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Towards Digital Sustainability Reporting: An Ontology for Mapping of Indicators in GRI and ESRS

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Abstract. Sustainability reporting by Small and Medium Enterprises (SMEs) is gaining importance. SMEs form the backbone of European industries, and their customers rely on them to ensure regulatory compliance. In preparing sustainability reports, a combination of standards is commonly used, which encompasses overlapping yet distinct requirements on sustainability indicators. Different standards categorize shared indicators under varying topics, while they also mandate unique indicators to assess identical sustainability phenomena. This poses challenges for SMEs in reporting against multiple standards. Considerable human efforts are demanded to determine the interconnected requirements across different standards. Additionally, reporting on overlapping indicators for new standards results in significant redundant work. Mapping of indicators between different standards allows the semantic interoperability of standards by indicating matching and distinct requirements, aiding in addressing these challenges. Therefore, this paper focuses on developing an ontology for mapping indicators from two significant standards, GRI and ESRS. We introduce the Sustainability Reporting Standards Ontology (RSO). RSO formally represents environmental indicators in GRI and ESRS, and is available online. Furthermore, we provide an ontology-based mapping between indicators, supported by concrete examples that illustrate the interconnections between them.

Keywords. Sustainability Reporting, Sustainability Indicator, Ontology Engineering, Semantic Interoperability, Standards Mapping

1. Introduction

Sustainability reporting of Small and Medium Enterprises (SMEs) is gaining importance. SMEs form the backbone of European industries, accounting for over 99% of all businesses in the EU [1]. Moreover, downstream customers rely on SMEs to ensure their own compliance with sustainability standards [2]. Furthermore, many SMEs have taken action for potential regulatory updates. In Germany, over a quarter of SMEs have prepared

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sustainability reports in 2023 [3]. In practice, SMEs may need to use several reporting standards in combination when preparing sustainability reports [4]. This necessity arises from serving a global clientele with diverse sustainability requirements. For example, a manufacturing SME in Germany may need to adhere to EU standards, globally recognized standards for non-EU clients, and investor-specific standards simultaneously.

Various standards and guidelines have been developed to gauge a corporation's performance concerning sustainability [5]. The Global Reporting Initiative (GRI) has developed a reporting framework that is widely adopted globally [6], while the European Commission introduced the first set of European Sustainability Reporting Standards (ESRS) in 2023 to strengthen sustainability reporting legislation in Europe [7]. These standards define both quantitative and qualitative indicators for organizations to report their impact on particular topics within the Environmental, Social, and Corporate Governance (ESG) dimensions. Sustainability standards often share commonalities but also exhibit distinctions in indicator requirements. For instance, both the GRI and ESRS standards mandate reporting on "Gross Scope 1 GHG emissions". However, this indicator is classified under the GRI topic "Emissions" [8] and under the ESRS topic "Climate change"[9], creating challenges for interoperability between standards.

The overlaps and distinctions in indicator requirements pose challenges for SMEs when reporting against multiple standards. Firstly, it relies mostly on human effort to determine interrelated indicator requirements across various standards. Given that SMEs have only recently initiated reporting and lack experience, it is difficult for them to grasp the interconnections of indicators across different standards. Secondly, reporting on various standards separately demands considerable human resources. Reporting on overlapping indicators for each new standard causes redundant work within this context.

To reduce human effort and avoid redundant work, standard mapping should be put into practice, especially in cases where multiple standards are used in combination. Mapping indicators across various standards enables semantic interoperability between sustainability standards. Ontologies provide a formal representation of the differing, overlapping, and /or mismatched concepts, structures, and methods [10]. They offer good communication between people and organizations, given that the knowledge encoded in the ontology can be analyzed both computationally and by humans. Ontologies have been used for mapping standards in security compliance [11,12], manufacturing [13], and software engineering domains [14]. In the realm of sustainability reporting standards, several studies have proposed the use of ontologies to represent indicators from diverse standards [15,16]. However, most of these works focus on developing generic structures for categorizing indicators from heterogeneous standards, without providing assistance to organizations in understanding specific indicator requirements. To the best of our knowledge, there has been no attempt to represent the interconnection among indicators across various standards.

In this paper we extend our previous work [17] and focuses on developing an ontology for mapping quantitative environmental indicators from the two significant sustainability reporting standards, GRI and ESRS. The contribution of this paper is threefold: 1) it introduces the Sustainability Reporting Standards Ontology (RSO[2]), which formally represents indicators in GRI and ESRS. 2) it further provides an ontology-based mapping between indicators in GRI and ESRS. RSO facilitates indicator mapping at both the

[2]RSO is available online at: https://github.com/OntoSustain/RSO

topic level and requirement level, indicating the overlapping and distinct indicators in the two standards. 3) These concepts are demonstrated and evaluated for the use case of corporate sustainability reporting using empirical data.

The work presented in this paper is embedded in an industrial project for a real-world use case from the manufacturing domain. RSO is envisioned to be integrated into the SME digital infrastructure. Accompanied by suitable digital infrastructure, the reporting system leveraging RSO as a knowledge base will empower the daily tasks of sustainability managers. Our focus in this paper is on introducing the preliminary result: the RSO ontology and the ontology-based indicator mapping.

