RESEARCH-ARTICLE

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This article addresses the complex challenges that public organizations face in designing, implementing, and evaluating their strategies, where public interest and regulatory compliance often intertwine with strategic objectives. This research investigates the application of ontologies in the field of public sector strategy management to enhance the capacity of organizations to make informed data-driven decisions, efficiently allocate resources, and effectively navigate the intricate landscape of the public sector. The LNEC - National Laboratory for Civil Engineering's strategy is used as an exploratory case study. Semantic web technologies are used to perform strategy analysis, including validating the strategy formulation and supporting the strategy execution by assessing performance indicators, verifying the design of cause-and-effect relationships between strategic objectives, and monitoring and empirically validating these relationships. The increased interoperability of these technologies enables information sharing across systems and organizations. Following the strategy analysis, recommendations are provided, leading to a more robust and data-driven strategic management approach, enabling accurate, traceable, and continuous monitoring of an organization's strategy. Theoretical and practical implications are discussed, along with limitations and future work. This research offers a blueprint for public sector organizations seeking to optimize their strategies, foster transparency, and deliver more effective services to the public they serve.

CCS Concepts: • **Information systems → Decision support systems**; **Semantic web description languages;**

Additional Key Words and Phrases: Strategy Analysis, Public Sector, Semantic Web, Balanced Scorecard, Ontology

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1 INTRODUCTION

Strategic management is a process undertaken by public organizations or other entities to formulate, implement, and evaluate strategies to achieve their long-term objectives and goals [3]. The importance of strategy validation and analysis in the public sector cannot be neglected, as it directly impacts public value, due to the nature of their mission. Organizational performance is significantly impacted by strategic planning in both private and public sectors and can be enhanced by the formalization of the strategic planning process [11]. However, most

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public organizations typically use strategic management systems with low comprehensiveness or formality and are usually decentralized [4].

Král [29] defines performance management as "*a strategic approach to management that provides managers, employees, and owners with the tools and techniques that they then use to plan, monitor, measure, and evaluate the performance of an organization.*" In public administration, the **Balanced Scorecard (BSC)** [22] still remains the most well-known approach to assess performance, due to the balance between non-financial and financial indicators across different perspectives [29, 43]. However, Manes-Rossi et al. [32] only found that 8% of the works in their literature review explore non-financial reporting from a strategy management perspective in the public sector. Furthermore, Král [29] identifies research directions in this field, including continued performance evaluation, use of official quantitative data, and clear and understandable (to policymakers, managers, and stakeholders) performance management systems. Moreover, the author defends that, when performance evaluation methods become overly complex, they often become less practical and less likely to be effectively applied in real-world situations. Sharing this concern, Tawse and Tabesh [43] state that "*the BSC has the potential to improve organizational performance, but to realize that potential it must be effectively implemented.*" The authors provide three recommendations: (1) develop a strategy map to ensure that BSC elements are related with cause-and-effect relationships, (2) ensure top management team commitment and support, and (3) improve key stakeholder engagement.

Semantic Web (SW) technologies, such as ontologies, have been used during the last years to encode knowledge in a way that allows it to be shared, be reused, and, most importantly, become machine-readable [16]. Kalampokis et al. [18] present these technologies as one of the emerging technologies in the public sector, highlighting the advantages of their usage, specifically the shared semantics and interoperability. Ontologies can be used to create a common semantic data model that can be useful to define unified report methods (beneficial for both reporters and readers) [15, 32], integrate or transfer data between public organizations [18], and automate processes using the formalization of knowledge from heterogeneous sources [17]. SW technologies have also been used to foster openness and transparency in the public sector [33]. Pucihar et al. [37] identified ontologies and SW as highly relevant research topics necessary for a holistic and dynamic government, with ontologies being used to improve interoperability and user experience in e-government services [24–28].

This article explores how public organizations, such as the **National Laboratory for Civil Engineering (LNEC)** in Portugal, can employ ontologies to assess their strategy formulation and execution. Furthermore, it investigates how ontologies can assist in the validation of the formulated strategy, evaluation of performance indicators, and validation of cause-and-effect relationships between strategic objectives. In doing so, this research aims to provide tools to enhance the capacity of organizations to make informed data-driven decisions, efficiently allocate resources, and effectively navigate the intricate landscape of the public sector. Understanding the nuances of strategy validation and analysis in this context, where objectives often intertwine with public interest and regulatory compliance, presents a complex challenge to which this article contributes.

This research aims to improve the body of knowledge of public sector strategy management through the use of SW technologies. Additionally, this research can potentially be used to inform public data-driven decision-making and policy definition, in line with what happened during Covid regarding public health policies [15].

The remainder of the article is structured as follows: Section 2 presents background research concerning ontologies and the BSC framework and introduces the **Balanced Scorecard Ontology (BSO)** used in this research. The methodology followed in this research is shown in Section 3. The case study, LNEC, is presented in Section 4, together with its current strategy formulation. Section 5 describes the ontology population process, explaining the mapping between LNEC's strategy and the BSO. Section 6 presents the use of BSO and other semantic technologies to validate and infer over the strategy, followed by strategy analysis, including a set of recommendations, in Section 7; Section 8 encompasses the discussion, which includes theoretical and practical contributions, limitations, and avenues for future work. Finally, Section 9 presents the conclusions.

2 BACKGROUND

This section presents background concepts related to ontologies and the balanced scorecard framework.

2.1 Ontologies

Ontologies are formal and explicit specifications of shared conceptualizations [40], used to represent knowledge pertaining to a specific domain of interest, encompassing its concepts, properties, and relationships. The purpose of ontologies is to facilitate the sharing, reuse, and analysis of knowledge, ultimately promoting interoperability and heterogeneity [35]. According to the **World Wide Web Consortium (W3C)**,[1] these qualities make ontologies an indispensable component of the SW. When populated with individual instances, an ontology is called a Knowledge Base [13].

The **Resource Description Framework (RDF)** is a W3C recommendation designed to enable the creation, exchange, and utilization of web annotations. In RDF, resources are described using triples in the form of *<subject, property, object>* [36]. SPARQL is a W3C query language for querying and manipulating data stored in RDF format, commonly used for querying SW data and knowledge graphs. The W3C **RDF Schema (RDFS)** provides a vocabulary for RDF introducing the concepts of classes and hierarchies. Building on RDFS, the **Ontology Web Language (OWL)** enhances expressiveness by incorporating elements such as disjointness, cardinality, object and data properties, and additional vocabulary. OWL comes in three sublanguages/types: Lite, DL, and Full, each offering varying levels of expressiveness. The choice of an OWL sublanguage depends on the specific problem domain and modeling requirements, with a tradeoff between expressiveness and inference capabilities (reasoning) [41].

2.2 Balanced Scorecard

The BSC model was presented in 1992 by Kaplan and Norton as a system for measuring an organization's performance [22]. Over the years, the BSC has evolved from a performance measurement tool to a strategic management system. Kaplan and Norton emphasized the importance of using the BSC to align the organization's strategy with its performance measures and to drive continuous improvement [19]. Further, the authors introduced the concept of strategy maps, a visual representation of the strategic objectives and the respective cause-and-effect relationships, helping organizations to better understand how their objectives are interconnected and how they can best allocate resources to achieve their goals [23]. The BSC is usually divided into four perspectives: financial, customers, internal processes, and learning and growth. The BSC is "*agnostic to the formulation model used*" [20], meaning that any business strategy formulation can be executed and communicated utilizing the BSC and its elements.

