta Review*. HM Treasury, London, UK.
- de Bruin, K., Kweku Kyei, C. and Henry, L., 2024. *Climate Change Impacts and Associated Economic Costs in Ireland*. ESRI Working Paper No. 788. Economic & Social Research Institute, Dublin, Ireland.
- De Rosa, M., 2018. Land use and land-use changes in life cycle assessment: green modelling or black boxing? *Ecological Economics*, 144: 73–81.
- DECC (Department of the Environment, Climate and Communications), 2022a. *Climate Action Plan 2023 (CAP23): Changing Ireland for the Better*. Government of Ireland, Dublin, Ireland.
- DECC (Department of the Environment, Climate and Communications), 2022b. *Ireland's Second National Implementation Plan for the Sustainable Development Goals 2022–2024*. Government of Ireland, Dublin, Ireland.
- DECC (Department of the Environment, Climate and Communications), 2024. *National Adaptation Framework: Planning for a Climate Resilient Ireland 2024*. Government of Ireland, Dublin, Ireland.
- Department of Housing, Local Government and Heritage, 2024. *Water Action Plan 2024: A River Basin Management Plan for Ireland*. Government of Ireland, Dublin, Ireland.
- Department of Public Expenditure and Reform, 2019. *Public Spending Code: Central Technical References and Economic Appraisal Parameters*. Government of Ireland, Dublin, Ireland.
- Department of Public Expenditure, NDP Delivery and Reform, 2023. *Open Data Strategy 2023–2027*. Government of Ireland, Dublin, Ireland.
- Department of Rural and Community Development, 2022. *Embracing Ireland's Outdoors: National Outdoor Recreation Strategy 2023–2027*. Government of Ireland, Dublin, Ireland.
- Department of the Taoiseach, 2023. *Understanding Life in Ireland: The Well-being Framework 2023*. Government of Ireland, Dublin, Ireland.
- Department of the Taoiseach, 2024. *Understanding Life in Ireland: The Well-being Framework 2024*. Government of Ireland, Dublin, Ireland.
- Diener, E., 1984. Subjective well-being. *Psychological Bulletin*, 95(3): 542–575.
- Diener, E., Oishi, S. and Lucas, R.E., 2015. National accounts of subjective well-being. *The American Psychologist*, 70(3): 234–242.
- DRMKC (Disaster Risk Management Knowledge Centre), 2024. DRMKC – INFORM. Available online: <https://drmkc.jrc.ec.europa.eu/inform-index> (accessed 20 February 2025).
- Drupp, M.A., Turk, Z.M., Groom, B. and Heckenhahn, J., 2024. Global evidence on the income elasticity of willingness to pay, relative price changes and public natural capital values. Available online: <https://doi.org/10.48550/arXiv.2308.04400> (accessed 14 January 2026).
- Duffy, C., Henn, D., Prudhomme, R. and Styles, D., 2024. GOBLIN Lite: a national land balance model for assessment of climate mitigation pathways for Ireland. *Journal of Open Source Software*, 9(100): 6732.
- Dworatzek, P., Miller, E., Lo, Kiona., Howarth, E. and Kazubowski-Houston, S., 2024. National ecological footprint and biocapacity accounts. Available online: <https://footprint.info.yorku.ca/data/> (accessed 20 February 2025).
- EnvEcon, 2015. *Air Pollutant Marginal Damage Values Guidebook for Ireland 2015*. EnvEcon Decision Support Series, Dublin, Ireland.

- EPA (Environmental Protection Agency), n.d. *Investigating PFAS from Source to Sink – Assessing Risk to Inform a PFAS Strategy in Ireland*. Available online: <https://www.epa.ie/our-services/research/epa-funded-research/epa-funded-projects/research-data-table-dev/investigating-pfas-from-source-to-sink---assessing-risk-to-inform-a-pfas-strategy-in-ireland.php> (accessed 28 April 2025).
- EPA (Environmental Protection Agency), 2017. Sewage treatment locations: discharge locations. Available online: <https://gis.epa.ie/EPAMaps/SewageTreatment> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2018a. CORINE Land Cover 2018. Available online: <https://data.gov.ie/dataset/corine-landcover-2018> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2018b. *Ireland's Update of National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2020. *River Monitoring – Aquatic Invertebrates*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2021a. *Final Report: Procurement and Processing of Environmental Samples for PFAS and BFR Analysis at Select Sites*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2021b. *Ireland's National Water Framework Directive Monitoring Programme, 2019–2021*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2021c. *Persistent Organic Pollutants, Landfill Leachate Sampling Study*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2022. *Water Quality in Ireland 2016–2021*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2023a. *Ireland's Climate Change Assessment: Synthesis Report*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2023b. *Ireland's Climate Change Assessment. Volume 3: Being Prepared for Ireland's Future Climate. Summary for Policymakers*. Available online: https://www.epa.ie/publications/monitoring--assessment/climate-change/ICCA_Volume-3-SPM.pdf (accessed 27 January 2026).
- EPA (Environmental Protection Agency), 2023c. *Ireland's National Water Quality Monitoring Programme 2022–2027*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024a. *Air Quality in Ireland Report 2023*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024b. WFD data and dashboards. Available online: <https://www.catchments.ie/wfd-data-dashboards/> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2024c. EPA geoportal. Available online: <https://gis.epa.ie/> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2024d. *Greenhouse Gas Emissions and Removals from Land Use, Land Use Change and Forestry*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024e. Greenhouse gas emissions (GHG): summary by gas. Available online: <https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/summary-by-gas/> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2024f. *Ireland's Greenhouse Gas Emissions Projections 2023–2050*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024g. *Ireland's National Inventory Submissions 2024: Greenhouse Gas Emissions 1990–2022*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024h. *Ireland's Provisional Greenhouse Gas Emissions 1990–2023*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024i. *Ireland's State of the Environment Report 2024*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024j. *Quarterly Greenhouse Gas Emissions Indicator Report: 2024 Quarter 1*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024k. Secure Archive for Environmental Research Data. Available online: <https://eparesearch.epa.ie/safer/> (accessed 20 February 2025).
- EPA (Environmental Protection Agency), 2024l. *The National Agricultural Inspection Programme: Summary Report 2023*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024m. *Urban Wastewater Treatment in 2023*. EPA, Johnstown Castle, Ireland.
- EPA (Environmental Protection Agency), 2024n. *Water Quality in 2023: An Indicators Report*. EPA, Johnstown Castle, Ireland.