2. Related Work

2.1. Sustainability Reporting and Reporting Standards

A sustainability report is a document published by a company or organization to publicly disclose information on what they see as the risks and opportunities arising from social and environmental issues and on the impact of their activities on people and the environment [18]. The embryonic stage of sustainability reporting can be traced back to the early 1990s when a few large organizations voluntarily disclosed information about their environmental performance [19]. As of today, close to 96% of the top 250 companies listed on the Fortune Global 500 ranking report on their performance on Environment, Social, and Governance (ESG) topics in 2022 [6].

In practice, sustainability reporting standards are important tools for demonstrating comparative sustainability performance [5]. The GRI Sustainability Reporting Standards (GRI Standards) enable an organization to report information about its most significant impacts on the economy, environment, and people [20]. The latest version of GRI Standards is organized into three series: 3 universal standards, 8 sector standards, and 35 topic standards. While GRI Universal Standards specify general compliance information, GRI Sector Standards provide likely topics for particular sectors. Conversely, each GRI topic standard centers on a particular sustainability topic, featuring an introduction, multiple disclosures (including indicators), and requirements. The ESRS standards were designed to align with the GRI standards [18], adopting a structure similar to GRI: 2 general standards and 10 topical standards [21]. Each topical standard covers disclosure requirements concerning sustainability impacts, risks, and opportunities.

The GRI standards have a long history and have been extensively studied in the literature. [5] However, due to time constraints, there have been relatively few publications focusing on the ESRS standards. Another widely studied sustainability reporting standard is the OECD standards developed by the Organization for Economic Co-operation and Development [5].

2.2. Ontologies for Mapping Standards

Several ontologies have been proposed for mapping standards to facilitate interoperability across multiple standards compliance in various domains. In the security compliance domain, Ramanauskaite et al. [11] proposed a new security ontology by integrating concepts from existing ontologies. Cheng and Lim-Cheng [12] present an ontology frame-

Table 1. Schemes and terms used for indicator categorization in previous works

Source type	Source	1st level	2st level	3rd level
Ontological source	[15]	Category	Aspect	Theme
	[16]	Area	Class	-
Non-ontological source	[24]	Dimension	Category	Subcategory
	[25]	Dimension	Theme	-
Standards	GRI	Dimension	Topic	Disclosure
	ESRS	Dimension	Topic	Disclosure Requirement

work aimed at working with existing Governance Risk and Compliance (GRC) systems to automate some of the tasks of determining overlapping requirements across multiple standards. In the manufacturing domain, Saha et al. [13] proposed a core domain ontology to capture the semantics of the welding concepts defined in various welding standards. The authors formalized the identified concepts as classes in a hierarchical form using OWL by assigning rules and axioms. In the software engineering domain, Henderson-Sellers et al. [14] constructed an ontological description of terminologies in all software engineering standards defined by one of the ISO sub-committees (SC7) to categorize existing standards and their relationship. In summary, most works use the ontology as an intermediary, linking matching concepts between covered standards and the proposed ontology to enable mapping between different standards.

2.3. Taxonomies for Sustainability Reporting Indicators

In the literature, GRI and OECD standards are often referred to as indicator sets [5,6,7]. However, the concept of an indicator is not explicitly defined in the latest versions of the GRI and ESRS standards. In the OECD sustainable manufacturing indicators, indicators are informally defined as "a well-established means of defining, tracking, and improving performance" [22]. [23] cites the definition given by the European Environmental Agency that an environmental indicator is "an observed value representative of a phenomenon under study". The authors in [24] found that the definition of indicator in the ISO standards was vague and informal, and therefore define an indicator as "a measure or an aggregate of measures from which conclusions can be drawn about the phenomenon of interest".

Several works have been published on the categorizations and representations of sustainability indicators. In terms of ontological sources, [15] presented ontologies for modeling sustainability indicators from GRI and OECD standards. The authors demonstrated that using the class hierarchy design can capture both overlapping and distinct features of indicators from heterogeneous standards. [16] aims to construct a unique knowledge graph based on the ontology developed to integrate ESG indicators from GRI and European Federation of Financial Analysts Societies (EFFAS) standards. In non-ontological sources, the authors in [24] reviewed 11 publicly available indicator sets and provided a categorization of indicators that are quantifiable and clearly related to the manufacturing domain. [25] investigated the use of indicators suggested by GRI in corporate sustainability reports in Canada. These works all adopt a hierarchical scheme to categorize sustainability indicators. Table 1 summarizes the schemes from different sources, where the 1st level can be referred to as the dimension of sustainability, the 2nd level as the broad topic, and the 3rd level as detailed topics.

2.4. Research Gap

Existing works on taxonomy for sustainability reporting standards [15,16,24,25] aim to establish frameworks for indicator integration and categorization. They offer similar hierarchical schemes for categorizing indicators from various standards, serving as valuable references. Moreover, these works define useful concepts to represent indicator characteristics that can be reused.