Today, the BSC is seen as a system for communicating and executing strategy [21, 30, 43], which includes elements such as the organization's mission, values, and vision statements; perspectives; strategic themes; strategic objectives; and **Key Performance Indicators (KPIs)** to measure the objectives, targets, and initiatives (projects that need to be executed to achieve the targets). The BSC has been successfully applied in many industries, including Higher Education [6, 8], Healthcare [2, 39, 44], and Tourism [9], improving organizational performance, enhancing strategic alignment, and facilitating communication and coordination across different departments and organizational levels. The BSC is also being used to promote sustainability and corporate social responsibility [10, 14]. Finally, combining the BSC with other systems and tools can lead to a more effective strategy formulation and implementation and improved decision-making [30, 42].

2.3 Balanced Scorecard Ontology

The BSO was developed to describe and store knowledge related to the BSC framework [31], including the strategy map, which presents the long-term strategy, and several quantification frameworks providing a short-term

[1] https://www.w3.org/

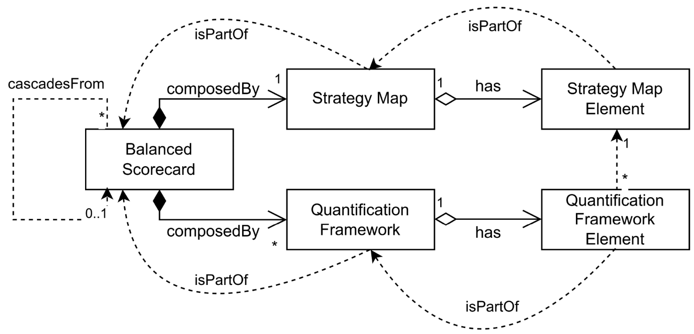

Fig. 1. Balanced Scorecard Ontology concepts.

view of the strategy execution (see Figure 1). The BSO allows any organization to formalize, communicate, align, and execute its BSC-based strategy. The ontology also allows for strategy validation (e.g., ensuring every strategic objective has a performance indicator) and can improve interoperability between performance management systems and the strategy formulation.

A BSC should be defined or cascaded across various organizational levels, enabling managers to formulate corporate, departmental, team, and individual strategies (aligned with the employees' incentive systems). Information requirements vary, as does the granularity (or summarization) of performance indicators and data. In essence, a BSC represents the aggregation of all defined BSCs, starting from the corporate level and cascading down to the lowest organizational level.

Two major components are needed to define a BSC at any strategic level: a Strategy Map and a Quantification Framework, as shown in Figure 1. A Strategy Map presents the long-term view of the strategy, typically including the following elements: strategy statement elements (i.e., vision, mission, and values), strategic objectives, perspectives, and themes. The Quantification Framework offers a shorter-term view containing the tangible indicators, goals, and initiatives needed to translate the strategy into operational terms. The BSO represents and provides information, formalizing these elements as classes (see Figure 2), while the relationships between these elements and their attributes are represented by object and data relationships, respectively. This formalization enables inference on BSC elements and the relationships between these elements (e.g., cause-and-effect relationships between objectives). In addition to the BSC, its components, and elements, the BSO also contains information related to actual values of Performance Indicators, which store corresponding values related to a particular time frame.

3 METHODOLOGY

To explore and evaluate how ontologies can be employed to formulate, validate, and ensure the effectiveness of strategies within public organizations, an exploratory case study based on a public organization was used. This case study used the recently developed BSO to overcome the complex challenges of strategy validation and analysis in the public sector. Lorvão Antunes et al. [31] present the design and development process of the BSO, including the demonstration and evaluation phases based on a real case study of a public faculty library. The current research aims to demonstrate the advantages and impact of SW technologies, specifically the BSO, in strategy management. Figure 3 presents the methodology used, which has the following starting points (inputs):

— **Balanced Scorecard Ontology.** In previous work [31], the BSO was designed and developed to describe and store knowledge related to the BSC framework (see Section 2.3). This formal, structured, and semantically rich representation of the BSC framework ensures consistency in how strategic objectives, performance indicators, and their relationships are defined and interpreted and provides decision-makers with a shared and unambiguous understanding of the BSC components and elements.

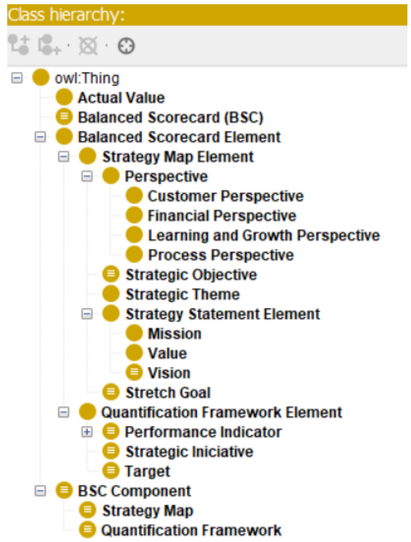

Fig. 2. Balanced Scorecard Ontology class hierarchy in Protégé (https://protege.stanford.edu/).

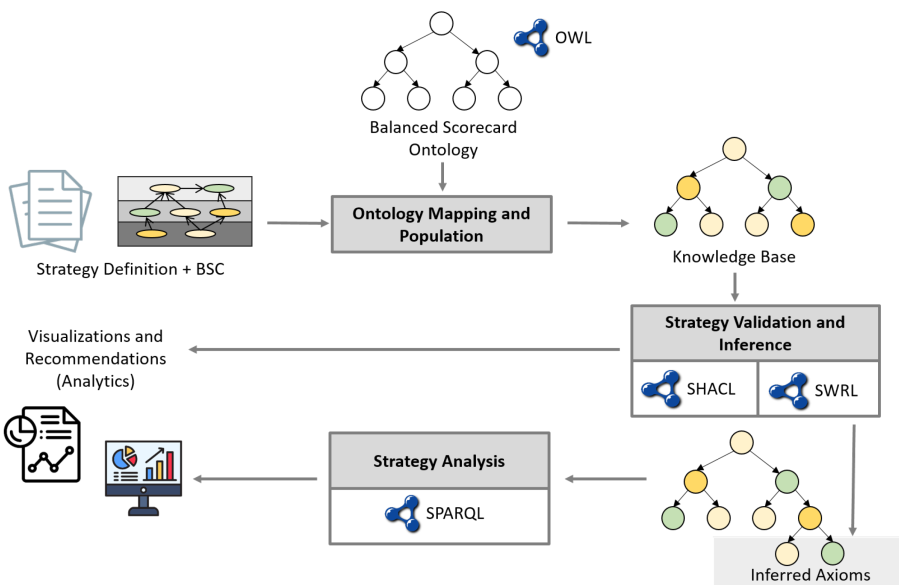

Fig. 3. Research methodology.

— **Strategy Definition and BSC.** The proposed research uses a real public sector case study to provide insights into the impact of semantic technologies in strategy management. A Portuguese public organization (LNEC) is used (see Section 4), having a current strategy recently defined using the BSC framework, allowing it to be represented and analyzed using the BSO.

The remainder of the methodology outlines the tasks that organizations must undertake to use ontologies in the assessment of their strategy formulation and execution. The output of each action can be used to provide managers and stakeholders with information, presented as recommendations (e.g., warnings, errors) and/or visualizations, for example, enabling ontology-driven strategic analysis.