- EPA (Environmental Protection Agency), 2025. EPA's assessments of water quality and agriculture. Available online: <https://www.epa.ie/environment-and-you/freshwater-and-marine/water-quality-and-agriculture/> (accessed 7 August 2025).
- EU (European Union), 1991. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. OJ L 135, 30.05.1991, p. 40–52.
- EU (European Union), 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJ L 206, 22.07.1992, p. 7–50.
- EU (European Union), 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. OJ L 327, 22.12.2000, p. 1–73.
- EU (European Union), 2003. Regulation (EC) No 1177/2003 of the European Parliament and of the Council of 16 June 2003 concerning community statistics on income and living conditions (EU-SILC). OJ L 165, 3.7.2003, p. 1–9.
- EU (European Union), 2011. Regulation (EU) No 691/2011 of the European Parliament and of the Council of 6 July 2011 on European environmental economic accounts. OJ L 192, 22.07.2011, p. 1–16.
- EU (European Union), 2016. Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. OJ L 344, 17.12.2016, p. 1–31.
- EU (European Union), 2020. Directive (EU) 2020/2184 of 16 December 2020 on the quality of water intended for human consumption (recast). OJ L 435, 23.12.2020, p. 1–62.
- EU (European Union), 2024a. Directive (EU) 2024/3019 of 27 November 2024 concerning urban wastewater treatment (recast). OJ L 2024/3019, 12.12.2024.
- EU (European Union), 2024b. Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869. OJ L 2024/1991, 29.7.2024, pp. 1–93.
- European Chemicals Agency, 2023. *Annex XV Restriction Report: Proposal for a Restriction on Per- and Polyfluoroalkyl Substances (PFASs)*. Available online: <https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea> (accessed 28 April 2025).
- European Chemicals Agency, 2024. *Report from Ireland on the Monitoring of the Implementation of Regulation (EU) 2019/1021 on Persistent Organic Pollutants (POPs Regulation)*. Available online: https://echa.europa.eu/documents/10162/16596982/report_pops_ie_en.pdf/f31f7f36-fa84-d599-6cd6-7f65b9aaf9cd?t=1667378478475 (accessed 1 May 2025).
- European Commission, 2018. *Adaptation Preparedness Scoreboard: Country Fiche for Ireland*. Available online: https://climate.ec.europa.eu/document/download/74ecaa3b-4352-45bd-a31a-06597dd3c96d_en?filename=country_fiche_ie_en.pdf (accessed 20 February 2025).
- European Commission, 2021a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “EU soil strategy for 2030: reaping the benefits of healthy soils for people, food, nature and climate”. COM(2021) 699 final, 17.11.2021, Brussels.
- European Commission, 2021b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “Forging a climate-resilient Europe – the new EU strategy on adaptation to climate change”. COM(2021) 82 final, 24.2.2021, Brussels.
- European Commission, 2022a. Factsheet – a greener and fairer CAP. European Commission, Brussels, Belgium.
- European Commission, 2022b. Proposal for a Directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration, and Directive 2008/105/EC on environmental quality standards in the field of water policy. COM(2022) 540 final, 26.10.2022, Brussels.
- European Commission, 2022c. Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) No 691/2011 as regards introducing new environmental economic accounts modules. COM(2022) 329 final, 11.7.2022, Brussels.
- European Commission, 2024a. Agri-food Data Portal. Available online: <https://agridata.ec.europa.eu/extensions/DataPortal/home.html> (accessed 5 October 2024).
- European Commission, 2024b. CAP 2023–27: dashboards and reports. Available online: https://agridata.ec.europa.eu/extensions/DataPortal/pmfef_indicators.html (accessed 20 February 2025).

