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Assessing Resource Efficiency of City Neighbourhoods: A Methodological Framework for Structuring and Practical Application of Indicators in Urban Planning

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Abstract: Today, changing framework conditions of living and working in cities drive urban planning processes for refurbishment, notably at the level of neighbourhoods, and provide a window of opportunity to enhance resource efficiency and sustainable urban development. Indicators, as part of sustainability assessment methods, may support the identification of the most beneficial planning alternatives or the selection of measures. However, the fact that a multitude of indicators are proposed in the literature discourages their actual use and hampers a sound application for decision support. To tackle these challenges, a manual has been developed proposing a framework for the use of indicators in urban planning. In this contribution, the theoretical foundations of the proposed framework are analysed. A conceptual outline of the framework is presented, which as its core has a typology of indicators, and its embedding in urban planning processes is discussed. The framework combines a theoretically concise unifying structure with a flexible practical approach for application in diverse areas of resource efficiency. Thus, it shall enhance transparency as well as comparability in the use of indicators, foster communication between stakeholders and in the long run support the application of indicators and use of sustainability assessment methods as regular parts of urban planning.

Keywords: indicators; indicator sets; indicator systems; sustainability assessment; resource efficiency; urban planning; neighbourhoods

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1. Introduction

Cities worldwide are centres of both economic growth and resource consumption, accounting for 80% of global GDP but also more than 75% of natural resource consumption [1]. While developing countries today focus on building up infrastructures and housing areas due to rapid population growth, cities in industrialised countries face the continuous challenge of adapting to changing framework conditions of living and working, e.g., an aging population, the change in industrial structures, and, recently, the sudden growth of the home office due to the COVID-19 pandemic. In addition, cities must adapt to local consequences of climate change, contribute to climate protection, and react to the megatrend of resource scarcity. Thus, today urban planning, notably at the level of city districts and neighbourhoods (also called small urban units or quarters), is a highly dynamic area, providing a window of opportunity to enhance the resource efficiency of cities in the long run as a contribution to sustainable urban development.

In planning and development processes for complex issues, assessment methods provide support in identifying the most beneficial alternatives out of a multitude of possibilities of how to act. As part of assessment approaches, indicators are in use, and their values denote the benefit of one or several alternatives quantitatively. Specifically, in the field of sustainability today, indicators are the most influential measuring and policy making tool [2,3]. Given this importance, the scope of this paper is an in-depth examination of the application of indicators in the area of resource efficiency of city districts and neighbourhoods. First, insights from the literature as to the definition, methodology, and application of indicators in general and in the area of sustainability assessment are presented. Second, in view of a substantiated and scientifically based practical use of indicators, a typology is derived, which forms the core of a framework to support the application of indicators in urban planning processes.

For the evaluation of complex issues, several indicators are usually applied, mirroring diverse aspects and influencing factors. As for resource efficiency of city districts and neighbourhoods, notably, the following areas intersect: building design and construction, which determine material inputs in buildings and energy performance in the use phase; urban infrastructures such as water and energy supply systems; and the social conditions of housing, including the needs of residents. Furthermore, the consequences of the conceptual and material shaping of districts and neighbourhoods for the economy and society as a whole have to be taken into account, which are related to societal goals of sustainability and ultimately to today's global sustainability framework of the 17 Sustainable Development Goals [4].

The literature contains a large body of publications on the subject of indicators for sustainability assessment in general and specifically for the area of urban planning (see, e.g., [2,5–7]). Here, methodological considerations for selection and quality assurance criteria are discussed; also, concrete indicator sets for specific topics or real cases of cities are proposed. However, for practitioners in urban planning, dealing with indicators is still a challenge. Usually, they do not have the time or the specific expertise to familiarise themselves with the theoretical foundations for a sound selection and application of indicators. Thus, the multitude of indicators or indicator sets proposed in the literature and in practical frameworks for sustainability assessment confuse practitioners (e.g., town planners) rather than giving a clear answer to the question regarding the indicators to be used in a real planning process. Consequently, practitioners may either be discouraged from using indicators in support of a planning process or run the risk of using indicators in a rather haphazard way.

The funding programme ""Resource-efficient urban districts for the future"" (RES:Z programme) by the German Federal Ministry supports 12 research projects involving more than 20 municipalities to develop novel concepts for resource efficiency of urban districts and neighbourhoods. Supported by a cross-sectional working group, the projects are expected to evaluate their contribution to resource efficiency by the use of suitable indicators. The experiences within this working group have confirmed the challenges faced by practitioners, mentioned above, as to the use of indicators, and have led to the development of a manual for practical guidance, which has recently been released as part of RES:Z [8]. The core of this RES:Z Manual is a framework for the use of indicators in urban planning at the district or neighbourhood level.

In this contribution, the authors analyse the theoretical foundations for the development of such a framework (based on a review of the literature), present a conceptual outline of the framework, and discuss its application and further development. The framework is related to a theoretically concise structure, but at the same time it is intended to be easy for practitioners to use. Thus, it shall enhance transparency as well as comparability in the use of indicators in urban planning and in the long run support sustainability assessment with a focus on resource efficiency as a regular part of urban planning.

2. Materials and Methods

In the following subsections, the methodological issues relevant to the scope of this paper are presented: First, relevant terms in the context of resource efficiency are clarified. Second, the literature is evaluated as to definitions, concepts, and application of indicators, initially in a general way and thereafter in the area of sustainability assessment and with regard to urban planning. Third, an overview of structuring approaches for urban planning is given, specified in relation to actor groups and areas of action and with reference to natural resources. Specific attention is given to neighbourhood-related assessment systems, where a distinction exists as to the construction of new neighbourhoods vs. the development of existing neighbourhoods.

Figure 1 presents the contribution of each subsection to the overall scope of the paper and the connection between concepts and urban planning. The insights from these three steps provide the basis for the outline of the proposed framework presented in Section 3.

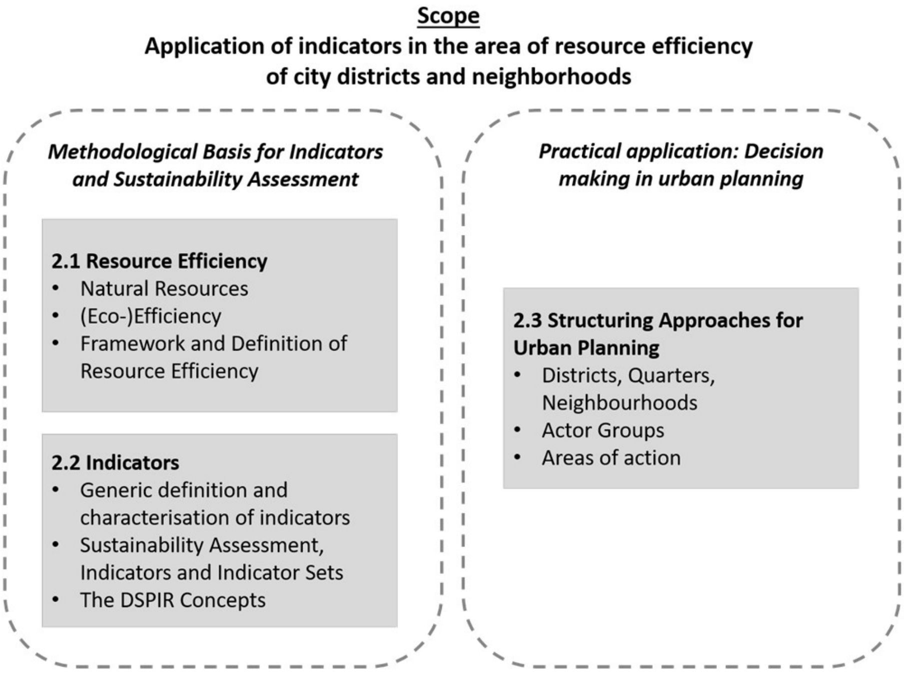

Figure 1. Overall structure of the paper.

