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Review

Sustainability Assessment in Water Infrastructure Projects—Existing Schemes and Challenges in Application

Sonja Cypra [1], Fabian Knepper [1], Susanne Kytzia [2] and Elke Petersson [1,*]

[1] Faculty of Architecture and Civil Engineering, Karlsruhe University of Applied Sciences, Moltkestraße 30, 76135 Karlsruhe, Germany; sonja.cypra@hs-karlsruhe.de (S.C.); knfa1017@hs-karlsruhe.de (F.K.)

[2] IBU Institut für Bauen und Umwelt, HSR Hochschule für Technik Rapperswil, Oberseestraße 10, 8640 Rapperswil, Switzerland; susanne.kytzia@hsr.ch

* Correspondence: elke.petersson@hs-karlsruhe.de; Tel.: +49-721-925-2639

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Abstract: Ecological, economic and societal challenges require decision-making and planning processes aiming at sustainability in water management. Such processes are increasingly informed and supported by sustainability assessment schemes. The focus of this article is on water infrastructure. A selection of national (German) and international assessment schemes is presented and compared. Both interdisciplinary schemes, applicable to a wide range of infrastructure measures, as well as schemes specialized in water infrastructure are considered. In addition to methodological aspects and dissemination, thematic priorities are analyzed and compared. Apart from methodological similarity, specialized schemes tend to be still in the development stage. In contrast, the interdisciplinary schemes have already been used commercially and have been applied in a considerable number of projects. The schemes considered differ significantly in the number of criteria. The interdisciplinary schemes tend to focus more on the ecological dimension while considering a small number of economic criteria. The assessment results depend on various subjective factors and the schemes do not produce true or false results in absolute terms. However, their application can make these factors visible and help identify the most stable solution with regard to different sustainability perspectives.

Keywords: sustainability; water infrastructure; sustainability assessment schemes; sustainable development; urban water management; hydraulic engineering

1. Introduction

In Germany, the construction industry is high in consumption of raw materials (90% of mineral raw materials mined in Germany) and generates more than 50% of waste produced [1–3]. Maintenance and operation of the resulting buildings and infrastructure again consume considerable resources, e.g., energy and water, throughout their long service life [2–4]. At the same time several planetary boundaries are already exceeded or in a critical state, e.g., biodiversity, biogeochemical flows or climate conditions [5]. Environmental protection and societal adaptation measures are needed to mitigate these developments and cope with their impacts. With this in mind, the development of our built environment through construction industry can make a substantial contribution to a sustainable development.

Following the definition of the Brundtland report [6], it is common understanding, that the notion of sustainable development requires a joint development of economic and ecological systems serving societal wellbeing of present and future generations. The interests, values and moral tenor of decision-makers and stakeholders keep changing though [7], making the concept ambiguous [8]. As a consequence, science and evidence provide the information basis for planning decisions, the resulting planning decisions are taken by individual persons or institutional bodies and, therefore, are only rational and objective to a certain extent [9]. Among others, the allowable degree of substitution between the three dimensions of sustainability is a central point of discussion [7,10–12]. The vagueness involved questions the meaning of any sustainability measurements [13].

Nevertheless, already in the planning phase the impacts of construction projects and the requirements regarding their functionality should be analyzed and assessed with regard to all three sustainability dimensions, considering a project's entire life cycle [14]. By providing a respective methodology, sustainability assessment schemes enable a transparent choice of the most sustainable option [15] and reduce trial and error.

One group of sustainability assessment schemes is based on the concept of multicriteria decision analysis (MCDA). They can be considered an example of integrated assessment in contrast to indicators and indices or product related assessment, referring to the classification introduced by Ness [16]. They draw up a catalogue of various criteria, which are evaluated individually using one or more indicators, depending on the available data. Usually the schemes set a weighting of the criteria against each other. By aggregating the individual results for each criterion across all criteria, considering the weights, comparable overall results are generated. By this means, the optimum of several alternatives can be identified or a project can be compared to a reference level. The schemes can also be used to analyze the impact of general future developments or different sets of weights on the robustness of the result.

In building construction, sustainability assessments and even certification schemes have been established, beginning in the early 1990s, and are continuously adapted to emerging requirements [17]. Formally, the development stage of sustainability assessment for infrastructure is lagging behind [18]. One possible reason might be the great diversity of infrastructure types, requiring consideration in respective schemes. On the other hand, infrastructure has a head start looking at developments, such as environmental impact assessment, participatory planning, integrated planning or other assessment methodologies [19].

As opposed to building construction, for infrastructure, there is no free market and certification after completion does not generate added value for the owner, as explained in [17] quoting [20], e.g., through higher rental or retail price. As explained in [18,20–22], instead, infrastructure often is characterized by:

- public ownership and framed by public development strategies and licensing procedures under public law;
- high external effects in case of failure, that society instead of the owner has to bear;
- large influence of site characteristics on sustainability see also [12].

Water is considered the common thread of all global challenges, such as energy, food, health, peace and so on [23]. In particular, water infrastructure is a pillar of prosperity and in industrialized countries often considered a default [15]. Globally there still is a lack of water and sanitation for all [24]. Water infrastructure provides flood and coastal protection, waterways, electricity generation as well as treatment, storage and pipe systems for drinking water, firefighting and waste water systems. At the same time, water infrastructure exerts pressure on the natural water cycle (increasing water demand, pollution through agriculture, industry, private use) and is particularly vulnerable to climate change impacts and demographic development [25,26].

While the general function of a specific type of water infrastructure remains unchanged, the implementation and operation of the respective water infrastructure widely differs in dependence of local or even site-specific conditions, i.e., in particular quantity, quality and availability over time of the water resources (e.g., optimizing water distribution systems to ensure minimum pressure or equal water distribution to all users) [27].

Besides the abovementioned general aspects of infrastructure, therefore, water infrastructure is characterized by a complex system context, large spatial spread, high investment and a long lifespan [28]. Methodologically, new uncertainties due to climate change [29] and socioeconomic developments make projections of the past inadequate [28]. Similarly, planning processes of the past, that were basically expert and technology driven and carried out by centralized public institutions [9], are considered too limited with regard to sustainable development and, in particular, public acceptance.

As a result, a broad variety of aspects and requirements needs to be considered when planning water infrastructure measures [30]. Complex decision situations arise that can no longer be solved intuitively on the basis of implicit knowledge alone [15]. Instead, the complex sociotechnical decision situations of today require anticipatory evaluation and decision-making processes, that generate sustainable results through holistic (scenario) analysis integrated in participatory multistakeholder processes giving special attention to the implications of uncertainty and sensitivity of results [12,31].

The application of MCDA in the water sector seems to focus on water policy and water resources management [32]. Following this understanding, in March 2019, a workshop on "Sustainable construction—an issue for water infrastructures?" was held at Karlsruhe University of Applied Sciences with participants from research, public institutions and practice. As a result, the application of sustainability assessment schemes was considered relevant for decision-making with regard to the selection of project or strategic alternatives by all 22 participants. In contrast to this understanding, the participants noted that, until now, respective schemes have been rarely applied in every day planning for sustainable construction of water infrastructure. Neither planning offices nor operators currently consider them to be standard within in their decision-making.