- European Commission, 2024c. Farm economy focus. Available online: <https://agridata.ec.europa.eu/extensions/DashboardFarmEconomyFocus/DashboardFarmEconomyFocus.html> (accessed 20 February 2025).
- European Commission, 2026. Soil Monitoring Law. Available online: https://environment.ec.europa.eu/topics/soil-health/soil-monitoring-law_en#:~:text=The%20Soil%20Monitoring%20Law%2C%20which,Loss%20of%20soil%20biodiversity (accessed 27 January 2026).
- European Environment Agency, 2023. The Natura 2000 Protected Areas Network. Available online: <https://biodiversity.europa.eu/natura2000/en/natura2000> (accessed 26 January 2026).
- European Environment Agency, 2024. CLCplus Backbone 2021 (raster 10 m), Europe, 3-yearly, Jun. 2024. Available online: <https://sdi.eea.europa.eu/catalogue/srv/api/records/71fc9d1b-479f-4da1-aa66-662a2fff2cf7> (accessed 20 February 2025).
- European Statistical System Committee, 2017. *European Statistics Code of Practice: For the National Statistical Authorities and Eurostat (EU Statistical Authority)*. Publications Office of the European Union, Luxembourg.
- Eurostat, 2020. Agri-environmental indicator – soil erosion. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_soil_erosion (accessed 20 February 2025).
- Evans, D.J., 2005. The elasticity of marginal utility of consumption: estimates for 20 OECD countries. *Fiscal Studies*, 26(2): 197–224.
- Fáilte Ireland, 2024a. *Annual Visitor Attraction Survey: Analysis of 2023 Performance and Attendances*. Fáilte Ireland/National Tourism Development Authority, Dublin, Ireland.
- Fáilte Ireland, 2024b. Visitor numbers to attractions dashboard. Available online: <https://www.failteireland.ie/Research-Insights/Activities/visitor-numbers-to-attractions-dashboard.aspx> (accessed 20 February 2025).
- Feeley, H.B., Bradley, C., Free, G., Kennedy, B., Little, R., McDonnell, N., Plant, C., Trodd, W., Wynne, C. and Boyle, S.O., 2020. A national macroinvertebrate dataset collected for the biomonitoring of Ireland’s river network, 2007–2018. *Scientific Data*, 7(1): 280.
- Fenton, O., Bondi, G., Bracken, C.J., O’Sullivan, L., Lopez-Sangil, L., Tuohy, P. and Daly, K., 2024. Relative and absolute difference in soil organic carbon stocks in grassland soils in Ireland: impact of rock fragments, bulk density and calculation methods. *Geoderma Regional*, 36: e00769.
- Fernandez-Ugalde, O., Scarpa, S., Orgiazzi, A., Panagos, P., Van Liedekerke, M., Marechal, A. and Jones, A., 2022. *LUCAS 2018 Soil Module: Presentation of Dataset and Results*. Publications Office of the European Union, Luxembourg.
- Geological Survey Ireland, 2024a. Tellus. Available online: <https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/default.aspx> (accessed 20 February 2025).
- Geological Survey Ireland, 2024b. Terra soil. Available online: <https://www.gsi.ie/en-ie/programmes-and-projects/tellus/projects/terra-soil/Pages/default.aspx> (accessed 20 February 2025).
- Geological Survey Ireland and Teagasc, 2024. Maps: predicted total organic carbon percentage (TOC %). Available online: <https://www.gsi.ie/en-ie/programmes-and-projects/tellus/projects/terra-soil/Pages/Maps.aspx> (accessed 20 February 2025).
- Gethin, A., 2023. *Revisiting Global Poverty Reduction: Public Goods and the World Distribution of Income, 1980–2022*. Working Paper No. 2023/24. World Inequality Lab, Paris, France.
- Global Footprint Network, n.d. CLUM country package. Available online: <https://www.footprintnetwork.org/licenses/clum-country-package/> (accessed 20 February 2025).
- Gómez-Baggethun, E., de Groot, R., Lomas, P.L. and Montes, C., 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. *Ecological Economics*, 69(6): 1209–1218.
- Government of Ireland, 2021. Climate Action and Low Carbon Development (Amendment) Act 2021. Number 32 of 2021. Government of Ireland, Dublin, Ireland.
- Government of Ireland, 2024a. Future Ireland Fund and Infrastructure, Climate and Nature Fund Act 2024. Number 16 of 2024. Government of Ireland, Dublin, Ireland.
- Government of Ireland, 2024b. Ireland’s Open Data Portal. Available online: <https://data.gov.ie/> (accessed 20 February 2025).
- Government of the UK, 2021. Environment Act 2021, Schedule 14. The Stationery Office, London, UK.