2.1. Terms and Definitions

2.1.1. Natural Resources, Resource Management, and Resource Efficiency

Resources and resource efficiency are terms that in a most general sense refer to the availability of some means and their efficient use for a purpose. They are often employed without a clear denotation in everyday language, whereas concrete definitions can only be found in the context of a specific application area or discipline. In the sustainability policy context, the European Commission has interpreted the term "resources" as so-called natural resources; the definition is given in the introduction of the EU thematic strategy on the sustainable use of natural resources (2005): "European economies depend on natural resources, including raw materials such as minerals, biomass and biological resources; environmental media such as air, water and soil; flow resources such as wind, geothermal, tidal and solar energy; and space (land area). Whether the resources are used to make products or as sinks that absorb emissions (soil, air and water), they are crucial to the functioning of the economy and to our quality of life" [9]. This definition since then has been the basis of current EU policies in the area of sustainable development, notably "A resource efficient Europe—flagship initiative of the Europe 2020 strategy" and "Roadmap to a resource efficient Europe" [10].

Due to its central significance for sustainability policies, subsequently, the term "resources" shall be used in the sense of natural resources, unless explicitly stated otherwise. Thus, a clear distinction has to be made between this definition and other definitions of the term "resources" in other disciplines, notably the following:

(i) In the economic context, resources generally denote inputs to production, i.e., labour, capital, land, and materials [11]. This definition of resources is synonymous with the term productive resources or factors of production.

(ii) In the geological context, the term "resources" is applied to raw materials and is defined as the amount of raw materials (also termed commodities) whose existence is known. Resources here are opposed to the term reserves, which covers only that part of resources whose extraction is currently economically feasible [12].

In view of the latter definition, it has to be emphasised that natural resources cover more than raw materials. Natural resources are linked to physical flows of materials between the natural environment and society, comprehending both input and output flows from the economy: inputs of primary raw materials (renewable and non-renewable) and outputs of emissions, wastes, and products to be used directly in the environment (e.g., fertilisers). As for the latter, the natural resource is linked to the function of the natural environment (air, water, soil) to act as a sink for the emissions of economic activities. The connection between material flows and natural resources is illustrated in Figure 2.

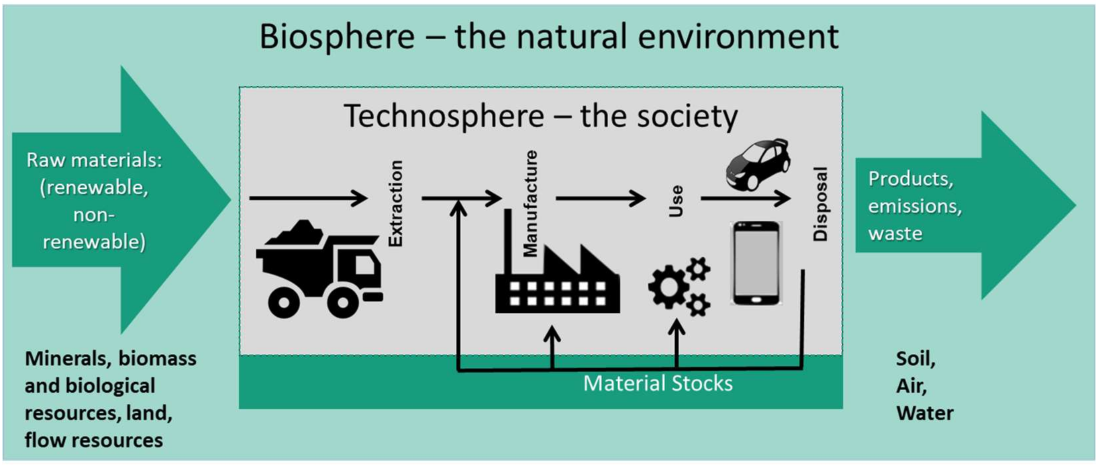

Figure 2. Material flows and natural resources.

In the context of natural resources, the term "ecosystem services" (ESS) is often applied. This term was introduced in the Millennium Ecosystem Assessment Report as follows: ESS "[. . .] include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth" [13]. In a simple view, it can be said that ESS display the impacts of resource use on the natural environment in the sense of the disturbance of natural functions upon which the survival or well-being of human society is dependent.

The use or consumption of natural resources by human activities can be direct or indirect. The direct use inside the system boundaries of a neighbourhood is that which is "on site": in particular, land use is direct, e.g., the occupation of land by buildings or roads; also, water use can be direct if the extraction of ground water takes place on site. In many cases, however, the consumption of natural resources takes place indirectly: in the neighbourhood, the final energy is used, but the natural resource behind it is the respective primary energy source, e.g., coal extracted and transported to a coal-fired power plant. The same applies to the use of the natural environment as a sink: also, in this regard, some cases of pollution occur locally, e.g., particulate matter from combustion processes in vehicles, but others indirectly, e.g., CO_2 from energy production. These distinctions have consequences with regard to the choice of methodical procedure by which the consumption of natural resources can be measured or assessed.

Measuring and assessing resource utilisation is the basis for management of natural resources. In general, all management approaches include the steps of target setting, identification and implementation of measures, and monitoring the success of measures. Specifically, management approaches have to be conceived for a concrete application area or object, for the level where the management shall take place, i.e., local, regional, or national/global, and in view of the actors involved, i.e., the active organisation driving a management process and stakeholders involved in the process or impacted by its outcomes. In this sense, resource efficiency can be seen as a management approach. Efficiency is a pervasive principle of the economics and management of business enterprises as well as the basis for one of the earliest concepts of sustainable development in business, the concept of eco-efficiency [14,15]. The principle of efficiency is described by the ratio of benefit to effort: efficiency can be improved by either increasing the benefit at constant effort or by reducing the effort at constant benefit. Although there are diverging interpretations of eco-efficiency, all agree that eco-efficiency is the ratio of an economic benefit to the connected impacts on the environment.

