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Implementation of the Sustainability Compass: A Bottom-Up Social Learning Approach in Initial Pilot Studies

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Abstract: This paper presents the Sustainability Compass as an emerging innovative bottom-up framework that promotes social learning about overall sustainability—i.e., human wellbeing and prosperity within environmental boundaries—by mean of its practical implementation in the Plan-Wise4Blue geoportal. The Sustainability Compass aims to put the theoretical idea of sustainability into practice by a systemic approach that continuously generates, refines and updates appropriate themes and metrics, through bottom-up enlarged participatory learning involving all researchers, entrepreneurs, environmental managers, and anyone else with an interest. Such inclusiveness promotes a common understanding of sustainability, cultivates a collective vision and facilitates the assessment of sustainability levels in different contexts, including national and regional planning efforts. The Sustainability Compass operationalises the generic, top-down and differently interpretable UN SDGs into more practical and bottom-up practice. This article outlines the finalised structure of the Sustainability Compass and presents its first application through case studies of cross-border aquaculture in Finland and Estonia, and a collaborative initiative in Finnish wind energy. Through detailed analysis of interviews and workshops, the article explains the empirical findings and offers a comprehensive guide to the use of the Sustainability Compass. This is exemplified by its integration with the PlanWise4Blue geoportal, demonstrating its practicality and effectiveness in real-world applications.

Keywords: sustainability evaluation; geospatial decision-support tool; bottom-up participatory social learning; experimental evidence-based science



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1. Introduction

Previous research has built, in its different phases, the Sustainability Compass [1]. Its initial version, realised for a project funded by the Office of the Finnish Prime Minister for the analysis of sustainable innovation, was further developed as part of the MAREA project. A more detailed description of the theoretical analysis and an updated research-based conceptual framework performed by the leading researcher is part of the delivered report [2]. The MAREA project has also laid the foundations for the first implementation of two case studies in the fields of aquaculture and wind energy. The aim was to improve the integration and understanding of the linkages between ecosystems and human wellbeing.

The Sustainability Compass originates in the need to present an alternative way to deal with issues that are characterised by high complexity and uncertainty. To this aim, earlier research by Funtowicz and Ravetz [3,4] proposed a philosophy of science that moved from the more traditional ‘normal’ science of Kuhn [5] to an idea of ‘Post-normal science’, able to treat issues that hardly could be covered by certain and value-free scientific methods [6]. When “facts are uncertain, values in dispute, stakes high and decisions urgent” ‘hard’, objective scientific facts are irremediably ‘soft’ and subjective value-judgements, while

policy decisions are hard [6]. As Ravetz admits [6], some could argue that these situations do not belong to science. However, in these cases, where ‘normal’ science can hardly be used, Post-normal science can provide an approach that interfaces between science and policy [6,7] as a possible solution that increases the quality of policy decisions. As Saloranta [8] mentions, in Post-normal science, various stakeholders, identified by Ravetz [6] as “extended peer communities”, “citizens’ juries”, “citizen foresight”, or “consensus conferences”, including institutions and movements, participate in the dialogue with a “plurality of legitimate perspectives” and contribute to the assessment of scientific knowledge in support to decision-making.

Scientific uncertainty and complexity are, according to the idea of post-normal science, often approached through a ‘science of consensus’, that mixes with traditional hard science. This implies a risk to obscure the knowledge about scientific uncertainty, and thereby to flatten all science at the same level, undermining the credibility of established ‘normal science’, as defined by Kuhn. In addition, this approach risks lumping all scientific disciplines, including mathematics, statistics and natural sciences, under the umbrella of social sciences, which are inherently influenced by subjective preferences and social or behavioural biases [9–15]. According to the literature regarding social psychology, the knowledge of an existing consensus within scientific and social communities induces even more consensus, even in the absence of hard scientific and measurable observations.

The Sustainability Compass challenges the approach of post-normal science by advocating a model that integrates multidisciplinary knowledge through a continuous, bottom-up refinement process, as opposed to the top-down, consensus-based method of post-normal science, which does not even belong to traditional science. Instead, the Sustainability Compass contrasts with the tendency of post-normal science to dilute the rigour of the hard sciences and seeks to elevate the socio-economic sciences to a level of objectivity similar to the hard sciences, focusing on more tangible aspects of wellbeing rather than fluctuating individual preferences [1]. In this framework, one participant’s findings may be completely contradicted by another, based on alternative existing evidence. Some specific aims and benefits of the Sustainability Compass are highlighted as follows:

- The promotion of systematic, participatory and evidence-based societal learning on sustainability across multiple dimensions within a specific field, encouraging both research and anonymous contributions.
- The simplification of complex sustainability issues into key factors, drivers and indicators that are most relevant to each case, using the precautionary principle in the face of uncertainty.
- The initiation of participatory, locally led processes for continuous and expanded learning in order to facilitate informed decision making, as opposed to unsustainable top-down approaches.
- The communication of genuine values and demonstration of proactive corporate responsibility throughout the value chain, going beyond basic environmental standards and mandatory regulations.

It is important to note that the abovementioned selection of relevant indicators is not aimed to hide information. For example, non-verified knowledge, an indicator highly correlated with another, or knowledge which only very partially explains the phenomenon at hand still remain in the system and is always available when searched for, if the author does not delete it. Though other information might refute it, or though it may seem irrelevant, it will nonetheless be used later. The selection of most relevant factors or indicators naturally emerges from the analysis, according to the well-established statistical analysis for the construction of composite indicators (e.g., GDP) or the European Innovation Scoreboard (ESI) built by selecting most relevant components [16].

In the light of the previous arguments, this article describes the first effort to put the Sustainability Compass into practice and to test its validity when performing a multidimensional evaluation of sustainability. To this aim, some research questions and the related actions to prove its validity are formulated in Table 1.

Table 1. The research questions, methods and outcomes.

Research Question	Adopted Method
What is the value of the Sustainability Compass tool?	Interviews on selected case studies of wind power and aquaculture.
Is the tool able to demonstrate and synthetically represent sustainability knowledge on the specific cases, thereby indicating the bottlenecks, trade-offs, uncertainties, drivers, lessons learned and development needs?	Bottom-up triangulation of results, including other sources and narrative descriptions. Representation on the PlanWise4Blue geoportal

Beyond this introduction, Section 2 outlines the literature review and its translation into the final structure of the Sustainability Compass, and Section 3 focuses on the methods applied for the case studies of wind energy and aquaculture. Section 4 reports the results and Section 5 describes how the Sustainability Compass works within the PlanWise4Blue geoportal. Section 6 describes a meta-evaluation, which monitors the level and quality of participation for the realisation of the bottom-up approach and describes some strategies for assuring wide inclusivity. The practical experience in the field of ecosystem services is analysed in Section 7. Section 8 describes the conclusions and Section 9 the developments and plans for future use.

2. Literature Review and Translation of the Theoretical Analysis into the Practical Final Structure for the Sustainability Compass

The initial implementation of the Sustainability Compass, aligned with the UN Sustainable Development Goals (SDGs), encountered practical challenges in the workshop due to the inherent characteristics of the SDGs [2], as follows:

- The SDGs are too generic and may be interpreted differently by different people, making it difficult to set specific, actionable targets.
- The SDGs are siloed and lack systemic interactions, preventing an understanding of potential cause-and-effect relationships between them.
- High correlations, trade-offs, contradictions or redundancies among the SDGs make it difficult for different society actors to match indicators with corresponding targets.
- The SDGs were developed in a top-down manner at the UN level, with a lack of integration with grassroots scientific discourse.

A structure for solving the challenges of the second, third and fourth points has been proposed by Sajeve et al. [2]. To tackle the first challenge, a supplementary literature review was conducted, cross-referencing UN SDGs with relevant sustainable development research [2]. This review led to an updated framework (Figure 1), organised by a Means & Goals approach to sustainable development [17] and their classification based on the Five Capitals Model of the Sustainability Forum for the Future [18].

The Means & Goals approach, based on Sen's concept of 'getting-by with a little assistance', or GALA, suggests economic and material growth are merely means by which to enhance human capabilities [19]. Sen emphasised the existing confusion between the means and goals of development, for instance mistakenly viewing wealth growth or technological advancements as direct enhancers of human wellbeing, rather than intermediate goals [19]. Sen's view is proposed in contrast with Churchill's idea of 'Blood, sweat and tears', or BLAST, meaning that development and growth shall be achieved through misery and pain [18]. Jackson adds that these goals should be pursued within environmental limits [19], as these represent the ultimate bottom line of human life. This theory aligns with the ancient concept of economics, οἰκονομία (oikonomia), defined as effective resource allocation to meet household needs, bridging natural and social sciences [1,20] (Figure 2).



Figure 1. The Means&Goals approach of the Sustainability Compass according to the Five Capitals Model of sustainability, including Natural (green), Human (blue), Social (orange) and Physical (grey) capitals.

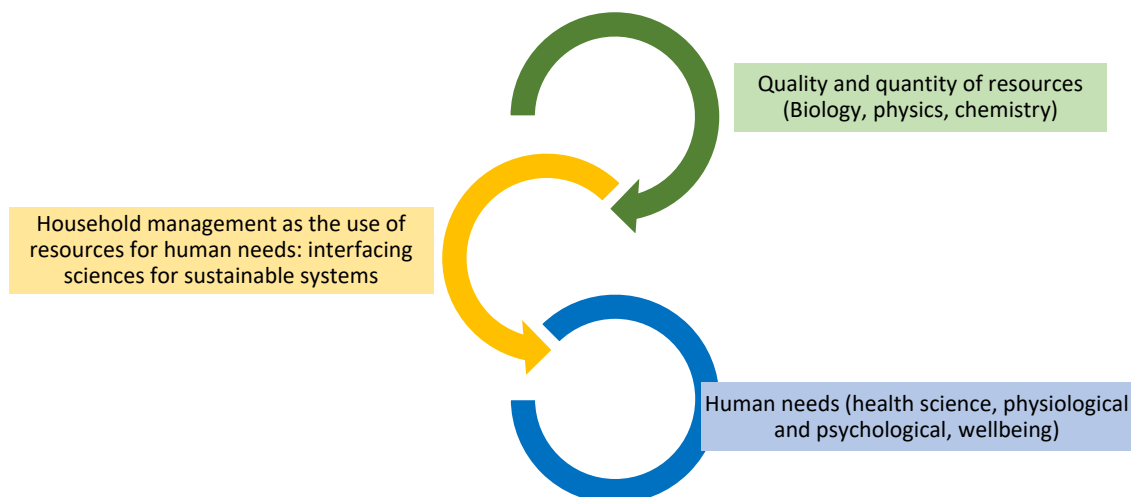


Figure 2. Economics (yellow) for natural (green) and human (blue) systems equilibrium [1].