- Grilli, G., Mohan, G. and Curtis, J., 2020. Public park attributes, park visits, and associated health status. *Landscape and Urban Planning*, 199: 103814.
- Groom, B. and Turk, Z., 2021. Reflections on the Dasgupta Review on the economics of biodiversity. *Environmental and Resource Economics*, 79(1): 1–23.
- Guillaumont, P., Wagner, L., Francis, T., Navoti, S., Schroderus-Fox, H. and Erdenebileg, S., 2021. *Multidimensional Vulnerability Index: Potential Development and Uses. Analysis and Recommendations*. United Nations, New York, USA.
- Hannigan, E. and Kelly-Quinn, M., 2016. *Characterisation of Reference Conditions for Rare River Types: A Literature Review*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Harrad, S., Drage, D., Sharkey, M. and Berresheim, H., 2020a. *Furthering Understanding of Emissions from Landfilled Waste Containing POP-BFRs and PFASs (FUEL)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Harrad, S., Drage, D., Abdallah, M., Wemken, N. and Coggins, M., 2020b. *Elucidating Levels and Pathways of Human Exposure in Ireland to Brominated Flame Retardants and Perfluoroalkyl Substances*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Harrad, S., Sharkey, M., Drage, D., Stubbings, W., Coggins, M. and Berresheim, H., 2023. *Persistent Organic Chemicals in the Irish Waste Stream*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Helliwell, J.F., Layard, R., Sachs, J.D., De Neve, J.-E., Akinin, L.B., Huang, H. and Wang, S. (eds), 2020. *World Happiness Report 2020*. Sustainable Development Solutions Network, New York, USA.
- Hoel, M. and Sterner, T., 2007. Discounting and relative prices. *Climatic Change*, 84(3–4): 265–280.
- Houses of the Oireachtas, 2017. *Genuine Progress Indicators and National Distributional Accounts Bill 2017*. Bill No. 96 of 2017. Houses of the Oireachtas, Dublin, Ireland.
- Houses of the Oireachtas, 2020. *Measuring Quality of Life in Ireland Bill 2020*. Bill No. 64 of 2020. Houses of the Oireachtas, Dublin, Ireland.
- Hudson, L.N., Newbold, T., Contu, S., Hill, S.L.L., Lysenko, I., De Palma, A., Phillips, H.R.P., Senior, R.A., Bennett, D.J., Booth, H. *et al.*, 2014. The PREDICTS database: a global database of how local terrestrial biodiversity responds to human impacts. *Ecology and Evolution*, 4(24): 4701–4735.
- Imhoff, M.L., Bounoua, L., Ricketts, T., Loucks, C., Harriss, R. and Lawrence, W.T., 2004. Global patterns in human consumption of net primary production. *Nature*, 429(6994): 870–873.
- Inland Fisheries Ireland, 2024a. *Inland Fisheries Ireland Summary Fish Counter Report 2023*. Inland Fisheries Ireland, Dublin, Ireland.
- Inland Fisheries Ireland, 2024b. *Sampling Fish for the Water Framework Directive: Summary Report 2023*. Inland Fisheries Ireland, Dublin, Ireland.
- Institute for Economics & Peace, 2023. *Ecological Threat Report 2023: Analysing Ecological Threats, Resilience & Peace*. Institute for Economics & Peace, Sydney, Australia.
- Institute for Economics & Peace, 2024. *Global Peace Index 2024: Measuring Peace in a Complex World*. Institute for Economics & Peace, Sydney, Australia.
- IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), 2019. *Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat, Bonn, Germany.
- IPCC (Intergovernmental Panel on Climate Change), 2023. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- ISSDA, 2026. Irish Social Science Data Archive. Available online: <https://issda.ucd.ie/> (accessed 30 January 2026).
- Joint Research Centre – European Soil Data Centre, 2024. *Erosion by water*. Available online: <https://esdac.jrc.ec.europa.eu/themes/erosion> (accessed 20 February 2025).
- Kahneman, D. and Tversky, A., 1979. Prospect theory: an analysis of decision under risk. *Econometrica*, 47(2): 263–291.
- Kaly, U.L., Pratt, C.R. and Mitchell, J., 2004. *The Environmental Vulnerability Index (EVI) 2004*. SOPAC Technical Report 384. South Pacific Applied Geoscience Commission, Suva, Fiji.
- Kavanagh, C. and Doyle, E., 2007. Human capital and productivity in the Irish context. In *Perspectives on Irish Productivity*. Forfás, Dublin, Ireland, pp. 297–314.

- Kelleghan, D.B., Tang, Y.S., Rowe, E.C., Jones, L., Curran, T.P., McHugh, K., Smart, S., Martin Hernandez, C., Taylor, P., Coyle, M. *et al.*, 2021. *National Ecosystem Monitoring Network (NEMN) – Design: Monitoring Air Pollution Impacts across Sensitive Ecosystems*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Keller, E., Newman, J.E., Ortman, A., Jorm, L.R. and Chambers, G.M., 2021. How much is a human life worth? A systematic review. *Value in Health*, 24(10): 1531–1541.
- Kiely, G., Leahy, P., Lewis, C., Xu, X., Zhang, C., He, Y., Dao, L., Golden, N., Zi, T. and Albertson, J., 2014. *Interactions of Soil Hydrology, Land Use and Climate Change and Their Impact on Soil Quality (SoilH)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Kohlheb, N. and Krausmann, F., 2009. Land use change, biomass production and HANPP: the case of Hungary 1961–2005. *Ecological Economics*, 69(2): 292–300.
- Kubiszewski, I., Costanza, R., Franco, C., Lawn, P., Talberth, J., Jackson, T. and Aylmer, C., 2013. Beyond GDP: measuring and achieving global genuine progress. *Ecological Economics*, 93: 57–68.
- Land, Environment, Economics and Policy Institute, 2019. Natural Environment Valuation Online (NEVO) technical documentation. Available online: <https://www.leep.exeter.ac.uk/nevo/?x=405000&y=410000&z=1> (accessed 20 February 2025).
- Layke, C., Mapendembe, A., Brown, C., Walpole, M. and Winn, J., 2012. Indicators from the global and sub-global Millennium Ecosystem Assessments: an analysis and next steps. *Ecological Indicators*, 17: 77–87.
- Liang, J., Wang, S., Liu, K., Wang, J., Zhou, J., Liu, X., Feng, K. and Fang, C., 2023. Agricultural HANPP embodied in consumption: tracing pressure on ecosystems based on an MRIO analysis. *Environmental Science & Technology*, 57(37): 13838–13850.
- Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Mancini, M.S., Martindill, J., Medouar, F.-Z., Huang, S. and Wackernagel, M., 2018. Ecological footprint accounting for countries: updates and results of the national footprint accounts, 2012–2018. *Resources*, 7(3): 58.
- Ma, T., Zhou, C. and Pei, T., 2012. Simulating and estimating tempo-spatial patterns in global human appropriation of net primary production (HANPP): a consumption-based approach. *Ecological Indicators*, 23: 660–667.
- Maes, J.T., Teller, A., Erhard, M., Conde, S., Vallecillo Rodriguez, S., Barredo Cano, J.I., Paracchini, M., Abdul Malak, D., Trombetti, M., Vigiak, O. *et al.*, 2020. *Mapping and Assessment of Ecosystems and Their Services: An EU Ecosystem Assessment*. Publications Office of the European Union, Luxembourg.
- Mayer, A., Kaufmann, L., Kalt, G., Matej, S., Theurl, M.C., Morais, T.G., Leip, A. and Erb, K.-H., 2021. Applying the human appropriation of net primary production framework to map provisioning ecosystem services and their relation to ecosystem functioning across the European Union. *Ecosystem Services*, 51: 101344.
- McGuire, J., Rogan, F., Daly, H., Glynn, J., Balyk, O. and Ó Gallachóir, B., 2020. *The Role of Carbon Budgets in Translating the Paris Agreement into National Climate Policy*. MaREI Centre, Environmental Research Institute, University College Cork, Ireland. Available online: https://www.marei.ie/wp-content/uploads/2020/10/Discussion-Paper_The-role-of-carbon-budgets-in-translating-the-Paris-Agreement-into-national-climate-policy.pdf (accessed 14 January 2026).
- McNamara, M., Binner, H., Hynes, E. and Andrade, L., 2022. *A Signpost for Soil Policy in Ireland: MUCKISOILS (Mapping Understanding and Current Knowledge of Irish Soils)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Meath County Council, 2023. *Meath County Council Climate Action Plan 2024–2029: Baseline Emissions Inventory BEI Report (Mitigation) Annex 2*. Meath County Council, Navan, Ireland. <https://www.meath.ie/council/council-services/environment/climate-action/climate-action-plan> (accessed 28 January 2025).
- Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-Being*. Island Press, Washington, DC, USA.
- National Aeronautics and Space Administration, 2023. HANPP collection: global patterns in net primary productivity (NPP). Available online: <https://catalog.data.gov/dataset/hanpp-collection-global-patterns-in-net-primary-productivity-npp> (accessed 20 February 2025).
- National Biodiversity Data Centre, 2024a. Explore Your Shore! Surveys. Available online: <https://exploreyourshore.ie/surveys/> (accessed 20 February 2025).
- National Biodiversity Data Centre, 2024b. Ireland's Citizen Science Portal. Available online: <https://records.biodiversityireland.ie/> (accessed 20 February 2025).