A similar view was taken for the first methodological framework for assessing resource efficiency in companies, the German VDI 4800 "Resource efficiency" [16]. These guidelines are based on the definition of natural resources and on a life cycle view on the methodological basis of life cycle assessment (LCA) according to the international standards ISO 14040/ISO 14044 [17,18]. The definition of resource efficiency, the "ratio between a certain benefit or result and the resource use required for it", is in line with the idea of eco-efficiency and also related to the methodology of LCA, which defines a so-called functional unit, displaying the benefit of the system under investigation. However, in comparison to LCA, the definition of resource efficiency is the inverse expression, as in this case, the benefit is the numerator and not the denominator as in LCA. This causes some confusion, so as an alternative, the term "resource intensity" is proposed, defined as "the inverse of resource efficiency, i.e., the ratio of resource input to the benefit or result achieved or result achieved with it" [19].

As an example of an approach based on the concept of eco-efficiency and on the methodology of LCA, Huysman et al. [20] present a framework for the resource efficiency of indicators. In practice, however, resource efficiency is much more often used as a qualitative expression of target setting or for statistics at the level of full economies (e.g., [21]).

2.1.2. Indicators in Environmental and Sustainability Assessment

The term "indicator", though frequently used in science as well as in politics and many practical applications (e.g., in engineering), does not have a clear and unambiguous definition [22]. Indicators are often used at the interface of science and policies [22], thus involving experts from different disciplines and non-expert decision makers. On the basis of a comprehensive analysis of the literature, Bauler [23] points out that policy actors seldom base their decisions on direct use of information and existing knowledge from science but much more often on indicators. In recent years, indicators are also increasingly promoted at the local scale in participatory processes, where non-experts are involved [24–26]. This wide distribution and broad scope of stakeholders emphasises the crucial need to clarify and/or categorise the definition and role of indicators.

In a most generic way, Heink and Kowarik [22] define the term "indicator" as "a synonym for 'indicans', i.e., a measure or component from which conclusions on the phenomenon of interest (the indicandum) can be inferred". In an analysis on the use of indicators in the area of ecology and environmental planning, they discern three definitions: First, the definition of an indicator as a "measure", i.e., a parameter or quantity that describes a property of an object (phenomenon, body, or substance), which can be assigned a magnitude. Second, in ecology an indicator may be defined as an ecological component, i.e., an object or phenomenon indicating a state of the natural environment. In this sense, the indicator is a "biological sensor" for the state of the environment, e.g., certain species as indicators for biodiversity. Concerning the third, rarely used, definition, Heink and Kowarik [22] interpret indicators as parameter values or concrete measured or calculated results, which in contrast to the first definition have a specific value.

Henceforth, as the most generic definition of an indicator, the interpretation as a measure according to Heink and Kowarik [22] is used. Consequently, an indicator must be described in a quantitative way, including its dimension, but it is not defined by a fixed value. To determine the value of an indicator for a specific situation, measurements are necessary in most cases. In this regard, a theoretical distinction is possible between direct and indirect measurement; however, the directness may lie along a spectrum, and no consistent criteria were found in the literature for distinguishing direct from indirect representation [22]. This finding seems important not only for simple cases, e.g., the question regarding whether the measurement of density is performed in a direct way or is derived from the measurement of volume and mass. More importantly, measures based on complex calculation algorithms or models can also be termed indicators.

Another finding by Heink and Kowarik [22] is that indicators may be defined as descriptive or normative, which from a theoretical as well as a practical perspective is a major difference. This is very important as in practice, the same measure is often used in either a descriptive or normative way. This accounts for the necessity of a reference value in order to derive a conclusion or decision support, a specifically crucial and pressing issue in sustainability assessment: "a given indicator doesn't say anything about sustainability, unless a reference value such as thresholds is given to it" [27] (cited from Singh et al. [3]). In such cases, descriptive and normative uses have to be clearly distinguished in order to avoid an ambiguous way of application [22].

In practical application, an indicator is mostly not used on its own but usually as part of a group of indicators, which is often designated as an indicator set. For the term "set", no general definition can be found besides the fact that it is a group of indicators that are applied together on one object or in the course of one application. In sustainability assessment, the term "indicator set" often overlaps with the terms "sustainability indices" and "composite indexing" [2,24]. Many publications address the compilation of groups of indicators, but few tackle the question concerning how to evaluate the quality of an indicator set in general. Motivated by the field of healthcare, but in a very generic way, Schang et al. [28] discuss the question of how to describe a good-quality indicator set. Starting from the premise "that a set of 'valid indicators' does not guarantee a 'valid set' of indicators", they propose that content validity should be constitutive for indicator sets, in the sense of ensuring that the content of the assessment instrument adequately reflects the targeted construct [28].

In the area of sustainability assessment, reviews give evidence that a plethora of methodologies and approaches exist (e.g., [2,29–31]). Ness et al. [29] discern three groups of sustainability assessment tools: indicators/indices, product-related assessment, and integrated assessment. Here, obviously, the use of the term "indicator" is not in line with the generic definition by Singh et al. [3] and Heink and Kowarik [22] because product-related and integrated assessment tools will also deliver measures, i.e., quantities. However, this approach reveals certain characteristics to further categorise the application of indicators: The term "indicator/indices" applies to tools at the level of the economy, i.e., the national or regional level, and product tools at the level of products (and in the sense of LCA, also services); integrated assessment methods can be used broadly and either aim to integrate multiple aspects or address one overarching aspect such as risk assessment. From this analysis, it can be inferred that three criteria characterise the application of indicators in assessment methods: (i) the object of assessment, e.g., a nation, a product, etc., (ii) the specific method that is used to measure or calculate an indicator, and (iii) the question concerning the extent to which single indicators are integrated or aggregated into a composed indicator.

A frequent use case of indicators or indicator sets is at the country level, which will not be considered further here (a review can be found in Mayer [32]). As for the focus of this publication, the urban level, Hezri and Dovers [33] show in a historical view how sustainability indictor theory and practice have been influenced by the evolution of both environmental science and urban studies: From the environmental perspective, concepts from ecology, biophysical assessment, ecosystem assessment, and ecological-economical approaches (such as eco-efficiency) have moved into the development of sustainability indicators. From the perspective of urban studies, the early literature on urban indicators focused on the technical aspects of indicator development, while there was a subsequent shift to a procedural debate on appropriate processes for the development of indicators.

As the most influential model of environmental reporting in practice, Hezri and Dovers [33] mention the Pressure-State-Response (PSR) model, developed by the OEDC [34], which is based on a causality chain. The concept of causality chains or so-called causal networks implies the basic idea of capturing and representing the causes, consequences, and responses of the environment to impacts from society in a systemic way. The Driving Forces-Pressures-States-Impacts-Responses (DPSIR) framework, developed by the OECD [35] and EEA [36] from the abovementioned PSR, is proposed by several authors as a conceptual basis for the reporting and analysis of environmental problems (e.g., [20,37]). Although developed originally in relation to the country level, this concept of a causal network can be seen as a universal one for depicting the interaction between the environment and society and the development of respective indicators [38] (e.g., [22,39]). The DPSIR causality chain, focused on the interaction between the environment and society, forms the conceptual link to methods of sustainability assessment [33,38]. Tscherning et al. [40] show that the DPSIR framework has been used on issues of sustainable development for decision-making support at regional or local scale.