Interestingly, a considerable number of sustainability assessment schemes are developed for water infrastructure projects. They pursue either a more general approach addressing all types of infrastructure or, in many cases, focus on specific types of water infrastructure. The resulting schemes differ with regard to the criteria considered, the methodology used, the sector and time of application, as well as the sustainability dimensions and life cycle phases addressed. To support future implementation of such schemes in everyday planning of water infrastructure, this article identifies these differences for a set of exemplary assessment schemes and discusses strengths and weaknesses identified from the comparison of the schemes. In particular, it aims to highlight relative differences between schemes using the more general interdisciplinary approach and those that focus on specific types of infrastructure. The obtained information supports the selection of a suitable assessment scheme for the sustainability assessment of a specific project and rises awareness for their implementation.

Following an overview of the legal basis for the sustainability assessment of water infrastructure in Section 2, this article looks at the differences of two types of assessment schemes, i.e., interdisciplinary and water-specific schemes. These are compared regarding different aspects, e.g., sector of application, project phase when applied, question to be answered, criteria and indicators used, life cycle phases considered and assessment methodology. In Section 3, four schemes for interdisciplinary application and four schemes specialized in water infrastructure are introduced with regard to these aspects. Section 4 highlights the conceptual differences between the schemes and summarizes the general understanding about the benefits and limitations of sustainability assessment schemes and their application. Section 5 highlights the conclusions of the article.

2. Legal and Normative Basis

Sustainable development is no longer a theoretical vision. Both legal and normative frameworks are in place on different administrative scales. They formally require the implementation of sustainable development and even provide some methodological support for decision-making in this context. Therefore, the following examples of respective frameworks illustrate the setting, in which sustainability assessment schemes have to be applied.

In Europe, for example, the legal framework for a sustainable water infrastructure is already in place. The European Water Framework Directive (WFD) is an important instrument in this context. It calls for an integrated, river-basin-related and transboundary water policy. With regard to water ecology, in addition, an integrated assessment strategy is required. By linking technical data with ecological, economic and social development goals, it sets the framework for sustainability-oriented development and decision-making strategies [22,33].

Another framework for sustainable development was established at the global level by means of the Agenda 2030 of the United Nations (hereinafter UN) [34]. The Agenda 2030 defines 17 Sustainable Development Goals (SDG), which are summarized in Figure 1. Several (sub) goals refer to the water infrastructure sector. They should be considered in sustainability assessment as part of decision-making processes. These are, for example, SDG 6 (Ensure availability and sustainable management of water and sanitation for all), that directly addresses water supply, or SDG 9, which requires, among other things, to build a sustainable and resilient infrastructure. By applying multicriteria assessment schemes, conclusions can be drawn about the contribution (positive or negative) of water management measures to individual SDGs [35].

Figure 1. The 17 sustainability goals of the UN; image section from [36].

With regard to the standardization of such sustainability assessment schemes, committees of standardization exist at both international (ISO) and European (CEN) level, dealing with sustainable construction as well as with standardization of assessment schemes. In 2018, the European Standard EN 15643-5 [14] and its respective national annexes were published, covering the sustainability assessment of civil engineering works (e.g., dams, bridges, sewerage systems, etc.). It aims to create a framework for the sustainability assessment of civil engineering works. It covers only the analytical part of an assessment methodology and defines requirements to be considered regarding the impacts and the system boundaries of the assessment scheme [14]. Calculation methods are defined in the European Standard prEN 17472:2020 that will be published in 2022 (currently in enquiry). It will define threshold or reference values for individual criteria. Yet, methodologies how to aggregate criteria information will still be missing.

Apart from the European level, SIA 112/2 is an important standard dealing with sustainability in the infrastructure sector [37]. Published in 2016 by the Swiss Association of Engineers and Architects (SIA), the standard's approach is of interest as it defines itself as an instrument of understanding between planner and client. Thus, in contrast to EN 15643-5, SIA 112/2 does not serve the standardization of sustainability assessment itself. Instead, its aim is to show planner and client the aspects relevant for sustainable infrastructure works. On this basis, the client is able to choose and weight the aspects that are most important for him. By providing this support for a common understanding between planner and client, SIA 112/2 aims to simplify planning and implementation of sustainable infrastructure [37].

The legal and normative framework is formally binding but at the same time not conclusive. In this broad setting sustainability assessment schemes have to be effective and flexible at the same time.

3. Current Status of Assessment Schemes in the Field of Water Infrastructure

A total of eight assessment schemes is considered below. Focus is on project assessment as opposed to water policy or general water resources management and on schemes for multiple use instead of schemes developed within and for one specific case study. Four of them are interdisciplinary schemes, applicable to a wide range of infrastructure measures. They are common schemes, which also permit international application. Care was taken that these schemes were developed independently of each other by different institutions. Although coming from different parts of the world, all originate in industrialized countries.

The other four schemes are specialized in water infrastructure. These are divided equally between the fields of urban water management and hydraulic engineering. Two schemes per sector are considered. The schemes in this group can only be examples, representing an almost endless number of schemes for very specific questions and regions. They were identified in order to represent a big variety of development backgrounds (large and small research projects, multistakeholder process), state of development (new to established) and types of alternatives covered (technologies, project alternatives or performance with regard to a reference level). For all schemes data availability and independence of developing institutions were prerequisites.

Most assessment schemes draw up a catalogue of various criteria, which are evaluated individually for the respective (construction) project using one or more indicators depending on the available data. The criteria depict the various impacts of the project. They are often clustered to form criteria groups or categories. However, the schemes considered do not use the same terms for the different grouping levels. In order to guarantee a good readability, the terms "criteria", "criteria group" and "category" are used in this article. Table 1 matches these terms with the original terms used in the documentation of the respective schemes. Thus, traceability of information between this article and the original documentation of the schemes (given as references) is ensured. Usually the schemes set a weighting of the criteria against each other. By aggregating the individual results for each criterion across all criteria, comparable overall results are generated. In this way, the optimum of several alternatives can be identified.

Table 1. Comparison of terms.

Article	CEEQUAL	Envision	IS Rating Scheme	SPeAR	DWA-A 272	MuBeWis	HsKA-Scheme	HSAP
Category	Category	Category	Theme	-	Main goals	Subgoal	Subject area	-
Criteria group	Assessment issues	Areas	Category	-	unnamed	Subordinate goals	Criteria group	-
Criteria	Assessment criteria	Credit	Credit	Indicator	Criteria	Criteria	Criteria	Topic

3.1. Interdisciplinary Assessment Schemes

Internationally, several sustainability assessment schemes exist that are applicable in the infrastructure sector and thus for all different types of infrastructure work. Among others, the two British schemes SPeAR (Sustainable Project Appraisal Routine, published 2001) and CEEQUAL (Civil Engineering Environmental Quality Assessment and Award Scheme, 2003) are worth mentioning, as well as the American scheme Envision and the Australian Infrastructure Sustainability Rating Scheme, that both were published for the first time in 2012.

