ARSINOE

CLIMATE-RESILIENT REGIONS THROUGH SYSTEMIC SOLUTIONS AND INNOVATIONS

Conceptualization of ARSINOE Collective Intelligence Knowledge Graph

Deliverable 4.6

WP4: Environmental Intelligence Management and Services

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EXECUTIVE SUMMARY

This document presents the conceptualization of the ARSINOE Collective Environmental Intelligence Knowledge Graph (KG), called SustainGraph. With the term KG, we refer to a knowledge base that uses a graph-structured data model or topology to integrate data. A KG can A knowledge graph can represent a network of real-world entities and illustrate the relationship between them. SustainGraph is a Knowledge Graph that aims to provide a solid representation of knowledge related to the tracking of Sustainable Development Goals (SDGs) targets and indicators, their relationship with policies' development, and the implementation of case studies within the project. The main challenge is to move from a data-centric to a knowledge-centric way of thinking, participatory modelling, and analysis, overcoming existing barriers in management of silos of data and custom data management software.

A Systems Innovation Approach (SIA) is considered with a bidirectional interaction among the applied participatory processes and SustainGraph development. Systems innovation refers to the development of novel participatory technological solutions and breakthroughs that can lead to major transformation in national and regional economies. The adoption of a SIA can be considered as an enabler for the participatory formulation and development of a KG. On the other hand, the usage of a KG can be considered as an enabler for supporting knowledge management processes within a team working based on a SIA.

In the current document, the main set of entities and relationships that are represented in SustainGraph are detailed. Interlinking of concepts coming from the SDGs, policies making, case studies implementation and emerging research frameworks has taken place. The provided specification is made openly available and is going to be accessible to any interested party. The objective is to promote its adoption and usage, the collection of feedback and the creation of a community that is going to maintain it. Thus, the detailed specification in this document is going to be continuously evolved during the ARSINOE project lifetime, considering the integration of new concepts, and identified relationships among them.

In the next few months, emphasis will be given on the development of data population mechanisms for introducing data in SustainGraph, as well as data analysis mechanisms for supporting modelling and analysis processes in the case studies. Exploitation of Machine Learning (ML) techniques will be considered in both cases. Furthermore, intense collaboration is envisaged with the teams working in the various case studies to promote the applicability of the developed mechanisms for supporting participatory modelling and analysis processes.

Related Deliverables: Deliverable 4.7 (M36) for the data population and analysis processes of the Knowledge Graph, D4.1 (M36) for the visualisations provided through the Knowledge Graph and D4.5 (M48) for the interlinking between the Data Hub and the Knowledge Graph.

1.0 Introduction

1.1. Scope of this deliverable

The development of effective climate change mitigation and adaptation solutions is one of the most crucial challenges that we face towards the transition to a sustainable and climate-neutral way of living. To address this challenge and adopt sustainable development paths, various policies and associated targets have been specified at international and national level. Following the specification of a wide set of policies, relevant monitoring frameworks have been designed and become operational to keep track of their implementation and assessment.

A wealth of data is made available (e.g., UN SDG repository (UN Statistics, 2022), EU SDG and Green Deal targets tracking (Koundouri et al., 2021), Nationally Determined Contributions monitoring (United Nations, Climate Action, 2022)), centred mainly around the need to monitor and track the evolution of indicators for the SDG targets at national and regional level. Given that these data are collected by various organisations worldwide, semantic consistency and data interoperability among them cannot be considered as granted. Furthermore, such data are made available in many cases as data silos, while specialised software or Application Programming Interfaces (APIs) may be required for getting access to them. Lack of data quality is also a barrier, since data processing (e.g., removal of outliers, tackling of diverse assumptions during data production, use of different semantics for data description) is required in most cases to manage to transform data to formats and structure that can be considered homogeneous. Thus, the proper management of the wealth of collected information is not straightforward. There is a need for information models and information management techniques able to capture the volatility of the data, manage semantic misalignment of the denoted concepts, and facilitate the identification of hidden patterns and relationships among them. In this way, a solid, open and interoperable data infrastructure can be made available, enabling the development of innovative solutions to produce systemic changes and make economies socially, economically and environmentally sustainable.

Under this perspective, in the current deliverable we present SustainGraph as a Knowledge Graph (KG) that has been conceptualised and developed to track SDG targets and indicators, their evolution across time and their interconnectedness with policies and targets defined at European Union (EU) and national level (Fotopoulou, 2022).

A KG is considered suitable for this purpose, since it provides a graph-based abstraction of data coming from diverse data sources and domains, while managing the semantic consistency of the detailed concepts and enabling the tracking of dynamic relationships among them (Hogan et al., 2021). A systemic nexus approach has been considered for supporting the data population processes of the KG, while taking advantage of participatory system mapping processes (Midgley and Lindhult, 2021; Matti et al., 2020). To take advantage of the wealth of available data, openness, and interoperability of SustainGraph with existing databases and Application Programming Interfaces (APIs) is promoted to automate -as much as possible- the provided data population processes. Over SustainGraph, socio-environmental and socio-ecological systems participatory modelling and analysis processes can take place, aligned with the main mechanics of a Systems Innovation Approach. Specifically, the effective fusion of the collected data and their transformation to systematised nexus-coherent knowledge, can lead to novel insights (Laspidou et al., 2020), significant improvement of the participatory processes (Matti et al., 2020) and the development of collective environmental intelligence (Zafeiropoulos et al., 2021) among the engaged stakeholders and communities.