On the procedural side, several authors point to the importance of the selection process, which is not only important for content-related quality of indicators but also for transparency and creditability [2,37]. A common distinction is between the "top-down" approach, where experts define a framework or overall structure that is the basis for deriving a set of indicators, and the "bottom-up" approach, characterised by a systematic participation of stakeholders to understand or select the framework and key indicators (e.g., [2]). Generally, the interaction between experts and non-experts is seen as a crucial issue [23]. Fraser et al. [25] state that the exclusive role of experts in developing indicators has often led to failures as these experts lack local knowledge as well as community support for policy changes. In a broader sense, the procedural side is connected to questions of governance and participatory approaches [41]. Bauler [23] argues that the performance of indicators as policy depends on their so-called institutional embeddedness, which can be related to the indicator's attributes of legitimacy, credibility, and salience. Several authors report on participatory research approaches for the development and application of indicators (e.g., [25,42,43]).

As for sustainability assessment in urban planning, a review of the literature shows a large number of publications and a broad application of indicators. Several publications address the content of specific indicator sets for urban development ([4,5,44]). For example, López et al. [45] evaluated 32 indicator sets, comprising 2060 single indicators, by means of content analysis. An overview of the topics of application areas of indicators from the literature can be found in the Supplementary Materials (see Table S2). A further general finding from the review of the literature is that publications mostly focus on the development or evaluation of the indicator sets themselves, often in the course of a case study, but not on an analysis of indicator use in regular urban planning processes. Generally, little attention is paid to the procedural aspects of urban planning and only cursory attention to specific decision-making processes that would allow or demand a possible routine application of indicators. This goes along with the finding that the intended users of indicators are mostly subsumed under the generic term "urban planners", and no detailed analysis of specific needs of decision makers in urban planning processes is performed. This is confirmed in an analysis of urban planning processes by Yigitcanlar and Teriman [46], who identify a lack of sustainability assessment mechanisms in the planning process to support planners' and other involved actors' decision making. They propose an operational scheme for a procedural integration of sustainability assessment at different stages of the planning process.

2.2. Structuring Approaches for Urban Planning

2.2.1. Districts, Quarters, and Neighbourhoods

A city can be interpreted as a territorially defined area, an administrative unit, a system with energy and material flows, a network of actors, a location for production, trade, education, and culture, or a living and working space for its inhabitants. There is public interest in shaping urban development in a way that makes it compliant with the planetary boundaries and that contributes to a sustainable development of the society and economy. The overarching subject of consideration here is the metabolism of cities. Comparable to the demand for climate neutrality in the sense of a science-based target, the goal of a "resource-light society" has been formulated [47,48].

Interlinking urban planning with the principles of sustainable development is a complex task. There are various requirements, concepts, and examples (e.g., [6]). In recent years, the urban quarter, also called small urban unit, city district, or neighbourhood, has emerged as an object of assessment and a level of action. In the literature, the terms "quarter" and "district" in general are used synonymously; however, a distinction is made between district and neighbourhood. A discussion and classification of the term "neighbourhood" is found in Yigitcanlar and Teriman [46]. In their study, the neighbourhood is clearly seen as a smaller unit where social contacts are close in comparison to the district; thus, it is also termed a "suitable planning unit to evoke direct participation from residents" [49]. Although this general classification of districts as being larger than neighbourhoods but smaller than the city as a whole is followed throughout the literature, there is no clear definition, e.g., as to the number of inhabitants or other criteria of size for districts or neighbourhoods. Definitions often follow the specific interest of investigation, e.g., energetic planning of districts, which calls for a more spatial boundary of quarters (e.g., [50]). Specifically, in the German discussion, the terms "neighbourhoods" and "districts" strongly overlap [51]. Consequently, the terms "district" and "neighbourhood" are used interchangeably henceforth.

2.2.2. Actors in Urban Planning

An urban quarter is a manageable and easily modelled unit of a city that can be interpreted as an object of assessment in the sense of a relatively independent subsystem. Of course, the interrelations with the city as a whole must be considered and included. Indicators support actors in assessing a situation, evaluating solutions, and/or measuring improvements in the sense of monitoring success. They can be used for different purposes and can be developed for specific issues as well as serve to support the decisions of concrete user groups. In this sense, indicators serve as a means of perception of problems and development of problem awareness in politics and society and must, therefore, be easy to understand for this purpose. Also, they support experts in the evaluation of complex interrelationships and the selection of solutions on the basis of comparisons of variants and should, therefore, be based on scientific principles for recording and evaluation.

In the field of urban and neighbourhood development, indicators may initially be used by the municipal administration and its departments, as well as by energy and water supply companies. Especially in the area of neighbourhood development, representatives of civil society and their interest groups are other user groups. Among others, the interest groups of house and property owners, traders, and businesses should be mentioned here. They play a mediating role, as they can involve their members in the collection of data and in measures.

Sustainable development presupposes the conscious and purposeful action of all actors. In addition to the city administration setting and influencing the framework for development, the approach of sustainable neighbourhood development benefits from the direct involvement of local actors. There is an interplay between strategic planning, including the setting of framework conditions and the establishment/maintenance of infrastructures at the municipal level, and the operative action of directly and indirectly involved actors. Whereas the directly involved groups of actors (e.g., owners of buildings) can actively shape the process, the indirectly involved groups of actors (e.g., tenants) will be affected by the consequences of their actions.

The issue of natural resources is an important part of the sustainable development of cities and, thus, of urban planning and neighbourhood development. In this regard, fields of need (of the inhabitants) and areas of action that have a direct and indirect influence on the use of the resources "land", "raw materials", "water", and "ecosystem services" can be identified (Table 1).

Table 1. Connections between fields of need, areas of action, and consequences of use of resources (xxx strong, xx average, x low).

Fields of Need					Selected Areas of Action	Consequences for . . .			
Other	Free time	Mobility	Nutrition	Housing		Land use and land use change	Raw material consumption	Use of water	Quality of ecosystem
(x)	x	x	x	xxx	Construction/deconstruction	x	xxx	x	x
(x)	xx	x	xx	xxx	Water supply/disposal	xx	x	xxx	x
(x)	xx	xxx	x	xxx	Land use management	xxx	x	xx	xx
(x)	x	x	x	xxx	Energy supply	x	xxx	x	xx
(x)	x	x	xx	xxx	Waste management	x	x	x	x

In urban planning, especially in neighbourhood development, a distinction must be made between the cases of development of a new neighbourhood and refurbishment or further development of existing neighbourhood structures. In the case of a new development, i.e., the conceptualisation, planning, and construction of a new neighbourhood and new buildings, several sustainability assessment systems have been developed (Table 2), partly derived from environmental assessment approaches for buildings (for an overview see, e.g., [52]). These approaches, also termed Neighbourhood Sustainability Assessment Tools in the literature, generally use self-contained systems of assessment criteria, indicators, and assessment rules. Here, self-contained systems mean a compilation of indicators based on a homogeneous common conceptual outline. The object of assessment is, as far as possible, the system as a whole, i.e., the neighbourhood. Several authors provide reviews on Neighbourhood Sustainability Assessment Tools, i.a. Sharifi et al. critically discuss their strengths and weaknesses as well as limitations in practical use [53].