The sustainability principles from the Forum for the Future [18] and the Natural Step [21] (Table 2) for the sustainability evaluation of private and public organisations, were directly applied to define the Means & Goals of the Sustainability Compass. These principles were aligned with the UN SDGs and other relevant literature from the MAREA project [2]. Adjustments were made following consultations with communication experts and scientists in order to ensure that the framework was accessible to a diverse user community.

The theoretical analysis [2] produced an updated framework (Figure 3) and a final process (Figure 4) and a structure of the Sustainability Compass (Figure 5). The circularity of the process of Figure 4 highlights the concept of continuous improvement and discussion around a single issue, the updating the findings and indicators in pursuit of sustainability goals. Following a paradigm of means and goals of sustainability [17], the ultimate goals are then represented by the Natural and Human capitals, numbered from 1 to 10 in Table 3 and in Figures 3 and 5, and the means, which can be merely means or also intermediate goals classified according to the Five Capitals Model of sustainability [18], numbered from 11 to 18 in Table 4 and in Figures 3 and 5. The legend in Figure 3 specifies the colours associated to the capitals of each single icon. Due to space constraints in Figures 3 and 5, detailed descriptions of means and goals are available in Tables 3 and 4.

Table 2. The main sustainability principles from the Forum for the Future [19] and the Natural Step [20].

	Forum for the Future		The Natural Step
Natural Capital	In their extraction and use, substances taken from the earth do not exceed the environment's capacity to disperse, absorb, recycle or otherwise neutralise their harmful effects (to humans and/or the environment)	In a sustainable society, nature is not subject to systematically increasing...	1... concentrations of substances from the earth's crust (such as heavy metals and minerals)
	In their manufacture and use, artificial substances do not exceed the environment's capacity to disperse, absorb, recycle or otherwise neutralise their harmful effects (to humans and/or the environment)		2... concentrations of substances produced by society (such as antibiotics and endocrine disruptors)
	The capacity of the environment to provide ecological system integrity, biological diversity and productivity is protected or enhanced		3... degradation by physical means (such as deforestation and draining of groundwater tables)
Human Capital	At all ages, individuals enjoy a high standard of health		4... concentrations of (exogenous) substances in human bodies (as an analogy to previous)
	Individuals are adept at relationships and social participation, and throughout life set and achieve high personal standards of their development and learning		
Social Capital	There is access to varied and satisfying opportunities for work, personal creativity, and recreation		5... and there are no structural obstacles to people's health, influence, competence, impartiality and meaning
	There are trusted and accessible systems of governance and justice		
	Communities and society at large share key positive values and a sense of purpose		
	The structures and institutions of society promote stewardship of natural resources and development of people		
Manufactured Capital	Homes, communities and society at large provide safe, supportive living and working environments		
	All infrastructure, technologies and processes make minimum use of natural resources and maximum use of human innovation and skills		
Financial Capital	Financial capital accurately represents the value of natural, human, social and manufactured capital		

Achievements in intermediate goals, such as wealth distribution or technological advancements, do not always enhance human wellbeing. This shortfall often occurs when few individuals or organisations control socio-economic arrangements and physical infrastructures, thereby limiting individual freedoms and rights and resulting in structural violence [1,2,22–24].

Figure 3 provides a generic vision and an example of Means&Goals as systemically interconnected, indicating cause–effect relationships, in which goals can be achieved by use of means (which can also be intermediate goals). However, these interrelations can change according to the specific case. Figure 3 is a framework by which users can imagine in which node they are located or make their specific map of causes and effects, for instance, about the role of a company within society. In addition to their own goals of business prosperity,

fair competition and self-sufficiency, a company uses other services and produces benefits for society in order to reach the final goals.

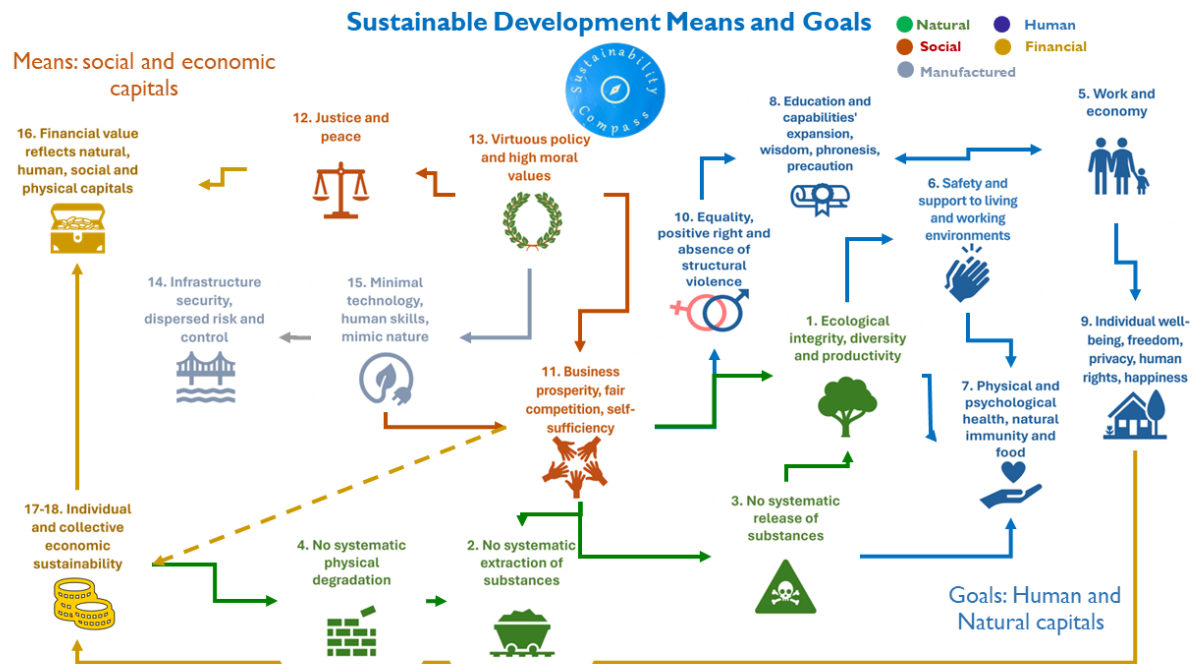


Figure 3. Sustainability as system thinking: the systemic interactions of Means&Goals according to the Five Capitals Model of sustainability [1,2,17,18]. In an ideal process going from left to right, actions can be determined, within the means society provides in order to pursue the goals. The figure shows a generic process which may change according to the specific case.

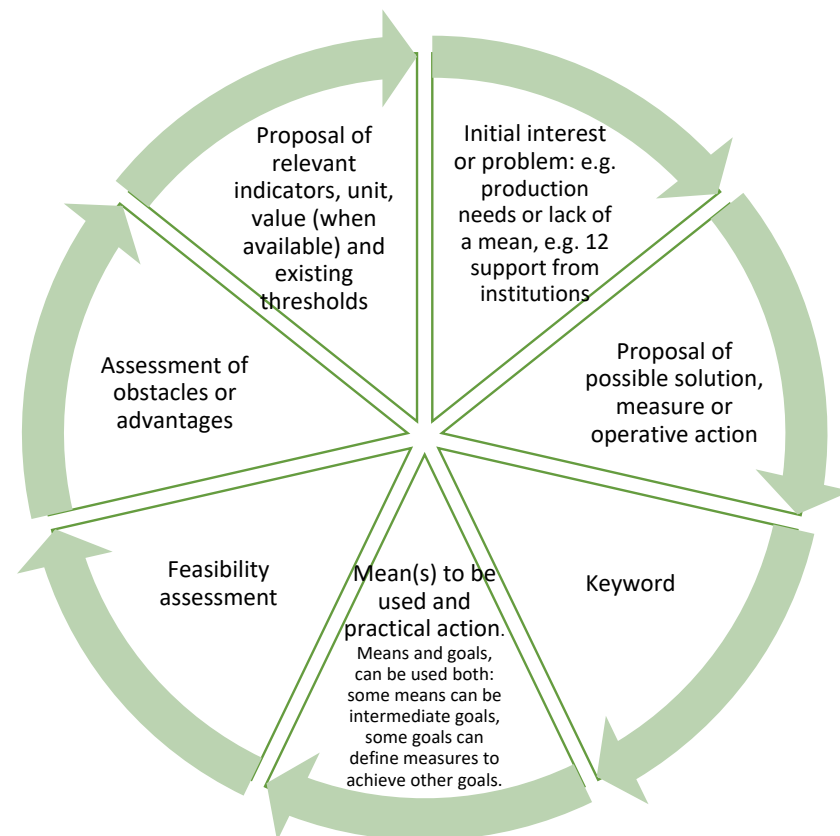


Figure 4. The process of the Sustainability Compass.

Table 3. The Sustainability Compass goals classified according to the Five Capitals Model of sustainability [1,2,17,18] (green for natural capital and blue for human capital).

Nature and Resources	
1. Ecological system integrity: maintaining biological diversity and productivity	1. Ecological integrity, diversity and productivity 
2. No systematic extraction of substances, exceeding the capacity of the environment to neutralise their harmful effects	2. No systematic extraction of substances 
3. No systematic release of substances, exceeding the capacity of the environment to neutralise their harmful effects	3. No systematic release of substances 
4. No degradation by physical means, exceeding the capacity of the environment to neutralise their harmful effects	4. No systematic physical degradation 
Human well-being	
5. Work and economy: access to varied and satisfying opportunities for work and business, especially rural depressed areas	5. Work and economy 
6. Safety and support to living and working environments	6. Safety and support to living and working environments 
7. Human health: high standard of physical and psychological health through precautionary principle, to avoid to systematically increase concentrations of substances in human body, e.g., good quality of water and of GMO free and organic food	7. Physical and psychological health, natural immunity and food 
8. Education and capabilities' expansion: independent and free education, open scientific debate, wisdom, phronesis and precaution	8. Education and capabilities' expansion, wisdom, phronesis, precaution 
9. Human well-being, freedom, privacy, individual human rights, peace, justice and happiness	9. Individual well-being, freedom, privacy, human rights, happiness 
10. Equality between individuals and organisations, based on race, gender, age, health state or wealth, positive rights and absence of structural violence and dominant position for assuring equal opportunities of development	10. Equality, positive right and absence of structural violence 

Table 4. The Sustainability Compass means, or intermediate goals, classified according to the Five Capitals Model of sustainability [1,2,17,18] (orange for social capital, grey for manufactured capital, i.e. the physical infrastructure, and yellow for economic capital, i.e., monetary or financial value).

