Shared Metrics of Sustainability: a Knowledge Graph Approach

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Abstract
Environmental, Social, and Corporate Governance (ESG) criteria allow to evaluate business's overall awareness and attention to social and environmental aspects. They are fundamental tools to direct investments towards sustainable projects and activities. However, each ESG rating agency has its own definitions, criteria and methodologies for the selection of the sustainable business portfolio, each not directly comparable with the other, which includes a set of indicators capable to measure sustainability. A shared understanding of what "sustainability" means is compelling. As a contribution in this direction, in the present paper we report ongoing work on the definition of a Knowledge Graph of some of the ESG indicators existing in the Literature. Links in the Knowledge Graph express semantically rich information including mathematical relations among indicators. We discuss the advantages for sharing, communication and comparison of this approach as well as open research issues.

Keywords
performance indicators, ESG, sustainability, knowledge graph, ontology

1. Introduction

Sustainability and resilience are central to the European political agenda. The Next Generation EU financial instrument places issues such as equitable climate and digital transitions and the fight against climate change at the centre of the European recovery strategy. Among recent research topics, that of Industry 5.0 is guided by the vision by which "in order to remain the engine of prosperity, industry must lead the digital and green transitions" fostering "a vision of industry that aims beyond efficiency and productivity as the sole goals, and reinforces the role and the contribution of industry to society" in the belief that "Industries can play an active role in providing solutions to challenges society including the preservation of resources, climate change and social stability"[1]. Public funds cannot by themselves support an economic revolution that is estimated in about 180 billion euros per year[2], and the role of finance is crucial to direct economic activities towards, and sustain the financial risk of, a green transition. However a shared notion of what it means to be "sustainable" and how to measure "sustainability" is necessary. Quoting

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[1] https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en

[2] https://www.consilium.europa.eu/en/press/press-releases/2020/04/15/sustainable-finance-council-adopts-a-unified-eu-classification-system

from EU: "In order to meet the EU's climate and energy targets for 2030 and reach the objectives of the European green deal, it is vital that we direct investments towards sustainable projects and activities. [...] To achieve this, a common language and a clear definition of what is *sustainable* is needed. This is why the action plan on financing sustainable growth called for the creation of a common classification system for sustainable economic activities, or an *EU taxonomy*[3]". The taxonomy was to come into effect in December 2021, but at present the process is still ongoing, slowed down by the lack of agreement among the different stakeholders. In the quest of shared criteria, Environmental, Social, and Corporate Governance (ESG) indicators have been introduced by organizations like the German Investment Professional Association (DVFA)[4] as early as 2008, to quantitatively measure sustainability. They received the endorsement of the European Federation of Financial Analysts Societies (EFFAS)[5], thus gaining the status of an official EFFAS Standard [1]. The Global Reporting Initiative (GRI)[6] has developed a set of widely accepted standards for sustainability reporting [2]. Other frameworks and standards have been developed by SASB[7], TCFD[8], CDSB[9] among others, each not easily comparable with the other, and efforts are underway towards homogenization and harmonization [3, 4]

In the present paper, we report on an ongoing work contributing to a common understanding of "sustainability" and integration of ESG indicators into a unique Knowledge Graph that can act as a semantic substrate. Links in the Knowledge Graph express semantically rich information including mathematical relations among indicators, that can be exploited to support their sharing, communication and comparison. In Section 2 we report relevant related work on semantic models for indicators and frameworks for ESG indicators. We describe the preliminary survey and analysis of ESG standards [1, 2] in Section 3, and their modeling as a Linked Open Dataset in Section 4. In Section 5 we then discuss some insights from the work done and discuss open research issues in Section 6.

2. Related work

Semantic modeling of indicators through shared vocabularies or ontologies emerged in recent years as an effective way to define measures through a precise, unambiguous representation.