Table 2. Assessment systems for urban districts and neighbourhoods (selected examples).

Example	Reference
DGNB (Germany): Urban districts	[54]
LEED (USA): Neighbourhood development	[55]
BREEAM (UK): Communities	[56]
HQE (France): Urban planning	[57]
2000 Watt (Switzerland): Site	[58]
CASBEE (Japan): Urban development	[59]
iiSBE (international): Neighbourhood development	[60]

In contrast, regarding the further development of existing neighbourhoods, individual questions of analysis, evaluation, and improvement demand more flexible assessment approaches, which are capable of involving the inhabitants impacted and their individual needs and interests [61]. In this case, open sets of criteria and indicators are more often applied, depending on stakeholder interest and perspective, as well as available data. Regarding this, criteria and indicators can be individually selected or additionally developed and introduced [7]. This approach follows a more process-based and participatory approach [62]. The object of assessment is usually an individual measure, which is, however, also evaluated with regard to its effects on the overall system.

The issues of sustainability assessment and indicators to support sustainable urban development are increasingly becoming the subject of international standardisation. Reference is made here in particular to the standards already published as a result of activities in ISO TC 268 (Table 3). Among other things, ISO 37120 deals with questions of the type and application of indicators. The standard itself distinguishes between "core", "supporting", and "profile" indicators. Core indicators are understood here as indispensable, while supporting indicators can be applied in the sense of supplements. Profile indicators characterise the neighbourhood to be evaluated and serve to determine its (non-)comparability with others. These indicators represent background information that usually cannot be directly influenced in the neighbourhood. This typology has a general usability for classifying indicators according to the degree of bindingness of their application: core or mandatory indicators and supporting or voluntary indicators. Moreover, "supporting" can also be interpreted in the sense of broadening the profile of recorded and assessed variables. This typology can be supplemented by the introduction of substitute and proxy indicators. These can be used if the information needed for the originally intended indicators is not available but alternative data sources can be developed.

Table 3. Standards for the assessment of sustainable development of cities.

Standard	Title
ISO 37101:2016	Sustainable development in communities—Management system for sustainable development—Requirements with guidance for use
ISO 37120:2018	Sustainable cities and communities—Indicators for city service and quality of life
ISO 37122:2019	Sustainable cities and communities—Indicators for smart cities
ISO 37123:2019	Sustainable cities and communities—Indicators for resilient cities

However, many other classification principles for indicators exist, including those based on the user group (e.g., expert versus civil society), the sustainability dimension under consideration (e.g., economic versus ecological), the type of recording (quantitative versus qualitative), and the classification in the process (planning versus measurement). These are not addressed by the standards. Also, the division into three standards according to different topics complicates rather than facilitates the development of an overarching basis for understanding between different actors and groups of urban and neighbourhood development as to the application and interpretation of indicators.

3. Results

3.1. A Framework for Development and Use of Indicators

The framework presented here was developed in response to the needs of practitioners, as encountered also in the working group of the BMBF funding measure RES:Z. The framework is conceptualised as overarching guidelines for the development and use of indicators in urban planning, taking into account the large diversity of issues in sustainability assessment and resource efficiency. Consequently, it is not narrowed down to a specific application area and does not predefine a concrete or mandatory list of indicators. Instead, the framework provides a generic and theoretically substantiated structure in which diverse application cases can be mapped. The benefit of such an approach is twofold: First, non-experts in a project or planning process can draw from a concise but easily understandable structure, which enables a sound use of indicators, notwithstanding the detailed area of interest. Second, the overarching use of this framework across individual projects or groups of stakeholders will foster understanding and communication between diverse involved stakeholders and decision makers as well as experts and non-experts. Also, due to its generic nature, the framework is open to the inclusion of more detailed approaches from the literature for further characterisation of indicators, the adaptation or development of indicators for specific application areas, and the development of specific lists or groups of indicators.

The theoretical basis of the framework is related to major insights in the definition and concepts of indicators from Section 2:

- Indicators are defined as measures according to Heink and Kowarik [22], i.e., as a quantity with a dimension.
- An indicator shall be described by a concise definition, comprehending (a) the textual description of the concept of the indicator; (b) the procedure for its derivation, including the dimension the indicator is expressed in; (c) the specification of a measurement rule (if applicable).
- Indicators shall be characterised by classifying them according to the concept of the causal network described by the DPSIR model. As the theoretical core of the framework, a typology of indicators based on this causal network is proposed (see the next subsection).

Furthermore, a guide for the application of the framework for practitioners in urban planning is developed, which is presented in Section 3.2. Both the description of typology and the guide for application follow the content of the RES:Z Manual [8].

Proposal for a Typology of Indicators

The DPSIR model was selected as the basis of the typology of indicators due to the following two reasons. First, its generic nature as a causal network enables a universal, easily understandable framework for structuring indicators independently of a topical area. Second, the DSPIR can be seen as an action-oriented framework of the interrelation between the social and ecological systems [38], which makes it particularly suited for use in urban development at the neighbourhood level and planning processes.

Figure 3 shows the basic structure of the DPSIR model and the interaction of its five components: It involves driving forces, which are the underlying trigger of pressures, which in turn affect the state of an object or system, which again leads to impacts on diverse areas or safeguards, e.g., human health or ecosystems. Responses from the social system may exert influence on all of these elements, with the ultimate goal of decreasing negative impacts. Thus, a typology based on the DPSIR structures will classify indicators based on their function—as drivers, pressures, etc.—within the interrelation between the social and ecological systems.

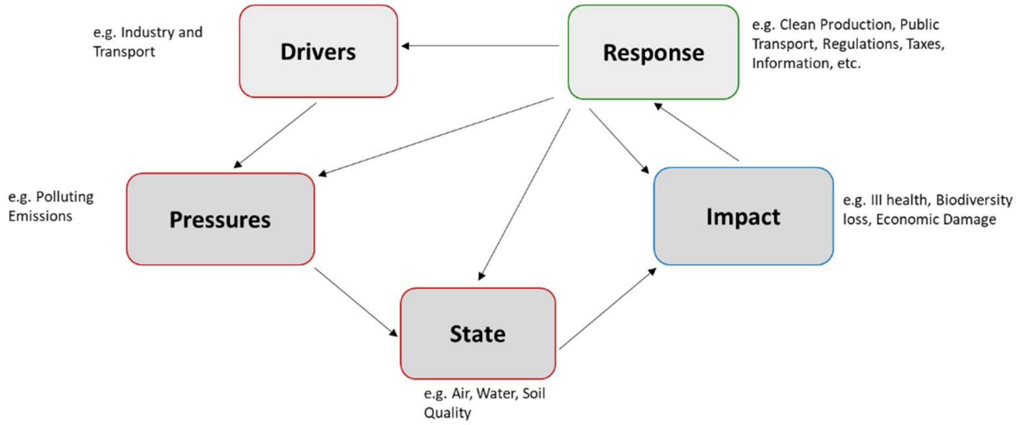

Figure 3. The DPSIR model (own illustration, adapted from EEA [36]).