- CEEQUAL [38] was developed by the Institution of Civil Engineers and now belongs to BRE Global Ltd. Both a scheme for the United Kingdom and Ireland and an international scheme are available. The latest version was released in 2019 as a merger of CEEQUAL with the pilot scheme "Building Research Establishment Environmental Assessment Method (BREEAM) Infrastructure", available since 2015. It can be used for all types of infrastructure and landscaping projects and provides two different schemes. The "CEEQUAL for Projects" scheme addresses both new projects and the rehabilitation of existing facilities. Within this scheme, the assessment of the sustainability quality is made possible at the project phases of strategy finding, object planning and construction, whereby the phases from strategy determination to operation are taken into account. It is the aim of the application to certify projects and thus increase awareness for sustainability. Basically, CEEQUAL consists of a list of weighted criteria with a focus on ecological quality. This list of criteria is divided into the following eight categories and 30 groups of criteria (in *italics*):

- Management: *Sustainability Leadership*; *Environmental Management*; *Responsible Construction Management*; *Staff and Supply Chain Governance*; *Whole Life Costing*;
- Resilience: *Risk Assessment and Mitigation*; *Flooding and Surface Water Run-off*; *Future Needs*;
- Communities and stakeholders: *Consultation and Engagement*; *Wider Social Benefits*; *Wider Economic Benefits*;
- Land Use and Ecology: *Land Use and Value*; *Land Contamination and Remediation*; *Protection of Biodiversity*; *Change and Enhancement of Biodiversity*; *Long-term Management of Biodiversity*;
- Landscape and Historic Environment: *Landscape and Visual Impact*; *Heritage Assets*;
- Pollution: *Water Pollution*; *Air, Noise and Light Pollution*;
- Resources: *Strategy for Resource Efficiency*; *Reducing Whole Life Carbon Emissions*; *Environmental Impact of Construction Products*; *Circular Use of Construction Products*; *Responsible Sourcing of Construction Products*; *Construction Waste Management*; *Energy Use*; *Water Use*;
- Transport: *Transport Networks*; *Construction Logistics*.

Using CEEQUAL, criteria performance is evaluated either by allocating a defined number of credits/points in the case of fulfillment or, for some criteria, by using a sliding scale (or benchmark) allocating a higher number of credits for a higher level of fulfillment.

Maintenance and operation of infrastructure that are carried out under long-term contracts is assigned to the "CEEQUAL for Term Contracts" scheme, which is not discussed further in this article.

- Envision [39] was published in 2012 by the American nonprofit organization Institute for Sustainable Infrastructure (ISI). Since 2018, Version 3 has been available. Envision is also based on a list of weighted criteria and indicators associated to each criterion. It considers all life cycle phases from planning to decommissioning and can be used at any point of the entire life cycle of a project. Basically, the application aims to serve as a guideline for decision-making in the respective project phase, e.g., to compare different project alternatives with each other or to contribute sustainability criteria to the decision-making process. However, Envision can also be used for certification. It is universally applicable to all types of public and private infrastructure. Like CEEQUAL, it focuses on ecological quality, but the current Version 3 also includes a social category (Quality of life) and individual economic criteria. In total, the criteria are divided into five categories, including 14 groups of criteria (in *italics*):

    - Quality of Life: *Wellbeing*; *Mobility*; *Community*;
    - Leadership: *Collaboration*; *Planning*; *Economy*;
    - Resource Allocation: *Materials*; *Energy*; *Water*;
    - Natural World: *Siting*; *Conservation*; *Ecology*;
    - Climate and Resilience: *Emissions*; *Resilience*.

Envision provides a point table, defining how many points are assigned in accordance with the level of achievement obtained by a criterion.

In each category, an additional criterion is added that rewards particularly innovative solutions. These criteria act as a bonus in the overall result.

- The Infrastructure Sustainability (IS) Rating Scheme [40] was published as an Australian/New Zealand scheme by the Infrastructure Sustainability Council of Australia in 2012. An international pilot version of the scheme is also available dating back to 2017 and aligning with the UN's SDGs.

It is also based on a weighted list of criteria. The IS Rating Scheme can be applied to different project phases such as planning, construction or operation. Certification of these phases is the aim of this assessment scheme and takes place at the end of the respective phase. The "IS Planning Guideline" covers earlier project phases. With the IS Rating Scheme, an assessment of a broad variety of infrastructure is possible, such as transport, utilities and public realm/open space, taking into account all life cycle phases.

However, in contrast to the national scheme, which is already available in Version 2.0, the international version does not include economic criteria within the six categories and the underlying 15 groups of criteria (in *italics*):

- Management and Governance: *Management Systems*; *Procurement & Purchasing*; *Natural Hazards*;
- Using Resources: *Energy and Carbon*; *Water*; *Materials*;
- Emissions, Pollution and Waste: *Discharges to Air, Land and Water*; *Land*; *Waste*;
- Ecology: *Ecology*;
- People and Place: *Community Health, Wellbeing and Safety*; *Heritage*; *Stakeholder Participation*; *Urban and Landscape Design*;
- Innovation: *Innovation*.

The majority of criteria are evaluated by assigning one of three performance levels on the basis of defined qualitative benchmark performance levels. Only few criteria are evaluated on the basis of a value scale (sliding scale).

- SPeAR [41] was developed by Arup, a British company, in 2000. It differs from the above-mentioned schemes in its focus on infrastructure as well as building construction. In addition, the sustainability assessment is visually presented in a rose diagram. The performance of each individual criterion is colored using a traffic light system (see Figure 2). The current 2017 review can be used over the entire life cycle from the early design phase of a project up to and including the operation phase. Objectives of SPeAR can be, for example, a gap or key indicator analysis before the start of the project, monitoring of project performance, decision-making between several planning alternatives or certification after completion.

  - SPeAR is available as a software. It consists of a criteria list with 24 core criteria, which can be supplemented by further criteria on a project-specific basis. All criteria are evaluated on a traffic light basis, ranged between +3 and −1, by aggregating information on the performance of subdivided indicators. While +3 obviously represents the best case, a score of zero represents a minimum standard (standard practice). Performance level −1 means that compliance with standards is not ensured. By default, these criteria are listed individually in the rose diagram. Each criterion is assigned to one of the three sustainability dimensions, as also shown in Figure 2. Being able to switch on or off the three dimensions of sustainability individually, it is possible to create roses with less criteria, i.e., only for one sustainability dimension or for combinations of two sustainability dimensions.

All the above-mentioned schemes are generally based on utility analysis. Both, CEEQUAL and Envision compare evaluation points achieved with the maximum possible points. In CEEQUAL, this comparison is made at criterion level, and the resulting degrees of fulfilment of the criteria are then offset against each other via the weightings. In Envision, the process is exactly the opposite: the points achieved are first added up via the weightings and then the comparison is made with the sum of the maximum points. In both cases, the result is an overall degree of fulfilment in percent. For the IS Rating Scheme the weighting of the criteria is set up in such a way that a maximum of 100 points can be achieved. This weighting can be determined on a project-specific basis within the scope of a weighting assessment. The individual evaluation of a criterion's performance multiplied by this weighting result in the score of a criterion. Aggregation can then be carried out simply by summation. Consequently, the overall result here is a score, which can, however, be understood as a percentage by the maximum score of 100. With SPeAR, on the other hand, no overall aggregation of all criteria is carried out at all, due to the graphical output. There is only an aggregation of individual criteria into categories or sustainability dimensions (see Figure 2).