However, certain research gaps remain. Firstly, while prior studies have employed comparable hierarchical structures for classifying indicators, they utilize synonyms that may introduce ambiguity, as demonstrated in Table 1. These terms are somewhat inconsistent with those used in the GRI and ESRS standards. Furthermore, existing studies typically represent the relationship between an indicator and the standards from which it was derived as "Indicator hasReference IndicatorSet," since these standards are commonly referred to as indicator sets in the literature (e.g. indicator total fuel consumption has reference GRI). However, this degree of formalization is insufficient for our use case, where the provenance of indicators (i.e., which specific piece of standard the indicator was defined in) is typically required in the sustainability report as a reference index to the adopted standards (e.g. indicator total fuel consumption has reference GRI 302 Disclosure 302-1). This is drawn from observations of sustainability reporting practices in large corporations, as evidenced by several publicly available reports [11,12]. Additionally, existing works have primarily focused on indicator categorization, with only a few non-ontological sources providing context regarding specific requirements for indicators. Moreover, none of these works have examined the representation of the interconnection of individual indicators from different standards, which is of significant importance for the sustainability reporting practice of SMEs. Finally, previous research studied different standards, and many of them employed outdated versions of the GRI standards. To the best of our knowledge, there is no publication that has attempted to represent environmental indicators from both the GRI and ESRS standards.

To bridge the identified research gap, we identified the following research questions:

RQ1. How do we classify indicators and represent the provenance of indicators in the GRI and ESRS standards using an ontology?

RQ2. How do we represent specific requirements for indicators in the GRI and ESRS standards using an ontology?

RQ3. How do we map indicators in the GRI and ESRS standards using an ontology?

3. The Sustainability Reporting Standards Ontology (RSO)

In this section, we present one of our main contributions, the Sustainability Reporting Standards Ontology (RSO).

3.1. Methodology

The development of RSO followed the Linked Open Terms (LOT) methodology [26] and the "Ontology Development 101" guideline [27]. The ontology development is delineated into five steps as follows:

1. **Ontology requirement specification:** we specified the ontology requirements in terms of purpose, user, and intended uses by collaborating with our project partner, a German manufacturing SME actively involved in sustainability reporting. Furthermore, we analyzed indicator characteristics in the GRI and ESRS standards, derived key concepts, and elaborated on requirements for the formalization. We also compiled a list of Competency Questions[3] (CQs) to delineate the ontology scope, which will serve as evaluation criteria in subsequent steps. Ontology requirements were specified in the ontology requirements specification document and are elaborated in Section 3.2
2. **Ontology implementation:** we used Protégé[4] to edit the RSO ontology in the RDF/OWL formalization. Regarding ontology reuse, we analyzed and extended ontological resources from previous works described in Section 2.3 and used LOV [28] to search for existing terms. Additionally, we used GraphDB[5] as a database for persistently storing and visualizing the terminologies and assertional indicators and reporting data from the organization. An overview of the RSO and reused ontologies is detailed in Sections 3.3.
3. **Ontology evaluation:** we evaluated the RSO ontology by converting the CQs into SPARQL queries and assessing the results against indicators derived from the GRI and ESRS standards, as well as real-world data from the sustainability report of a manufacturing company that is avaliable online. We also used the OntOlogy Pitfall Scanner (OOPS!) [29] to detect potential modeling errors.
4. **Ontology publication:** the RSO ontology is available online in public Github repositories under the CC by 4.0 license. We used WIDOCO [30] to generate the ontology documentation[6] and improved the visualization by manually adding illustrative examples.
5. **Ontology maintenance:** as sustainability reporting standards are subject to change, we will track new requirements, concepts, and issues through GitHub issue trackers in the corresponding ontology repositories.

3.2. RSO Requirement Specification

3.2.1. Ontology Purpose and Use

The purpose of RSO is to facilitate the interoperability of sustainability standards by indicating the matching and distinct indicators. Indicator mapping will provide further information, for example, which report data can be reused for another standard, and what distinct requirements exist for the overlapping indicators in the two standards. This information will then be used by sustainability managers during the preparation of sustainability reports and has also been documented as requirements in the form of competency questions.

The domain of RSO encompasses the representation of quantitative environmental indicators in the GRI and ESRS standards, along with their associated concepts. These associated concepts include organization, sustainability report, report value, etc.

[3] CQs and SPARQL queries are available at: https://github.com/OntoSustain/RSO/tree/main/cqs-and-sparql-queries

[4] https://protege.stanford.edu/

[5] https://www.ontotext.com/products/graphdb/

[6] The RSO documentation is available at: https://ontosustain.github.io/rso.github.io/

3.2.2. Analysis of Indicators and Requirements in Formalization

To specify requirements for indicator formalization in RSO, we investigated indicator characteristics within the two standards. On the basis of the observations obtained, we were able to refine the ontology requirements.