Social: Collective Institutions, Regulations and Social Infrastructures and Services	
11. Business prosperity and competitiveness especially for of small-scale business and depressed areas, bottom-up approaches of cooperation and avoidance of monopoly or dominant positions	11. Business prosperity, fair competition, self-sufficiency 
12. Justice: assurance of trusted, effective fair, accessible and just institutional, legal and judicial services and protection of the citizens, peace, democracy and plurality, public participation and bottom-up approaches. Assurance of basic human rights of physical and psychological integrity.	12. Justice and peace 
13. Virtuous policy and high moral values: social structures and institutions support human rights and development and to the environmental sustainability, absence of corruption, transparency, accountability, ethics, wisdom and phronesis	13. Virtuous policy and high moral values 
Manufactured: physical infrastructures for production and services	
14. Security of critical infrastructure: avoiding systems' risk concentration, and of relying on a unique infrastructure or organisation or losing control from users. Non-adoption of innovation when usefulness or absence of harm for individuals is not proven. Efficient, secure and less invasive infrastructure systems and technology, learning from nature. Assurance of individual freedom and privacy	14. Infrastructure security, dispersed risk and control 
15. Minimal infrastructure, technologies and processes at support of human well-being, minimum use of natural resources and manufactured capital and maximum use of human work and skills (help to humans)	15. Minimal technology, human skills, mimic nature 
Financial/economic	
16. Financial capital accurately represents the value of natural, human, social and manufactured capital	16. Financial value reflects natural, human, social and physical capitals 
17, 18. Economic sustainability for 17. individuals, and 18. public/private organisations	17-18. Individual and collective economic sustainability 

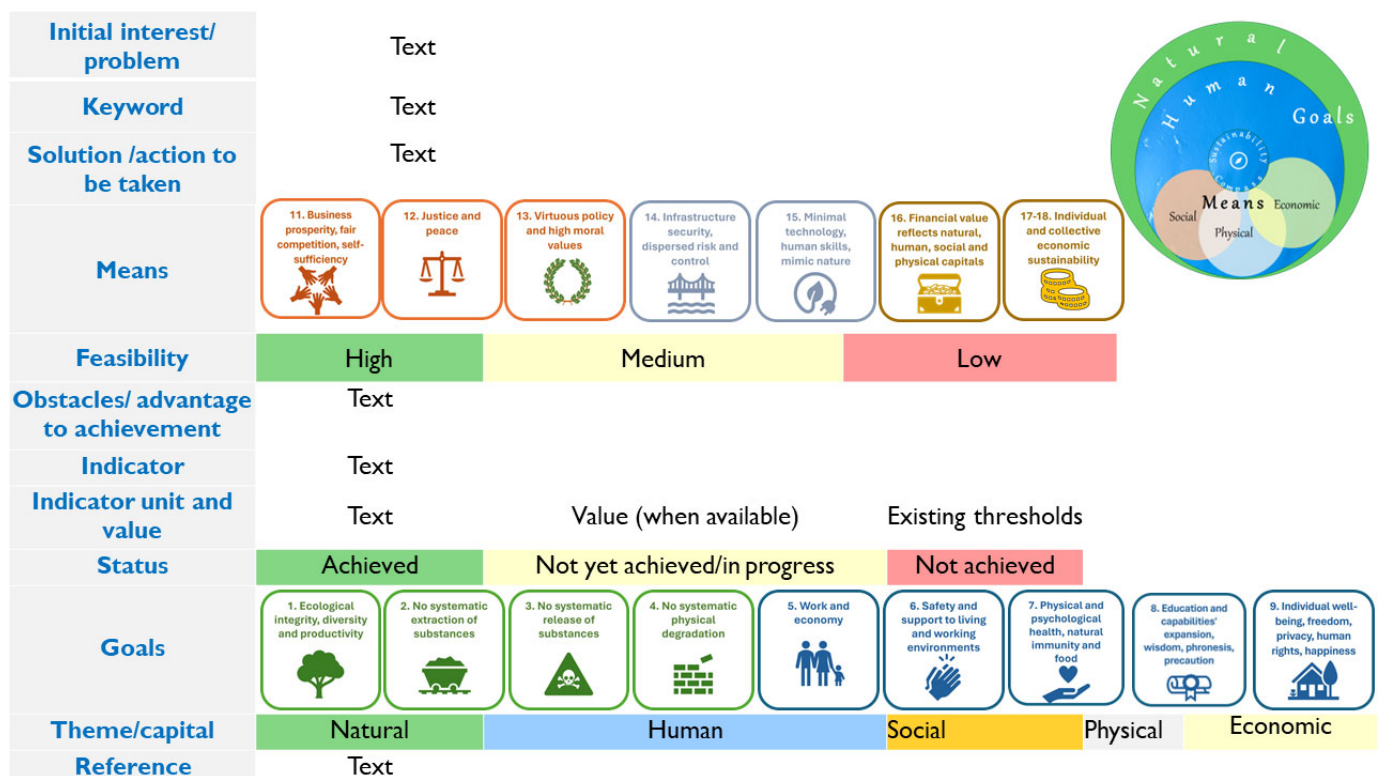


Figure 5. The final structure of the Sustainability Compass during the workshops and within the PlanWise4Blue geoportal [2].

3. Methods: The Process and Methodology for Constructing the Sustainability Compass as Applied to Case Studies and Organisations

The case studies aim to develop a preliminary framework for the Sustainability Compass in fish farming and wind power sectors. This framework will enable companies to understand the impacts of their operations more comprehensively across various sustainability dimensions—natural, human, social, economic, and physical infrastructure—and their regional effects. Through a systematic process involving participants, researchers, and companies, the framework will map out cause–effect relationships which are produced in the process going from core business activities to sustainability goals, creating scenarios that are based on alternative choices that can be used to achieve these objectives.

This approach utilises a back-casting process, outlined in Figure 6, to generate scenarios of cause–effect relationships. The framework draws on established evaluation methods from the theory of change [25] and logic models [26]. Previous studies integrating the theory of change with sustainable development goals, particularly those predicting future impacts, were also reviewed [27,28]. The Sustainability Compass has been specifically applied to aquaculture and wind power in the Baltic Sea region, as detailed in Table 5 and Figure 7.

Although differing significantly, both the aquaculture and wind power sectors impact natural and human life in the Baltic Sea region. The chosen case studies provide initial insights into sustainability themes and indicators for these sectors but are not intended to be exhaustive. The final aggregation of data from multiple sources is managed by an online tool. The primary goal of these studies was to generate preliminary content for the development of the Sustainability Compass in these areas and to evaluate the tool's structure by testing it for inconsistencies. The findings were compiled into datasets for the portal. The methodologies differed between the two studies due to structural differences in the sectors, collaboration willingness, and available time. In wind energy, the approach was streamlined because of limited time commitments from companies, yet the classification in

the final geoportal remained consistent. This flexibility in data sourcing is advantageous for robust triangulation. Crucially, the tool supports a bottom-up participatory approach, enabling users to independently derive conclusions.

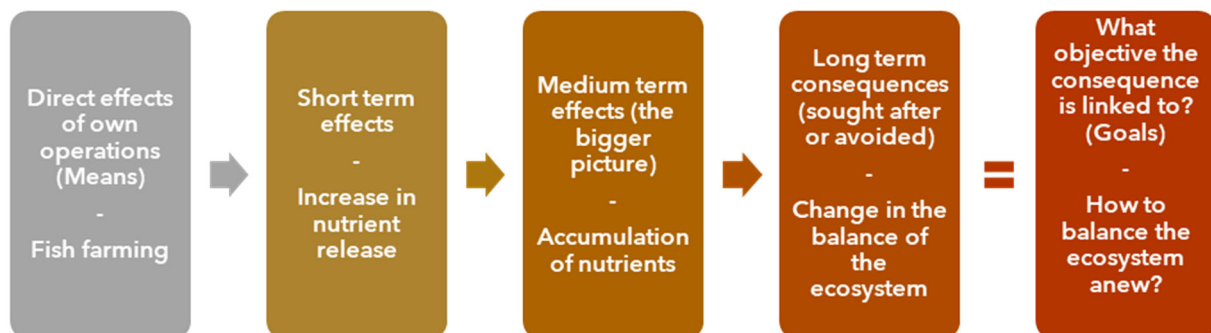


Figure 6. Sustainability framework and cause–effect thinking in the process from operations towards sustainability goals.