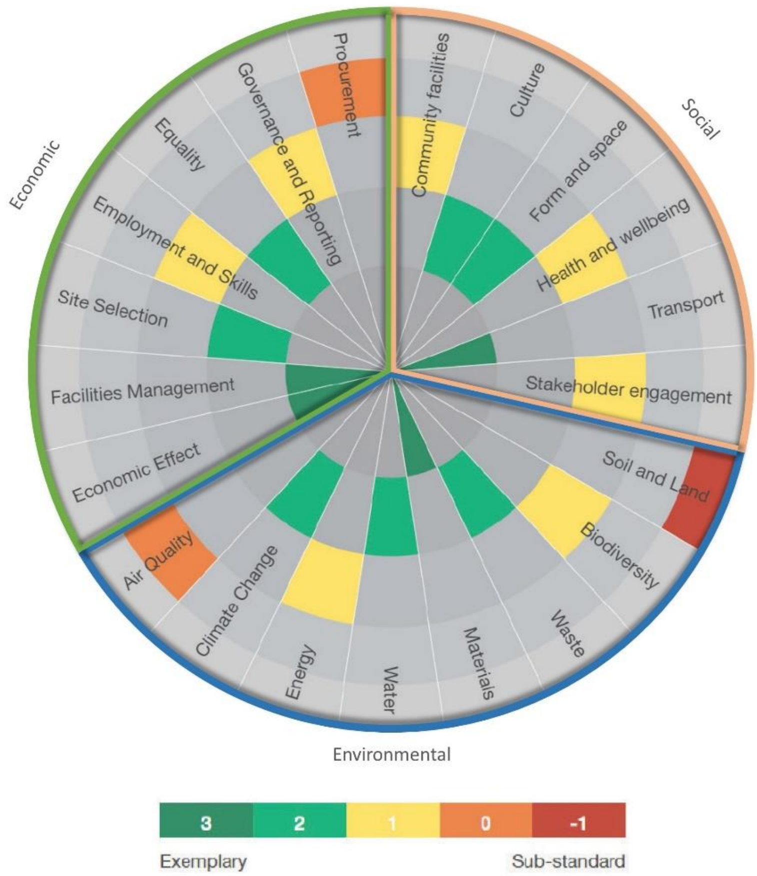

Figure 2. Output of SPeAR showing individual criteria and evaluation traffic light [41] supplemented by the assignment to three sustainability dimensions in accordance with [41].

3.2. *Assessment Schemes for Water Infrastructure*

Increasingly, assessment schemes are developed, that explicitly focus on water infrastructure and even specific subareas. In Germany, high levels of activity can be identified in water supply and wastewater infrastructure, which is why two such schemes (DWA-A 272 & MuWeBis) are considered in this comparison. In addition, a scheme for weirs developed at Karlsruhe University of Applied Sciences is discussed and the Hydropower Sustainability Tools developed by an international multistakeholder group are considered.

- For the area of wastewater infrastructure, the German Association for Water, Wastewater and Waste (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA)) has presented an assessment scheme in its technical standard DWA-A 272 "Principles for the Planning and Implementation of Novel Sanitation Systems (NASS)" [42] in 2014. It is intended to support decision-making in the comparison of alternatives as part of further development or new planning of (sub)systems of wastewater disposal with such NASS. Accordingly, the time of application is located between preliminary and design planning, aiming to determine the alternative to be implemented in design planning. Designed as utility analysis focus is on the operation phase, supplemented by individual criteria covering the construction process. The scheme contains a total of 34 criteria in 14 criteria groups (in *italics*), which are grouped into five categories:

- Environmental and Resource Protection: *Water Protection*; *Soil Protection/Groundwater Protection*; *Climate Protection*; *Resource Efficiency*;
- Hygiene and Health Protection: *Environmental Hygiene/Hygienic Safety*; *Food Safety*;
- Economic Objectives: *Business and Economic Cost Optimization*; *International Competitiveness*;
- Social Objectives: *Acceptance*; *Creation of Qualified Jobs*; *Creation of Environmental Awareness*;
- Technical Objectives: *Operational Safety/Robustness*; *Resilience/Expandability*; *Compatibility*.

Indicator values are used to describe the performance of each individual criterion. Subsequently they are normalized to performance levels between 0 and 1 using a value function. Where possible, minimum levels required by law or average values are used for the value function. These criteria performance levels can then be aggregated using the categories and the respective weightings. Thus, comparable overall utility values between 0 and 1 are generated, that can be used to compare project alternatives.

Different types of criteria are distinguished in this scheme. Besides criteria that "must" be considered and criteria that "can" be considered, depending on the project, dealbreaker criteria (i.e., knockout criteria) require to be both considered and fulfilled. Furthermore, some criteria of the criteria list refer e.g., to evaluation on technology level and hence are not considered relevant for individual projects. This subdivision into different types of criteria enables the scheme to distinguish between the following three approaches to weighting:

1. All "must" and "can" criteria are equally weighted.
2. The "can" criteria are weighted half as much as the "must" criteria.
3. Only the "must" criteria are taken into account.

In addition to distinguishing between the different types of criteria, the scheme provides several options for the weighting of the categories. Either emphasis is put on one of four categories or an equal weighting in the strict sense of the sustainability definition is applied (cf. Table 2). By analyzing the impact of different weightings, a sensitivity analysis is carried out, allowing for the selection of the most stable project alternative across all weighting scenarios.

Table 2. Options for weighting of categories in the DWA-A 272 scheme according to [42].

Categories	Weightings in %				
	Weighted Equally	**Economically Weighted**	**Ecologically Weighted**	**Socioecologically Weighted**	**Technically Weighted**
1. Environmental and resource protection	25	15	55	40	15
2. Hygiene and health protection	Criteria were classified as KO criteria or assigned to other criteria				
3. Economic objectives	25	55	15	10	15
4. Social objectives	25	15	15	40	15
5. Technical objectives	25	15	15	10	55

- The "Method for the Comprehensive Assessment of Water Infrastructure" (MuBeWis) [43] complements the DWA-A 272 scheme with requirements from drinking water supply and spatial planning. Thus, the user shall be enabled to compare innovative water supply and wastewater disposal systems both with each other and with conventional systems. MuBeWis is the result of the German research project TWIST++ and was presented in 2017. The primary field of application is "the comparison of fundamentally different infrastructure concepts" [35], taking place in early project phases from strategy finding up to early planning. Since MuBeWis is based on the DWA scheme, focus is on construction and operation phases. Equally it is an utility analysis, based on a criteria catalogue comprising 21 criteria in the following five categories and 12 criteria groups (in *italics*):

    - Ecological Objectives: *Water Protection*; *Soil Conservation*; *Climate Protection*; *Resource Protection*;
    - Safety Objectives: *Health Protection*;

- Economic Objectives: *Economics*; *Flexibility*;
- Social Objectives: *Acceptance*; *Avoiding Externalities*;
- Technical Objectives: *Operational Reliability/Robustness*; *Adaptability*; *Dependence*.