Observation 1. Indicator categorization in GRI and ESRS exhibits different levels of granularity. As outlined in Section 2.3, both the GRI and ESRS standards organize indicators following a similar scheme, which can be generalized as "dimension-topic-disclosure (disclosure requirement)". At the first level, both standards adopt the ESG dimensions. Disparities arise at the second level. Although both standards use the term "topic", it is evident that the scope of topics varies between the standards, encompassing different levels of environmental issues. Each GRI topic represents a singular environmental issue, whereas ESRS topics may encompass multiple issues. For instance, the ESRS topic "Climate change" encompasses indicators about both "energy" and "emission" topics. Similarly, while each GRI disclosure can be viewed as an independent subtopic, ESRS disclosure requirements combine several subtopics.

Observation 2. Indicators sharing identical names may entail different requirements. These requirements manifest in several aspects, including different measurement units, calculation variables, and the applicability of standards. For instance, concerning the indicator "total energy consumption within the organization", GRI requires the unit "joules or multiples" whereas ESRS mandates reporting values in Mega-Watthours. Moreover, GRI necessitates deduction of the amount of "electricity, heating, cooling, and steam sold" for indicator value calculation, whereas ESRS does not stipulate specific requirements for this variable. As another example, for the indicator "location-based scope 2 GHG emissions", GRI indicates that "if applicable, the reporting organization shall report this information", while ESRS mandates the organization to report this value.

Observation 3. Standards may require distinct quantity kinds for indicators measuring identical environmental phenomena. For instance, in quantifying the usage of renewable materials for producing the organization's products and services, GRI mandates reporting the "total weight or volume of renewable materials", whereas ESRS requires providing information on "the weight in both absolute value and percentage of renewable input materials".

Observation 4. Indicators measuring the same type of phenomena may demonstrate different hierarchical levels. For example, in quantifying total electricity consumption, GRI mandates reporting one value representing the total electricity consumption. In contrast, ESRS requests information on the consumption of purchased electricity from renewable and non-renewable sources separately. From the formalization perspective, "total electricity consumption" can be viewed as a broader concept encompassing "electricity consumption from renewable (non-renewable) sources".

Based on these observations, the new ontology should tackle the different levels of granularity in indicator categorization. Moreover, the new ontology should use a vocabulary that aligns with the terminology used in these two standards. Furthermore, considering the insufficient representation of indicator provenance in previous works, additional concepts are required in the new ontology to depict the origins of indicators derived from different standards. Since indicators cannot be directly matched with their semantic meaning, the new ontology must represent the requirements for indicators and subsequently map indicators based on these requirements.

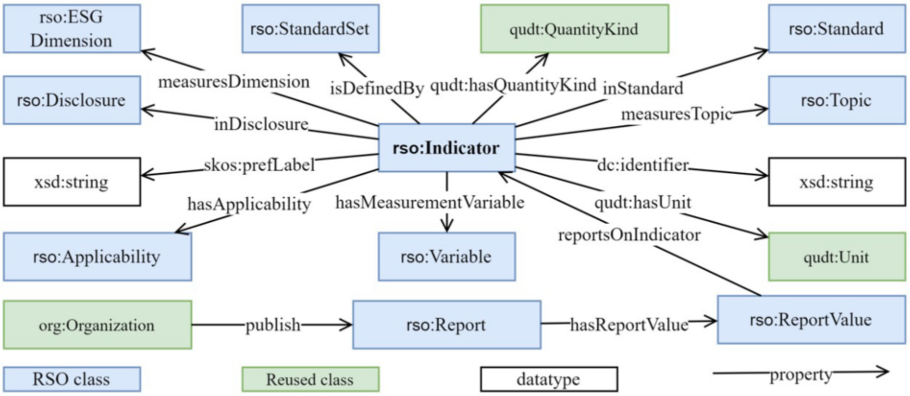

Figure 1. Overview of the RSO ontology

3.3. RSO Overview

Figure 1 shows an overview of the RSO ontology, including main classes and properties centered around the Indicator class. Terms in the RSO ontology have the *rso* prefix, while terms from imported ontologies use their corresponding prefixes. We reused terms such as *org:Organization* from The Organization Ontology (org) [31] to define the reporting company, *qudt:Unit* and *qudt:QuantityKind* from the QUDT ontology [32] to specify indicator requirements. Additionally, terms from the Simple Knowledge Organization System (SKOS) [33] and DCMI Metadata Terms [34] were used to to describe resources in RSO.

The main classes in RSO are described as follows:

- *rso:Indicator*: We refined the definition in [24] and defined an indicator as "a single measure from which conclusions on the phenomenon of interest can be inferred".
- *rso:ESGDimension* covers the three dimensions of sustainability and is defined as enumerated class.
- *rso:StandardSet* models a series of sustainability reporting standards. Exemplary instances are the GRI standards and the ESRS standards.
- *rso:Standard* is a piece of standard that is defined by a specific standard setter. For example, the standard GRI 301: Materials 2016 is part of the GRI standards.
- *rso:Disclosure* covers indicators that allow an organization to report information about sustainability issues. This class is further subdivided into *rso:GRIDisclosure* and *rso:ESRSDisclosureRequirement* based on terms used in each standard.
- *rso:Topic* delineates sustainability issues.
- *rso:Applicability* indicates whether an indicator is required mandatorily or optionally by the corresponding standard.
- *rso:Variable* contains a hierarchy of subtopics of certain sustainability topics. A variable expresses a measurable value of a phenomenon, such as "total energy consumption".
- *rso:Report* represents the annual sustainability report published by a certain organization and complies with certain standards.