- National Biodiversity Data Centre, 2024c. Monitoring & tracking change. Available online: <https://biodiversityireland.ie/monitoring/> (accessed 20 February 2025).
- National Parks & Wildlife Service, n.d. Habitat and species data. Available online: <https://www.npws.ie/maps-and-data/habitat-and-species-data> (accessed 20 February 2025).
- National Parks & Wildlife Service, 2020. Red lists. Available online: <https://www.npws.ie/publications/red-lists> (accessed 20 February 2025).
- National Parks & Wildlife Service, 2024a. *Ireland's 4th National Biodiversity Action Plan 2023–2030*. Department of Housing, Local Government and Heritage, Dublin, Ireland.
- National Parks & Wildlife Service, 2024b. Irish Wildlife Manuals. Available online: <https://www.npws.ie/publications/irish-wildlife-manuals> (accessed 20 February 2025).
- National Transport Authority, 2024. *TFI Customer Satisfaction Report 2023: Customer Satisfaction on Travel Across Bus, Rail and Tram for 2023*. National Transport Authority, Dublin, Ireland.
- Ní Dhúill, E. and Sheehy, I., 2024. *Valuing and Accounting for Nature in Ireland: Embedding the Natural Capital Approach and Natural Capital Accounting in Irish Policy for the Benefit of People and Planet*. Research Paper No. 27. National Economic & Social Development Office, National Economic and Social Council, Dublin, Ireland.
- Nielsen, O.-K., Plejdrup, M.S., Bruun, H.G., Gyldenkærne, S. and Christensen, J.H., 2020. *MapElre: National Mapping of Greenhouse Gas and Non-Greenhouse Gas Emissions Sources Project*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Norton, D., Hynes, S. and Boyd, J., 2016. *Valuing Ireland's Marine Ecosystem Services*. National University of Ireland, Galway, Ireland.
- O'Brien, C., 2018. SILC Module on well-being, 2018. Central Statistics Office. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-smwb/silcmoduleonwell-being2018/backgroundnotes/> (accessed 20 February 2025).
- O'Brien, D. and Shalloo, L., 2019. *A Review of Livestock Methane Emission Factors*. Environmental Protection Agency, Johnstown Castle, Ireland.
- O'Callaghan, D. and Prior, S., 2018. *Central Technical Appraisal Parameters: Discount Rate, Time Horizon, Shadow Price of Public Funds and Shadow Price of Labour*. IGEES Unit, Department of Public Expenditure and Reform, Dublin, Ireland.
- O'Driscoll, C., Crowley, F., Doran, J. and McCarthy, N., 2023. Land-use mixing in Irish cities: implications for sustainable development. *Land Use Policy*, 128: 106615.
- OECD (Organisation for Economic Co-operation and Development), 2021. *Agricultural Policy Monitoring and Evaluation 2021: Addressing the Challenges Facing Food Systems*. OECD Publishing, Paris, France.
- OECD (Organisation for Economic Co-operation and Development), 2024. *How's Life? 2024: Well-Being and Resilience in Times of Crisis*. OECD Publishing, Paris, France.
- OECD (Organisation for Economic Co-operation and Development) and Joint Research Centre, 2008. *Handbook on Constructing Composite Indicators: Methodology and User Guide*. OECD Publishing, Paris, France.
- Office for National Statistics, 2024. UK natural capital accounts: 2024. Available online: <https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalaccounts/2024> (accessed 20 February 2025).
- O'Rafferty, S., 2020. *Identifying "What Matters" for Community Wellbeing with the Irish Public Participation Networks*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Owusu-Twum, M.Y., Kelleghan, D., Gleasure, G., Forrestal, P., Lanigan, G.J., Richards, K.G. and Krol, D.J., 2024. Ammonia emission factors from cattle production systems in Ireland – a review. *Irish Journal of Agricultural and Food Research*, 62(1): 75–95.
- Parker, N., Naumann, E.-K., Medcalf, K., Haines-Young, R., Potschin, M., Kretsch, C., Parker, J. and Burkhard, B., 2016. *National Ecosystem and Ecosystem Service Mapping Pilot for a Suite of Prioritised Services*. Irish Wildlife Manual No. 95. National Parks & Wildlife Service, Dublin, Ireland.
- Phillips, H., De Palma, A., Gonzalez, R.E., Contu, S., Hill, S.L.L., Baselga, A., Borger, L. and Purvis, A., 2021. The Biodiversity Intactness Index – country, region and global-level summaries for the year 1970 to 2050 under various scenarios. Available online: <https://data.nhm.ac.uk/dataset/bii-bte> (accessed 20 February 2025).
- Poljanšek, K., Marzi, S., Galimberti, L., Dalla Valle, D., Pal, J.S., Essenfelder, A.H., Mysiak, J. and Corbane, C., 2022. *INFORM Climate Change Risk Index: Concept and Methodology*. Joint Research Centre Technical Report. Publications Office of the European Union, Luxembourg.