A variety of approaches for semantic representations of indicators have been proposed in the Literature, for documentation of indicators and their sharing, or with the goal to simplify and support design and analysis of multidimensional data cubes or statistical datasets. In some cases, indicators are directly used to design a monitoring framework like in [5]. In such a work, an ontology is proposed for definition of Process Performance Indicators (PPIs) making the relationship between an indicator and a process explicit and thus supporting design-time analysis of process performance.

[3]https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en
[4]https://www.dvfa.de/dvfa.html
[5]https://effas.com
[6]https://globalreporting.org
[7]https://www.sasb.org
[8]https://www.fsb-tcfd.org
[9]https://www.cdsb.net/

Most work focuses on definition of atomic indicators, with little or no representation of their calculation formulas. Some exceptions include a formula representation with limited support to manipulation, that is mostly performed through ad-hoc software modules [6],[7].

Few contributions include a formal notion of dependency among indicators, e.g. in [8] where relations among indicators are represented by logical predicates. In such a work, organization goals are tied to performance indicators and reasoning is performed to check consistency of goal structures when designing a new organization structure. These approaches are often exploited also to support the organisation as well as the reuse, exchange and alignment of business knowledge on indicators. A more recent example is [9] where an OWL ontology and SWRL rules are developed for reasoning on KPIs, with the goal to support selection and analysis of indicators and detect inconsistencies.

For what concerns semantic-based formats and standards for representation of indicators, the Statistical Core Vocabulary (SCOVO) was one of the first proposals for the publication of statistical datasets on the web as RDF. It included a minimal set of classes that however could not fully support multidimensional modeling. Such a vocabulary was then superseded in 2013 by the Data Cube vocabulary (QB), a W3C Recommendation allowing to publish statistical data following the Linked Data principles, and capable to model the schema of a cube as a set of dimensions, attributes, and measures. QB enables the definition and the sharing of a statistical dataset as a multidimensional cube, but a number of issues remained open, in that it does not provide means to represent hierarchical relations between dimension levels and dimension members, and lacks a controlled vocabulary for measures. Some proposals elaborated on this standard to include further functionalities, e.g. to support OLAP operations on QB (e.g. [10], [11]) and fully represent OLAP cubes in RDF as in QB4OLAP [12]. Our previous work on the KPIOnto ontology, as discussed in the next section, was on the other hand driven by the goal to extend Data Cube towards a formal representation of calculation expressions for indicators, that is required to guarantee meaningful comparisons.

We report also on recent proposals for semantic frameworks aimed to represent ESG indicators. The SDG Interface Ontology (SDGIO) [13], focuses on the formal specification and representation of Sustainable Development Goals (SDGs) defined by the United Nations. The framework represents key entities involved in the SDG process, linking them with the goals, targets, and indicators. It integrates several existing ontologies, applying best practices in ontology development from mature work of the Open Biological and Biomedical Ontology (OBO) Foundry and Library. The SDG KOS [14] defines a formal knowledge organization system, based on SKOS and developed for representing the SDGs, with the purpose to enable data publishing using common terminologies. Unlike our proposal, the framework is focused on United Nations indicators only, without considering multiple standards and their integration, and for a different purpose and abstraction level, namely supporting global measuring of sustainability goals. Furthermore, with respect to our proposals, indicators in SDG include neither a formal representation of the calculation formula nor a detailed characterization, e.g. in terms of unit of measurement, dimensions of analysis, aggregation functions.

3. Analysis of ESG Standards

ESG has become synonym of sustainability, and criteria aimed at measuring and controlling the sustainability of business's activities can be decomposed along these three dimensions. Environmental criteria focus on the impact of the business on environment. Social criteria assess the impact on the community with which a business interacts, like people, employees, other companies in the value chain. Finally, criteria related to governance aim at assessing how much ethics and good practices drive the management of business, considering equity or transparency of decisions among others. In this work we started the analysis of two of the existing standards, the DFVA-EFFAS standard [1] and the GRI standard. [2]. The former has been one the first standardization attempts and has laid down the basis to develop standard procedures and criteria for the integration of ESG data into business reporting, while the latter is one of the most widely adopted standards.