- *rso:ReportValue* provides a structure to represent a single report data. Each data contains a numerical value and a measurement unit and is linked to a specific indicator.

3.3.1. Formalization of Indicator Classification

To classify indicators in RSO, we adopted the scheme "Dimension-Topic-Subtopic", which aligns with the structure and terminology of the two standards. In Figure 2a, subclasses of the *Indicator* class are demonstrated based on this classification scheme. At the dimension level, indicators are further categorized into *EnvironmentalIndicator*, *SocialIndicator*, or *CoporateGovernanceIndicator*. Although our focus is primarily on the environmental dimension, we have defined comprehensive subclasses to allow for future extension.

Moving to the topic level, we further subdivide the *Topic* class into subclasses *CoreTopic*, *GRITopic*, and *ESRSTopic*. While individuals of *GRITopic* and *ESRSTopic* are directly derived from the respective standards, individuals of *CoreTopic* are borrowed from the GRI standards. We opted to reuse topics defined in the GRI standards because each GRI topic represents a singular environmental issue, facilitating indicator classification. Consequently, indicators are further classified into subclasses such as *EmissionIndicator*, *EnergyIndicator*, and *WasteIndicator*.

At the subtopic level, we derived subtopics from both standards and established a class hierarchy using the *Variable* class. Each subtopic is a subclass of the *Variable* class, enabling indicators to be further classified into the appropriate subclass based on the specific variable they measure. As an example, Figure 2b and 2c illustrate subclasses of the *EmissionIndicator* class and subclasses of the *Emission class*, respectively, demonstrating that the indicator classification aligns perfectly with the subtopic structure.

Additionally, we also categorize indicators into *AbsoluteIndicator* and *WeightedIndicator* based on whether they represent the total quantity of a phenomenon or consider additional factors through weighting.

3.3.2. Formalization of Indicator Provenance

To formalize the indicator provenance and to enhance the simplistic "Indicator hasReference IndicatorSet" relationship employed by previous works, we subdivided the indicators into subclasses *GRIIndicator* and *ESRSIndicator* based on the standard set from which they originated. Furthermore, we introduce additional properties with different do-

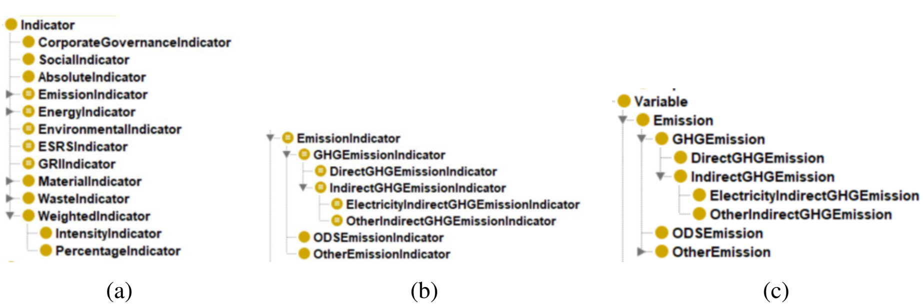

Figure 2. Illustration of represented taxonomies for 2a *Indicator*s, 2b *EmissionIndicator*s in particular, and 2c *Emission* variables.

Table 2. RSO Properties for the Formalization of Indicator Provenance along with the Competency Questions, Domains and Ranges.

Competency question	Property	Domain	Range
Which Core topic does this indicator measure?	measuresCoreTopic	Indicator	CoreTopic
Which GRI topic does this GRI indicator measure?	measuresGRITopic	GRIIndicator	GRITopic
Which specific GRI standard defines this GRI indicator?	inGRIStandard	GRIIndicator	GRIStandard
Which specific GRI disclosure defines this GRI indicator?	inDisclosure	GRIIndicator	GRIDisclosure
Which ESRS topic does this ESRS indicator measure?	measuresESRSTopic	ESRSIndicator	ESRSTopic
Which specific ESRS standard defines this ESRS indicator?	inESRSStandard	ESRSIndicator	ESRSStandard
Which specific ESRS disclosure requirement defines this ESRS indicator?	inDisclosureRequiement	ESRSIndicator	ESRSDisclosureRequirement

mains and ranges to furnish information such as the associated disclosure (disclosure requirement) and the specific standard section from which the indicator was derived. These properties are detailed in Table 2, along with the defined competency questions.