Table S3 (Supplementary Materials) shows how this DPSIR model can be transferred to the area of urban development at the neighbourhood level. From this transfer, the principal suitability of the DPSIR approach for application in the context of resource efficiency in urban neighbourhoods becomes clear, as well as the complexity of the approach. In order to simplify and adapt the approach for practical use in urban planning, the following typology of indicators is proposed (Table 4).

Table 4. Typology of indicators [8].

Indicator Type	Related DPSIR Element	Definition
State indicators	State (Drivers, Pressures)	State indicators describe concrete conditions of a neighbourhood at a certain point in time, both in terms of structural and other aspects, including the (technical) systems directly related to the neighbourhood (e.g., waste water system). These indicators can be determined from measurements, surveys, or interviews directly in the respective neighbourhood. The definition of state indicators here is set in a broader sense. It also includes driving forces (e.g., growing population) and pressures (e.g., emissions of particles) of a neighbourhood.
Performance indicators	Response	Performance indicators are used to capture characteristics and properties of measures. This type of indicator is used to assess the suitability of a measure for its intended purpose. Accordingly, performance indicators can only be defined in connection with concrete measures (e.g., efficiency of a plant, evapotranspiration performance of a green space).
Impact indicators	Impact	Impact indicators describe the effects of neighbourhood activities and/or measures on the economy, society, and the environment. They, therefore, also refer to ecological, economic, and social circumstances outside the neighbourhood. Their determination, thus, requires the inclusion of further information outside the neighbourhood and, if necessary, the application of complex methodological approaches/models. Impact indicators are used for sustainability assessment with reference to the objectives of sustainable development (e.g., greenhouse gas emissions, consumption of abiotic raw materials).

As noted above, in the RES:Z Manual [8], state indicators subsume three DSPIR elements: drivers in the sense of the background information for neighbourhoods, pressures in the sense of the state of energy and material flows at a given point in time, and the environmental state of the neighbourhood. The latter can be termed state indicators in a narrower sense, complying with the "state indicators" from the DPSIR approach. The reason for subsuming these indicators is that they all apply to the neighbourhood (in contrast to response), and in this way, a simpler structure results: Here, the transitions between pressure as a trigger and state as a result are fluid and, thus, complex to interpret for practitioners. If desired, however, D, P, and S can easily be displayed as subgroups of the RES:Z state indicators. For examples of each of the three types of indicators (state, performance, impact), see Table S5 (Supplementary Materials).

The general principle for the application of indicators based on the RES:Z Manual Typology is depicted in Figure 4. State and impact indicators can be used for the description and assessment of both the initial state and final (target) state of districts and neighbourhoods. In contrast, measures that affect the transition between the actual and target states in urban planning and development processes are evaluated by means of performance indicators. Such indicators are notably used for technical and construction-related measures. In the case of an organisational measure, its process performance can be the object of assessment. Both the probability of achieving the objectives from a technical point of view and the performance of the measure with regard to achieving the objectives are assessed here. Indicators for assessing the effects on the environment, economy, and society are included in the evaluation and selection of measures. With impact indicators, the effects of policies and measures on the environment, the economy, and society can be recorded and assessed using evaluation criteria. The effects (here in the sense of impacts) within and outside the system boundaries of the neighbourhood are included. All types of indicators can also be applied in the sense of benchmarking, i.e., the comparison of the determined value of an indicator with a corresponding target value (benchmark).

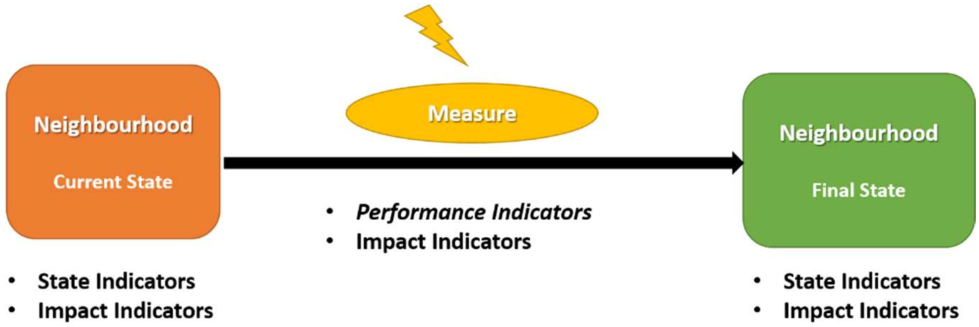

Figure 4. Application of indicators based on the RES:Z Manual Typology, simplified from RES:Z Manual [8].

By sticking to these general guidelines, the flexible adoption or—if expertise and capacity is available—development of indicators is possible. In this regard, one can draw from other existing frameworks in the literature that are oriented—among other options—towards the following issues: (1) dimensions of sustainability (ecological, socio-cultural, economic); (2) type of statement (quantitative, qualitative); (3) binding nature (mandatory/core indicators, additional voluntary/supporting indicators); (4) place in the impact chain (direct/indirect, side, follow-up); (5) type of assessment (assumption, calculation, measurement, survey, invoice); (6) use case (inventory, assessment); (7) main user (policy researcher, town planner, society).

Also, in addition to the typology, indicators can be further classified hierarchically. For practical application in this case, it may be helpful to group indicators into these subdivisions: (i) core/main indicators (core list of indicators), (ii) additional indicators, and (iii) substitute/proxy indicators.

The core indicators deal with central issues directly related to sustainable development and can be supplemented by additional indicators. Particularly, when supporting the process of sustainable neighbourhood development, the problem of not having all the required information for the given indicators often arises. This problem can be solved by the precautionary designation of substitute and proxy indicators. They are to be used when there are information gaps that can be filled by data from areas related to the topic. Relevant aspects for further development, description, and characterisation of urban indicators can be found in Lützkendorf and Balouktsi [7].

3.2. Guide for Practical Application of the Framework

The practical application of indicators in urban planning is structured into two parts, the selection process and the application of indicators during the course of planning processes or in a project (Figure 5). A summarised description of both parts is given in the following subsections. In order to directly guide practitioners, in the RES:Z Manual, each part is further structured into single working steps.