As a special feature, the weightings of the criteria against each other are determined using the AHP method (Analytical Hierarchy Process) based on a survey of experts and project participants [35]. This method allows the creation of an individual weighting scheme for each project, involving the respective stakeholders. The individual criteria performance is standardized as in the DWA-A 272 scheme (using e.g., average values for Germany). Thus, both individual criterion results as well as the overall result obtained by weighted aggregation range between 0 and 1.

- Focusing on hydraulic engineering, Karlsruhe University of Applied Sciences (HsKA) has developed an assessment scheme for weirs [44]. The objective of this scheme is to support the decision process between basic maintenance of an existing weir and replacement of the existing weir. The assessment scheme was developed for use from early planning phases up to the design stage. However, since it is intended to serve as a comparison of project alternatives, the existence of at least two alternatives is required. Based on the German assessment scheme for sustainable construction of the DGNB (German Sustainable Building Council), it was designed as a utility analysis. The assessment considers construction and operation phase as well as deconstruction in overall 17 criteria, assigned to seven groups of criteria (in *italics*) and five categories:

    - Ecological Quality: *Ecological Quality*;
    - Economic Quality: *Life Cycle Costs*; *External Costs*;
    - Socio-cultural and Functional Quality: *Functionality*; *Health and Comfort*;
    - Technical Quality: *Quality of the Technical Execution*;
    - Location Quality: *Location Quality.*

Each criterion is evaluated using points ranging from 0 to 10. With regard to qualitative criteria checklists specify the assignment of points. In the case of quantifiable criteria a linear value function is used, that allows to compare project alternatives with regard to a set reference alternative. Aggregation across criteria takes place by multiplying the criteria results with the individual weighting of each criterion and subsequent summation of these. The overall result is a percentage that describes the degree of fulfillment of the alternative under consideration compared to the maximum possible score.

- At an international level, the Hydropower Sustainability Tools have been developed specifically for hydropower projects. They are governed by a multistakeholder body, the Hydropower Sustainability Assessment Council. The Tools consist of three complementary parts. Firstly, as a key document, the Hydropower Sustainability Guidelines on Good International Industry Practice (HGIIP Guidelines) define good international industry practice. Project assessments based on these guidelines can be carried out using in accordance with [45]:

    - the Hydropower Sustainability Assessment Protocol (HSAP), assessing the sustainability of projects in comparison with current practice; and
    - the Hydropower Sustainability ESG (Environmental, Social and Governance) Gap Analysis (HESG) tool, identifying which sustainability aspects have not yet been sufficiently addressed (gap analysis).

Since this article deals with assessment schemes, the HSAP will be dealt with exclusively in the following. The HSAP [45] was first presented in 2010 by the International Hydropower Sustainability Assessment Forum. The most recent publication is a review from 2018. The assessment scheme consists of four subsystems for the assessment of the early stage, preparation (planning), implementation (construction) and operation of hydropower projects. Each of these subsystems can be used as a stand-alone system in the respective project phase. The application's objective is to evaluate the project in the respective phase in order to obtain decision support for further/future measures and improvement opportunities (ideally from repeated applications of the tool). Each of the four subsystems consists of individual criteria lists without grouping the criteria into categories. The number of criteria per subsystem differs:

- Early Stage: 9 criteria;
- Preparation: 24 criteria;
- Implementation: 21 criteria;
- Operation: 20 criteria.

The Early Stage subsystem covers criteria such as Demonstrated Needs, Technical Issues and Risks, and Options Assessment. The criteria in the other three subsystems differ only in some criteria. For example, all three include Communications and Consultation, Environmental and Social Impact Assessment and Management, Financial Viability as well as Biodiversity and Invasive Species. However, some criteria are only relevant for individual subsystems and are considered accordingly, such as the Procurement in Preparation and Implementation subsystems or Waste, Noise and Air Quality in the Implementation subsystem.

The Early Stage subsystem serves as an assessment guideline; a quantitative evaluation of individual criteria is not possible. The other three subsystems work as checklists. Each criterion can be evaluated on a scale from level 1 to 5. The evaluation of the individual criteria is carried out by means of qualitative scoring statements, in which the objectives to be achieved for each level are described verbally. There is no aggregation of the individual scores to an overall result of the project. Instead, the results of the individual criteria are presented in a table or diagram (analogous to SPeAR) as sustainability profiles.

4. Comparison of the Assessment Schemes

The key data of the considered sustainability assessment schemes are listed in the following two tables. Table 3 refers to the interdisciplinary schemes. Table 4 gives an overview for the schemes specialized in water infrastructure. Following the aspects used to structure the tables, the text describes differences and similarities of the considered schemes and subsequently discusses and interprets these findings.

4.1. Project Phase When Applied and Life Cycle Phases Considered

Application of the sustainability assessment schemes predominantly takes place in planning/design and operation phase. CEEQUAL can be applied from strategy finding to construction phase only. All other interdisciplinary schemes as well as HSAP allow for application from design to operation phases. HSAP in addition provides a subsystem for early project phase. Application of the remaining three water-specific schemes takes place in the planning phase or even before.

With regard to the life cycle phases considered, Envision, IS Rating Scheme and SPeAR cover the entire life cycle, while CEEQUAL and HSAP comprise strategy finding to operation phase. The other three water-specific schemes all cover construction and operation phase. In addition, the HsKA-scheme includes dismantling.

Table 3. Interdisciplinary assessment schemes, applicable to a wide range of infrastructure (based on data from: [38–41]).

Aspect	CEEQUAL for Projects	Envision	IS Rating Scheme	SPeAR
Release	2003	2012	2012	2000
Origin	UK	US	Australia	UK
Current Version	Version 6 (Launch: 2019)	Version 3 (Launch: 2018)	international: Version 1.0 (Launch: 2017)	2017 review
Sector of Application	New construction and refurbishment of all types of infrastructure and landscaping projects	All types of both public and private infrastructure	Infrastructures from the sectors transport, utilities and public realm/open space	New infrastructure, masterplans and individual buildings
Project Phase when Applied	From strategy finding to construction phase	From planning/design to operational phase	Planning (IS-planning-guideline), design (pre-certification), finished building and operation	From planning/design to operational phase
Life Cycle Phases Considered	Strategy finding to operation phase	Entire life cycle [1]	Entire life cycle [1]	Entire life cycle [1]
Assessment Methodology	Utility analysis (via list of weighted criteria)	Utility analysis (via list of weighted criteria)	Utility analysis (via list of weighted criteria)	List of criteria
Arrangement of Criteria	8 categories 30 criteria groups 248 criteria	5 categories 14 criteria groups 64 criteria	6 categories 15 criteria groups 43 criteria	3 categories 24 core criteria + additional criteria (if necessary)
Performance Levels (Degree of fulfilment increasing from top to bottom)	1. Pass (30%) 2. Good (45%) 3. Very good (60%) 4. Excellent (75%) 5. Outstanding (90%)	1. Verified (20%) 2. Silver (30%) 3. Gold (40%) 4. Platinum (50%)	1. Commended (25–50 Pt.) 2. Excellent (50–75 Pt.) 3. Leading (75–100 Pt.)	Graphical output in rose chart based on traffic lights
Dimensions of Sustainability [2]	Ecological (Economic) Social	Ecological (Economic) Social	Ecological Social	Ecological Economic Social

[1] Planning/design, construction, operation, dismantling. [2] Brackets mean that there are only few criteria assigned to this dimension, but assessment of this dimension is not considered to be comprehensive.