3.3.3. *Formalization of Indicator Requirements*

Based on our observations regarding the requirements for indicators described in Section 3.2, we have defined several properties to formalize indicator characteristics and requirements. Each indicator possesses a unique name represented using *rdfs:label* and *skos:prefLabel*, as well as an unique identifier represented using *dc:identifier*. Furthermore, an indicator is associated with certain measurement variable(s), linked to individuals of *Variable* class by *rso:hasMeasurementVariable*. Additionally, an indicator is linked to information about the measurement quantity kind (*qudt:QuantityKind*) using *qudt:hasQuantityKind*. For the weighted indicators, we have further defined subproperties *rso:hasDenominatorVariable*, *rso:hasDenominatorQuantityKind*, *rso:hasNumerator-Variable*, and *rso:hasNumeratorQuantityKind* to specify the measurement variable and quantity kind for the denominator and numerator, respectively. Moreover, each indicator may be linked to information about the unit of measurement (*qudt:Unit*) specified in the standards using the object property *qudt:hasUnit*. Finally, each indicator is linked to an instance of the *Applicability* class to indicate whether this indicator is mandatorily or optionally required by the standards.

Figure 3 illustrates an example of how indicator requirements are formalized using the properties described above. The upper part depicts the original text excerpt concerning the ESRS indicator E5 Climate change, while the lower part, delineated by a black border, represents the fragment of the turtle serialization for the corresponding indicator and relationships.

It is noteworthy that the text description mentioned two indicators derived: one absolute indicator for the total amount and one weighted indicator for the percentage of non-recycled waste. It is imperative to treat them as distinct indicators due to their differing

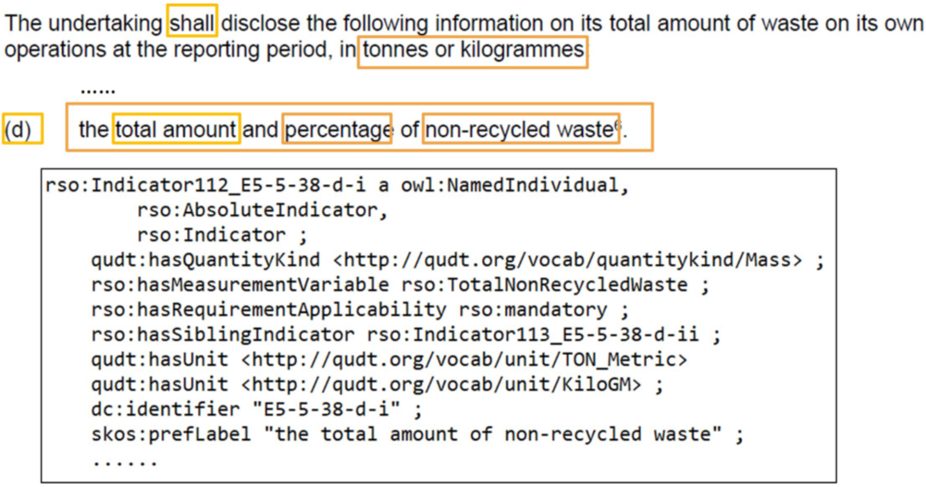

Figure 3. Excerpt of the formalization of Indicator requirements using RSO terms in the Turtle syntax.

quantity kinds. This distinction allows for more accurate comparison and matching of indicators from various standards, facilitating the identification of reporting data suitable for reuse. Furthermore, these two indicators are linked using *rso:hasSiblingIndicator*, which is defined as a symmetric property. In RSO, two indicators are considered sibling indicators if they originate from the same standard, share identical measurement variables, but exhibit different quantity kinds. This relationship provides valuable insights into addressing the question: what distinct indicators are required to measure the same subtopic across various standards. Further detailed information about this aspect is elaborated upon in Section 4.1.2.

4. Ontology-based Indicator Mapping and Experiment

In this chapter, we present how our designed ontology streamlines indicator mapping between the GRI and ESRS standards. Based on RSO, we identified four types of mapping across two levels: topic-based **N-to-n mapping**, and requirement-based **One-to-one**, **One-to-n**, and **N-to-one mapping**. For each mapping type, we outline the relevant use case, the addressed problem, and the used terms from RSO to get the mapping results. Subsequently, we detail the experimental outcomes obtained by executing SPARQL queries on real-world sustainability reporting data, including comprehensive mapping examples.

4.1. Use Case and Mapping Description

In preparing the sustainability reporting, one common approach entails initially compiling the report based on one standard, then incorporating additional information required by other standards, and finally generating content indexes for all standards. Given the widespread global adoption of GRI standards, we assume the scenario where preexisting information is grounded in GRI standards, and a sustainability manager is now tasked with incorporating information compliant with an additional standard, specifically the ESRS standards. Hence, a critical question confronting the sustainability manager pertains to how the sustainability topics and indicators in the ESRS standards correlate to the GRI standards, and how to reuse the preexisting information for the new ESRS requirements.

4.1.1. Topic-level Indicator Mapping

Regardless of whether the organizations opt to report according to the GRI or ESRS standards, they typically identify sustainability topics pertinent to their business activity or industry. Subsequently, they prepare information based on the requirements defined in the respective topic standards. Consequently, in preparing supplementary information according to the ESRS standards, two critical questions arise for the sustainability manager, formalized herein as two competency questions:

CQ16. What is the corresponding sustainability topic in ESRS for a topic delineated in GRI?