In the current deliverable, focus is given on the conceptualization of SustainGraph. As detailed, two approaches have been followed. The first one regards the description of SustainGraph in the form of a labelled property graph (LPG) model and the second one the description of SustainGraph in the form of an ontology. The first representation is selected for better managing an ever-evolving graph data structure, while the second one for better supporting semantics in the KG. Their proper maintenance can be considered as complementary.

It should be noted that the detailed conceptualization regards a solid basis for SustainGraph, however not a frozen specification. As we progress in the project, further concepts and relationships may be represented and introduced. To provide up-to-date documentation along with open access to the emerging developments, a live Gitlab repository[1] is set up and is going to be maintained. Furthermore, a collaboration has been established with the Neo4j community in the framework of the Graphs for Good initiative[2], aiming to disseminate SustainGraph to a wide scientific community, attract the interest and collect feedback by interested parties.

The work presented in D4.6 is going to be associated with the work presented in future deliverables and mainly D4.7, D4.5 and D4.1. In D4.7, detailed description of the data population mechanisms for introducing data to SustainGraph, along with the data analysis mechanisms that will be applied over SustainGraph will be provided. In D4.5, the interlinking of the data population mechanisms with the interfaces provided by the Data Hub will be presented, while in D4.1 the provided visualisation tools on behalf of SustainGraph to the overall ARSINOE visualisation framework will be detailed.

1.2. Structure of this document

The deliverable is organised as follows. In Section 2, background information related to the evolution of Knowledge Graphs (KGs) and their mapping with a Systems Innovation Approach (SIA) is presented. Following, in Section 3 a set of functional and non-functional requirements are listed and prioritised that will guide the development of the KG. Section 4 provides the overall conceptualization of SustainGraph, focusing on the description of the basic entities represented in the graph along with their relationships, while it also details the development process that is being followed along with the current development status. Section 5 describes the SustainGraph Ontology, as accompanying material that provides details for the semantics followed for the development of SustainGraph. Section 6 presents a set of mechanisms considered for data population of SustainGraph, along with mechanisms that can be applied for knowledge management and analysis purposes. It also provides a set of indicative use cases, highlighting some of the potential uses of SustainGraph for providing information based on specific questions or issues to be examined. Section 7 briefly refers to the conclusions a set of identified challenges that must be tackled.

[1] https://gitlab.com/netmode/sustaingraph
[2] https://neo4j.com/graphs4good/

2.0 Background Information

2.1. Knowledge Management based on a Systems Innovation Approach

Systems innovation refers to the development of novel participatory technological solutions and breakthroughs that can lead to major transformation in national and regional economies (De Vicente Lopez and Matti, 2016). The formulation of a system is a basic concept in the systems innovation approach, where a system is formed by several elements and their relationships that can be dynamic across time. The dynamicity of a system can be attributed to changes in internal or external parameters and the influence posed to the individual elements (Matti et al., 2020). Knowledge management is a fundamental part of the systems innovation approach since a collective understanding of the system is crucial to develop transformative solutions.

The adoption of a systems innovation approach can be considered as an enabler for the participatory formulation and development of a KG. On the other hand, the usage of a KG can be considered as an enabler for supporting knowledge management processes within a team working based on a systems innovation approach. The overall information flow in a systems innovation approach is covering the various parts of the DIKW (Data, Information, Knowledge, Wisdom) pyramid (Rowley, 2007) (see Figure 2). The first part of the flow (Data and Information parts in the pyramid) is associated with the population of the data in the KG. Through participatory processes, data collection and/or generation is taking place, considering data coming from various stakeholders. Such data can be introduced -upon processing- to the KG and populate it, creating a unique point of information management. By considering the interlinking between the denoted concepts based on the provided information, knowledge is produced.

The second part of the flow (Knowledge and Wisdom parts in the pyramid) regards the extraction of data from the KG to support participatory modelling processes. By getting access to semantically aligned and interlinked data, a participatory modelling process can be facilitated. Interdisciplinary scientists can collaborate more easily and co-create their models, given the alignment of terms coming from different scientific domains. Such modelling processes can be based on the adoption of modelling tools, such as System Dynamics Modelling, to better understand complex systems and lead to the creation of new knowledge by revealing feedback loops as well as interlinkages and cascading effects that propagate through the system (Laspidou et al., 2020). Resource nexus systems have such complexity and systemic approaches that incorporate biophysical, socio-economic and policy layers can promote knowledge elicitation and creation of new intelligence (Laspidou et al., 2019; Papadopoulou et al., 2022; Ramos et al., 2022). Resilience can be assessed successfully only through such systemic analyses (Ioannou and Laspidou, 2022). Along these lines, a KG can support the provision of input data to such models and supplement the produced intelligence through the identification of hidden relationships and/or patterns. Through the exchange and adaptation of existing information, practice-based knowledge can be co-created and applied in new contexts (Matti et al., 2020).

It should be noted that, nowadays, there are limited methods for modelling systemic changes, where there is also lack of knowledge for the processes that lead to systemic shifts in social systems (Elsawah et al., 2020). By capturing systemic changes of socio-environmental systems in the KG, such a challenge can be tackled. By getting access to visualisation and analysis results, data interpretation becomes simpler while opportunities for innovation can be identified. For instance, social network analysis and network maps can be used to analyse the system dynamics and the role of each stakeholder within a case study.