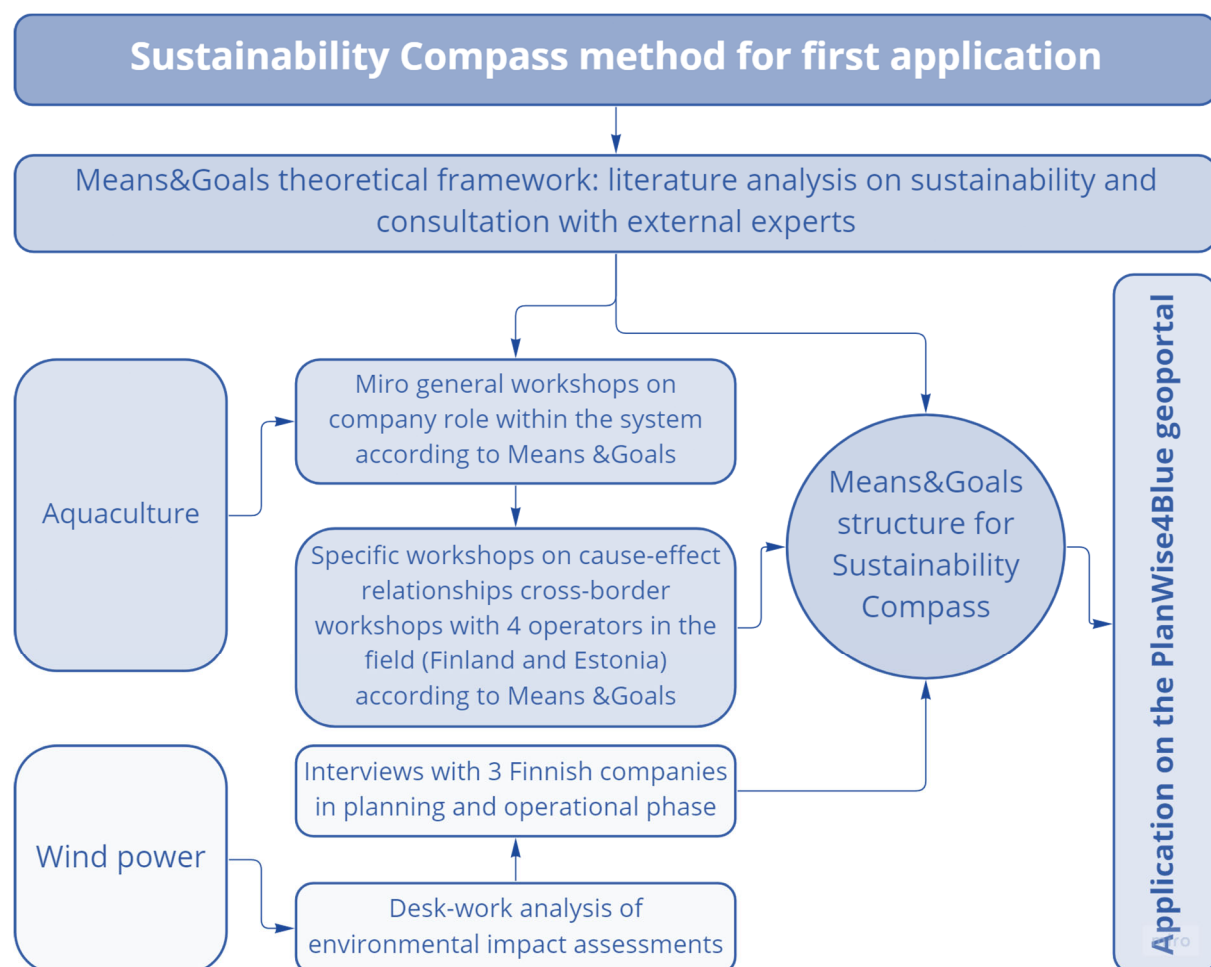


Figure 7. The methodological structure for the construction of the first Sustainability Compass [2].

The cross-border approach in aquaculture was successful, with participation from four companies, two each from Finland and Estonia, providing diverse perspectives. However, the wind power analysis was limited to Finnish companies, restricting it to a national perspective. Desk research and interviews were conducted with three Finnish wind power companies, some in operational and others in planning stages. The findings were documented in company-specific Excel spreadsheets and uploaded to the

PlanWise4Blue geoportal, which visually displays information accessible to all users (see Figure 7). The Sustainability Compass tool is integrated into the PlanWise4Blue geoportal (<https://gis.sea.ee/pw4b/survey/compass>, accessed on 13 May 2024). Anonymity was maintained for all participants to facilitate engagement, a practice that will continue in future uses of the Sustainability Compass. While individual company analyses remain confidential on the geoportal, they contribute to broader sector-level scenarios that are publicly shared.

Table 5. Case studies and company collaboration approaches.

AQUACULTURE Workshops by Miro Collaboration Platform for In-Depth Bottom-Up Sustainability Assessment with 4 Local Companies in Finland and Estonia	OFF-SHORE WIND POWER (Also in Phase of Planning) Preliminary Review of Key Sustainability Issues And interviews with 3 Local Companies in Finland
Description of the collaboration process	Identification of key sustainability issues by analysis of environmental impact assessments as basis for interview
Phase I. Brainstorming about the role and sustainable functioning of the company within the whole system	In-depth in-person or online interviews with company collaborators
Phase II. Building the framework of cause-effect relationships	Analysing key findings from the interviews
Reviewing the final structure of the framework	Reviewing the final structure of the framework

3.1. The Methods for the Case Study of Aquaculture

The initial development of the Sustainability Compass in aquaculture involved a participatory approach involving collaboration with the Finnish Fish Farming Association. Two member companies were selected for their expertise and willingness to engage in targeted workshops. These workshops aimed to construct cause-and-effect chains, mapping out means, feasibility levels, potential barriers, and indicators relevant to sustainability goals across environmental, social, economic, and infrastructural aspects. The structure of these sessions was clear to participants, who contributed detailed insights on various sustainability themes, extending beyond standard environmental impact assessments required for fish farm licensing. These workshops effectively met their objectives by enriching the sustainability framework with field-specific knowledge.

The first workshop introduced the Sustainability Compass, providing a clear and usable structure for participants to understand. Subsequent workshops on the PlanWise4Blue geoportal explored the company's role within the socio-ecological system, detailed in Figures 4 and 5. Participants identified their operational inputs and outputs, assessing how their activities could support broader sustainability goals.

The second workshop, conducted within the Miro framework (<https://miro.com/>, accessed on 13 May 2024), involved participants undertaking the following:

- Familiarizing themselves with the system's icons and definitions.
- Positioning their company within the socio-ecological system.
- Analysing the means necessary for operation and potential impacts on and from other actors, as shown in Figure 3.
- Identifying relevant outcomes and impacts of their activities using the icons in Figure 3.

In the workshops, participants from the fish farming sector used the "fish farming" box to select relevant means (inner circle) and goals (outer circle), marking actions or impacts with color-coded sticky notes based on capital classification (Figure 8). Not all sustainability goals and means needed to be covered and only key goals and means were highlighted, with notes explaining their relevance or irrelevance.

Notes from these discussions were captured for use in the third workshop, where participants crafted a specific scenario for their company using a template from Figure 9 and Miro's collaboration tools. In addition, company representatives raised a number of resolved or unresolved issues during the discussion.

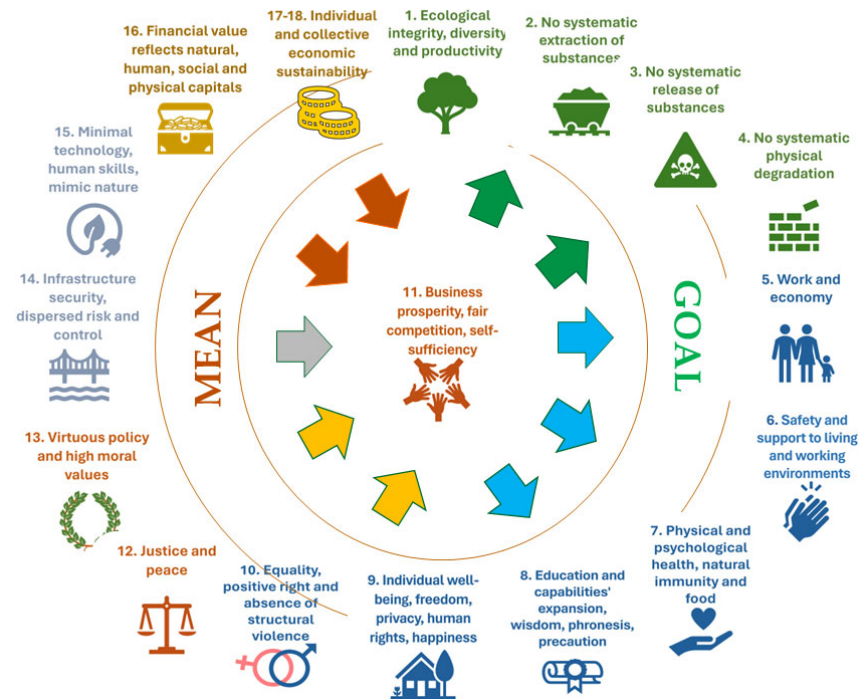


Figure 8. Means&Goals for a single case and organization, within the whole interconnected system [2].

Final goals were placed on the outermost ring, with notes between detailing critical actions or means, organized by cause-and-effect logic (Figure 9). Information on potential indicators and metrics was noted, including data availability. This setup facilitated the creation of tailored scenarios for each company, documenting benefits to various stakeholders and potential external impacts, illustrated by a non-real example in Figure 10.

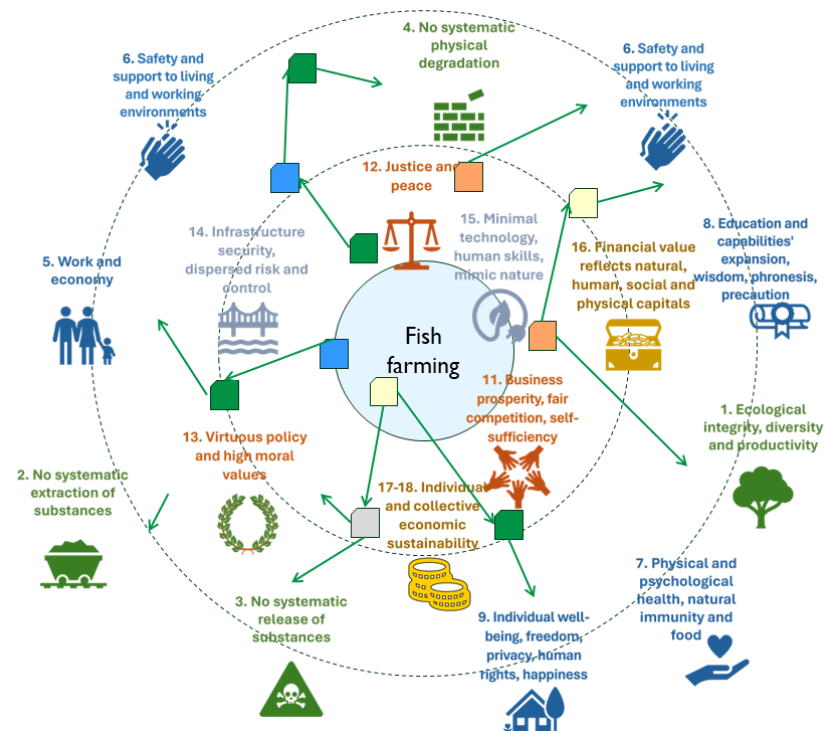


Figure 9. The scheme for the workshop development [2].

The last workshop reviewed these outcomes, ensuring accurate interpretation aligned with the final structure of the Sustainability Compass (Figure 5).