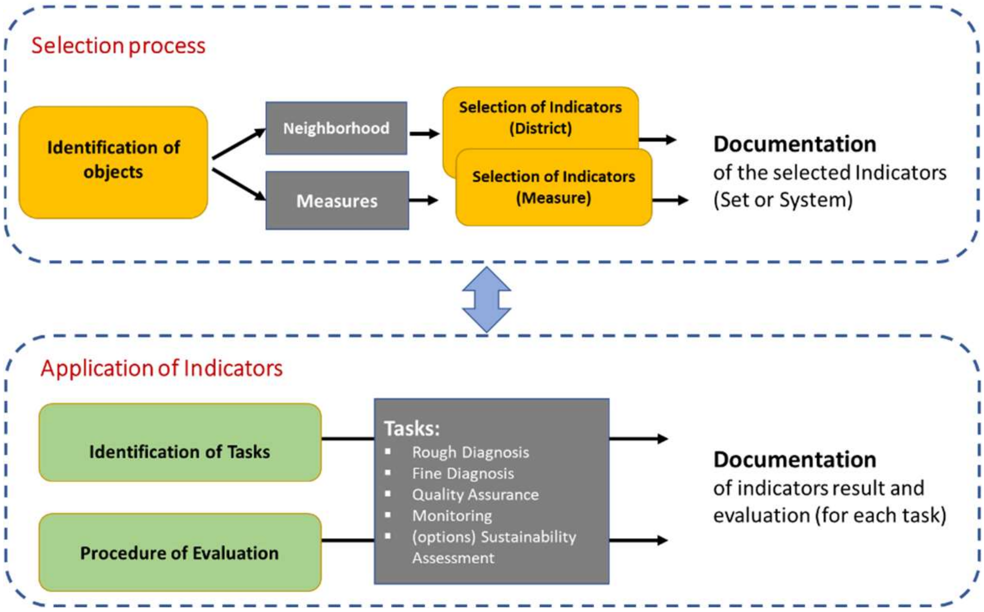

Figure 5. Scheme for practical use of indicators, simplified from RES:Z Manual [8].

3.2.1. Selection Process of Indicators

In accordance with the general objective of the framework, the practical selection of indicators shall be open to the needs of the active stakeholders and flexible as to the content-related choice of indicator. Also, the selection shall comply with the simple but elementary principles of the framework. To support stakeholders, the Manual further clarifies two important issues in the selection process: the issue of the objects for which indicators shall be defined and the issue of how to compile diverse indicators for joint application as an indicator set.

For objects, the definition of the typology is already based on the distinction between the neighbourhood itself as the object of evaluation and a measure. This distinction is emphasised in the practical guidance because at different points in planning processes, different objects may become the focal interest of evaluation; thus, practitioners should always be aware of what precisely is the object and, consequently, the suitable indicators. For the neighbourhood, as has been explained, state and impact indicators shall be applied. The uses at a certain point in time enable before/after comparisons, and the benchmarking of a present state to a desired state may be evaluated by state and impact indicators. In contrast, if the interest is on the support for sustainable neighbourhood development as a "process", the need is to evaluate the options for action and activities for its change. Accordingly, the object of evaluation is the measure. This term can be clarified further as a collective term for all options for action and activities described by the type, intensity, and direction of effect of activities for the improvement of an actual state in the direction of a target or desired state. Furthermore, a measure may include the use of products, which may also be developed specifically for neighbourhoods as part of a project (e.g., green facade systems). Thus, a product can also be defined as the object of consideration and will be first described in terms of technical/functional characteristics and properties. Its effectiveness and efficiency can be assessed by the use of selected performance indicators. In addition, products are assessed using impact indicators with regard to their effects on the society, the environment, and the economy, and are, thus, subjected to sustainability evaluation; in this case, the system boundary is usually their complete life cycle.

With regard to the compilation of several different indicators to be used in a planning process or project, for clarification and in relation to the theoretical aspects discussed in Section 2, the terms "open indicator sets" and "self-contained systems of indicators" are distinguished. Open indicator sets are defined as collections of indicators from which actors can choose depending on the question and situation, or which are individually compiled depending on the specific situation. These sets can assemble indicators that assess a situation from different perspectives. This is why double counts do not play a role here; however, as a major caveat, it follows that open indicator sets must not be aggregated. In contrast, self-contained systems of indicators are based on a homogeneous conceptual or model-theoretical approach. Typically, they are used for evaluation of tasks connected with a top-down sustainability assessment. They often contain procedures for partial or full aggregation on the basis of weighting factors. Therefore, double counting has to be avoided here, which has to be ensured by the underlying conceptual approach. Well-known examples are the impact models of life cycle assessment, which according to the respective impact model may be aggregated to indicators for safeguards in the sense of "endpoints", i.e., human health or the natural environment [62].

The selection process of indicators is completed by a documentation of all selected indicators. This documentation shall comply with the necessary definition of each indicator, which in the guidelines is complemented by the requirement that the assignment of each indicator to its respective RES:Z type is given. The description of an indicator can be done in the case of adoption of existing indicators via the source reference, or if indicators have been developed and formulated individually.

3.2.2. Application in the Course of Urban Planning

Use Cases of Urban Planning

For application of indicators in urban planning, a distinction between two use cases is of importance. The first use case is the sustainability assessment of newly developed or already existing neighbourhoods in the sense that a certification according to existing schemes of sustainability assessment is achieved. In this case, self-contained systems of indicators are used in combination with assessment scales/indicators and weighting factors for the criteria and indicators, which enable an assessment result in the form of a partially or fully aggregated summary.

Whereas a sustainability assessment can be easily integrated for newly constructed neighbourhoods and is a means of motivating and supporting project developers, the assessment of existing neighbourhoods is much more conflictual: Municipalities may fear the disadvantages of failing to fulfil criteria of positive assessment; practical obstacles are the large number of actors involved, the dispersed ownership of real estate, and the lack of a central point of contact. Consequently, such a process has to be steered by involving many stakeholders, e.g., by introducing "neighbourhood managers".

The use case of a sustainability assessment that is geared exclusively towards certification as a result of project development of new or existing neighbourhoods is not pursued further here. Instead, the main interest is the second use case, which is the continuous process of further development and transformation of an existing neighbourhood. This process will be mainly based on open sets of indicators throughout different steps of planning. However, it is possible to make the goal of a (successful) sustainability assessment certification part of the planning and development process, which is discussed in detail below.

Application in Neighbourhood Development

To point out the use of indicators, the process of development and transfer of existing neighbourhoods is structured in the following tasks: rough diagnosis, fine diagnosis, quality assurance, monitoring, and sustainability assessment (optional). Each task is described by a certain outcome for which decision support is provided by the application of suitable indicators. However, each task may involve several steps in order to prepare a decision, e.g., by the acquisition of data or performing certain work. Tasks, expected outcomes, and necessary steps are listed in Table 5.

Table 5. Tasks in urban planning and their relation to expected outcomes of decision support.