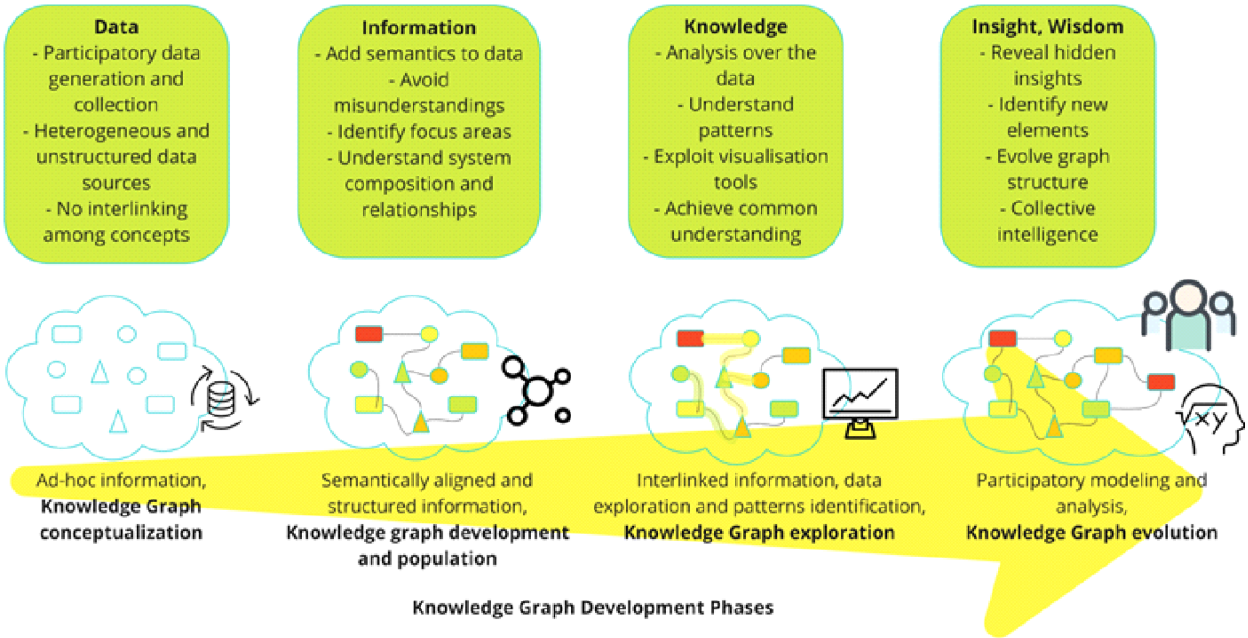

Figure 2.1: Knowledge Graph Development Phases aligned with a Systems Innovation Approach

2.2. Knowledge Graphs for Information Management

Knowledge Graphs (KGs) are emerging, since they are considered suitable to manage challenges that have arisen in modern data practices. The main challenge has to do with the existence of silos of data or dedicated software and Application Programming Interfaces (APIs) for managing such data (Sequeda and Lassila, 2021). Industry-specific data representation schemas are defined and adopted that -in many cases- may differ, even for the management of the same types of data. In parallel, dedicated software and APIs are being developed for data management in specific sectors, where the data semantics are hidden from the end users and are tackled by the internal software components. This makes the software usable only for the purpose that has been initially designed and hinders its adoption, re-usability, and interoperability with other data management tools (Sequeda and Lassila, 2021).

KGs are considered suitable for bridging data silos, by interlinking the concepts represented in the graphs with well-defined semantics (see Figure 3). In this way, the interconnected datasets in the KG can be enriched with meaning, misalignment of terminologies of the same concepts under different data schemas can be tackled, while relationships among concepts can be made explicit. Thus, the main motivation for the development of a KG is the usage of graphs to represent data -that can be interconnected and enriched with meaning- to explicitly represent knowledge (Hogan et al., 2021; Noy et al., 2019). Data volatility is managed, since relationships among nodes in a KG can be dynamic, making them suitable for representation of complex and dynamic systems (e.g., socio-environmental systems (Zafeiropoulos et al., 2021)). Keeping a high standard of data quality in a KG is challenging and is related mostly with the data quality of the input data. Quality management processes have to be applied to identify data quality issues (e.g., data inconsistency, data redundancy, missing values) and proceed to improvements (e.g., outlier removal) (Xue and Zou, 2022). By developing and maintaining a KG, data reusability, extensibility and interoperability can be considered as granted, relaxing a lot the constraints posed to data scientists in existing data management practices.

Moving one step further, KGs facilitate reasoning over the available data and support analysis and complex decision-making (see Figure 3). Reasoning over KGs is required to obtain new knowledge, extract insights and conclusions from existing data (Chen et al., 2020a). Through reasoning, KG completion and evolution can be supported via the identification and prediction of new relationships among entities (Chen et al., 2020a, b; Issa et al., 2021). As already mentioned, KGs can also act as an enabler for participatory analysis of dynamic and complex systems by interdisciplinary scientists). A data scientist can take advantage of the interlinked data in the KG to identify transformative patterns and extract new knowledge and insights. The existence of semantically aware and up-to-date data within a graph database enables the co-design of data management and analysis processes that can be integrated within dynamic modelling systems.

The role of Artificial Intelligence (AI) is highlighted since Machine Learning (ML) pipelines can be developed for supporting both data population and data analysis in the KG. The existence of a KG can act as a catalyst for the incorporation of a set of ML processes over a unified knowledge repository. The exploitation of ML techniques must be carefully considered, considering that a study that details the implications that AI may have on the delivery of all 17 SDG goals and the associated 169 targets (Vinuesa et al., 2020). It is stated that AI can act as an enabler for 134 targets, while it may also introduce negative impact on 59 targets (Vinuesa et al., 2020). With regards to the negative impact of AI, this is mostly related with the existence of biases in the data, the need for examination of the long-term impact of the applied algorithms in terms of equity and fairness and the unequal distribution of educational and computing resources throughout the world. To, at least partially, tackle these aspects, emerging technologies applied over KGs can be considered. For instance, the areas of explainable and responsible AI are emerging that can take advantage of semantic layers of knowledge provided through a KG to produce explainable and ethically aligned decisions (Hitzler et al., 2020). The adoption of open-source and open-access policies can also reduce the barriers for the usage of the produced software by a wide community.