The DFVA-EFFAS Standard

One of the first attempts to define a guideline for the inclusion of ESG criteria in company evaluation is the work done by DVFA, subsequently adopted by EFFAS and described in [1]. The document points out a minimum set of metrics, or Performance Indicators (PI or KPI), that should be adopted by companies. At the core of PI definition, there are some principles that can be synthesized as follows: (1) correlation between metrics and companies risk/success factors; (2) significance for investment decisions; (3) quantifiability and comparability.

Environment, Social and Governance are considered as different segments of the general sustainability problem. In addition, a fourth area called LongTerm Viability (identified by the letter V) is defined, that represents the ability of a company to produce long-term profits without sacrificing resources or skills in the short term. Indicators used to quantify and report on companies sustainability are organized according to an ESGV taxonomy that organizes KPIs in General (i.e. applicable to any industrial sector) and sector-specific ESGs topics for each area. Table 1 shows an excerpt of General indicators.

For each indicator a specification is given, shown in Table 2 for indicators ESG 2-1 and ESG 2-2. The specification remains at a very abstract and informal level. Note that indicator ESG 2-2 is in fact a set of specific indicators differing in practice for the normalization factor. Sometimes the normalization procedure is reported, e.g. for the industrial specific ESG 11 NO, SO Emissions, the Unit/Calculation is specified as "Total NO,SO Emissions/total passenger-km" but in general calculation rules are not reported, not even in a descriptive way. Furthermore, it is unclear the relation existing between ESG 2-2 and ESG 11 (i.e., are NO and SO greenhouse gases?)

The standard has undergone through several revisions up to 3.0 [15], including changes to KPI identifiers, organization of KPIs in a taxonomy, introduction of new KPIs.

The GRI Standard

The GRI Standard is a system of interrelated documents organized into three series: GRI Universal Standards, GRI Sector Standards, and GRI Topic Standards for a total of 37 documents (2021 edition). The first two contain guidelines on how to report information about the impact of a company on the economy, environment, and people, including human rights. The Topic

Area	ESG	Indicator
E	ESG 1 Energy efficiency	ESG 1-1 Energy conpsumption, total ESG 1-2 Energy consumption, specific (intensity)
	ESG 2 GHG emissions	ESG 2-1 GHG emissions, total ESG 2-2 GHG emissions, specific
S	ESG 3 Staff Turnover	ESG 3-1 Percentage of employees leaving p.a./total employees
	ESG 4 Training & qualification	ESG 4-1 Percentage of trained employees p.a./total employees ESG 4-2 Average expenses on training per employee p.a
	ESG 5 Maturity of workforce	ESG 5-1 Age structure/distribution (number of employees per age group, 10 year intervals) ESG 5-2 Percentage of workforce to retire in next 5 years
	ESG 6 Absenteeism rate	ESG 6-1 Number of mandays lost per employee p.a.
G	ESG 7 Litigation risks	ESG 7-1 Expenses and fines on filings, law suits related to anti-competitive behavior, anti-trust and monopoly practices ESG 7-2 Reserves on preventive measurements against anti-competitive behaviour, anti-trust and monopoly practices ESG 7-3 (other) litigation payments, total ESG 7-4 (other) litigation payments, reserves
	ESG 8 Corruption	ESG 8-1 Percentage of revenues in regions with TI corruption index below 6.0
V	ESG 9 Revenues from new products	ESG 9-1 Percentage of revenues from products at end of life-cycle ESG 9-2 Percentage of new products or modified products introduced less than 12 months ago

Table 1
DVSA-EFFRA: Overview of General ESGs and their PIs.