Table 4. Assessment schemes specialized in water infrastructure (based on data from: [35,42–46]).

Aspect	DWA-A 272	MuBeWis	HsKA-Scheme	HSAP
Release	2014	2017	2019	2009
Origin	Germany	Germany	Germany	International
Current Version	-	-	-	2018 review
Sector of Application	Further development and planning of new sanitary systems (NASS) = wastewater disposal systems	Novel and conventional water supply and wastewater disposal systems	Weirs (comparison of basic renovation and replacement building)	Hydropower projects
Project Phase when Applied	Between preliminary and design planning	Strategy-finding phase up to early planning stages	Preliminary and design planning	4 subsystems for Early Stage, Preparation, Implementation and Operation
Life Cycle Phases Considered	Construction and operation phase	Construction and operation phase	Construction and operation phase, dismantling	Strategy finding to operation phase
Assessment Methodology	Utility analysis (via list of weighted criteria)	Utility analysis (via list of weighted criteria)	Utility analysis (via list of weighted criteria)	Early Stage: assessment guide without quantitative result Preparation; Implementation and Operation: list of criteria with qualitatively described objectives
Arrangement of Criteria	5 categories 14 criteria groups 34 criteria	5 categories 12 criteria groups 21 criteria	5 categories 7 criteria groups 17 criteria	Early Stage: 9 criteria Preparation: 24 criteria Implementation: 21 criteria Operation: 20 criteria
Performance Levels (Degree of fulfilment increasing from top to bottom)	Comparison of alternatives within the total utility value range from 0 to 1	Comparison of alternatives within the total utility value range from 0 to 1	Comparison of alternatives within the total utility value range from 0 to 1	For each criteria of the subsystems Preparation, Implementation and Operation: Level 1—Significant gaps to basic good practice Level 2—A significant gap to basic good practice Level 3—Basic good practice Level 4—One significant gap in the requirements for proven best practice Level 5—Proven best practice
Dimensions of Sustainability	Ecological Economic Social	Ecological Economic Social	Ecological Economic Social	Ecological Economic Social

In general, the scheme selected should be applicable in the project phase needed and cover the life cycle phases desired. Selecting a water-specific scheme, criteria considered have to match the project analyzed. As a result, the selection of a suitable assessment scheme is a multicriteria decision in itself. It cannot be bought ready-made but requires precise formulation of expectations and respective problem structuring.

In contrast, for the schemes considered it is apparently assumed, that all problem structuring can be outsourced to the development of the assessment schemes. This implies that all projects can be measured by the same yardstick, which contradicts the general characteristics of water infrastructure projects such as being site-specific. A project-specific problem structuring leading e.g., to a value-focused development of project alternatives to be compared is not provided for by any of the schemes, although, as Keeney stated already in 1992 [47]: "In most decision-making methodologies a philosophical approach and methodological help to understand and articulate values and to use them to identify decision opportunities and create alternatives is missing". The schemes could, e.g., be applied comparing different alternatives of increasing the transport capacity of a water supply pipe system, without analyzing demand side management options.

Later application of the schemes within a project's life cycle logically implies less scope of action regarding the alternatives to be compared. To conclude that application in construction and operation cannot generate benefits, as implicitly or explicitly done by the water-specific schemes DWA-A 272, MuBeWis and HsKA-scheme, seems short sighted, though.

4.2. Assessment Methodology and Performance Levels

The sustainability assessment schemes in this study are relatively similar in structure. All schemes under consideration use a list of criteria, usually combined with a utility analysis. The overall results for different alternatives, that are compared, are given as performance levels using percentage degrees of fulfilment ranging 0 to 1 (the three water-specific schemes except for HSAP) or are assigned to predefined performance levels (the three interdisciplinary schemes except for SPeAR). This allows a simple comparison of alternatives. Only SPeAR and HSAP do not aggregate the results across the criteria. Instead they provide sustainability profiles at the level of the individual criteria or subareas. In doing so, the HSAP explicitly intends to identify gaps and drive continuous improvement.

The provision of performance levels tempts users to focus on the overall result as true or false in absolute terms. The critical performance of alternatives with regard to individual criteria gets less attention. Mathematically speaking, the same average does not express information on the spread of the individual values. Similarly, the seemingly measurable distance of performance levels of different alternatives might be misinterpreted as a true margin how much better one alternative is over the other. Schemes using the full range from 0 to 1 are more at risk towards this aspect than tools defining a limited number of three to five preset performance levels.

Results are always influenced by a variety of subjective factors, assumptions or uncertainties, such as the selection and evaluation of criteria and their weighting but also methodological uncertainties in impact analysis and criteria evaluation. However, the schemes can make these very factors and their influence visible and thus help to identify for example the most sensitive criteria in a case or the most stable solution across all subjective sustainability perspectives. Independently of the scheme selected, both the overall performance level as well as the information output on criteria level should be used to improve the interpretation of results and obtain a better understanding of the decision problem.

4.3. Project Application

A comparison of the interdisciplinary assessment schemes with those specialized in water infrastructure shows that the specialized schemes currently still tend to be in a development stage. In contrast, the interdisciplinary assessment schemes have already been used commercially and have been applied in a large number of sustainability assessment projects.

Since its publication in 2003, CEEQUAL has been used to evaluate over 300 projects, mainly in the United Kingdom, but a double-digit number of international applications is also reported. Due to its general approach, projects covered many types of infrastructure. With regard to water infrastructure a wide range of projects from both urban water management (water supply and waste water) as well as hydraulic engineering (e.g., flood alleviation, river management, coastal management) have been evaluated [48].

For Envision, the website lists a total of 71 evaluated projects, again with a focus on the country of origin (US). With more than 30 projects, the water infrastructure sector accounts for almost half of the projects, again covering hydraulic engineering as well as urban water management [49].

The IS Rating Scheme lists 63 project applications, thus being comparable to Envision regarding the number of projects implemented. However, with only nine projects according to the website water infrastructure makes up for only a minor part. Nevertheless, projects from urban water management (e.g., waste water treatment plant) have already been rated, as have hydraulic engineering projects (e.g., river restoration) [50].

A total of more than 100 projects in more than 10 countries have been evaluated using SPeAR [41], though Arup does not provide any further information on these applications. It is obvious, that SPeAR has moved beyond the research stage and has become a common application.