- Ramsey, F.P., 1928. A mathematical theory of saving. *The Economic Journal*, 38(152): 543–559.
- RePEAT Project, n.d. RePEAT Project. Available online: <https://sites.google.com/view/project-repeat/home> (accessed 1 May 2025).
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., Von Bloh, W. *et al.*, 2023. Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37).
- Riitters, K.H., Wickham, J.D. and Wade, T.G., 2009. An indicator of forest dynamics using a shifting landscape mosaic. *Ecological Indicators*, 9(1): 107–117.
- Rodrigues, C.I.D., Brito, L.M. and Nunes, L.J.R., 2023. Soil carbon sequestration in the context of climate change mitigation: a review. *Soil Systems*, 7(3): 64.
- Roux, N., Kaufmann, L., Bhan, M., Le Noe, J., Matej, S., Laroche, P., Kastner, T., Bondeau, A., Haberl, H. and Erb, K., 2022. Embodied HANPP of feed and animal products: tracing pressure on ecosystems along trilateral livestock supply chains 1986–2013. *Science of the Total Environment*, 851(2): 158198.
- Sachs, J.D., Lafortune, G. and Fuller, G., 2024. *Sustainable Development Report 2024: The SDGs and the UN Summit of the Future*. Dublin University Press, Dublin, Ireland.
- Saunders, M.J., Afrasinei, G.M., Zimmerman, J., Premrov, A., Black, K. and Green, S., 2022. *Soil Organic Carbon and Land Use Mapping (SOLUM)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Scholes, R.J. and Biggs, R., 2005. A biodiversity intactness index. *Nature*, 434(7029): 45–49.
- Schwab, K. and Zahidi, S., 2020. *The Global Competitiveness Report: Special Edition 2020: How Countries are Performing on the Road to Recovery*. World Economic Forum, Geneva, Switzerland.
- Secretariat of the Convention on Biological Diversity, 2016. *Biodiversity and the 2030 Agenda for Sustainable Development: Technical Note*. Secretariat of the Convention on Biological Diversity, Montreal, Canada.
- Sen, A., 1976. Poverty: An ordinal approach to measurement. *Econometrica*, 44(2): 219–231.
- Sen, A., 1995. Rationality and social choice. *The American Economic Review*, 85(1): 1–24.
- Sen, A., 1999. *Development as Freedom*. Oxford University Press, Oxford, UK.
- Stiglitz, J.E., Sen, A. and Fitoussi, J.P., 2010. *Mismeasuring Our Lives: Why GDP Doesn't Add Up*. The New Press, New York, USA.
- Stout, J.C., Farrell, C.A., Kelly-Quinn, M., Coleman, L., Kinsella, S., O'Donoghue, C., Norton, D., Obst, C., Eigenraam, M., Smith, F. *et al.*, 2023. *Irish Natural Capital Accounting for Sustainable Environments (INCASE)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Styles, D., Duffy, C., Prudhomme, R., Bishop, G., Ryan, M. and O'Donoghue, C., 2024. *Towards a Climate-Neutral Land Sector by 2050: Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals (SeQUEsTER)*. Environmental Protection Agency, Johnstown Castle, Ireland.
- Tailte Éireann, 2026. Height data. Available online: <https://tailte.ie/map-shop/professional-map-products/height-data/> (accessed 28 January 2026).
- Tailte Éireann and Environmental Protection Agency, 2023. *National Land Cover Map of Ireland 2018: Final Report*. Tailte Éireann, Dublin, Ireland.
- Teagasc, n.d. National Agricultural Soil Carbon Observatory. Available online: <https://www.teagasc.ie/environment/climate-change--air-quality/soil-carbon/national-agricultural-soil-carbon-observatory/> (accessed 20 February 2025).
- Teagasc, 2021. PastureBase Ireland. Available online: <https://www.teagasc.ie/crops/grassland/pasturebase-ireland/> (accessed 20 February 2025).
- Teagasc, 2024a. Harvest report 2024. Available online: <https://teagasc.croproreport.ie/reports/harvest-report-2024> (accessed 20 February 2025).
- Teagasc, 2024b. National farm survey reports. Available online: <https://www.teagasc.ie/rural-economy/rural-economy/national-farm-survey/national-farm-survey-reports/> (accessed 20 February 2025).
- Teagasc, Environmental Protection Agency and Cranfield University, n.d. Irish Soil Information System. Available online: <http://gis.teagasc.ie/soils/map.php> (accessed 20 February 2025).
- Timoney, K., 2023. *Demystifying Ireland's National Income: A Bottom-Up Analysis of GNI* and Productivity*. Working Paper No. 21. Irish Fiscal Advisory Council, Dublin, Ireland.
- Turk, Z., 2024. *The Geometry of Growth and Inequality*. Available online: <https://doi.org/10.2139/ssrn.5024322> (accessed 1 January 2026).
- Uisce Éireann, 2016. *National Wastewater Sludge Management Plan*. Uisce Éireann, Dublin, Ireland.
- United Nations, 2015. *Sendai Framework for Disaster Risk Reduction 2015–2030*. United Nations, New York, USA.