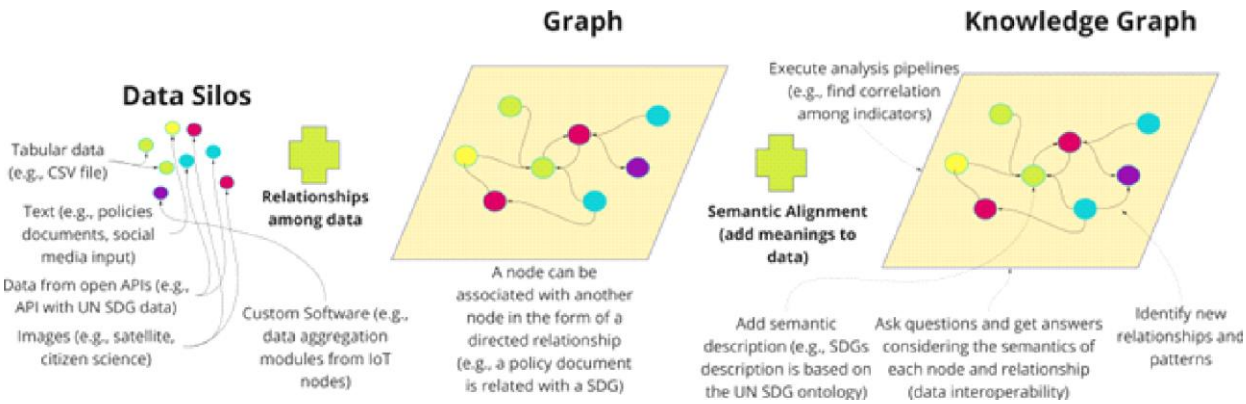

Figure 2.2: Knowledge Graph Development Phases aligned with a Systems Innovation Approach

3.0 Requirements

To properly proceed with the design and development of SustainGraph, we have collected a set of requirements that have to be fulfilled. We are considering two types of requirements, namely functional and non-functional requirements. Functional requirements specify what a system should do. They regard a set of functionalities that are offered to the end users during the usage of the developed software. Non-functional requirements refer to qualitative aspects that the provided software must satisfy. Such aspects may be related, among others, to the availability or the reliability of the software.

Prior to listing the set of requirements, we shortly refer to the type of end users that are going to use SustainGraph. We are considering three types of users, namely software developers, data scientists and simple users. Software developers are able, amongst others, to manage the structure of SustainGraph, to populate it with data, to process the data and to edit and submit queries in a declarative language. Allocation of proper access rights for part of CRUD (create, read, update, delete) operations will take place. A small set of software developers that maintain SustainGraph are going to have full access rights. Data scientists can retrieve data from SustainGraph and apply data analysis processes over them. The outcome of the analysis may be also fed back to SustainGraph. Simple users can navigate in SustainGraph and to get access to user-friendly interfaces for producing visualisations, to compose queries in a user-friendly way, and to get access to the required data.

Following, we provide a list with the main identified requirements for SustainGraph. Per requirement, we shortly refer to its main description, the considered end users, the priority level and the difficulty level to fulfil it. The fulfilment of the set of requirements will be evaluated upon the end of the development phase and reported accordingly to D4.7.

Table 3.1 Functional Requirements

ID	Title	Description	End User	Priority	Difficulty
F01	Graph navigation	The end user can visually navigate the nodes and properties of the KG.	Software developer Data scientist Simple user	High	Low
F02	Query submission	The end user can submit queries to retrieve specific information from the KG. The queries may regard one or more entities of the KG. In the latter case, transversal of the nodes of the KG will take place.	Software developer Data scientist	High	Low
F03	User friendly interface for queries	The user can compose queries in a user-friendly way.	Software developer Data scientist Simple user	High	High
F04	Import data from csv files	A data population mechanism exists for importing data from	Software developer	High	Medium

ID	Title	Description	End User	Priority	Difficulty
		csv files.			
F05	Import data from text files	A data population mechanism exists for importing data from csv files, taking advantage of Natural Language Processing (NLP) techniques.	Software developer	High	High
F06	Import data from open APIs	A data population mechanism exists for importing data from open APIs from open data repositories.	Software developer	High	Medium
F07	Produce visualisations	A visualisation kit exists for producing visualisations with data from the KG.	Software developer Data scientist Simple user	High	Medium
F08	Spatial data integration	Support the population of the KG with spatial data and the management of such data.	Software developer	Medium	High
F09	Interoperability with socio-environmental systems modelling tools	Support interoperability with existing modelling tools, focusing mainly on open-source modelling tools.	Software developer	Medium	High
F10	Data population periodicity	Support periodicity in the data population mechanisms to be able to introduce fresh data in the KG.	Software developer	Medium	Medium
F11	Semantic description of entities	Provide semantic description for the conceptualised entities, taking advantage of existing ontologies.	Software developer	High	Low
F12	Export data in tabular format for analysis	Support the extraction of data in a tabular format to be easily fed as input to an analysis process.	Software developer Data scientist	Medium	Low
F13	Data quality management	Support processes for improving the quality of the introduced data.	Software developer Data scientist	High	Medium