CQ17. What are the indicators associated with each respective topic in both standards?

Considering the variation in terminology of the two standards, sustainability managers less familiar with the two standards may struggle to pinpoint answers. To address these questions, *rso:CoreTopic* serve as an intermediate for achieving interoperability between topics across the two standards. Each derived instance of *rso:Indicator* is linked to both an instance of *rso:CoreTopic* and an instance of either *rso:ESRSTopic* or *rso:GRITpopic*. Consequently, if topics within the GRI and ESRS standards encompass indicators measuring the same RSO core topic, they possess an indirect relationship. Using the designed SPARQL query, we can retrieve the name and reference standard of the ESRS topic, along with multiple indicators specified in both standards. Hence, at the topic level, we establish N-to-n indicator mapping.

4.1.2. Requirement-Level Indicator Mapping

Upon obtaining information regarding the indicators measuring related topics in both standards, a natural question arises: which indicators overlap in the two standards and what are the unique requirements for them in each standard? Given the varying requirements for indicators (e.g. measurement unit, quantity kind, and variable), alongside the hierarchical structure of the measurement phenomenon, we delineate three types of mappings at the requirement level, outlined as follows:

In a One-to-one mapping scenario, indicators from different standards measure the same phenomenon and possess identical quantity kinds for that phenomenon. This mapping type primarily focuses on facilitating information reuse, considering two key requirements: the measurement phenomenon and the quantity kind. For instance, if we already possess data on the GRI indicator "the total energy consumption of the organization", we can repurpose this information if the ESRS standard also mandates disclosure of this information. Other requirements, such as the unit of measure, indicator applicability, required information for other quantity kinds are regarded as "soft constraints" and can be extracted via the designed SPARQL query (refer to CQ18 to CQ21).

The One-to-n Mapping and N-to-one Mapping concepts stem from the observation that indicators assessing the same type of phenomena may exhibit varying hierarchical levels. While direct reuse of information for these indicators may not be feasible, they

Table 3. Corresponding sustainability topics in ESRS for topics outlined in GRI (with the number of indicators derived from each topic specified).

GRI Topic	GRI Standard	ESRS Topic	ESRS Standard
Materials (9)	GRI 301	resource use and circular economy (5)	ESRS E5
Energy (13)	GRI 302	climate change (18)	ESRS E1
Emissions (16)	GRI 305	climate change (9)	ESRS E1
Waste (25)	GRI 306	resource use and circular economy (19)	ESRS E5

can be repurposed following certain operations, offering valuable insights and expediting the reporting process. One-To-n Mapping denotes a scenario where a GRI indicator measures a broader phenomenon within a specific topic compared to several ESRS indicators. In such cases, the value of the GRI indicator necessitates further disaggregation in accordance with ESRS criteria. Conversely, N-to-one mapping signifies instances where several GRI indicators gauge narrower phenomena than a single ESRS indicator within a specific topic. Here, the values of the GRI indicators can be aggregated to derive the value for the ESRS indicator. These mapping types are also framed as competency questions (refer to CQ22 and CQ23).

4.2. Experiment Results

To validate the designed concepts for indicator mapping and furnish detailed examples of each mapping type, we performed several experiments based on empirical data. We converted CQs for each mapping type into SPARQL queries. These queries were executed against the constructed RSO Knowledge Graph (RSOKG [7]). The RSOKG encompasses 114 quantitative indicators sourced from the GRI and ESRS standards, focusing on environmental topics such as materials, energy use, emissions, and waste. These topics were selected due to their particular significance within the manufacturing domain. Additionally, RSOKG contains reporting values extracted from a publicly accessible sustainability report of a manufacturing firm based in Germany, available on its website. The report was published in 2022 and complies with the GRI standards.

We manually created the instances in the knowledge graph and determined the mapping results for each identified mapping type. The pre-determined results were then used as ground truth to evaluate the mapping results obtained by conducting SPARQL queries to validate the accuracy of these results. As a result, the mapping results obtained by the SPARQL queries in the designed experiment are consistent with the human-written results, which proves that the designed ontology and knowledge graph are competent for the intended use case.In the subsequent sections, we present the outcomes of our experiments, elucidating the mapping results[8] in detail.