ESG	ESG 2 GHG emissions		
Description	Greenhouse gas emissions are the main cause of climate change. This Indicator can be used to explain targets for regulations or trading systems at international or national levels. It also provides insights into the potential cost implications of taxation or trading systems for reporting companies.		
KPI	ESG 2-1	ESG 2-2	ESG 2-2
Description	GHG emissions Total	GHG emissions per unit of production volume	GHG emissions per employee
Shortname	GHG.emiss.total	GHG.emiss.production	GHG.emiss.employee
Unit/Calc.	Total GHG Emissions in Million tons	Total GHG Emissions in Million tons	Total GHG Emissions in Million tons
Format	xxx,xxx,xxx.xx MtGHG	xxx,xxx,xxx.xx MtGHG	xxx,xxx,xxx.xx MtGHG
Sector	All	All	All

Table 2
DVFA-EFFAS: Specification of PI ESG 2-1.

standards are those of interest for the purpose of this work, containing each a set of indicators for a specific so-called *material topic*, ranging from economic and financial performance, to the usage and production of materials and resources. An explicit taxonomy does not exists, although the subdivision in documents reflect some form of organization of indicators, as well as reference to general ESG areas. For instance, the standard GRI 305 - Emissions provides 7 indicators: Direct GHG emissions; Energy indirect GHG emissions; Other indirect GHG emissions; GHG emissions intensity; Reduction of GHG emissions; Emissions of Ozone-Depleting Substances (ODS); Nitrogen oxides (NOx), sulfur oxides (SOx), and other significant air emissions. For each indicator a guideline for the calculus is provided by a mathematical expression or, more often, as a textual description. For instance, in the case of GHG emissions intensity:

> Calculate the ratio by dividing the absolute GHG emissions (the numerator) by the organization-specific metric (the denominator).

Gases included in the calculation; whether $CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3$, or all.
The list of organization-specific metrics include: units of product; size, number of full-time employees, monetary units.

The standard also provides other recommendations for the calculation, like the breakdown of the indicator by business, country or type of activity, or the unit of measure.

From this brief analysis it should be clear the difficulty to precisely make sense of these informal specifications and translate them in an actual procedure for the calculation of the indicators. As a result different companies, or the same company in different times, may easily interpret and implement them differently, with outcomes hardly comparable.

4. Ontology model for ESG

The Knowledge Graph has been defined by referring to the KPIOnto ontology [16], which provides terminology for definition of an indicator and its properties, including a description (*KPIDescription*), the unit of measurement (*unitOfMeasure*), its objective (*hasBusObj*), the aggregation function (*aggrType)*, the compatible dimensions of analysis (*hasDimension*), and its computation formula if available (*hasFormula)*.[10] The ontology has been extended with a further set of domain-oriented object properties, classes and instances, to specify the link between an indicator and the ESG class it refers to (*forESGClass*), the standard in which it is defined (*inESGStandard*) and the official name used in such a standard (*hasESGCodeName*).

To make an example, the following triples define the indicator “ESG 2-2 GHG emissions, total”. It is an Environmental KPI, measured in million of tons, that can be aggregated through sum and can be analysed along the Time dimension. The prefix *kpi* refers to KPIOnto, while prefix *esgo* refers to the ESG extension and *esg* stands is used for definition of indicators.

```
esg:GHG_Emiss_Tot a kpi:Indicator;
  kpi:KPIDescription "GHG Emissions, total"@en;
  esgo:hasESGDescription [
        esgo:forESGClass esgo:GHG_Emissions;
        esgo:inESGStandard esgo:DVFA_EFFAS;
        esgo:hasESGCodename "ESG 2-1" ], [
        esgo:forESGClass esgo:GHG_Emissions;
        esgo:inESGStandard esgo:GRI;
        esgo:hasESGCodename "GRI 305-1" ];
  kpi:unitOfMeasure esgo:MLNtons;
  kpi:hasBusObj esgo:Environmental;
  kpi:aggrType kpi:Sum;
  kpi:hasDimension esgo:Time;
  kpi:hasFormula [
        kpi:hasFunction om:plus;
        kpi:hasArgument [
        kpi:hasArgumentPosition "1"^^xsd:int ; kpi:hasArgumentName "addend" ;
        kpi:hasArgumentValue esg:Tot_CO2 ],
        .........].
```