Table 3.2 Non-functional Requirements

ID	Title	Description	Priority	Difficulty
NF01	Availability	Support high availability of the provided services through the KG.	High	Medium
NF02	Reliability	Provided reliable services to end users.	High	Medium
NF03	User friendliness	Develop user-friendly interfaces for facilitating the adoption of the provided services.	High	High
NF04	Portability	Support portability in terms of deployment to different infrastructure.	Medium	Low
NF05	Extensibility	Provide extensible software and interfaces to be able to add further functionalities in the future.	High	Medium
NF06	Openness	Develop the KG based on open-source technologies and develop open APIs for its usage.	High	Medium
NF07	Documentation	Provide documentation for both the development processes and the usage of the KG.	High	Low

4.0 SustainGraph Conceptualization and Walkthrough

4.1. Conceptualization and Walkthrough

SustainGraph is specified and developed in the form of a property graph model (Fotopoulou, 2022). In this model, a graph consists of a set of nodes (discrete objects) and relationships. Relationships are directional while both nodes and relationships can have properties to describe their characteristics. To properly detail the semantic information associated with each node and relationship, a SustainGraph ontology[3] has also been made available. The ontological description of the main concepts introduced in SustainGraph can be considered as accompanying information of the structure introduced in the property graph model. Following, we focus on the description of the property graph model of SustainGraph. A high-level view of SustainGraph structure is provided in Figure 4.1.

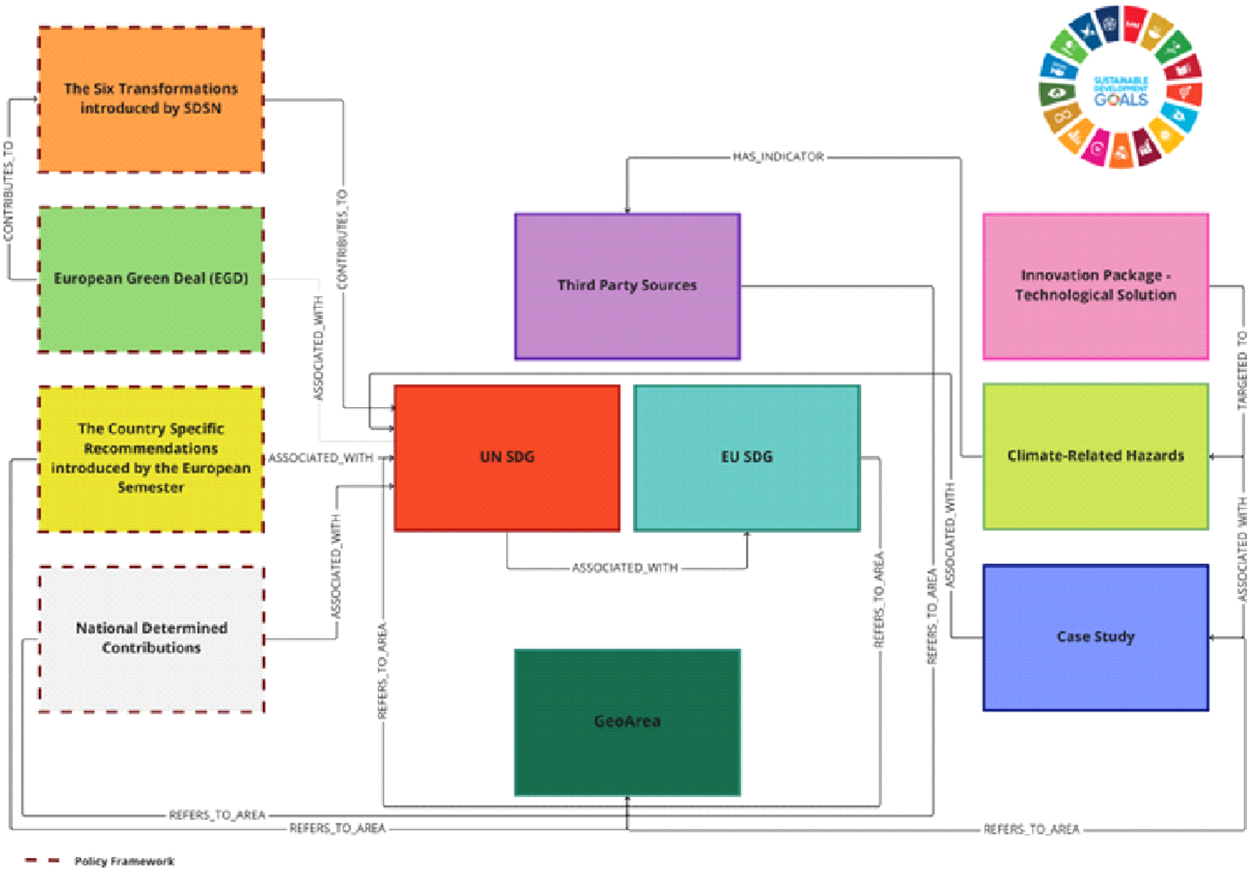

Figure 4.1: High level view of SustainGraph.

The main set of entities in SustainGraph has to do with the description of the structure of the UN Sustainable Development Goals (SDGs), building upon an existing formal knowledge organisation system for this purpose (Joshi et al., 2021). Within SustainGraph, a *Goal* has a set of *Targets*, where each *Target* is associated with one or more *Indicators*. Each Indicator is measured based on *Series* of data. Each data *Series* is accompanied by *SeriesMetadata* where details for the metric that is measured is provided, while

[3] https://netmode.gitlab.io/sustaingraph-ontology/

it includes a set of *Observations*. To support geolocation characteristics, each *Observation* refers to a specific geographical *Area (GeoArea)*.