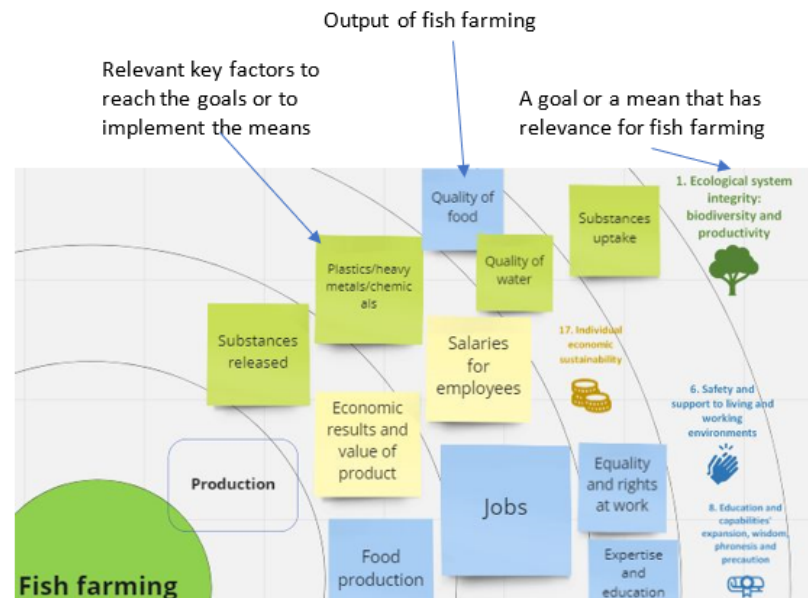


Figure 10. An example of the process of construction of the Sustainability Compass by Means&Goals brainstorming [2].

3.2. The Methods for the Case Study of Wind Power

For the wind power sector case study in the Baltic Sea region, an initial survey identified four companies: two with established offshore wind sites and two in the planning stages. Collaborative efforts were coordinated with the Finnish Wind Power Association and the Finnish Association for Impact Assessment to facilitate the participatory work.

The initial review of Environmental Impact Assessments for offshore wind projects helped identify relevant sustainability themes and potential indicators organized by Environmental, Economic, and Social/Human Capital. Data were structured in Excel following the Sustainability Compass framework (Section 4) for easy integration into the PlanWise4Blue geoportal. Interviews with representatives from three of the four Finnish companies were structured around these themes, focusing on feasibility, obstacles, and status, with outlines sent in advance (Figure 11). These discussions verified the relevance of topics, feasibility of actions, and potential implementation barriers.

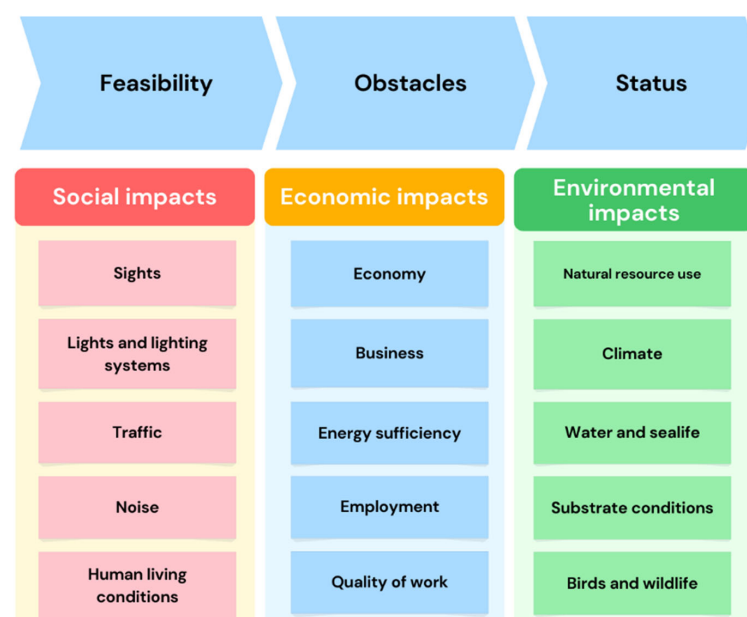


Figure 11. The themes and sub-themes covered in interviews [2].

4. Results

The results of the analysis carried out for the case studies are reported in the following sub-sections.

4.1. The Results for the Case Study of Aquaculture

The results for aquaculture have been classified per theme, and reported in the following subsections.

4.1.1. The Results of the Workshops: Licensing

In Finland, fish farming requires a license from the Finnish Centre for Economic Development, Transport, and the Environment, described as a significant bottleneck by industry participants. Licenses are site-specific and set maximum production volumes, making it challenging to increase output or establish new sites. Obtaining a license is difficult, costly (hundreds of thousands of euros), and time-consuming, often delayed by appeals from environmental groups, individuals, and authorities. This situation particularly disadvantages smaller companies and startups, deterring them from entering the market.

The licensing process primarily aims to maintain ecological integrity and biodiversity (Goal 1). However, the restrictive process also touches on justice and access to fair institutional services (Goal 12), supports business prosperity and prevents monopolies (Goal 11), promotes equality (Goal 10), and enhances work and economic opportunities (Goal 5).

When applying for licenses, companies prefer sites with minimal limitations, considering environmental factors like water turnover and sea depth, and other practicalities, like proximity to existing facilities and land and water rights. The FINFARMGIS geospatial method (FINFA) analyses and spatially represents data to assess the suitability of fish farming locations, thereby providing aid for the selection of optimal sites (<https://www.luke.fi/en/services/the-finfarmgis-method-helps-to-assess-the-location-of-a-fish-farm>, accessed on 13 May 2024).

4.1.2. The Results of the Workshops: Employment

In relation to the themes of employment and working conditions, goals 9 (human wellbeing, freedom, privacy, individual human rights, peace, justice and happiness) and 5 (work and economy, access to varied and satisfying opportunities for work and business, especially rural depressed areas) are considered the most important goals of the Sustainability Compass.

In Finnish fish farming, fry is reared in inland waters and mature in sea nets. The size of a company's workforce depends on its specialisation, which ranges from fry rearing to fish cleaning and processing. Labour requirements also depend on the technology used and the production volume. Participating companies focus on open water net farming and the sale of unprocessed fish, with the potential for workforce expansion as they diversify into processing or acquire new production licences.

Fish farming technology is mainly mechanised, sometimes automated, feeding and net condition monitoring using cameras. Where fish cleaning is involved, the use of machinery has an impact on the number of workers. The industry is seasonal, peaking in spring with fry transport and summer for growth, and declining in autumn and winter when nets are stored ashore. This seasonality often requires part-time or seasonal workers, depending on the specialisation, technology and scale of production of each company. The viability of part-time employment depends on the availability of local jobs in both the private and public sectors. However, in sparsely populated fish farming areas, employment opportunities are limited.

Companies also employ workers indirectly, by purchasing services or fish from other companies. Logistics services are crucial, but their demand is limited by current production limits due to licensing restrictions.

Worker retention is influenced by job satisfaction and perceptions of safety in the workplace. Limited educational opportunities in the fishing industry lead to a shortage of

skilled workers which forces companies to train employees internally, through on-the-job training or educational cooperation such as apprenticeships. This reveals a deficit in public services (mean 12) to produce goal 8 and in turn goal 11 for business prosperity, in turn affecting Goal 5.

In Estonia, additional challenges include finding skilled workers in rural areas, which requires attractive working conditions. Participants identified a need for more bioeconomy education modules and highlighted the lack of efficient IT infrastructure as an obstacle to digitisation and workflow improvement. Over-regulation, with slow and complex licensing, hinders business growth and expansion.

4.1.3. The Results of the Workshops: Working Conditions

Labour legislation sets the baseline for labour-related standards, and workshop participants agreed that meeting these legal requirements is fundamental to social sustainability. However, companies have the freedom to go beyond these standards. For example, while occupational health care is mandatory, companies can provide additional services. Regular wellbeing surveys, some participants noted, are crucial to maintaining employee wellbeing. One participant highlighted how the pursuit of certifications, such as the Aquaculture Stewardship Council (ASC) certificate, can further improve working conditions. These certifications often require higher standards than labour laws, such as more extensive employee training, but can be costly. Another aspect discussed was supplier audits conducted by customers, which look not only at financial metrics, such as turnover and EBITDA, but also at the physical and mental safety of employees. A key concern in the marine environment is safety, particularly the risk of drowning. One participant mentioned the development of safe working practice guidelines, which emphasise the responsibility of the worker to assess weather conditions for safe sea travel. This responsibility can be daunting, particularly for younger workers. Regular statutory boat inspections were also identified as an important safety measure.

4.1.4. The Results of the Workshops: Feeding of Fish

Table 6 summarizes the cause–effect relationships in fish farming, specifically focusing on feed regulations. Fish require phosphorus and nitrogen for skeletal development, which is regulated strictly under environmental permits that set exact feed limits. Fish farming companies argue that the regulated emission levels are minimal compared with agriculture, and that they manage some recovery of this through cleaning processes. This stricter regulation compared with other sectors is seen as unfair by both companies and external experts, particularly when the broader issue is the ongoing addition of these substances to the Baltic Sea, contradicting the sustainability goal of preventing systematic release of substances that exceed the environment’s capacity to neutralize harmful effects (goal 3). A potential solution would be to circulate existing marine nutrients without systematic additions, addressing the key issue of eutrophication. Alternatives to traditional fish feed, like soy-based options, are considered, adhering to regulations that prevent live fish from being fed to other live fish under the Animal Protection Act.

Table 6. Exemplification of the results, in terms of actions taken to reach the goals.

Problem	Mean	Action	Goal and Indicator
Feeding of fish: limits of feed amount in the license	12	Using already existing amounts in the Baltic Sea, recycling instead of adding	3, 11 at risk
Natural type of feed	12	Fish cannot be fed to other fish, lack of suppose for natural cycles	3 non achievable
Eutrophication	12	Integration of mussel and fish farming	11 not achievable in some cases
Feed supply from other companies	11, 12	Action non feasible at the moment for a lack of mean	10 (number of domestic producers), 5

In Estonia, the integration of mussel and fish farming has proven effective for removing nitrogen and phosphorus, and licensing for such operations is free if nutrient absorption is assured, aligning with mean 12. An Estonian company is even developing a line to produce edible mussels from smaller ones, adding economic value and enhancing impact mitigation efforts.

Conversely, in Finland, this integration is not economically viable due to the inadequate market size of the mussels, making goal 11 unattainable. Additionally, tightening nutrient limits could further jeopardize this goal, as maintaining nutrient availability for fish is crucial. Alternative, more natural growth methods have been proposed, though they have not been embraced by the industry.

Feed supply in the Baltic Sea region, crucial for achieving goal 11 and impacting goal 5, related to employment, faces challenges with only two suppliers, one of which is potentially closing in Finland. This may necessitate the import of feed from Denmark and could benefit from institutional support by which to boost domestic production and achieve related sustainability goals. Currently, these goals are not deemed feasible.