- United Nations, 2023. *The Sustainable Development Goals Report 2023: Special Edition. Towards a Rescue Plan for People and Planet*. United Nations, New York, USA.
- United Nations, 2024. *The Sustainable Development Goals Report 2024*. United Nations, New York, USA.
- United Nations Development Programme, 2024a. *Human Development Report 2023/24: Breaking the Gridlock: Reimagining Cooperation in a Polarized World*. United Nations Development Programme, New York, USA.
- United Nations Development Programme, 2024b. *Human Development Report 2023/2024 Technical Notes*. United Nations Development Programme, New York, USA.
- United Nations Environment Programme, 2023. *Stockholm Convention on Persistent Organic Pollutants: Text and Annexes (Revised in 2023)*. United Nations Environment Programme, Nairobi, Kenya.
- United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank, 2014. *System of Environmental-Economic Accounting 2012: Central Framework*. Document No. ST/ESA/STAT/Ser.F/109. United Nations, New York, USA.
- Vysna, V., Maes, J., Petersen, J.-E., La Notte, A., Vallecillo, S., Aizpurua, N., Ivits-Wasser, E. and Teller, A., 2021. *Accounting for Ecosystems and Their Services in the European Union (INCA): Final Report from Phase II of the INCA Project Aiming to Develop a Pilot for an Integrated System of Ecosystem Accounts for the EU: 2021 Edition*. Publications office of the European Union, Luxembourg.
- Wall, G., 2013. *Quarterly National Household Survey Quarter 3 2013: Module on Volunteering and Well-Being Questionnaire*. Central Statistics Office, Dublin, Ireland.
- Waterford City & County Council, 2023. *Waterford City and County Council Climate Action Plan 2024–2029: Appendix C, Tier 2 Baseline Emission Inventory: April 2023*. Waterford, Ireland. Available online: <https://consult.waterfordcouncil.ie/en/system/files/materials/2707/Appendix%20C%20Baseline%20Emission%20Inventory%20Waterford%20County.pdf> (accessed 14 January 2026).
- Weikard, H.-P. and Zhu, X., 2005. Discounting and environmental quality: when should dual rates be used? *Economic Modelling*, 22(5): 868–878.
- Wetland Surveys Ireland, 2024. Map of Irish wetlands. Available online: <https://www.wetlandsurveys.ie/miw-intro> (accessed 20 February 2025).
- World Bank and Government of Ireland, 2021. *Ireland's Human Capital: The Contribution of Education and Skills Development to Economic Transformation. Building Human Capital: Lessons from Country Experiences*. International Bank for Reconstruction and Development/World Bank, Washington, DC; Government of Ireland, Dublin, Ireland.
- Zhang, Y., Li, Z., Bai, K., Wei, Y., Xie, Y., Zhang, Y., Ou, Y., Cohen, J., Zhang, Y., Peng, Z. *et al.*, 2021. Satellite remote sensing of atmospheric particulate matter mass concentration: advances, challenges, and perspectives. *Fundamental Research*, 1(3): 240–258.

Appendix 1 Exclusion of Some Promising Indicators

In this appendix, we discuss the rationale for excluding certain promising indicators. The selection of indicators was influenced by their recommendation across multiple sources. In particular, Tier III indicator selection was influenced by their listing in other assessment frameworks composed of multiple indicators. The lists of indicators were first standardised and condensed where possible following the methodology discussed in section 2.3. In addition to their listing in other frameworks, we stipulated that the indicators had to be applicable to conditions in Ireland, be expected to vary within the country and somehow relate to land use. On the final requirement, we did not initially require an expectation that land use changes would result in changes in the indicator, instead evaluating this later in the process. We took these steps to include the widest possible set of potentially informative statistics. The current and future capacity for collection was also not considered at the indicator selection stage, but rather was evaluated as a separate step, to ensure that data availability did not dictate indicator selection, as “what gets measured, gets managed” is a central guiding concept for this research.

Consequently, some indicators were selected and then removed from our indicator set at a late stage. Those indicators are discussed here. Initially, we included the Living Planet Index as an alternative option to the IUCN Red List indicator of the planetary boundaries Tier II indicators. However, we then focused on the use of the IUCN Red List Index for assessing extinction risk, with a view to focusing limited resources on the most pressing, irreversible issues for prioritising conservation efforts. In many ways, the Living Planet Index offers a broader ecosystem-level perspective, tracking trends in population abundance across potentially several species. However, this makes it less suitable when resources are constrained. This supports the action-oriented nature of the framework.

The Aerosol Optical Depth indicator relates to atmospheric aerosol loading – a more encompassing measure of air quality. It was removed from the framework’s list of Tier II planetary boundaries indicators. While traditionally connected to land use,

changes in Ireland – such as the quite recent banning of agricultural waste burning – significantly reduce its relevance as a land use-related indicator. Additionally, natural sources such as sea mist play a substantial role in Ireland’s aerosol loading yet are unrelated to land use. This removal does not detract from the importance of other components, such as $PM_{2.5}$, but acknowledges that the Aerosol Optical Depth indicator in Ireland is now more relevant to measuring non-land use sources of atmospheric aerosol loading – particularly the burning of biomass for heating – than it is to informing land use policy.