The structure for the representation of the UN SDGs has been generalised to support the measurement of similar indicators in EU level, as well as indicators provided from third party sources. At EU level, EU SDG indicators are provided by Eurostat and can be associated with the UN SDG indicators. Multi-purpose indicators are defined, where one EU SDG indicator may contribute to more than one goal. Data coming from third party sources are also represented, aiming at supporting interdisciplinary scientists to realise analysis over such data. This is mainly applicable in the envisaged analysis within case studies, especially in cases where the existing SDG indicators are not sufficient to properly feed the developed models for the considered socio-environmental or socio-ecological systems. The *Source* of the *Indicator* (e.g., coming from UN SDG, EU SDG or a third-party source) is specified in the homonymous entity.

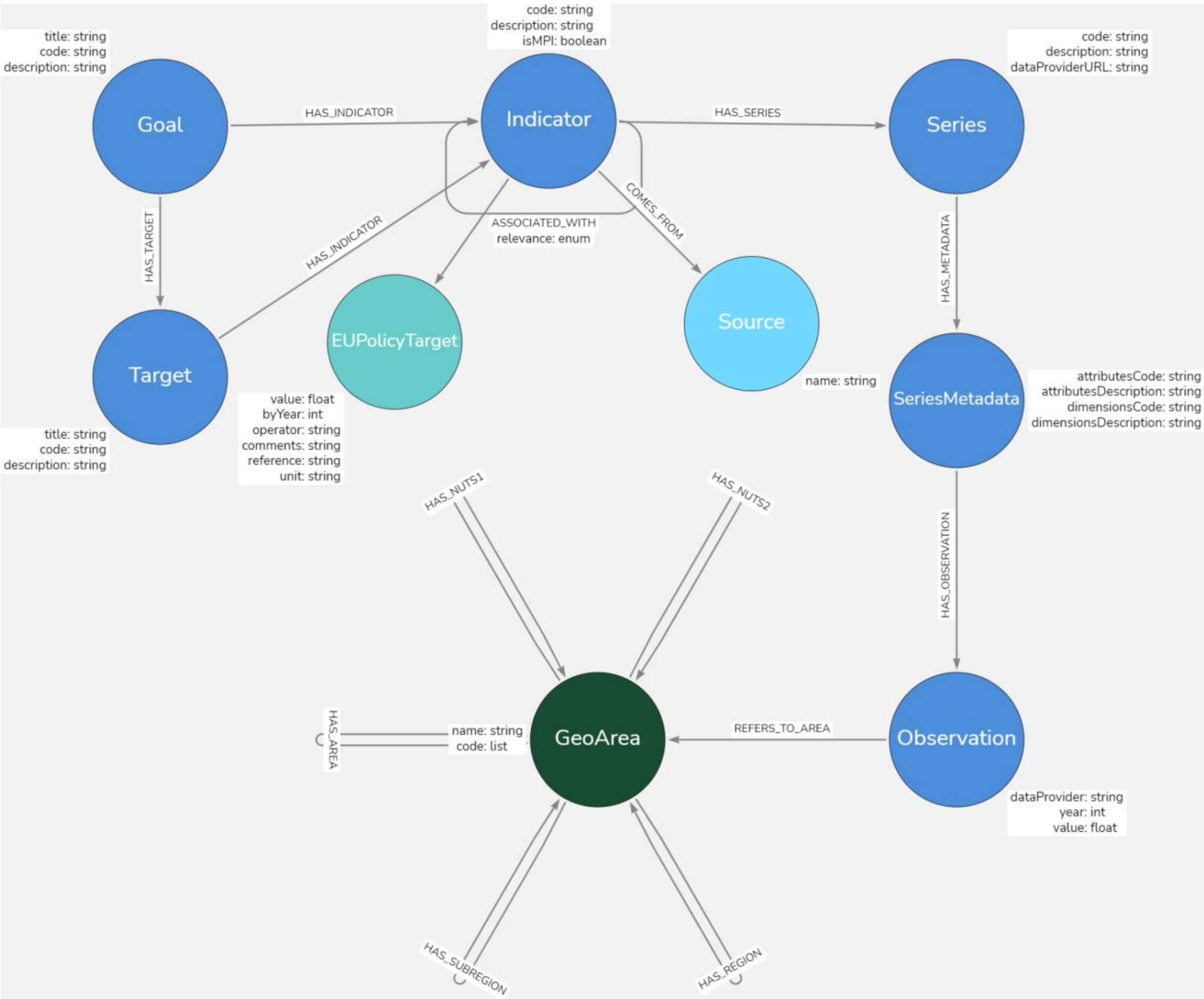

Figure 4.2: Sustainable Development Goals, Targets, and Indicators in SustainGraph.

A main characteristic that is supported in SustainGraph regards the capability to declare relationships among *Indicators*. Each *Indicator* can be associated with any type of *Indicator* within SustainGraph. For instance, this is applicable in the case of EU SDG indicators, where each EU SDG indicator may be similar to, part of or identical to an UN SDG indicator. In this way, the relationships among indicators tracked by different monitoring frameworks are represented, enabling data interlinking and interoperability. Furthermore, a relationship is added where each EU SDG Indicator can contribute to a specific *Policy Target* defined at EU level. A view of this part of the specification within SustainGraph is depicted in Figure 4.2.