- **Ontology Mapping and Population.** This process is responsible for creating a BSO knowledge base, i.e., an instantiation of the BSO containing the case study's strategy data. Prior to the ontology population, the strategy definition and the BSC need to be analyzed and mapped to BSO entities, and import rules must be created. Section 5 presents the mapping and population process of LNEC's strategy.
- **Strategy Validation and Inference.** Once the knowledge base is obtained, the strategy can be validated. Besides OWL constraints, the SW framework provides other technologies, such as SHACL and SWRL (see Section 6) that are used to validate and infer ontological knowledge. This process is responsible for the detection of errors and warnings related to the BSC's implementation and for obtaining new knowledge related to the strategy and its execution, through a set of logical rules.
- **Strategy Analysis.** Lastly, this methodology defines a set of SPARQL queries that enable the validation of the formulated strategy, evaluation of performance indicators, and validation of cause-and-effect relationships between strategic objectives. The results of these queries can be used by external applications to provide managers and other decision-makers with visualizations and recommendations regarding strategies and their executions.

4 LNEC: A CASE STUDY IN THE PUBLIC SECTOR

The National Laboratory for Civil Engineering (LNEC) in Portugal was established in 1946 to provide specialized services in civil engineering. As a public laboratory, it has been involved in national projects (e.g., dams, communication routes, river and sea hydraulics, and large structures) and international collaborations, performing scientific and technical works in almost 50 countries. Over the years, LNEC expanded its competencies, becoming a hub for research, experimentation, postgraduate education, and community/local services. LNEC underwent several changes in its organizational structure and legal framework, with the most recent reorganization in 2012 and 2013 resulting in improved autonomy in scientific, administrative, and financial matters. In 2021, a BSC approach was used to formulate the strategy for 2021–2027.

As a public institute, LNEC must follow a set of regulations and practices, namely those presented in its organic law and mission letter. Furthermore, LNEC has the duty and responsibility to report on its activities and performance, publishing annual activity plans that include, among other things, evaluations of the objectives and indicators of the **Evaluation and Accountability Framework (QUAR)**. QUAR is a mandatory framework for assessing and monitoring the performance of Portuguese public services,[2] ensuring alignment with strategic objectives, legal requirements, and user satisfaction, while also promoting transparency through public disclosure. QUAR includes various components such as the service's strategic statements (mission and vision), strategic objectives, operational objectives, indicators, targets, and results achieved. It should be noted that strategic objectives, as defined by QUAR, are not quantifiable. Operational objectives must be divided into the following categories: effectiveness, efficiency, and quality. Moreover, operational objectives are measured with a set of weighted indicators, grouped by these categories, which in turn are also weighted to provide an overall organizational performance score.[3]

4.1 LNEC Strategy for 2021–2027

A BSC approach was used to define LNEC's strategy for 2021–2027, including the definition of strategic objectives and indicators used to monitor its execution. The approved strategy map is presented in Barateiro et al.

[2]Article 10, Portuguese Law n.º 66-B/2007, from December 28, 2007.
[3]LNEC QUAR definition for 2023 can be found in Annex III of the activity plan report, available at https://www.lnec.pt/pt/downloads/download.php?id=1037 (in Portuguese).

Table 1. LNEC's Mission, Values, and Vision Statements [1]

Strategy Statement	Description
Mission	LNEC's mission is to undertake, coordinate, and promote scientific research and technological development, aiming for the continuous improvement and the good practice of civil engineering
Values	Excellence; Impartiality; Rigor; Responsibility
Vision	To be a reference in the various fields of civil engineering and related areas

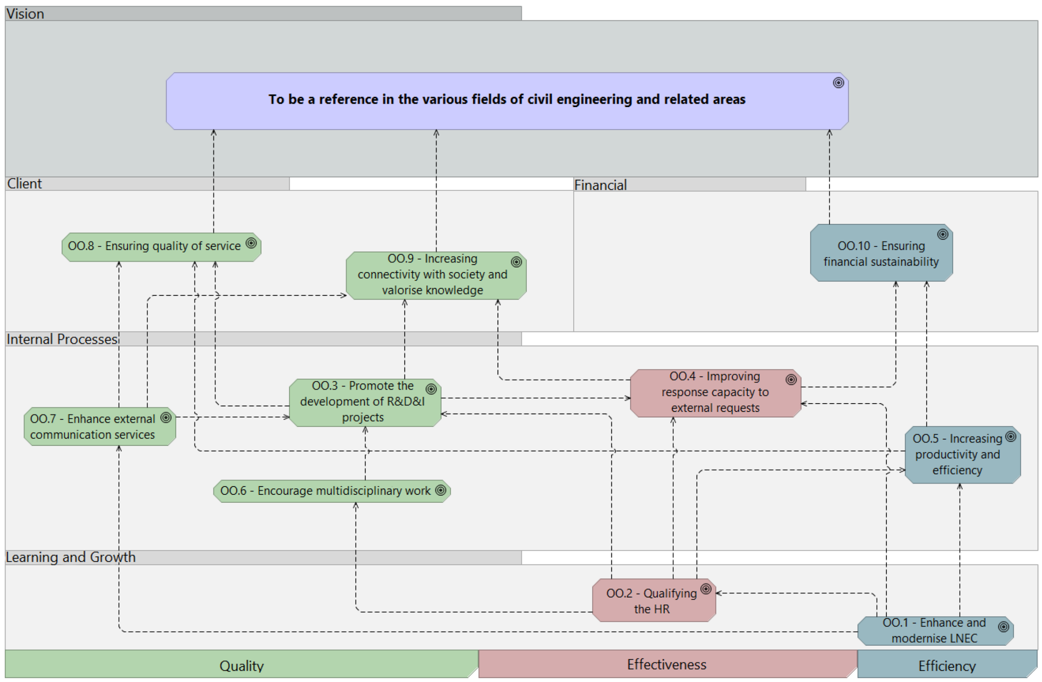

Fig. 4. LNEC's strategy map. Adapted from [1].

[1], designed in Archi[4] and reproduced in Figure 4. The institutional report [1] contains an overview of LNEC's current strategic context using **Political, Economic, Social, Technological, Environmental, and Legal (PESTEL)**; **Strengths, Weaknesses, Opportunities, and Threats (SWOT)**; and TOWS (or reverse SWOT) analyses. Additionally, it also includes a risk management analysis.

The strategy formulation of LNEC includes the mission, values, and vision statements (see Table 1), aligned with QUAR's formulation. The definition of a strategic objective is distinct in a BSC and in QUAR. Contrarily to what the BSC proposes, QUAR strategic objectives are not quantified. Thus, the QUAR strategic objectives could, at most, be considered as BSC strategic themes. However, in the LNEC strategy map, it was chosen to use the three objectives categories prescribed by QUAR as vertical strategic themes, crossing the perspectives of the BSC: Quality, Effectiveness, and Efficiency (see Figure 4).

The LNEC's strategy for 2021–2027 was mapped into 10 strategic objectives (based on QUAR's operational objectives), divided into four perspectives (financial, customers, internal processes, and learning and growth). The strategy map design also comprises the definition of cause-and-effect relationships between the strategic objectives, considering the above-mentioned strategic themes. For each strategic objective, a set of indicators

[4] https://www.archimatetool.com/

was defined, with 22 indicators being defined in total. Some (nine) of these indicators are directly related to QUAR indicators. The yearly activity plans, available on the LNEC's website,[5] present target values and yearly values for QUAR indicators.