4.2.1. Experiment Results for Topic-level Mapping

Using the designed SPARQL query for CQ16, we retrieved the corresponding topics in ESRS for those outlined in GRI, along with the specific topic standards. The results are summarized in Table 3, where the number of indicators derived from each topic is specified. Additionally, we retrieved the indicators defined for each pair of corresponding

[7]The RSOKG is avaliable at: https://github.com/OntoSustain/RSO-examples

[8]All mapping results are available at: https://github.com/OntoSustain/RSO/tree/main/indicator-mapping

Table 4. Examples of one-to-one matched indicators within the emissions topic

Mapping result	Result1	Result2
GRI indicator	Gross direct (Scope 1) GHG emissions in metric tons of CO2eq	Gross location-based energy indirect (Scope 2) GHG emissions in metric tons of CO2eq
ESRS indicator	The gross Scope 1 GHG emissions in metric tonnes of CO2eq	The gross location-based Scope 2 GHG emissions in metric tonnes of CO2eq
variable	Gross Scope 1 GHG emissions	Gross location-based Scope 2 GHG emissions
quantity kind	mass	mass
GRI value	694057	1187339
unit	Metric Ton	Metric Ton

Table 5. Example of one-to-n mapping within the energy topic

Mapping result	Result1	Result2
GRI indicator	In joules, watt-hours or multiples, the total: i.electricity consumption	In joules, watt-hours or multiples, the total: i.electricity consumption
GRI variable	Consumed purchased electricity	Consumed purchased electricity
ESRS indicator	consumption of purchased or acquired electricity from non-renewable sources	consumption of purchased or acquired electricity from renewable sources
ESRS variable	Consumed purchased electricity from non-renewable source	Consumed purchased electricity from renewable source

topics in the two standards using the query for CQ17. Taking the emissions topic as an example, we found 13 GRI indicators and 18 ESRS indicators both measuring this topic. A comprehensive list of the N-to-n mapping results is available in our GitHub repository.

4.2.2. Experiment Results for Requirement-level Mapping

For one-to-one mapping, we derived 2 results for the material topic, 2 results for the energy topic, 4 results for the emissions topic, and 15 results for the waste topic using the corresponding query. For one-to-n mapping, we derived 13 results for energy indicators, including 5 distinct GRI indicators, and 24 results for waste indicators, including 11 distinct GRI indicators. For n-to-one mapping, we found 2 results for material indicators, and 14 results for waste indicators. For illustrative purposes, we present a selection of representative results for each mapping type. The complete set of results, including additional details, can be accessed in our repository. Table 4 demonstrates the one-to-one matching indicators within the emissions topic. Table 5 illustrates an example of one GRI indicator mapped into two ESRS indicators, indicating that GRI indicators measure broader phenomena and that the GRI value has to be further broken down to repurpose the ESRS value. Table 6 demonstrates two GRI indicators mapped into one ESRS indicator, indicating that the ESRS value can be repurposed by aggregating the GRI values.

5. Conclusion and Future Works

In this paper, we introduced the Sustainability Reporting Standard Ontology RSO – an ontology for mapping quantitative environmental indicators in the GRI and ESRS standards. RSO encompasses the formalization of the classification, provenance information,

Table 6. Example of n-to-one mapping within the materials topic

Mapping result	Result1	Result2
GRI indicator	Total weight of non-renewable materials that are used to produce and packaging the organizations primary products and services during the reporting period	Total weight of renewable materials that are used to produce and packaging the organizations primary products and services during the reporting period
ID	301-1-a-1-i	301-1-a-1-ii
GRI variable	Non-renewable Material	Renewable Material
ESRS indicator	The overall total weight of products and materials used during the reporting period	
ID	E5-4-32-a	
ESRS variable	material	

and requirements for indicators. Based on RSO, four types of mapping were identified, namely: topic-based **N-to-n mapping**, and requirement-based **One-to-one**, **One-to-n**, and **N-to-one mapping**. The proposed ontology and mapping concepts have been validated based on experiments based on empirical data.

RSO-based indicator mapping facilitates semantic interoperability between GRI and ESRS by indicating the overlapping and unique indicators. Consequently, it facilitates addressing the questions, such as how the sustainability topics defined in the ESRS standards correlate to the GRI standards, how to reuse the pre-existing reporting information for the new ESRS requirements, and which unique requirements for indicators are specified in ESRS compared to the GRI standards. The proposed ontology-based indicator mapping equips sustainability managers with expert insights into the semantic connections among sustainability reporting standards. By leveraging this system, managers can streamline their reporting processes, avoiding redundant work associated with reporting on overlapping indicators for each new standard.

Our vision is to empower digital sustainability reporting in terms of automating sustainability data collection, data analysis, and report generation through the utilization of semantic web technologies. This paper presents our preliminary results regarding using ontology for sustainability report generation in compliance with multiple reporting standards. At the time of writing, the published version of the ontology is undergoing implementation in an industrial project aimed at developing an in-house digital infrastructure in a manufacturing SME in Germany. To enhance the usability and accessibility of our solution, we acknowledge the need for front-end user-friendly tools. We are actively developing a front-end tool that will leverage the developed ontology and knowledge graphs, thereby enabling more companies to report on their sustainability more efficiently and accurately. In future endeavors, we also intend to broaden the scope of our ontology to include more granular sustainability data resources. This expansion will facilitate data integration from heterogeneous sources both within and without the organization. We intend to achieve this by refining the existing taxonomy of sustainability variables and elucidating the relationship between these variables and the organization's business activities. Additionally, our future work includes the completion of the current scope of standards, encompassing the integration of indicators from other sustainability topics as well as additional sustainability standards.

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