[10] Ontology specification is available at https://kdmg.dii.univpm.it/kpionto/specification/

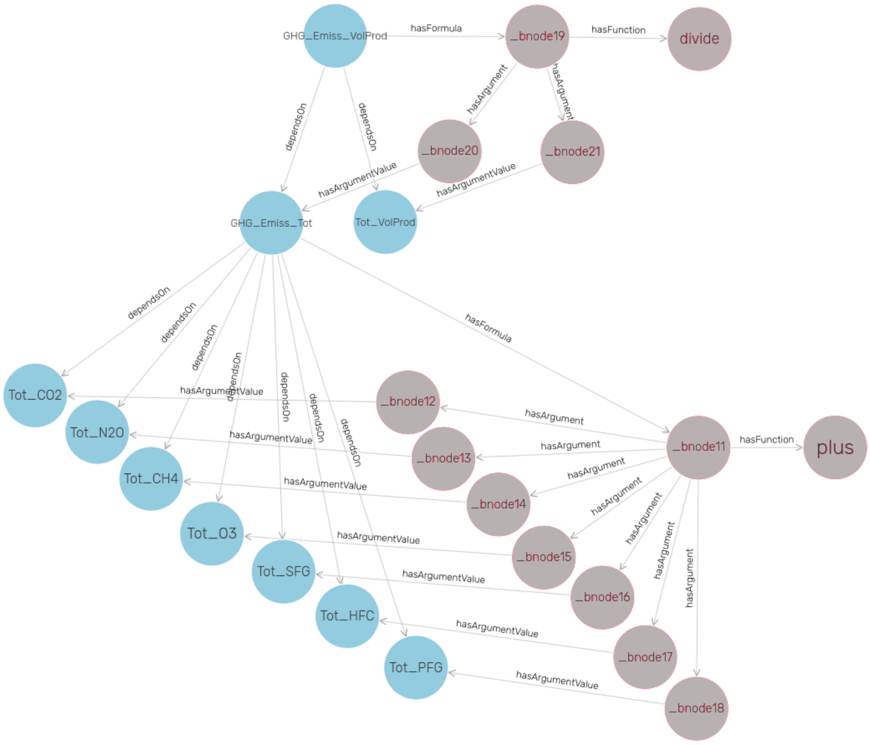

Figure 1: Graph representing some relevant classes and properties describing a formula for *GHG_Emiss_VolProd* indicator. The direct links among indicators (blue nodes) correspond to inferred relations of type `dependsOn`.

Whenever a computation formula is available, it is represented as a mathematical expression including arguments and operator(s). The formula can be derived from the GRI Standard as the summation of several pollutants, and is only partially reported due to the lack of space. The following triples define the complete formula for indicator "ESG 2-2 GHG emission per unit of production volume", that can be calculated by dividing the total GHG emissions by the total volume of production. The fragment of the Knowledge Graph representing the above-defined formulas is shown in Figure 1.

```
esg:GHG_Emiss_VolProd kpi:hasFormula [
    kpi:hasFunction om:divide;
    kpi:hasArgument
        [ kpi:hasArgumentPosition "1"^^xsd:int ; kpi:hasArgumentName "dividend" ;
          kpi:hasArgumentValue esg:GHG_Emiss_Tot],
        [ kpi:hasArgumentPosition "2"^^xsd:int ; kpi:hasArgumentName "divisor" ;
          kpi:hasArgumentValue esg:Tot_VolProd ]
        ].
```

The Knowledge Graph contains the definition of 150 indicators, including all 125 indicators from DVSA_EFFRA standard, along with a selected set of indicators from GRI. A number of 57 indicators are compound and their calculation formulas have been defined. It was implemented