5 ONTOLOGY MAPPING AND POPULATION

Instance data was added to the BSO, allowing strategy validation and analysis. The process of incorporating instances into the ontology, referred to as ontology population, was achieved using a Protégé plugin known as Cellfie.[6] Cellfie enabled us to establish a collection of import rules and mappings, utilizing the Manchester OWL Syntax,[7] to translate data from Excel spreadsheets into OWL axioms. Ultimately, a strategy map and a set of quantification frameworks related to LNEC's BSC were imported into the ontology.

5.1 Mapping LNEC's Strategy Map

First, the strategy map and its elements were mapped into ontology entities. The strategy statement elements (mission, vision, and values), BSC perspectives, strategic themes, and strategic objectives were mapped to their respective BSO classes. When appropriate, additional instance metadata was imported using annotation such as RDF Schema's "label" or Dublin Core's[8] "title" and "description." The following properties were used to formalize the strategic objectives relationships:

- **isElementOf**: Relationship between a BSC Element and a BSC Component. In this case, the relationship between a strategic objective and the strategy map
- **contributesToPerspective**: Direct contribution from a Strategic Objective to a Perspective (functional property)
- **contributesToTheme**: Direct contribution from a Strategic Objective to a Strategic Theme
- **hasCauseEffectRelationship**: Direct contribution from a Strategic Objective to another Strategic Objective

5.2 Mapping Quantification Frameworks

Quantification frameworks are defined to evaluate the strategy's execution over a certain time frame, usually a year. Quantification frameworks define indicators used to evaluate the strategy map's strategic objectives. These indicators should be either Lead (i.e., drivers, enablers, predictive) or Lag (i.e., results) indicators. The BSO also defines a number of data relationships to characterize indicators (e.g., data source, acquisition frequency).

LNEC's 22 indicators for the current strategy were added to the ontology, including their codes and description, and related to the quantification frameworks (using the "isElementOf" property). Indicators are connected to strategic objectives using the "isEvaluatedBy" object property. The yearly activity plans publish data concerning 9 indicators from the original 22 introduced in Barateiro et al. [1], all related to QUAR.[9] A quantification framework was created for each activity plan, from 2021 to 2023, and the following relationships were used to complete each framework:

- **hasTarget**: Object property used to relate an indicator with a target. Targets are imported for each of the available indicators with their respective target values and target date (end of the respective year).
- **hasActualValue**: Object property used to relate an indicator with an actual value. Current values for the available indicators are presented in the yearly activity plan and loaded into BSO with their respective date.

[5] https://www.lnec.pt/pt/lnec/instrumentos-de-gestao/documentos-institucionais/
[6] https://github.com/protegeproject/cellfie-plugin
[7] https://www.w3.org/TR/owl2-manchester-syntax/
[8] https://www.dublincore.org/
[9] Quantitative data from a 10th indicator from QUAR is also presented in the activity plans. However, the indicator was divided into two indicators in the current strategy, meaning that the data for these indicators cannot be retroactively obtained.

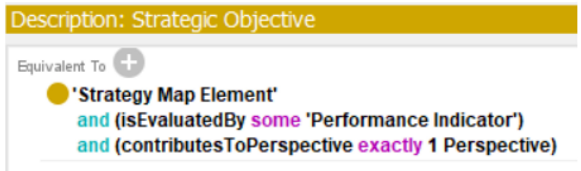

Fig. 5. Strategic objective definition in BSO.

Every year, LNEC defines a set of strategic guidelines to guide LNEC's activities during the year and to help achieve the annual targets. While similar in purpose to BSC's initiatives, the formalization level of these guidelines was considered insufficient when mapping this information into BSO. BSO defines initiatives as strategic projects with a significant organizational commitment (buy-in), with defined dates and resource allocations (e.g., budgets, responsibles), and with impact in at least one strategic indicator of the quantification framework. In this case study, the strategic guidelines are not linked with indicators or strategic objectives, and are usually defined as single-sentence actions. Therefore, they were not loaded as initiatives in the BSO.

6 ONTOLOGY-BASED STRATEGY VALIDATION AND INFERENCE

Once the information from the LNEC's strategy is loaded into the BSO, the information can be validated using SW technologies. Protégé's default reasoner, Hermit,[10] was used to infer new relationships and to detect inconsistencies. No inconsistencies were found using this method. To further explore the benefits of ontological knowledge representation, other technologies were used. **Shapes Constraint Language (SHACL)**[11] and **Semantic Web Rule Language (SWRL)**[12] are two technologies within the SW framework that can be useful in validating the BSO.

SHACL is a constraint language designed to validate the structure and the data of RDF graphs used to represent ontologies. SHACL allows the definition of shapes (templates) that describe the ontology's expected structure. This includes specifying the necessary classes and properties, their cardinality, and the relationships between them. These specifications serve as a safeguard, ensuring that the ontology statements follow the predefined model. Moreover, SHACL can also be used for data validation within the ontology. For example, it enables the definition of constraints that require certain properties to have specific data types, ranges, or formats, which help maintain data integrity and accuracy in the ontology. SHACL also provides a mechanism for checking constraints on the ontology that can identify violations, such as missing data or data that does not conform to defined rules.

The SHACL shapes can be used to validate information in the BSO. For example, a strategic objective is defined in the BSO as shown in Figure 5, stating that any strategic objective needs to be related to at least one value indicator, which would be the case if any of the QUAR strategic objectives were included in the strategy map. In that case, Hermit would not classify the ontology as inconsistent due to the Open World Assumption used in semantic languages such as OWL. SHACL could be used to warn users that these objectives should be evaluated by a set of indicators. Listing 1 presents an example of a shape that ensures that any strategic objective is evaluated by at least one indicator. The QUAR strategic objectives would be identified with a warning message (see Figure 6) since they do not have any indicator.

SWRL is an expressive rule language that allows users to define complex semantic rules for reasoning over ontologies. SWRL can also be used to check for inconsistencies or ensure data quality in the ontology. However, SWRL is known for its inference capabilities that can help derive implicit information from an ontology. This can

[10] http://www.hermit-reasoner.com/
[11] https://www.w3.org/TR/shacl/
[12] https://www.w3.org/submissions/SWRL/

SHACL constraint violations: 4

Severity	Message	FocusNode
http://www.w3.org/ns/shacl#Warning	A Strategic Objective must be evaluated by at least one Indicator	https://www.iscte-iul.pt/ontologies/BSO#OE.1
http://www.w3.org/ns/shacl#Warning	A Strategic Objective must be evaluated by at least one Indicator	https://www.iscte-iul.pt/ontologies/BSO#OE.2
http://www.w3.org/ns/shacl#Warning	A Strategic Objective must be evaluated by at least one Indicator	https://www.iscte-iul.pt/ontologies/BSO#OE.3
http://www.w3.org/ns/shacl#Warning	A Strategic Objective must be evaluated by at least one Indicator	https://www.iscte-iul.pt/ontologies/BSO#OE.4

Fig. 6. SHACL constraints violations resulting from Listing 1's shape.