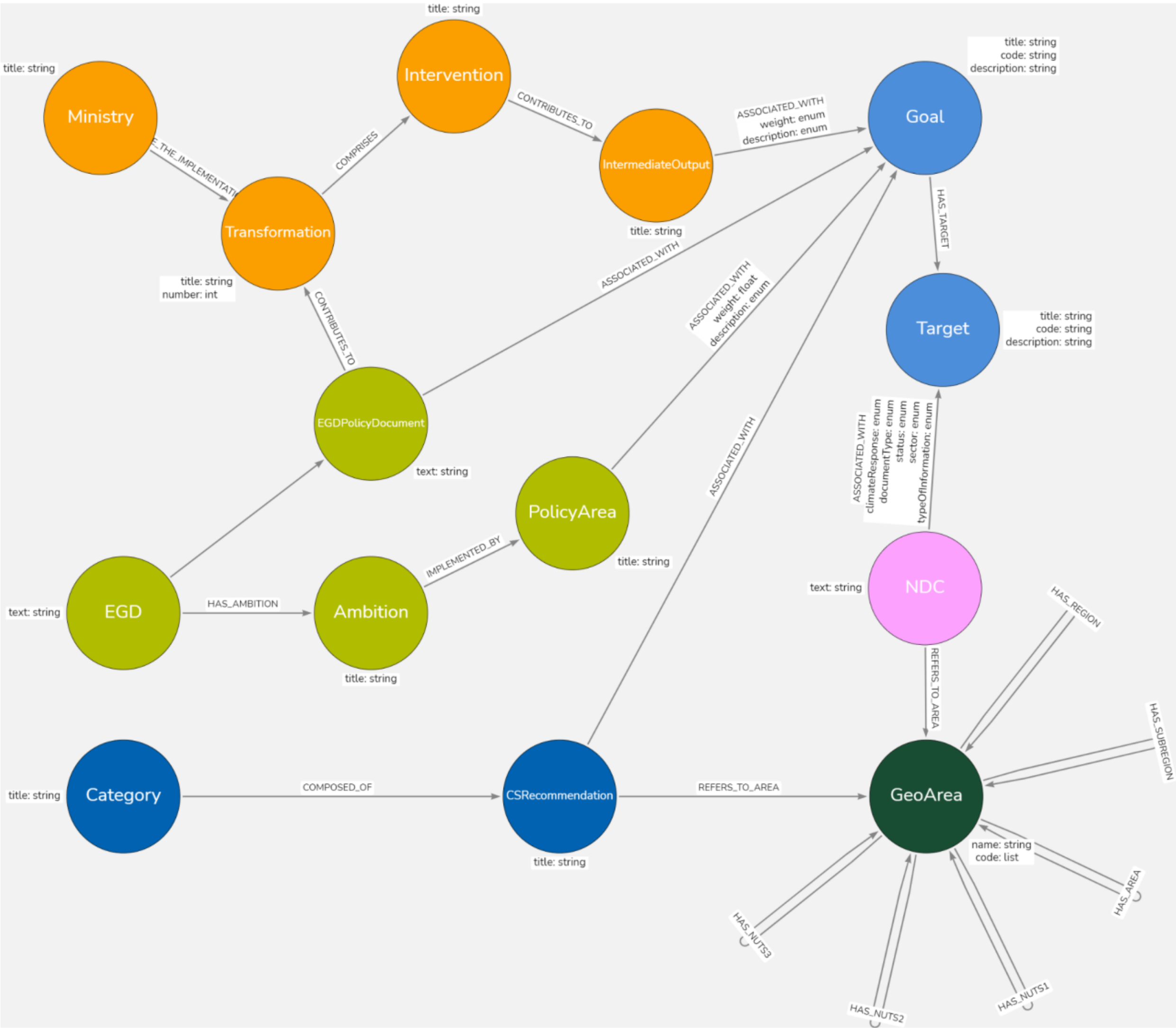

Figure 4.3: Sustainable Development Policy Frameworks in SustainGraph.

By having conceptualized the way that time series data from various indicators can be represented in SustainGraph, the next step was to consider data coming from policies frameworks and directives to adapt policies frameworks. Various policies are emerging at global, national, and regional level. Keeping track of the targets posed on policies documents and their status of achievement or not across time is important. At the current version of SustainGraph, focus is given on the representation of concepts coming from the *European Green Deal (EGD)*, the National Determined Contributions (NDCs), the *Country Specific Recommendations (CSRs)* and the *six SDG Transformations* proposed as modular building-blocks of SDG achievement (Sachs et al., 2019, 2021). For the *EGD*, the supported entities regard the defined

Ambitions of the EGD and their implementation through specific *Policy Areas*, where each *Policy Area* can be associated with one or more SDGs. Various *EGDPolicyDocuments* are produced to implement the *EGD*, where each *EGDPolicyDocument* can contribute towards the six SDG *Transformations* detailed at (Sachs et al., 2019).