Indicators related to the marine environment, such as plastic debris density, fish stock status, fish landings and the Coastal Water Quality Index, were initially considered for inclusion. These indicators provide valuable insight into marine ecosystem health and its role as a substitute for land-based production, particularly for protein. However, after a review of their relevance to land use policy, these indicators were removed, to ensure that the framework’s focus is on land use outcomes that can be attributed to specific land use changes and locations. Additionally, much of Ireland’s fish stocks are either managed by the EU via the Common Fisheries Policy (implemented by the DAFM) or impacted primarily by international actors, as the majority of fishing activity in Ireland’s Exclusive Economic Zone (EEZ) is conducted by foreign entities. These are issues that cannot be managed by land use policy.

Yet, we note that increases in agricultural activity could reduce reliance on marine protein sources in Ireland, regardless of who harvests from Ireland’s EEZ. Water quality near Ireland’s coasts will also be impacted by nutrient run-off from agriculture, even if attribution to specific locations is not possible – making it impossible to link Coastal Water Quality Index changes to changes at sites. Plastic debris density is also a vital indicator for tracking marine pollution and its impacts on ecosystems and human industries. However, plastic pollution originates from myriad global sources, primarily not tied to land use or even to Ireland. However, an alternative perspective is to treat Ireland’s EEZ areas as synonymous with

land-based production, viewing fisheries management as being parallel to agricultural land management. This integrated view would support holistic policymaking but would be constrained by EU management of fisheries and international marine pressures. Municipal solid waste generation and solid waste recovery and recycling rates were also initially considered for inclusion as indicators. However, these metrics exhibit a weak relationship with land use policies. Instead, the causal relationship is most likely reversed – increased waste generation may drive greater land use for waste

processing and storage. As such, these indicators have been excluded to prevent waste-related land use impacts from influencing policy. However, we note that municipal solid waste generation and recycling rates are relevant for understanding Ireland's progression towards a circular economy and reducing demand for landfills. These indicators highlight the environmental impacts of consumption and recycling behaviour, as does wastewater treatment as a critical issue for protecting Ireland's waterways – even if it is not primarily land use driven.

Abbreviations

AQI	Air quality index
BHI	Biodiversity Habitat Index
BII	Biodiversity intactness index
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CCAC	Climate Change Advisory Council
CLCPlus	CORINE Land Cover Plus
CMEF	Common Monitoring and Evaluation Framework
CO₂e	Carbon dioxide equivalents
CORINE	Coordination of Information on the Environment
CSO	Central Statistics Office
DAFM	Department of Agriculture, Food and the Marine
DECC	Department of the Environment, Climate and Communications
EAD	Ecosystem Accounts Division
EAGLE	European Abstraction Grid for Land Information Exchange
EDE	Equally distributed equivalent
EEZ	Exclusive Economic Zone
EFBA	Ecological Footprint and Biocapacity Accounts
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
ETR	Ecological Threat Report
EVI	Environmental Vulnerability Index
GCI	Global Competitiveness Index
GDP	Gross domestic product
GDPR	General Data Protection Regulation
GNI	Gross national income
GNP	Gross national product
GPI	Genuine Progress Indicator
HANPP	Human appropriation of net primary production
HDI	Human Development Index
ICCA	Ireland's Climate Change Assessment
IEP-GPI	Institute for Economics & Peace Global Peace Index
INFORM	Index for Risk Management
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LULUCF	Land use, land use change and forestry
MAES	Mapping and Assessment of Ecosystems and their Services
MEA	Millennium Ecosystem Assessment
NBAP	National biodiversity action plan
NBDC	National Biodiversity Data Centre
NCC	Net capital change variable
NMP	Non-market and public goods variable
NPP	Net primary production
NPWS	National Parks & Wildlife Service

PFAS	Per- and polyfluoroalkyl substances
PM_{2.5}	Particulate matter of $\leq 2.5 \mu\text{m}$
PM₁₀	Particulate matter of $\leq 10 \mu\text{m}$
PMEF	Performance Monitoring and Evaluation Framework
POP	Persistent organic pollutant
SDG	Sustainable Development Goal
SFDRR	Sendai Framework for Disaster Risk Reduction
SILC	Survey on Income and Living Conditions
SOM	Soil organic matter
SRC	Stockholm Resilience Centre
SWB	Subjective well-being
UN-MVI	United Nations Multidimensional Vulnerability Index
WQI	Water quality index

An Gníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaoil a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaoil a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeán, spriocdhírthe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- > Gníomhaíochtaí tionscail, dramhaíola agus stórála peitрил ar scála mór;
- > Sceitheadh fuíolluisce uirbhig;
- > Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- > Foinsí radaíochta ianúcháin;
- > Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- > Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- > Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- > Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- > Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbhig a fhorfheidhmiú
- > Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- > Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- > An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaoil.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaoil

- > Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- > Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- > An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- > Reachtaíocht ar rialú ceimiceáin sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- > Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- > Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéal uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- > Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- > Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Gníomhú ar son na hAeráide;

- > Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaoil

- > Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- > Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- > Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- > Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- > Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaoil na hÉireann.

Taighde agus Forbairt Comhshaoil

- > Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- > Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- > Monatóireacht a dhéanamh ar leibhéal radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- > Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as tasmí núicléacha;
- > Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- > Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- > Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- > An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- > Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- > Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- > Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíochta agus ranna rialtais chun cosaint comhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhuanaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Gníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair inmí agus le comhairle a chur ar an mBord.

EPA Research

Webpages: www.epa.ie/our-services/research/

LinkedIn: www.linkedin.com/showcase/eparesearch/

Twitter: @EPAResearchNews

Email: research@epa.ie