Listing 1. SHACL Shape Example

```
ObjectiveIndicatorValidation
        a sh:NodeShape ;
        sh:targetClass Strategic_Objective;
        sh:property [
                sh:path isEvaluatedBy;
                sh:minCount 1;
                sh:severity sh:Warning;
                sh:message "A Strategic Objective must be evaluated by at least one
                    Indicator";].
```

be valuable in identifying missing or implied relationships between entities in the BSO. For example, the layout of perspectives in the strategy map is defined in BSO using the "isBaseFor" object relationship. This means that if perspective A "isBaseFor" perspective B, perspective A should be visually presented below perspective B. This relationship also implies that perspective A is a driver for perspective B, in the sense that the performance of strategic objectives in perspective A drives the performance of objectives in perspective B.

Listing 2. SWRL Rule for isBaseFor Inference

```
contributesToPerspective(?o1, ?p1) ^ contributesToPerspective(?o2, ?p2) ^
hasCauseEffectRelationship(?o1, ?o2) ^ differentFrom(?p1, ?p2) ->
isBaseFor(?p1, ?p2)
```

While the "isBaseFor" object property was not explicitly stated when loading LNEC's information to the ontology, SWRL can be used to infer this connection between perspectives. Using the rule shown in Listing 2, the "isBaseFor" object property is inferred based on the cause-and-effect relationships of objectives related to each perspective. The "isBaseFor" object property is asymmetric and irreflexive, and, although it is theoretically transitive, it was not formalized as such because OWL reasoners could not infer over complex properties [38]. However, using SWRL, a transitive rule can be used to achieve the same effect, which allows the rule engine to correctly infer this relationship between perspectives. The results of this inference can be seen in Figure 7, where the "isBaseFor" object property was correctly inferred between the learning and growth and the other perspectives.

In summary, SWRL and SHACL play complementary roles in validating the BSO. Leveraging both technologies ensures that the ontology is not only semantically correct and complete but also structurally and data-wise compliant with the BSO model, ultimately leading to a more reliable and accurate representation of a BSC.

Over the years, Kaplan and Norton have perfected an adaptable performance management framework that allows executives and managers to design and use the BSC with the level of detail required by their organizational strategy. However, due to this adaptability, there is not a standard formalization of rules defining what constitutes a complete and well-defined BSC. To this end, the BSO was defined as a way to formalize the BSC framework, which can now be complemented with SWLR rules and SHACL shapes.

Caldeira [5] presents a simple set of rules for strategic objectives and cause-and-effect relationships between them in the Portuguese civil services. Cardoso [7] also presents a set of similar rules, but generic for any BSC,

Fig. 7. Learning and growth perspective inferred properties.

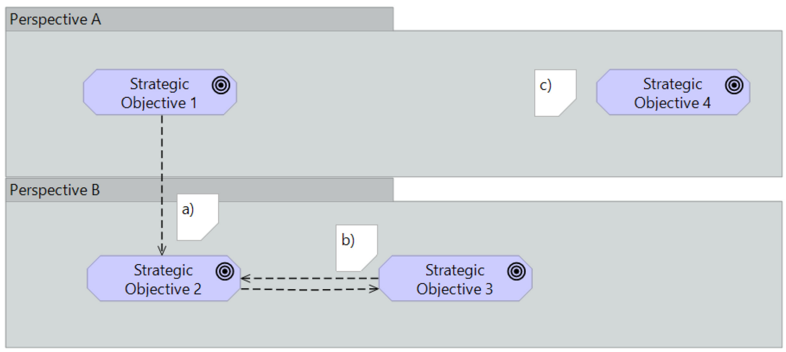

Fig. 8. Set of validations for strategy map's cause-and-effect relationship. Adapted from Caldeira [5] and Cardoso [7].

with dos and don'ts of the cause-and-effect relationships definition. These guidelines (see Figure 8) are important since they represent strategic hypotheses in terms of the expected impact of the performance of each objective. Monitoring these relationships is challenging and time-consuming and has been appointed for many years as one of the limitations of the BSC [34, 43]. Using the ontology (OWL), SWRL, and SHACL, any strategy, such as the one from the LNEC's case study, can now be validated against these rules. Table 2 showcases how each rule can be validated using the aforementioned technologies.

7 STRATEGY ANALYSIS

The populated ontology and the inferred axioms were exported from Protégé and imported to GraphDB,[13] a linked data environment compliant with W3C standards (i.e., RDF, OWL, SPARQL). Once stored in this semantic graph database, the ontology can be queried or updated using SPARQL endpoints. While not strictly necessary for this analysis, GraphDB allows the ontology to be accessed by external applications, such as Power BI,[14] a **Business Intelligence (BI)** tool that allows users to create interactive reports and dashboards, which can be used to visualize the strategy execution.

The BSO can be now be queried to obtain information either explicit or implicit in the ontology. Queries such as the ones presented in Listing 3 and 4 allow the user to explore information related to the ontology. The first query returns information related to the main elements of the strategy map, namely the strategic objectives, perspectives, and strategic themes. The second query returns any strategic objective that is directly or indirectly

[13] https://graphdb.ontotext.com/
[14] https://powerbi.microsoft.com/

Table 2. Validation of Rules of Cause-and-effect Relationships in a Strategy Map

Rule	Description	Technologies	Validation
a	Cause-and-effect relationships should not be defined in a descendent direction, since they contradict the logic of the model.	OWL, SWRL	SWRL infers "isBaseFor" object property based on cause-and-effect relationships between strategic objectives (see Listing 2). If there is a downward relationship, the rule will infer that perspective A "isBaseFor" perspective B and vice versa. Due to the asymmetric characteristic of this property, the reasoner will find the ontology to be in an inconsistent state.
b	Cause-and-effect relationships should not be defined with two-directional arrows, because it becomes impossible to distinguish the cause from the effect.	OWL	hasCauseEffectRelationship object property is asymmetric and irreflexible.
c	"Orphans" objectives, i.e., not linked to any objective, should not exist, because they do not express how they can contribute to the strategy.	SHACL	Shape for strategic objectives ensures that the objective is either in range or in the domain of at least one hasCauseEffectRelationship property.

Adapted from Cardoso [7].

(transitive property) affected by a certain objective (the notation of a class name between angle brackets (<>), e.g., $< Strategic\_Objective >$ is used to define any instance of that class).

Listing 3. SPARQL Query for Strategic Objectives

```
SELECT ?perspective ?objectiveID ?theme
WHERE{
    ?objectiveID rdf:type Strategic_Objective;
                 contributesToPerspective ?perspective;
                 contributesToTheme ?theme.
} ORDERBY ?perspective ?objectiveID
```

Listing 4. SPARQL Query for Strategic Objectives' Cause-and-effect Relationships

```
SELECT ?objectiveID
WHERE{
    <Strategic_Objective> rdf:type Strategic_Objective;
             isElementOf ?StrategicMap;
             hasCauseEffectRelationship+ ?objectiveID.
    ?StrategicMap hasElement ?objectiveID.}
```

Table 3 presents the Quantification Framework for 2022, based on the activity plan for the same year. For each objective, it includes the indicator's target value, the actual value achieved, and the result status. The results reveal the performance against the predefined targets, with some indicators labeled as failed (for falling short of expectations) and others marked as success (for meeting or exceeding their targets). There are no target or actual values available for 13 indicators, and three objectives (OO.4, OO.7, and OO.8) lack associated indicators for evaluation. It should be noted that although indicators have been defined for these objectives, no target or actual values are publicly available. Indicator 5 (related to the monthly average of research grants) associated with objective OO.2 (Qualify HR) also had a substantial shortfall compared to its target (only achieving 10% of the target). However, notwithstanding the failed result, indicators 8 (OO.3) and 22 (OO.10) achieved more than 95% of their corresponding targets.