4.1.5. The Results of the Workshops: Animal and Human Health

With regard to the prevention of fish diseases, it has been reported that the European Union sets limits, which is a classic example of top-down regulation on which companies depend. Compliance with these regulations is the only action that companies take. In terms of disease prevention, it has been noted that antibiotics are only used in specific cases, when necessary, while vaccines are given to all young fish. However, information on the composition of these vaccines is not readily available to assess their compliance with goals 3 and 7.

An external expert provided insight, noting that interventions to prevent pests or diseases are necessary in aquaculture when large numbers of fish of the same species are concentrated in a limited space, similar to large-scale monocultures in agriculture. In this context, the interviewer asked whether alternative aquaculture models that mimic natural environments are feasible. According to the interviewees, such approaches would not be practical.

4.1.6. The Results of the Workshops: Water Quality and Environmental Aspects

Water quality is critical for fish farming (goal 3), impacting fish health and contributing to human health standards (goal 7) by ensuring that water is free of harmful substances, including GMOs and non-organic materials. The quality of water directly affects business operations (mean 11) due to its influence on product quality. Challenges include the lack of unbiased reference samples and comparative data, primarily because companies often take samples only from their own operations. This lack of external benchmarking impacts policy integrity and ethical standards (mean 13), which encompasses human rights support, environmental sustainability, and transparency. Adequate indicators for this issue would include both the quantity and quality of samples taken and the comprehensiveness of the sampling plan. The absence of neutral sampling points, independent of mandatory requirements, also poses a problem, and coverage by the sampling plan could serve as a related indicator.

4.2. The Results for the Case Study of Wind Power

The environmental impact assessment process is widely recognised by respondents as effective in capturing sustainability aspects of offshore wind projects. However, there is a lack of consensus on indicators for assessing these issues, making them impractical for use by companies. Certain issues, such as noise and visual impact, are less relevant for offshore than for onshore wind farms. Issues such as flashing lights have been mitigated by stable red lights, similar to those on radio masts.

Licensing rules for offshore wind are long and complex, largely due to poor administrative coordination rather than the rules themselves. There is less administrative

experience of licensing offshore wind than onshore, but regulators are developing their collaborative approaches.

Industry concentration is high, with three companies covering 75% of the Finnish Baltic Sea sector. Local acceptance is crucial and is improved by the use of local services and contractors. While local contractors are often subcontractors due to the size of offshore projects, their involvement benefits the local economy, especially in marina services and repair work.

Recycling of wind turbine blades is a future consideration, with the current focus on innovative solutions such as integrating blades into concrete. Technological advances are essential in order to improve efficiency and profitability. This means that recycling plans are at present missing and their feasibility unknown.

With regard to wildlife, research suggests that birds at sea fly higher than the height of the turbines and can navigate past them. Finnish law prohibits methods such as painting a blade black to deter birds, opting instead for expensive bird cameras. Environmental impact assessments adequately address growing concerns about wildlife.

Geographical and seasonal constraints, such as the freezing of the Baltic Sea in winter, limit construction activities. Companies strive to minimise the impact on bird nesting seasons during construction.

Offshore wind investment could also stimulate ancillary developments such as data centres. A notable lack of awareness of existing research, such as blade erosion, suggests a tendency to defer life cycle assessment issues rather than to proactively address them.

5. The Sustainability Compass within the PlanWise4Blue Geoportal

The integration of the Sustainability Compass into the PlanWise4Blue geoportal (<https://gis.sea.ee/pw4b/survey/compass>, accessed on 13 May 2024) facilitates a bottom-up approach to social learning about sustainability, directly impacting business operations, consumer behaviour, and policymaking. This systemic learning enhances the ability to sustain human-nature systems effectively.

5.1. Technical Guide for General-Purpose Application

The Sustainability Compass geospatial tool, embedded within the PlanWise4Blue geoportal, operates on a database compiled from various actors, integrating challenges, solutions, and measurable goals across ecological, social, and economic domains. Each database entry represents a challenge, identifies obstacles, and tracks progress through specific indicators. This setup allows for easy data updates, additions (e.g., via CSV upload), and customization in order to filter information by activity, theme, or goal.

Participatory learning from diverse social actors—entrepreneurs, environmental managers, researchers, and the public—enhances the tool’s functionality, fostering a unified approach to sustainability. Figures 4 and 5 outline the Sustainability Compass’s process: identifying problems, suggesting solutions, assessing feasibility, defining obstacles or advantages, and establishing measurable indicators and goals. This system not only tracks progress but also facilitates the integration of new insights, ensuring dynamic and up-to-date sustainability assessments.

5.2. Practical Examples of Application

The study included case studies on aquaculture in Finland and Estonia, and offshore wind power planning in Finland, using the PlanWise4Blue geoportal. Within this portal, users can select the Sustainability Compass section, add data through a table view (Figure 12), and visualize outcomes (Figure 13). Data input triggers automatic updates of graphics and tables, which can be refined using filters for specific topics like aquaculture.

The tool visualizes the journey from problems to solutions and goals, with interactive elements that allow users to explore connections and details by hovering over keywords (Figures 4 and 5). Starting with identifying a problem and associating it with a keyword, users can proceed to detail a solution in the geoportal. Each problem–solution–

indicator–goal sequence must be entered in a separate row; if multiple solutions exist for a problem, each requires a new row, duplicating other elements as necessary. For instance, solutions for minimizing bird collisions—like using radars and cameras or painting one blade black—would each occupy separate rows, with individual assessments of feasibility, obstacles, advantages, and status for each solution.

Item card

Activities performed
wind

Location
Finland, no location

Initial interest/problem
Reduced catch, loss of fishing grounds during

Keyword
Fishery impacts

Solution/Action to be done
Compensation to commercial fishers

Feasibility
high

Obstacles for achievement
None

Status
Achieved

Indicator
Cost of compensation

Indicator unit
Effect on catch volume, travel time, gear conflict

Mean/Goal
18. Economic sustainability for public/private organisations

Theme
Economy

Cancel Save

Figure 12. A closer view of the Sustainability Compass item card [2].

In one example from the PlanWise4Blue geoportal, minimizing bird impacts via radars and cameras in offshore wind farms was deemed highly feasible based on interviews with Finnish companies. Despite high costs and potential equipment sourcing challenges, the solution status was marked as “object achieved.” The associated indicator, “bird mortality”, measured by the number of birds killed by turbines, relates to the theme of “natural system” and to goal 1: ecological system integrity.

Another case involved the impact of construction on local fishers, noted as “reduced catch and loss of fishing grounds.” The solution, “compensation to commercial fishers”, was highly feasible and common, with no obstacles reported and “none” recorded for obstacles. The cost of compensation was the indicator, impacting catch volume, travel time, and gear conflicts. This case, aimed at “objective achieved”, fell under the “economy” theme and to goal 18: economic sustainability for public/private organizations.

Data in the Sustainability Compass tool of the PlanWise4Blue geoportal (Figure 13) can be visualized in a Sankey diagram, where users can filter by ‘activities performed’, ‘themes’, and ‘means and goals.’ Each filter allows for multiple selections to refine the displayed data. In the Sankey diagram, ‘keywords’ and related ‘solutions or actions’ connect to their respective ‘means’ or ‘goals’ through colour-coded lines, with hover functionality highlighting the paths between elements. Additionally, a table view is available for a comprehensive display of all filtered data.

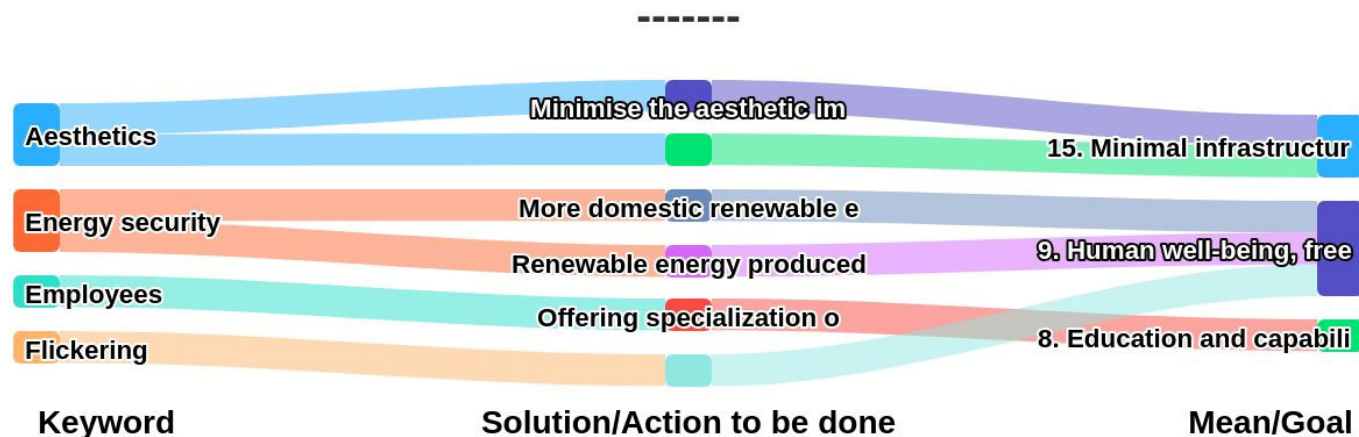


Figure 13. Sankey diagram for offshore wind [2].

6. Meta-Evaluation of Bottom-Up Inclusivity Depth of the Sustainability Compass and Strategies for Enhanced Participation

The novelty of the Sustainability Compass derives from the way that the tool is clearly not known. Therefore, a challenge consisting in the assurance of a thorough participation for the realisation of a real bottom-up approach exists. Earlier experiences of the GAME [29], and Eco-GAME (for the EU-funded Bonus MARES project) meta-evaluations assessed the quality of knowledge through natural, social, human and economic dimensions [30]. Building on this conceptual framework, the portal is being planned to host a meta-evaluation around three dimensions:

1. The depth of bottom-up participation across the spectrum of involvement of different types of actors within society.
2. The width of representation of the sustainability dimensions, based on the Five Capitals model of sustainability.
3. The level of uncertainty, by assessing the composition of qualitative and quantitative knowledge and the availability of data for the proposed indicators.