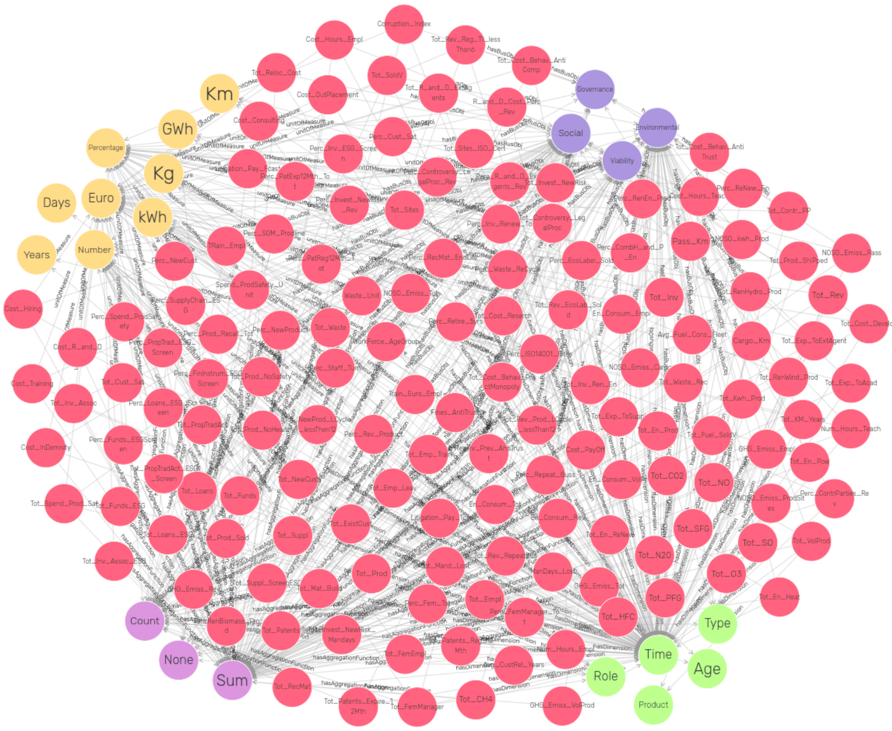

Figure 2: A subset of the Knowledge Graph of ESG indicators (red), with units of measurement (yellow), dimensions (green), aggregation functions (pink) and objectives (violet).

as a RDF graph in GraphDB, which provides standard SPARQL-based access mechanisms. A fragment of the resulting Knowledge Graph is shown in Figure 2.

5. Reasoning-based Applications

The Knowledge Graph representation brings a number of advantages: first of all it provides a formal description of the informal specifications contained in the standards. This often requires to make the meaning of those specifications explicit, and thus should be checked against the original intended meaning of author's standards, but again the formal representation can simplify the browsing and verification of definitions. Browsing can support also final users when they need to get acquainted with standards, e.g. by supporting to analyse formula-based relations among indicators, as well as by applying formula drill-down, since simple unfolding mechanisms allow to decompose a KPI into its components [17]. It can be adopted as the enterprise reference vocabulary in a supply chain to deal with interoperability of their ESG data and reporting. Ultimately, if the Knowledge Graph is certified by standardization bodies, it can become an invaluable tool for companies and financial institutions to certificate and compare ESG disclosures.

Besides advantages simply related to the existence of a reference model, reasoning mechanisms can be developed on the Knowledge Graph to define flexible and powerful tools for interoperable ESG management. They rely on a set of logic-based functionalities, which also includes math-aware services in Logic Programming to provide non-standard reasoning capabilities[16]:

- Automated calculation of Performance Indicators is provided by reasoning services. Composition of indicators in formulas, based on the semantics of mathematical operators, in fact enables their automatic manipulation through symbolic resolution of equations. Such services are capable to derive all alternative formulas for a given indicator (*get_formulas*), to evaluate the common set of dependencies among a set of indicators (*get_common_dependencies*), or to derive what indicators can be computed starting from those already available (*get_computable_indicators*).
- On top of the reasoning services, advanced functionalities can be defined with the purpose to support monitoring of indicators across multiple organizations. This may be particularly useful for cooperating organizations to assess the status of shared Business Processes. The set of KPIs produced by the organizations is compared in order to derive, through the exploitation of *get_common_dependencies* and *get_computable_indicators*, common indicators among them. They include not only indicators that are mapped to the same ontological concepts, but also indicators that can be calculated from those available.
- Management of the graph, including the creation of new indicators or the maintenance of their definitions rely on consistency check mechanisms. They are capable to verify that a new indicator is neither equivalent to nor incoherent with already defined ones. While *equivalence_check* may help to perform de-duplication of indicators to minimize redundancy, the guarantee given by *coherence_check* is critical to keep the graph consistent by avoiding contradictory definitions [16].

6. Discussion

From the analysis of standards it emerges a profound heterogeneity in the format, structure, terminology adopted in the definition of indicators, and in the approach to their categorization. This is widely recognized as a limit to the development of actions towards a green transition, as discussed in the Introduction. In this respect, semantic technologies can and should provide support to efforts towards homogenization and harmonization. The present paper provides a contribution in this direction, starting from the construction of a Knowledge Graph for the modeling of ESG indicators. This sometimes required a hard work of interpretation of underspecified definitions, that could be not correct or shared by standardization bodies. We believe that the formal representation produced would ease a possible verification and dialogue with stakeholders.

The inherent modularity and flexibility of a graph structure, combined with the ability to represent and reason on the compound nature of indicators, has demonstrated to be suitable to tackle the challenge in an incremental way, checking time by time the coherence of the overall graph.

Still, several open issues exist that are not covered in this preliminary proposal and represent interesting research directions:

- while the expressivity of the model has demonstrated itself sufficient to represent the ESG indicators structure (formula), some information contained in the standards still remains uncovered. It is mainly related to the semantics of atomic indicators that, despite being atomic, often have an underline calculation procedure not falling in the formula category. As an example, "processed orders" can be defined as a subclass of orders, but besides requiring to resort to domain ontologies, which is certainly possible, it is purely terminological and does not solve the ultimate challenge of providing the *interpretation*. A step towards the implementation of effective tools for the calculation and certification of indicators would require a data integration system and GAV/LAV mappings as a means to directly refer to data in business's information systems that correspond to an atomic indicator.
- There is evidence of specifications at different abstraction levels in the standards. For sure the standard cannot cover the lowest enterprise level. This suggest that the model should be extended to explicitly deal with and support abstraction management.
- Localization issues: there is evidence of different implementations of the standards, for instance the GRI standard is provided in several languages, with different names for indicators. This issue can be addressed by referring to best practices for multilingual ontologies, ranging from simple design patterns such as referring to textual labels for the indicator name/description with an attached language tag, to more complex patterns such as language content negotiation. However, other more tricky localization issues exist, related to the definition of the indicator's formula, for instance due to differences in country's constraints and regulations (e.g. the definition of employee and its categories, the components of a salary)
- Standards are "living bodies" subject to revision. Hence the model should be endowed with the capability to support changes and versioning.
- The graph model simplifies the integration of different standards, however instead of adopting this view, an alternative approach towards interoperability of standards can be pursued. This implies the modeling of each standard as a distinct Knowledge Graph with its own categorizations and definitions, building relations between graphs' concepts. Interoperability would correspond to more flexibility and simplicity in the management of standards than a design-time integration of the different views provided by the standard. Organizations may disclose their ESG indicators following the preferred standards, and suitable reasoning over the Knowledge Graphs would still provide proper translations and correspondences. In this direction, the model easily supports the derivation of the equivalence of compound indicators provided that "same-as"relations are established among atomic indicators in different Knowledge Graphs. This reduces the cost of a manual alignment or of generating large shared vocabularies of indicators terms, at the same time improving the quality with respect to simple terminological similarity techniques.

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