Access to real data enables a data-driven assessment and in-depth analysis of both the execution of a strategy and the quality of its formulation, i.e., evaluating whether the strategy was well defined and if it is delivering the intended results toward the fulfillment of the vision (future position). For instance, when managers

Table 3. Analysis of Performance Indicators Based on the 2022 Activity Plan

Objective	IndicatorID	Indicator	Target Value	Actual Value	Result
OO.1	Ind.1	Investment in research infrastructure/total expenditure	0.09	0.064	failed
OO.2	Ind.5	Number of contracts for junior researchers and LNEC research grants (monthly average)	40	4	failed
OO.3	Ind.8	Number of strategic research studies in partnership with other entities	65	62	failed
OO.3	Ind.9	Percentage of external funding for Strategic Research relative to total expenses	0.075	0.093	**success**
OO.5	Ind.11	Number of technical publications (reports, technical notes, opinions, etc.) per researcher	3.7	3.07	failed
OO.6	Ind.13	Total revenue from internal processes/total revenue	280	375	**success**
OO.9	Ind.18	Own revenue from contract activities linked to research projects/total expenditure	70	86	**success**
OO.9	Ind.19	Number of scientific and technical events organized or co-organized by LNEC	110	135	**success**
OO.10	Ind.22	Percentage of self-financing amount relative to total expenses	0.45	0.449	failed

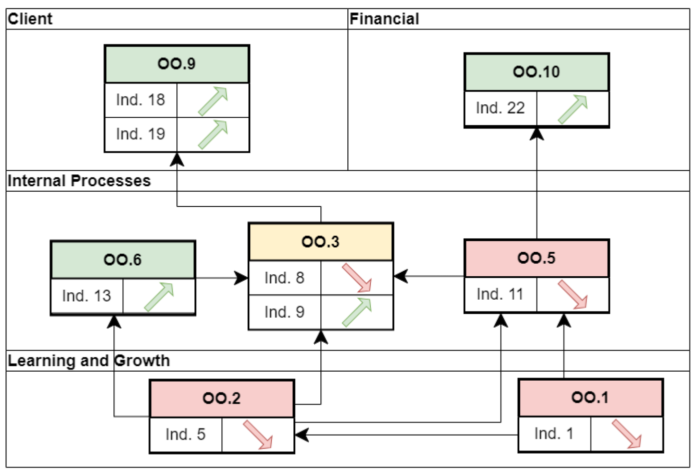

Fig. 9. LNEC's strategy map with trend analysis between 2021 and 2022 (excluding objectives that are not being measured).

establish cause-and-effect relationships among strategic objectives, they are essentially formulating hypotheses about how these objectives and their associated indicators are interconnected (e.g., if customer satisfaction improves, it should lead to increased sales; if production costs decrease, it should result in higher profits). By linking the LNEC's strategy map with its quantification frameworks, the set of strategic hypotheses can now be empirically validated. Figure 9 displays the strategic objectives, cause-and-effect relationships, and measured indicators,[15] together with their growth trend, related to the evolution shown between the 2021 and 2022 quantification frameworks. The color of strategic objectives and indicators represent their growth trend: green—positive, red—negative, and yellow—inconclusive. Without defining the weights of the impact for each indicator, OO.3's trend growth cannot be determined.

When a strategic objective is linked to another, this relationship can be extended to their respective indicators. That is, if the performance of the indicator measuring the "cause" objective increases, it is expected that

[15]Note that Figure 9 is a simplification since indicators are not part of the strategy map or its visualization.

the performance of the indicators measuring the "effect" objective will also improve. The cause-and-effect relationships assessment need to take into account the weights of indicators measuring a particular objective. In Figure 9, if a particular indicator demonstrates an upward trend across these quantification frameworks, signifying an increase in value, it is anticipated that the indicators related to the affected objective will exhibit a similar trend. It is worth noting that, in the LNEC's case, this analysis is simplified since all indicators have a positive polarity. The BSO enables the definition of the indicator's polarity using a data property. The same can be expected in the opposite situation, as shown in Figure 9 for all OO.1 cause-and-effect relationships. However, all other objectives and indicators present an unexpected behavior, with some type of disparity in cause-and-effect relationships. There can be several underlying factors contributing to these observed disparities:

- **Inaccurate cause-and-effect relationships formulation.** The cause-and-effect relationship is not proven by the data itself, meaning that the anticipated connections and relationships between strategic objectives could not be substantiated by the data (e.g., relationships between OO.2 and OO.6 or OO.5 and OO.10). This can happen because the cause-and-effect link between the objectives does not exist after all, or because this relationship is not as direct as initially formulated (a third strategic objective might be needed to correctly depict the organization's reality).
- **Inaccurate or incomplete objective evaluation.** While cause-and-effect relationships may exist between objectives, the accurate evaluation of a strategic objective can be compromised by the absence of an indicator or misformulation of the indicator (wrong level of detail/aggregation or wrong context). For example, the cause-and-effect relationships from OO.2 to OO.6 or OO.5 to OO.10 might exist, but the associated indicators do not allow an accurate or complete evaluation of the objectives.
- **Impact of multiple cause-and-effect relationships.** Strategic objectives and their indicators can be influenced by a multitude of sources. However, it is important to recognize that not all indicators respond uniformly to their strategic objective's cause-and-effect relationships. The impact of a cause-and-effect relationship may be partly observed in some of the indicators related to a strategic objective, while the remaining indicators are affected by different cause-and-effect links originating from other strategic objectives and indicators. Furthermore, even if the cause-and-effect relationships between these indicators could be verified, there may be a significant variation in the impact of each cause in the indicator. This complexity is especially pronounced in the analysis of OO.3's cause-and-effect relationships, for example, as the direct impact of each indicator lacks formalization, especially the weights of each relationship. For example, Ind. 8 and 9 are affected by OO.2, OO.5, and OO.6. Observing the Ind.9 growth trend, different scenarios can be possible. For instance, Ind. 9's growth trend can be fully explained by OO.6's performance, with OO.2 and OO.5 only affecting Ind. 8; or Ind. 9's may be impacted by all of the objectives, with OO.6's performance having a higher impact on this indicator than the other two objectives combined. A similar logic can be applied to the cause-and-effect relationship between OO.3 and OO.9.
- **Data issues.** In some cases, organizations may lack comprehensive data to fully evaluate the impact of cause-and-effect relationships. This can be due to data gaps, measurement challenges, or limited historical information. Incomplete or incorrect data can hinder the accurate assessment of the performance of strategic objectives.

Finally, the knowledge contained in the ontology and all the queries and analyses presented in this section can be used by external applications to create visualizations and provide recommendations. GraphDB allows the creation of access points that can be used for applications via REST API or similar software interfaces. The information in Table 3 was retrieved for all available quantification frameworks and exported from GraphDB to PowerBI. Figure 10 presents a dashboard that can be used for strategy execution analysis, based on the BSO knowledge. The average target completion percentage is presented for each strategic objective evolution, together with the evolution of each indicator with the respective target defined in the quantification frameworks (filtered for 2021 and 2022).