A meta-evaluation framework is proposed in Table 7. This can serve as a monitoring system, i.e., a meta-assessment about the participants and the areas they represent. It aims at analysing and understanding the degree of inclusiveness of participation, thereby suggesting actions to prevent or limit domination by any particular interest group. To this aim, the geoportal hosts questionnaires with which to collect relevant information, such as sector affiliation or expertise. This allows any sustainability assessment to include a meta-evaluation that assesses the depth of participation, the width or scope of sustainability, and the specificity of the knowledge provided.

Table 7. The meta-evaluation of participation depth and sustainability width of the Sustainability Compass.

The Meta-Evaluation of the Sustainability Compass			
Depth of Bottom-Up Participation	Width: Multidimensional Representation of Sustainability (Five Capitals-Based)	Level of Specific Knowledge	Score
Direct and open involvement of actors with limited or absent communication strength, also in anonymous forms	Focused on human and natural capitals, the goals of sustainability	Quantitative indicators for which data are available	4
Participation extended to experimental, yet non-published knowledge	Focused on human or natural capitals	Quantitative indicators	3

Table 7. *Cont.*

The Meta-Evaluation of the Sustainability Compass			
Depth of Bottom-Up Participation	Width: Multidimensional Representation of Sustainability (Five Capitals-Based)	Level of Specific Knowledge	Score
Participation extended to green literature and other minor sources of knowledge or non-official organisations	Focused on means or intermediate goals, social, economic or infrastructural capitals	Qualitative assessment by attributes	2
Participation extended to represent main societal sectors (policy, industry, finance, unions, peer-reviewed journals)	Focused on selected aspects of sustainability and ignoring or undermining others	Qualitative generic information, evidence based	1
Dominant participation by actors with stronger communication channels	Focused on the objectives for specific policies, interests or sectors	Non-supported educated guess, generic or lacking evidence, or theoretical models based on non-verified assumptions	0

Another crucial aspect involves strategies by which to increase participation. The user-friendliness of the geoportal can be a good strategy for achieving inclusivity and encouraging wider participation. The ongoing development of the interface aims to further enhance this aspect.

Another powerful strategy is to communicate the real opportunities this tool offers to underrepresented or unheard segments of society, thereby motivating them to engage with the tool to share their voices and experiences. This strategy for achieving a high level of inclusiveness and participation has involved the following: (a) directly integrating knowledge from a variety of sources, such as publications and reports, as well as from external experts, to stimulate reactions and discussion and (b) conducting workshops and interviews with field actors and posing them targeted questions based on the knowledge previously gathered. This strategy facilitates triangulation and complements existing knowledge—sometimes confirming findings and sometimes introducing different or even controversial arguments.

This approach, successfully piloted, can easily be extended to other social groups and sources of information. For example, a new project proposes to create local communities of practice. These communities would be permanently involved in the use of the tool, providing knowledge and input for its practical refinement. Examples of the substance treated by these approaches are described, in further detail in the following subsections, as being able to increase participation.

6.1. Direct Introduction of Knowledge from a Variety of Sources

The direct introduction of knowledge from different sources can stimulate the open discussion and participation from various actors, addressing socially sensitive and even politicised social issues, thereby bringing the discussion to a more experimental level.

Via the inclusion of alternative, yet existing and relevant, knowledge, it is possible to break the inertia that Kahneman et al. talked about [13], encourage and motivate engagement in an active community of practice, and allow one to make one's own analysis and experiences, instead of passively aligning with prevalent beliefs or narratives [14].

These considerations may explain why wind power, for example, is often considered to be unambiguously sustainable, due to its zero CO₂ emissions. This 'undiscussed and indisputable truth' overlooks or completely ignores other existing evidence, even among the practitioners in the field. For example, studies have demonstrated that erosion of wind turbines releases microplastics and other hazardous chemicals [31,32]. Concerns have also been raised about other forms of pollution, such as microwave emissions [33].

The widespread belief in the effectiveness of wind energy in reducing carbon dioxide emissions warrants further scientific investigation to uncover new evidence. The question is how much the need and urgency of controlling carbon dioxide weights in relation to other impacts. Despite claims of a consensus on human-induced climate change, with 97% of published papers reported to support this view [34], there is controversy. Critics point out that only 0.5% of these studies explicitly state and quantify the anthropogenic cause, while the rest simply take it for granted and assume its veracity without detailed analysis [35]. This aspect was confirmed by the answer of one energy expert, to the question about the percentage of CO₂ attributed to human activity and its role as ‘oxygen’ for plants. He reported that he does not question the major anthropogenic role in climate change and trusts IPCC’s assessment, even when he admitted being unaware about correlations and cause-and-effect relationships between carbon dioxide and temperature, as well as about the possibilities that carbon neutral technologies can control climate.

The scepticism about the clear evidence of global warming and climate emergency is echoed by Physics Nobel Laureate Ivar Giaever, who resigned from the American Physical Society [36], and by over a thousand professionals and scientists [37]. These significant uncertainties about the underlying mechanisms challenge the primary rationale for promoting wind energy and question the basis for other restrictive environmental policies. Despite the apparent consensus, the sustainability and effectiveness of wind energy, particularly its role in reducing anthropogenic CO₂ emissions, continues to be strongly debated.

The above discussion highlights the inherent uncertainty in the sustainability of wind energy and its reliance on a ‘post-normal’ approach based on consensus and trust in that consensus. According to Carter, the IPCC functions as both a scientific and political body [38], and its approach to climate science is largely categorised as ‘post-normal’, emphasising consensus [8].

This reliance on consensus raises concerns about the potential blurring of the boundaries between science and policy, which threatens the credibility of the science itself. The ongoing debate highlights the need for a clear distinction between scientific research and policymaking in discussions about the sustainability of wind energy. It also highlights the importance of obtaining more comprehensive data and analysis to reduce uncertainties and address scientific scepticism. The geoportal aims to bring these issues to the forefront to promote social learning and to encourage further analysis based on verifiable evidence rather than consensus.

Incorporating and analysing controversial knowledge can help overcome the challenges associated with accepting new information, such as confirmation bias. This approach encourages open dialogue and critical evaluation, which are essential for refining our understanding of, and responses to, complex issues such as climate change. For instance, this means including both the knowledge contained in IPCC reports [39] and the existing criticism, e.g., Carter’s questioning about the reliability of IPCC reports, referring to a lack of clear correlations between CO₂ levels and temperature changes, and the claimed failure of deterministic computer models to predict and project these changes [38] or Sarkomaa’s and Ruotto’s claim of erroneous IPCC’s models [40]. The aim of this is to triangulate knowledge and understand which of these claims are more robust than others and in which cases, and whether their findings are refuted.

The introduction of these hot arguments and knowledge into the geoportal and the Sustainability Compass can trigger discussion and give voice to less visible arguments about uncertain and strongly debated issues that the post-normal science of consensus cannot handle. The aim is to break the mentioned inertia and confirmation bias and to trigger social learning, thereby engaging in the scientific process of free refutation or verification thereby facilitating the emergence of the most robust knowledge. The possibility to remain anonymous and bring knowledge detached from own identity can also help this process. The geoportal can indeed host insights, based on scientific evidence, that stimulate discussion and therefore increase participation. This is particularly relevant for highly

uncertain and debated issues, especially when the lack of rigorous and hard correlations risk moving the discussion, as Post-normal science admits, to softer educated guesses and a science of consensus. The confrontation of views can allow stronger arguments to emerge, not only on the basis of peer-reviewed papers, but also on logical reasoning and refutation of insufficiently supported arguments. This would induce an increase in the use of the tool for evidence-based scientific discussion, wider participation, and additional research, rather than claims (true or untrue) about consensus and incontrovertibility, which would cut off any deeper investigation attempts. As it is open for discussion for a wider community of practice, the geoportal can, in this way, become more reliable than a peer-reviewed paper.

In the final evaluation made by the Sustainability Compass, the most relevant indicators are then selected and assessed by the described meta-evaluation, in order to form a string of values that correspond to the different dimensions of sustainability. This can also be eventually aggregated in a composite indicator. Clearly, this can be undertaken for quantitative information. In case only qualitative information is available, two options are available:

1. Data collection for the indicator for which data are missing.
2. Qualitative evaluation by attributes and scores, to assimilate the knowledge to pure quantitative and allow aggregation.

6.2. Workshops and Interviews to Increase Participation

A second strategy was the realisation of interviews and workshops, posing questions on important and socially sensitive issues, which facilitated the inclusion of the contributions of the participants.

For example, in the context of the sustainability challenges facing wind turbines, and as discussed in the previous subsection, interviews with companies in the wind energy sector revealed a lack of awareness of relevant research in this area. Similarly, discrepancies in views and possible actions were observed in aquaculture, particularly in relation to the management of produced phosphorus and opportunities for its recovery. Presenting these challenges has the potential to increase participation and encourage more in-depth analysis by the industry sector to either confirm or refute findings from other sources. This approach is planned to be extended to the communities of practice directly and permanently involved in the process.

7. Integrating Research and Practice: What Experience in the Field Means in Terms of Ecosystem Services

The ecosystem services approach values the often-unquantified aspects of natural resource use that are not reflected in traditional economic costs and benefits. This approach is an integral part of broader sustainability assessments, translating knowledge gained from interviews into impacts on these services. The Common International Classification of Ecosystem Services (CICES) [41] provides a standardised framework for categorising and describing ecosystem services, which is critical for ecosystem accounting and broader applications. CICES divides ecosystem services into three primary categories: provisioning, regulating and cultural, while supporting services are considered part of the intrinsic structures and processes of ecosystems. This uses a five-level hierarchy for detailed, specific descriptions. Ecosystem services can be either degraded or enhanced by human activities. In particular, regulation of services can mitigate adverse human impacts. However, environmental impact assessments often focus on negative impacts and overlook the importance of regulating services. A holistic assessment of how green bioeconomy planning interacts with ecosystem services would greatly benefit sustainable development strategies.

7.1. The Case-Study of Aquaculture [2]

In workshops, fish farming companies conducted self-evaluations, focusing on the negative impacts of phosphorus and nitrogen emissions from feeding, aligned with the CICES ecosystem services classification (Table 8). These emissions were noted for their dual

impact on provisioning services. Workshop participants also recognized negative impacts on regulating ecosystem services due to these emissions (Table 9) but highlighted positive aspects, such as the low incidence of disease and the absence of the salmon louse in the Baltic Sea. Additionally, they pointed out mitigating factors like the minimal emissions relative to other sources, use of fry vaccinations, and limited antibiotic use [2].