Comparing the project applications of the specialized schemes MuBeWis and the HsKA-Scheme with these figures, the difference to the commercially used schemes becomes obvious. The applicability of MuBeWis has been tested in three field studies for one rural and one urban area as well as for one area being reutilized from industrial use [43]. Further project applications could not be identified so far. Similarly, for the HsKA-Scheme, its applicability was proven in principle in a sample project within the scope of the development. These two schemes are thus well behind the interdisciplinary assessment schemes in terms of their development stage. In part, further research is required to implement their regular application in practice. The number of possible applications of the water-specific schemes might be much more restricted as compared to the interdisciplinary schemes.

The two schemes specialized in water infrastructure, DWA-A 272 and the Hydropower Sustainability Tools, are already one step further in development. According to the website, the Hydropower Sustainability Tools have already been used 18 times to evaluate hydropower projects [51]. Thus, the development stage can be considered exceeded. In addition, this assessment scheme has the largest international spread of all schemes considered, with applications in 15 different countries.

Although no data are available on the application of the scheme from DWA-A 272, this scheme is part of the DWA technical standard. Being integrated into the norm-like documents of the DWA, this scheme is embedded in practice in a fundamentally different way than is the case with the interdisciplinary schemes. While the latter are applied commercially by the developing organizations, DWA-A 272 provides a standard-like methodological approach for use by all different kinds of institutions. This approach and the associated objective are also the basis of SIA 112/2: to promote transparency of the topics covered in the planning process and reconcile the interests of actors involved such as planners, clients, environmentalists and affected people.

Currently, the main advantage of the interdisciplinary assessment schemes is their higher experience in application and, as a consequence, the opportunity to implement resulting feedback. They are well-recognized, common schemes. They can be used for a variety of infrastructure types and sufficient reference projects are available that allow for feedback loops and improvement of the schemes. In addition, they allow for an interdisciplinary comparability that can never be achieved by specialized schemes. For example, special-purpose associations, municipalities or even large companies can evaluate different types of projects in their field of activity with the same scheme and thus create a comparable basis for planning, construction and operation. With regard to the definition of sustainable infrastructure projects across disciplines, the interdisciplinary schemes have an advantage.

However, their more general orientation might cause gaps or inaccuracies when applied to specific infrastructure. Thus, a comprehensive assessment specific to a particular type of infrastructure cannot be achieved without further adjustments [17,52]. In particular, individual criteria that allow to analyze issues specific to the respective type of water infrastructure in detail are sometimes missing, e.g., heat recovery from wastewater. Moreover, the interdisciplinary schemes often do not yet equally represent the three dimensions of sustainability (see Figures 3 and 4). Often the economic dimension is neglected in this type of assessment, possibly arguing that the economic aspects are generally considered the most important KO aspect anyway.

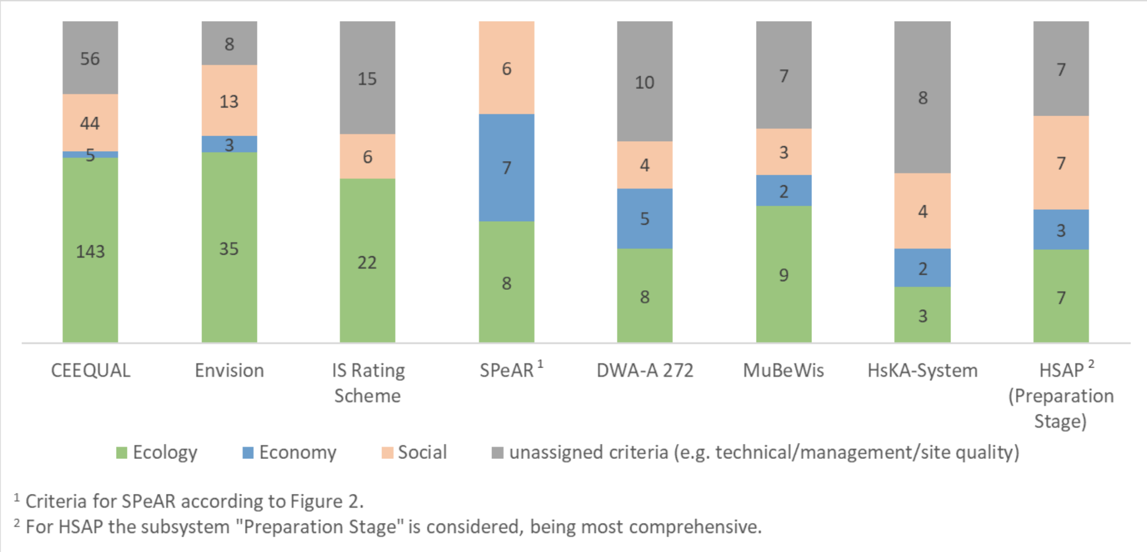

Figure 3. Number of criteria covering the three sustainability dimensions in different schemes.

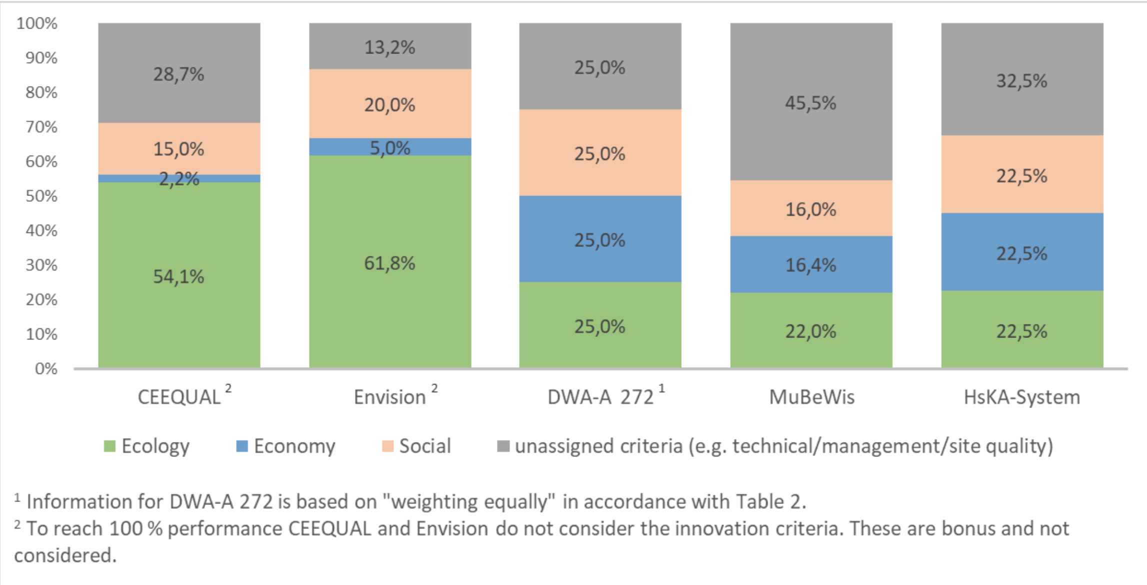

Figure 4. Weighting of the three sustainability dimensions in selected schemes.