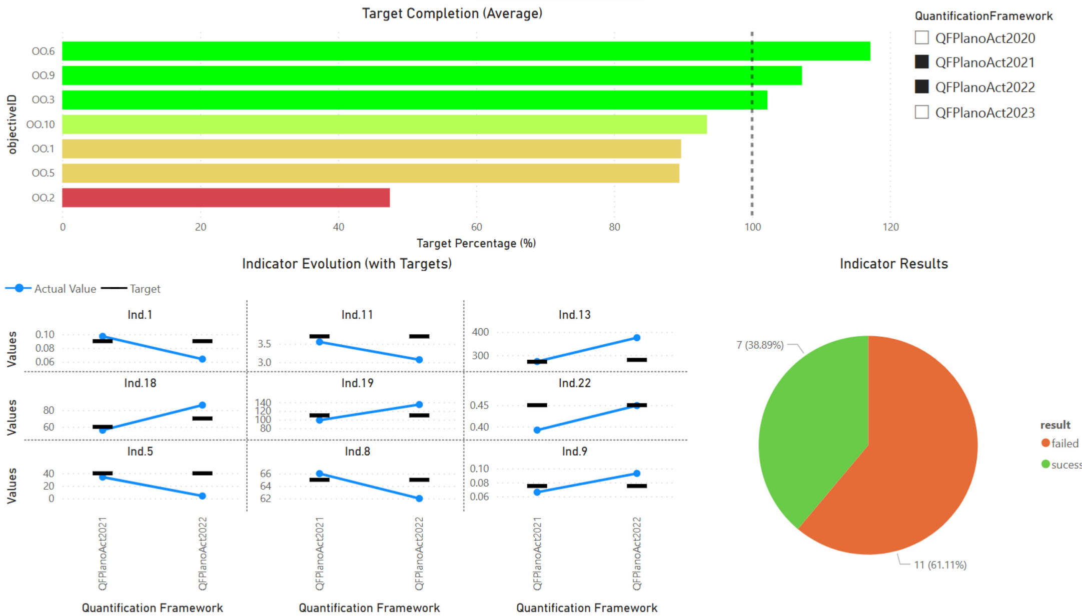

Fig. 10. Dashboard for strategy execution analysis in power BI.

7.1 Recommendations

The absence of data for a significant portion of the defined indicators has a notable adverse impact on the effectiveness of the strategic analysis. Incomplete data can hinder the ability to assess strategy success and the true performance of strategic objectives and their associated indicators. It may result in an incomplete or inaccurate understanding of the organization's progress toward its goals, potentially leading to sub-optimal decision-making.

On the other hand, the frequency of mandatory reporting, while providing a consistent basis for analysis, might be too long for an adequate and timely performance evaluation. This can be a limitation that affects an organization's ability to make real-time decisions and adapt as needed to achieve their intended targets. The strategy execution evaluation should monitor and report on real data managed by organizational information systems. Ideally, the values should be retrieved from information systems, such as BI systems, and loaded into the ontology using an automated or semi-automated process. Implementing a comprehensive data collection and respective reporting mechanisms enables an accurate and continuous evaluation of the strategy execution, leading to the realization of an integrated strategic management and execution system, and allowing for timely adjustments and interventions throughout the year.

Furthermore, it is imperative that LNEC's vision can be quantifiable and measured. The BSO states that an organizational vision contains a quantifiable stretch-goal, with a well-defined niche, time limit, and target. The stretch-goal establishes a performance indicator and a target value with a clear time frame to achieve it, enabling a clear quantification of the vision statement for the specific strategy cycle. Without a quantifiable stretch-goal, managers cannot measure how close or how far they are to their future expected position, and therefore cannot take action to ensure the long-term organization's success. The niche clarifies the scope of the strategy, defining the boundaries that will guide the organization's actions.

There is room for improvement in the identification and definition of strategic guidelines. The formalization of these guidelines as actual BSC initiatives would provide real action plans that operationalize the strategy to

Table 4. Strategic Guidelines Impact by Indicator

Objective	Indicator	Growth %	Trend	Number of Guidelines
OO.1	Ind.1	−33.85	decreasing	2
OO.2	Ind.5	−88.24	decreasing	1
OO.3	Ind.8	−6.06	decreasing	3
OO.3	Ind.9	39.46	increasing	3
OO.5	Ind.11	−13.52	decreasing	0
OO.6	Ind.13	37.36	increasing	1
OO.9	Ind.18	53.57	increasing	0
OO.9	Ind.19	36.36	increasing	3
OO.10	Ind.22	14.62	increasing	0

help achieve a set of targets, leading to an effective strategy execution. These strategic projects must have a clear resource allocation, such as a budget, and outline the strategic objectives and indicators that will be impacted. By importing strategic initiatives to the ontology, the impact of each initiative could be validated both in its formulation and influence on indicator performance. For example, a SHACL shape similar to the one presented in Listing 1 would reveal which initiatives do not impact any indicators. Initiatives' impact on each indicator could be analyzed, similar to the analysis in Table 4, which shows the indicator performance trend between 2021 and 2022, and the number of strategic guidelines defined in the quantification framework for 2022 associated with each indicator.[16] There is only one indicator (Ind. 11, from objective OO.5) that has a downward tendency and is not the target of a strategic guideline. Furthermore, defining budget allocation for strategic initiatives would enable a real and accurate analysis of the organizational commitment to each objective, providing greater insight into the growth trend of each indicator.

The observation of a downward growth trend in the base perspective (learning and growth perspective) in Figure 9 may be a cause for concern. This may indicate a potential lack of investment in critical areas that serve as the foundation for achieving other strategic objectives. Neglecting these foundational elements can have cascading effects on overall performance and hinder future achievements.

In conclusion, addressing these types of issues is essential to enhance the effectiveness of strategic analysis and improve the ability to achieve strategic objectives. These recommendations can contribute to a more robust and data-driven strategic management approach, increasing the organization's ability to adapt and improve.

8 DISCUSSION

This research explores how public organizations, such as LNEC, can employ ontologies to assess their strategy formulation and execution. The BSO was used to validate the formulated LNEC's strategy, using the OWL reasoner, SHACL, and SWRL to find inconsistencies and allow inference over the strategic knowledge. The use of these technologies ensures that the ontology is not only semantically correct and complete but also structurally and data-wise compliant with the BSO model, ultimately leading to a more reliable and accurate representation of the BSC framework.

Furthermore, it investigates how the ontology can be used to assess the implementation and execution of the strategy. The quantification framework analysis can be done to evaluate performance indicators and validate the cause-and-effect relationships between strategic objectives. Formulating a strategy, especially the cause-and-effect relationships from the BSC, is a complex and subjective process that relies on the creation of hypotheses based on managers' knowledge, insights, and "gut feelings." With the BSO, the design of these relationships can now be improved, since the ontology enables their monitoring and empirical validation. Lastly, SW technologies offer increased interoperability that can be used to share information across systems and organizations.

[16]This association was not provided by any official LNEC document. It was obtained manually to provide an example for this analysis.