Table 8. Example of an evaluation of the interaction of fish farm activity with provisioning ecosystem services [2].

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in situ aquaculture for nutritional purposes	Animals by amount, type	Positive: Growing fish is an effective way to produce protein from feed. Negative: Fish are not able to roam freely as in nature. Feeding fish increases the load of phosphorus and nitrogen. Alleviation of impact: Fish farms are typically located in areas with a better water flow. Fish are fed according to need, as excess feed cannot be given as the operating license does not allow it.
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in situ aquaculture for direct use or processing (excluding genetic materials)	Animals by amount, type	Positive: The side streams of fish production, such as, fisheyes, fish blood and cleaning waste can be used for energy. Negative: efficient uses for fisheyes and blood, apart from energy, are not viable.

Table 9. Example of an evaluation of the interaction of fish farm activity with the regulation and maintenance of ecosystem services [2].

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Regulation and maintenance (biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration by micro-organisms, algae, plants, and animals	By type of living system, or by water or substance type	Negative: fish farming increases the phosphorus and nitrogen content of the seawater and strengthens eutrophication. Alleviation of impact: the increase is observed mainly in the vicinity of the fish farm, a fish farm site increases phosphorus and nitrogen primarily during the summer. Additionally, the water turnover at the open sea, where the fish are grown to full size, is high.
Regulation and maintenance (biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	By reduction of incidence, risk, area protected by type of living system	Positive: salmon louse does not inhabit the area of concern as the Baltic Sea is a low-salted sea. Alleviation of impact: fry are vaccinated at the size of 15 g. In Finland antibiotics are used only if necessary for the health of the fish and only with the permission of a veterinarian.

Table 9. Cont.

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Regulation and maintenance (biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	By reduction of incidence, risk, area protected by type of living system	Alleviation of impact: medicine is not generally needed. Fry are vaccinated at the size 15 g. Antibiotics are given only if necessary and with the permission of a veterinarian. The risk of runaway fish transmitting diseases to natural fish populations is low.
Regulation and maintenance (biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	By type of living system	Negative: the increase in phosphorus and nitrogen levels in seawater caused by the fish farm cannot be regulated by the living organisms, which influences eutrophication. Alleviation of impact: fish farming is a relatively small emitter of phosphorus and nitrogen.

7.2. The Case Study of Wind Power [2]

Business self-evaluations highlighted potential negative impacts from offshore activities, including harmful substances in seabed sediments and various construction-phase effects, such as electromagnetic fields, light and shadow, underwater noise, and habitat change [2]. These impacts were classified under the CICES ecosystem services (Table 10) as negative for both provisioning and regulating services. However, expert evaluations noted that regulating services might mitigate these impacts (Table 11). Recognizing these interactions could preserve the regulatory benefits of ecosystem services, with windmills also potentially offering positive effects like the reef effect. These examples highlight the importance of understanding the interactions between human activities and ecosystem services. Notably, wind energy itself functions as an ecosystem service, essential for the economic viability of windmills (Table 12) [2].

Table 10. Example of an evaluation of the interaction of windmill activity with provisioning ecosystem services [2].

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Provisioning (biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	Plants, algae by amount, type	Negative: possible harmful substances in seabed sediment Impact on fish: construction phase impacts, electromagnetic fields, light and shadow effects, underwater noise, change of habitat
Provisioning (biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	Animals by amount, type,	Negative: Impact on fish: Construction phase impacts, electromagnetic fields, light and shadow effects, underwater noise, change of habitat

Table 11. Example of an evaluation of the interaction of windmill activity with regulating and maintaining ecosystem services [2].

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Regulation and maintenance (biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bioremediation by micro-organisms, algae, plants, and animals	By type of living system or by waste or subsistence type	Alleviation of impact: possible harmful substances in seabed sediment
Regulation and maintenance (biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	By type of living system, or by water or substance type	Alleviation of impact: possible harmful substances in seabed sediment
Regulation and maintenance (biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Noise attenuation	By type of living system	Alleviation of impact: underwater noise may affect marine wildlife
Regulation and maintenance (biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (including gene pool protection)	By amount and source	Negative: risk of losing benthic communities, reefs and/or sandbanks from the area Positive: Impact on fish: change of habitat, reef effect Negative: Risks for fauna: disturbance (during construction and operation), change of habitat
Regulation and maintenance (biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	By type of living system	Alleviation of impact: degradation of water quality during construction phase

Table 12. Example of an evaluation of the interaction of windmill activity with provisioning abiotic ecosystem services.

Section	Division	Group	Class	Class Type	Evaluation of Interaction
Provisioning (abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind energy	Amount by type	Essential prerequisite for windmills

8. Conclusions

The piloting of the Sustainability Compass analysis for the case studies of aquaculture and wind energy has provided explanations about sustainability outcomes, which can be used in support of decision making. The research has explained this in the following various ways:

- The narrative text, indicating the chain of cause–effect relations, starting from the definition of the problem and going through the proposed actions and means towards the realisation of the sustainability goal.

- The indication of relevant indicators and their measurement units.
- The representation of the same narrative in a graphical and geospatial form through the geoportal, developed in an ad hoc manner.

Complex local contexts, which vary widely, defy simplistic, one-size-fits-all regulatory frameworks. Centralised regulations often fail to promote accountability and responsibility, key tenets of good governance. Distance between decision makers and citizens can obscure local issues and increase susceptibility to external influences, thereby undermining representation. In addition, complex decisions affecting human and natural wellbeing can have irreversible impacts, requiring ethical decision making.

Moreover, many scientific matters are characterised by high levels of complexity and uncertainty, which can hardly be reduced. In such situations the traditional scientific approach is unable to provide answers in the short run, and the claimed urgency at the political level has led to the adoption of approaches of Post-normal science, which moves from traditional empirical evidence to consensus. This involves a risk of confusing science with policy and to consequently be subject to the influence of the predetermined political lines of the strongest players. Many smaller actors, both in business and civil society, may remain powerless and the blurred distinction in people's minds between science and politics may undermine the credibility of science itself.

While scientific evidence is crucial, it differs from political consensus in that it focuses on observation and the testing of existing knowledge. The scientific method values uncertainty as a source of knowledge, in contrast with political processes.

The Sustainability Compass aims to address these complexities and uncertainties, as well as moving away from the tendency to reduce uncertainty by consensus and adhere to the original conception of scientific discovery. Although it is currently a pilot within the PlanWise4Blue geoportal and focuses on cases such as aquaculture and wind farms and so not exhaustive, it does offer basic insights. By integrating interview results with existing reports, it highlights uncertainties and key findings, and informs case-specific sections within the geoportal.

The Sustainability Compass is designed as a social learning process, bringing together existing knowledge and grassroots experience to highlight reliable sustainability practices. It encourages active participation and competition, rather than simple compliance. This method could reduce bureaucratic burdens and encourage bottom-up, culturally sensitive approaches.

The analysis highlighted the challenges posed by the UN Sustainable Development Goals (SDGs), which are often criticised for being too generic and obvious, e.g., 'no poverty', 'zero hunger' or 'decent work and economic growth'. These goals have been staples of government programmes throughout recent history and are subject to different, sometimes conflicting, interpretations due to the lack of clear and measurable targets that concretely measure and aim to improve people's well-being or the health of the environment. In addition, the lack of a systemic approach can lead to an underestimation of systemic interactions, trade-offs and redundancies between different but highly correlated objectives. Furthermore, the predominantly top-down approach of the SDGs often prevents meaningful integration and discussion at the operational science level.

The shift towards the more practical and systemic Means&Goals of the Sustainability Compass allows for the operationalisation of the broad, top-down SDGs through a local, bottom-up approach to sustainable development. The definition of specific and measurable indicators evolves dynamically in response to the continuous production of scientific knowledge and related debate, thereby monitoring the progress towards sustainability goals.

This approach allows for a more effective and context-sensitive application of sustainable development strategies. Socially driven, bottom-up behaviour can be more effective than top-down regulations and become an integral part of individual mindsets. A connected meta-evaluation, such as that proposed in Section 6 can monitor the depth of bottom-up participation, the width of multidimensional representation of sustainability, by

mean of the Five Capitals Model of sustainability as well as the uncertainty and quality level of the specific knowledge.

The Sustainability Compass serves as a foundational tool for this transformation, aiming to apply its principles in different contexts to identify sustainability trends. It seeks to empower citizens and organisations in local settings, overcoming the challenges posed by centralised regulation and scientific limitations. Often, scientific data alone are not enough; a wider range of social learning and diverse data sources are essential.

The implementation of the Sustainability Compass in the PlanWise4Blue geoportal promotes decentralised, participatory decision making and fosters a voluntary culture of sustainability. It embodies the idea of a bottom-up, participatory approach and provides a platform for increased community engagement and sustainability trends.

The generic nature of the Means&Goals of the Sustainability Compass refers to universal principles and criteria of sustainability according to a multidimensional approach. This is important to guarantee the applicability and scalability of the geoportal to other regions, cases, local communities and specific ecosystems.

9. Plans for Future Application

The Sustainability Compass portal serves as a platform for inclusive, open discourse and addresses sensitive issues such as the environmental impact of wind farms and forest conservation. It is not designed for marketing or political propaganda, but for building science-based knowledge. By allowing different methods, theories and data sources, it encourages the accumulation of scientific evidence. Participants contribute their expertise, and the Sustainability Compass rewards research-based solutions over mere rhetoric. It transforms scientific uncertainty into supporting information for decisions rather than debate fodder. Currently being integrated into the PlanWise4Blue geoportal, the Sustainability Compass has the potential to outperform traditional peer-review processes in terms of reliability. This methodological shift depends on its full implementation within the geoportal.

The Sustainability Compass is not a tool for political conflict resolution. It is a tool for making best practices and for allowing more relevant knowledge, from an objective and scientific perspective, to emerge. Anyone can input information and knowledge, on the basis of evidence or experimental data, and this guarantees equity.

However, as the tool is voluntary, in certain cases 100% inclusivity cannot be guaranteed. Therefore, as previously treated, the geoportal can include a list of criteria of inclusivity, and a related meta-evaluation, in order to communicate the depth of participation for selected cases. It is a meta-analysis measuring the inclusivity rate of the bottom-up approach, as well as the inclusivity of the sustainability dimensions. This is useful for the promotion, evaluation and improvement of inclusivity. Nevertheless, the results achieved are not affected by the number of preferences, but rather by the robustness of the evidence brought, according to a principle of scientific evidence.

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