Task	Expected Outcome for Decision Support/Used Type of Indicators	Steps	Content
I: Rough Diagnosis	Demand for action; State/Impact	1	Description and characterisation of the neighbourhood
		2	Analysis of general conditions
		3	Problem identification
II: Fine Diagnosis	Formulation, analysis, and selection of options for action; State/Impact/Performance	4	Formation of opinion, prioritisation if necessary, detailed analysis
		5	Target setting
		6	Identification of measures
		7	Detailed planning and creation of preconditions
III: Quality Assurance	Ensuring the defined Quality of Construction; State/Impact	8	Realisation and commissioning
IV: Monitoring	Ensuring the defined performance of operation/Performance; Impact	9	Operation, operational supervision/monitoring, adjustments if necessary
		10	Ensure continuity and the cycle concept
V: (optional) Sustainability Assessment	Certification—Closed Indicator System	11	Application of certification procedure and scheme

These tasks may be part of a project that is carried out as a one-time event, e.g., a research project as part of RES:Z. At the same time, this structure can be used as the basis of a scheme for regular urban planning that clearly defines single levels for application of sustainability assessments where clear outcomes can be set, independent of the specific decisions and the related needs of decision makers within a task.

4. Discussion

Indicators are promoted as a means of decision support in urban planning by a vast body of literature. New approaches for the development of indicator sets and/or their application in real case studies are continuously published, i.e., also as part of research projects carried out in the funding program "Resource-efficient urban districts for the future" (see Schinkel et al. [63]. Still, in view of the practical application of indicators to enhance resource efficiency in the course of urban planning, major problems are identified. First, the diversity of possible indicator sets and frameworks, specifically in the case of bottom-up flexible open indicator sets, reveals a trade-off between different objectives: While, on one hand, open indicator sets are desirable or even indispensable to account for individual conditions of planning projects and targets of actors, on the other hand, their large variety may obscure the part of the evaluation that is oriented towards the common societal goals of sustainability and resource efficiency. Second, as for the question about how to identify a "good" indicator set, the literature provides several approaches for selection procedures and quality assurance; however, these approaches are seldom rigidly transferred or even acknowledged in practical urban planning processes. One reason for this is that the complexity of theoretical approaches for quality assurance would demand profound interaction between experts, practitioners, and involved stakeholders. This interaction in the literature is generally identified as intricate or even prone to conflicts [7].

From this analysis, the necessity of bridging the gap between theoretically sound but complex approaches and the practical need for individual and easy to understand but significant and comparable indicators become obvious. In general, this calls for the development of overarching and unifying approaches; however, a balance has to be struck: On one hand, in practice and in the literature, there is strong criticism against applying uniform indicators for any city or case of urban planning, e.g., Kitchen opposes the assumption of "a universalism in the validity of measures and method across place—that it should be possible to measure, visualise and compare the same facts between cities in a standardised fashion" [64]. On the other hand, without a common ground of understanding of indicators and their outcomes for decision support in urban planning, the risk of arbitrariness in steering resource efficiency and sustainability for neighbourhoods will increase with the development of more individual approaches.

The framework proposed here is intended as a first step to tackle these problems through a unifying but still flexible approach. The framework transfers a theoretical foundation in terms of the DPSIR model into a simple structure that can also be easily communicated to non-experts. Its structuring elements can be seen to be partly specific and partly generic. The specific element is the typology of indicators along the causal network. This, in contrast to unspecific typologies (e.g., quantitative/qualitative, binding/non-binding), allows a unified content-related characterisation of indicators regarding the function and object an indicator shall be used for. In contrast, the generic element is the application scheme, which enables the overarching use for single areas of urban planning (e.g., construction and water supply). Thus, the typology can be flexibly adapted to each area, facilitates communication between stakeholders from these areas, and supports a holistic evaluation of resource efficiency.

As for the practical application of the framework, it accounts for two important issues: The first is a clear distinction between selection and application of indicators. This enables, for example, the inclusion of different procedures for development of indicators and, along with the documentation of all steps, contributes to the enhancement of legitimacy, transparency, and reproducibility of indicator use. Second, the structure for application throughout the tasks of the urban planning process opens the way for a future routine integration in urban planning processes, which so far has been a comparatively little considered topic in the literature and in practice but is a major prerequisite for a continuous urban development to have increased resource efficiency. In view of the concrete planning implications of the framework, the tasks listed in Table 5 provide a structure for interlinkage with different stages of decision making in urban planning. Local municipalities and planners are familiar with these tasks, and the framework is intended to guide them on how to integrate indicators for decision making into these tasks. At the beginning of one task, e.g., Task II—fine diagnosis, suitable indicators have to be selected in relation to the envisaged decision support, which in Task II is the formulation, analysis, and selection of suitable options for action, based on the prior rough diagnosis. As Table 5 shows, state indicators shall be selected in order to describe the features of the neighbourhood at the status quo and the outcomes of a possible option for action; performance indicators are selected if a measure, e.g., the application of a technology for enhancing energy efficiency, is already known, and impact indicators will be selected in order to show the outcomes at the societal level, e.g., possible saving of climate gas emissions. Following and in parallel with the execution of the task, data are collected notably for state and performance indicators, which describe the initial status of the neighbourhood and the expected status after a possible option for action as well as the expected performance of a measure. When all data have been gathered, the desired impact indicators will be calculated using suitable methodology and databases. Finally, results will be prepared for decision making by comparing the initial to the final status of each option for action, using the selected indicators. Decision makers can use this representation of indicator results together with other important information in their decision making and in participatory processes. After the decision is made, they can also use the results of the indicators to communicate a decision to stakeholders.

The proposed framework shall now be disseminated and evaluated in cooperation with practitioners from the RES:Z projects. As the main perspective, the framework should foster the process of enhancing common understanding of the nature and function of indicators and the facilitation of communication and mutual learning between different projects, initiatives, stakeholders, and decision makers. A further development of the framework could be envisaged in several aspects. As for the typology itself, the incorporation of further criteria, e.g., concerning the binding nature of an indicator, can easily be performed. This could be complemented by working out further procedures to support the selection process of indicators, e.g., regarding the interaction between open sets and closed indicator systems. With respect to the application of indicators, notably, the integration into concrete decision-making processes in the course of urban planning could be further worked out in transdisciplinary projects with practitioners. In the long run, the process of gaining experience and further development of this framework could possibly contribute to easy communication between experts and practitioners in view of the common goal of sound and efficient procedures for decision support with regard to enhancing the resource efficiency of neighbourhoods and the sustainability of cities.

Supplementary Materials: The supporting materials can be downloaded at: https://www.mdpi.com/article/10.3390/su14137951/s1; Table S1: Listing of the studies reviewed on the application of indicators in urban planning; Table S2: Topics on application areas for indicators in urban planning (total: 46 publications, multiple entries possible); Table S3: Interpretation of the DPSIR Model for the neighbourhood level; Table S4: Scheme for classification of indicators into the typology; Table S5: Selected examples of indicators.

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