Therefore, for a systematic, routine application to projects in the water infrastructure sector, schemes specifically designed for the respective context are considered more appropriate. They allow for a comprehensive consideration of all impacts with regard to the respective type of water infrastructure. Furthermore, they can be used to address very specific issues, such as the selection of a NASS technology in the DWA-A 272 scheme or the comparison of basic maintenance and replacement with a new construction in the HsKA-Scheme. Criteria that are significant while at the same time exclusive with regard to the specific issue get lost in the interdisciplinary schemes.

However, the development of assessment schemes for individual cases is not economically feasible. Hence professional organizations, state institutions or private companies that can apply the schemes several times in their context must take over the development. As can be seen from the example of the Hydropower Sustainability Tools, international cooperation is beneficial for respective developments, and can lead to a defined and accepted sustainable development on an international level.

4.4. Dimensions of Sustainability and Contents

The following Figures 3 and 4 compare the number of criteria and the weighting of the schemes' content. Focus is on the three sustainability dimensions of ecology, economy and social issues. Most of the schemes contain further topics, but these differ from scheme to scheme. Topics include, for example, Integrated Project Management, Infrastructure Safety, Responsible Construction Management, Risk Assessment and Mitigation, Technical Objectives, Site Quality, Stakeholder Participation or Innovation.

Comparing the schemes in terms of content, it becomes obvious that the number of criteria and the focus of the schemes differ. While CEEQUAL and Envision consider a large number of criteria, the other schemes cope with much smaller numbers, although the range of topics is similar in all schemes. It is also evident that CEEQUAL, Envision and IS Rating Scheme, i.e., the majority of the interdisciplinary schemes, focus strongly on the ecological dimension, while at the same time the number of economic criteria, in particular, is very small. SPeAR, on the other hand, put more emphasis on the economic assessment early on, beginning in the year 2000. Hence, it also shows a more balanced assessment with regard to the three sustainability dimensions.

In Figure 4, the weighted share of the three sustainability dimensions in the overall result is compared for those schemes providing the respective data. The IS Rating Scheme is not considered, because it assigns weights using a project-specific weighting assessment, which also enables the analysis of multiple set of weightings of different stakeholder groups. SPeAR and HSAP do neither specify weights nor aggregate across criteria and are therefore neither considered. Again, CEEQUAL and Envision have a strong environmental focus. In contrast, the three specialized schemes, DWA-A 272, MuBeWis and HsKA-Scheme, have an almost balanced structure with regard to the sustainability dimensions. It should be remembered that DWA-A 272 explicitly offers different weightings to enable sensitivity analysis, though. Here, the equal weighting of the different dimensions was considered. Furthermore, all schemes contain unassigned criteria that cannot be assigned to the dimensions of ecology, economy or social issues.

5. Conclusions

The preceding comparison of sustainability assessment schemes in the field of water infrastructure has shown that, although the respective schemes are at least partly new, the underlying methodological and content-related aspects are not a new issue. However, the importance and necessity of using such schemes in general and for water infrastructure in particular has increased in recent years, due to the new uncertainties and an increasing complexity explained in Section 1. Originally, local, obvious, environmental problems were the driving factors to start environmental protection. Today humanity faces problems on a global system scale, such as climate change, loss of biodiversity or population growth that, if not solved, entail considerable economic and social consequences and possible conflicts. Therefore, problem solving needs to address the three dimensions of sustainability and their dependencies. Resilience and flexibility for adaptation are for example upcoming criteria, representing not only the three dimensions but sustainability as such [19].

It becomes clear that there is not a single "correct" assessment scheme for either infrastructure or water infrastructure. Depending on the project-specific context, different priorities are set in terms of content and, besides, the weighting may vary. Both the project phase when the scheme shall be applied and the life-cycle phases considered in the assessment should be suitable for the specific project to be analyzed. Unsurprisingly, with regard to the water-specific schemes, criteria considered have to match the analyzed project. In particular, systematic guidance on how to select a suitable scheme or an explicit documentation of the limitations for the different schemes are missing.

Besides the scheme itself, a sound application needs more guidance and more research on how to develop alternatives: are there delimitations in current problem structuring that handicap alternatives questioning the existing system or system boundaries as e.g., technology change or “do nothing”? How can sustainable project alternatives be developed in the first place, before choosing only the most sustainable alternative from a more or less random set of alternatives.

Furthermore, due to the volume of sustainability assessments a conflict line appears between thoroughness (with regard to information, stakeholder groups involved, number of criteria . . .) and ability to act (when does a decision have to be made, monetary funds) that needs to be negotiated on a societal level. This conflict is one possible cause for the observed discrepancy between relevance of sustainability assessment schemes and lack of practical application that was formulated at the workshop on “Sustainable construction—an issue for water infrastructures?” in Karlsruhe in March 2019. Research is needed on the practical integration of respective schemes to the existing planning processes and licensing procedures.

The schemes do not produce true or false results in absolute terms or even a true margin of how much better one alternative is over the other. The schemes only make the multitude of subjective aspects involved visible and thus help to identify the most stable solution across all subjective sustainability perspectives. It is recommended that, independently of a scheme’s specific methodology, the overall performance level as well as the information output on criteria level should be used to improve the interpretation of results and obtain a better understanding of the decision problem.

To adequately consider the sustainability perspectives of different stakeholder groups involved, the application of sustainability assessment schemes is not considered sufficient, though. As discussed in [28] all participatory processes, sensitivity analysis regarding at least criteria performance and weights and scenario analysis are prerequisites for successful planning aiming at sustainable development. It needs to be emphasized that SPeAR and the DWA-A 272 are the only schemes that provide methodological guidance on assigning project-specific weights or initiate sensitivity analysis for the weighting, respectively. The other schemes provide fixed weightings, thus being unable to analyze different sets of weights of different stakeholder groups.

The main advantage of the interdisciplinary assessment schemes is their higher experience in application together with the greater range of infrastructure types they are applicable to. As their criteria catalogue is more general, it might cause inaccuracies with regard to specific characteristics of a certain type of water infrastructure. On the other hand, the fixed criteria catalogue enables comparison across infrastructure sectors.

Overall, the specific schemes are considered more appropriate as they are adapted to address all issues and in particular the very specific issues. To finance their development synergies and cooperation between different types of companies is required. A two-level assessment using a general set of criteria in combination with water infrastructure specific criteria could be supportive in minimizing the efforts needed for the development of specific schemes.

The overall number of criteria differs considerably in the schemes compared, while the range of topics covered is similar. The interdisciplinary and more commercial schemes are found to have a stronger focus on ecological criteria, except for SPeAR, which is more balanced with regard to the three dimensions of sustainable development. Looking at the weighted share of the three sustainability dimensions in the overall result again CEEQUAL and Envision focus on the environmental dimension, while the water-specific tools that result in a performance level are more balanced with regard to the three dimensions of sustainability.

In building construction, too, there were and are various schemes. In recent years, these have been partially aligned with each other. At the same time, they have developed enormously and gained in importance. In view of ecological development, economic pressure but also further urbanization, it can be assumed, that sustainability assessment schemes will also become increasingly established in the infrastructure sector and the water sector in particular.

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