8.1 Contributions to the Theory

The present study contributes to the existing literature by addressing various identified gaps associated with strategy analysis in the public sector, specifically the low comprehensiveness and formality of strategic management systems [4]. This research explores how ontologies can be used to overcome this gap, enabling data-driven decision and improving strategy formulation and evaluation. As shown in previous research [15, 17, 18, 32], SW technologies are one of the emerging technologies in the public sector, providing shared semantics and enabling interoperability across public organizations.

The BSO ontology was previously developed to formalize the BSC [31], which is the most recognized approach for performance assessment in public administration [29, 43], providing insight into financial and non-financial objectives and indicators, addressing the often overlooked non-financial aspects of the public sector [32]. The BSO was developed to enable accurate, traceable, and continuous monitoring and improvement of the strategy execution, based on a data-driven approach. Existing studies, such as those by Kumar et al. [30] and Tawse and Tabesh [43], also emphasize the importance of combining the BSC with other systems and tools for an effective implementation, which can be facilitated through the increased formalization and interoperability from the ontology.

Using the proposed methodology (see Section 3), SW technologies can be used to support strategy management as long as the organization's strategy is formulated using a BSC. Formalizing knowledge through techniques such as ontologies offers several benefits, including enhanced interoperability between systems, knowledge validation and inference, and improved communication through semantics [40]. These benefits can be leveraged to address identified gaps in the literature, such as ensuring effective implementation of the BSC as a strategic management system and fully harnessing the framework's benefits [31, 43]. Additionally, SW technologies enable continuous performance evaluation, creating clear and understandable performance management systems (minimizing misunderstandings inside and outside the organization) [29].

8.2 Contributions to the Practice

Using the BSO and SW technologies can offer multiple advantages for managers and decision-makers. Primarily, it ensures the alignment between the BSC and the organization's overarching goals. The ontological structured representation allows managers to assess whether elements within the BSC align with the organization's strategy, preventing the misallocation of resources to nonessential or redundant indicators and objectives.

The BSO provides an unambiguous representation of the BSC framework, promoting a shared understanding of the strategy, strategic objectives, and indicators among all stakeholders. This enhanced clarity can improve communication and alignment across the organization, spanning different organizational levels or departments and serving as a valuable tool for knowledge transfer within the organization. By formalizing the cascading impact of each BSC element, the contribution of individual or departmental objectives to the overall organizational strategy can be clarified, offering a deeper understanding of the strategic framework to employees and stakeholders, potentially acting as a motivational factor.

Moreover, SW technologies play a crucial role in supporting compliance and governance initiatives by enhancing external communication and alignment. SW technologies streamline documentation and reporting and enable managers to verify organizational adherence to regulatory requirements and compliance with relevant standards, such as those established by policymakers. This is particularly significant for policy compliance, reporting, and performance evaluation in the context of international policies and public administration. For example, the European Commission can provide a set of rules (formalized using SWRL and SHACL) that can be validated against an organization's strategy and its execution.

The European Green Deal[17] is a perfect example of the potential application of this research contribution. The European Green Deal defines several policy initiatives for climate neutrality, including legal obligations, such

[17] https://www.consilium.europa.eu/en/policies/green-deal/

as the European climate law, where the EU and its member states are committed to cutting net greenhouse gas emissions in the EU by at least 55% by 2030, compared to 1990 levels.

Furthermore, integrating the BSO into the strategic decision-making process ensures the alignment of all decisions with the organization's mission, vision, and strategic objectives. This proactive approach prevents decisions that may not contribute to the organization's long-term success. The BSO facilitates dependency analysis, providing insights into how changes in a specific indicator or objective may impact the overall strategy. Additionally, using an ontological model can streamline the integration of data from various sources into the BSC model, making the collection, analysis, and reporting of performance indicators more efficient. The automation of these processes is crucial for supporting real-time or near-real-time monitoring of performance indicators and data-driven decision support. This contribution is particularly significant given the growing importance of leveraging data in strategic decision-making processes within an evolving business environment, as highlighted by Grant [12].

8.3 Limitations and Future Work

This research explored how public organizations can take advantage of SW technologies to assess their strategy formulation and execution, based on a real case study of a public Portuguese organization (LNEC). While there are no perceived barriers to generalizing and implementing the proposed methodology in other scenarios, the adaptability of this work must be explored in other contexts or industries (public or private). This is a necessary step to ensure that the only restriction to the reproducibility of a similar analysis using the BSO is the translation of the organizational strategy into a BSC.

Additionally, it is essential to note that while most of the methodology processes can be automated (namely, the use of SW technologies for validation and analysis), the ontology mapping and population is still a semi-automated process since knowledge is usually retrieved from non-structured data. While import rules (or other existing ontology population methods) can be defined based on a data template, data related to the BSC is usually only available in non-structured documents, leading to a case-by-case mapping process. Following the same premise, the BSC framework's adaptable nature poses challenges in employing SW technologies such as SWRL and SHACL, as their application will depend on the level of detail and validation rules required by each manager or organization (see Section 6).

As discussed in Section 7, ontologies and SW technologies can be used to enable strategy validation and analysis for managers and decision-makers. For example, Figure 10 shows how external applications can benefit from ontology knowledge to provide end-users with strategic information, using a simple visualization. However, additional work is required to fully showcase the potential of these technologies as part of a fully integrated solution or framework where managers can interact, monitor, analyze, and receive alerts or even analytical recommendations regarding their strategy implementation and execution.

Furthermore, data access presents a notable challenge regarding strategy evaluation. As emphasized earlier, monitoring and analyzing the strategy execution requires actual data managed by the organizational information systems. However, establishing a seamless relationship between this data encompassing values collected for each indicator and their ontological representation is intricate. The complexity arises from variations in indicators defined at different levels of detail. Values should be extracted from information systems, like BI systems, and integrated into the ontology through an automated or semi-automated process. Overcoming these limitations is crucial for ensuring the robustness and applicability of the ontology and methodology in supporting an effective strategy execution and decision-making.

9 CONCLUSION

This article presents an applied research based on the impact and potential of SW technologies, such as ontologies, in the assessment of strategy formulation and execution in public sector strategy management. The LNEC was used as a representative case study in this research, which ultimately tries to enhance organizational performance and enable accurate, traceable, and continuous monitoring of an organization's strategy.

The BSO, an ontology design to describe and store knowledge related to the BSC framework, was used to validate the strategy formulation from LNEC. When complemented by semantic technologies such as SHACL and SWRL, the BSO can be used to validate any set of rules and ensure that the ontology is consistent and is structurally and data-wise compliant with the BSC model. The BSO can also be used to evaluate performance indicators and monitor or validate cause-and-effect relationships between strategic objectives. Lastly, the BSO increases the interoperability of strategic information.

In public sector organizations, like LNEC, the efficient use of resources directly impacts society at large, so there is a pressing need to enhance strategic decision-making and resource allocation. This research showcases the potential of ontology-driven strategic analysis to enhance organizational efficiency, adaptability, and decision-making capabilities while ensuring a shared understanding of strategies and data. Ultimately, this research offers a blueprint for public sector organizations seeking to optimize their strategies (i.e., more informed, efficient, and impactful strategies), foster transparency, and deliver more effective services to the public they serve.

Automating strategy analysis and connecting it to data is a critical need in today's dynamic business landscape. It promises enhanced efficiency, real-time insights, and the ability to handle the complexity of modern organizations. Public sector organizations, such as LNEC, stand to benefit significantly from this approach, as it ensures that resources are allocated effectively, strategies remain adaptable, and decisions are data driven.

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