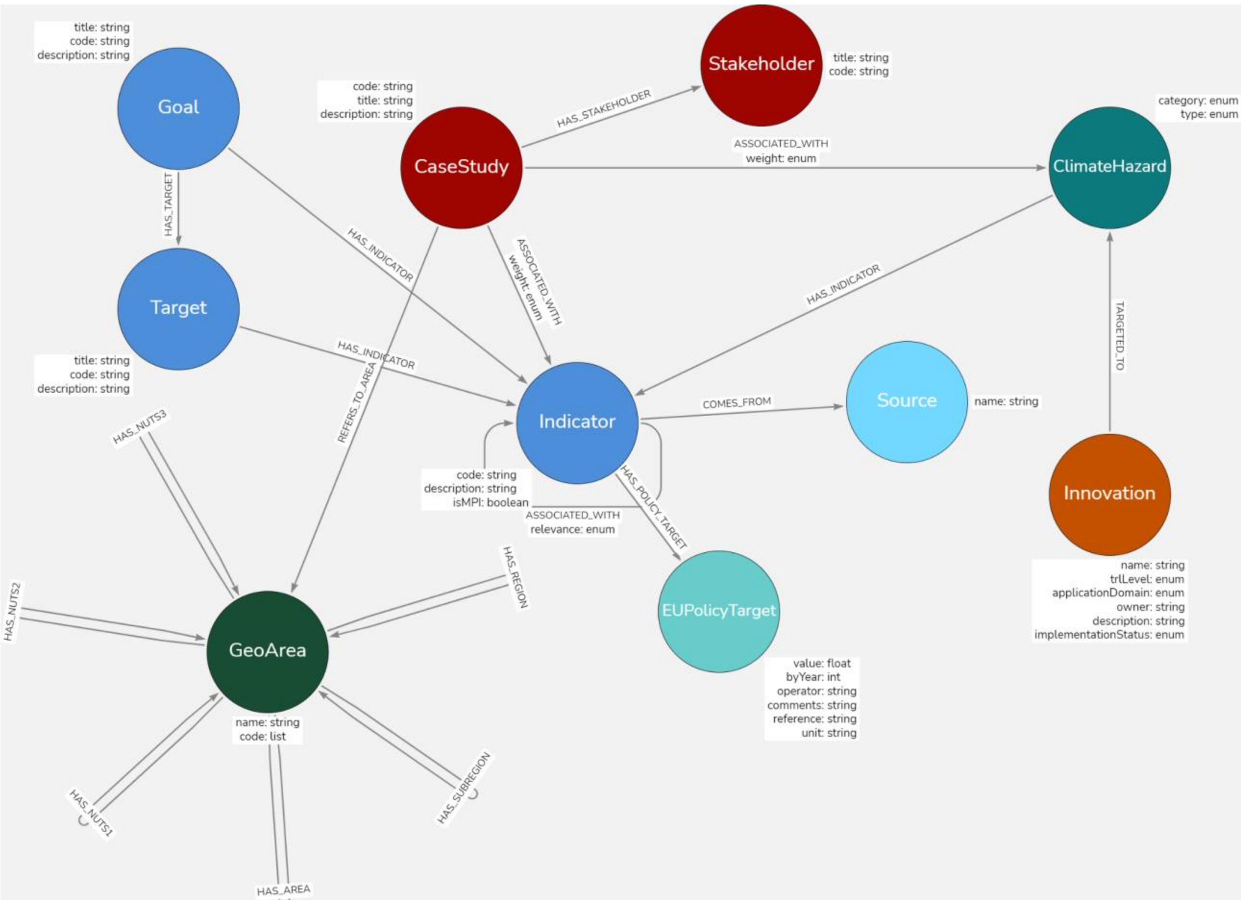

Figure 4.4: Case Studies, Climate related Hazards and Innovations in SustainGraph.

In the case of CSRs, once again, the *Recommendations* issued per country can be associated with one or more SDGs. These *Recommendations* are usually provided annually, thus it is important to keep track of the focus on SDGs across time. Regarding the *NDCs*, they provide action plans to cut emissions and adapt to climate impacts. An action plan is associated with specific SDG *Targets* and *Indicators* and specifies a set of targets that must be achieved at national level by a specific point of time along with their current status, the main application sector (e.g., health, water, agriculture, energy efficiency) and the type of climate response (e.g., mitigation, adaptation) considered. With regards to the six SDG *Transformations*, per *Transformation* we consider the suggested *Interventions* that may take place through the associated ministries, as well as the expected *Intermediate Output* from the transformation. A view of this part of the specification within SustainGraph is depicted in Figure 4.3.

Another important set of entities represented in SustainGraph is related to the implementation of Case Studies across Europe to develop climate-resilient regions through the adoption of systemic solutions and innovations. These entities regard the Case Studies, the Climate-related Hazards they aim to tackle and the Innovations that can be adopted and applied within each case study. Per Case Study we consider information related to a short description of the main challenges, actions and envisaged impact, the set of Stakeholders involved in the Case Study and the application GeoArea. Each Case Study is associated with SDG Goals, Targets, and Indicators, while it also includes information for Indicators defined by third-party data sources. Such information may be provided by monitoring infrastructure provided within the case study (e.g., Internet of Things (IoT) nodes, satellite images, data coming from citizen science platforms) or made available from other initiatives or monitoring frameworks (e.g., happiness index, corruption perception index). For the Climate-related Hazards, we have adopted the classification of hazards provided by the European Environmental Agency for tracking the Europe's changing climate hazards (Crespi et al., 2020). 32 climate hazard Indicators are made available, organised according to 16 hazard categories, grouped into 6 main types (heat and cold, wet, and dry, wind, snow and ice, coastal, open ocean) (Crespi et al., 2020). Moving one step forward, the Innovation entity is introduced to represent innovative solutions that are developed to support adaptation and mitigation measures for climate change, based on the description of such innovations in the Climate Innovation Window developed by the BRIGAID project (Mintsje van Loon-Steensma, 2018). Each Innovation is associated with specific Climate-related Hazards and is applicable to specific application domains. Information related to the owner of the Innovation and its Technology Readiness Level (TRL) is made available. A view of this part of the specification within SustainGraph is depicted in Figure 4.4.

Finally, attention is given on the proper representation of spatial information in SustainGraph. Spatial information is applicable to almost all the entities that are conceptualized in SustainGraph, given the importance to support high spatial resolution of the collected data. To achieve so, we support a hierarchical way of declaring information related to the location of the various entities. Country codes are supported based on both the International Standard ISO 3166-1 for the representation of names of countries and their subdivisions, as well as the M49 standard country or area codes for statistical use by the Statistics Division of the United Nations Secretariat. Furthermore, for EU countries, the Nomenclature of territorial units for statistics (NUTS) classification provided by Eurostat is introduced. Based on the NUTS classification, NUTS 1 areas are referring to major socio-economic regions, NUTS 2 areas to basic regions for the application of regional policies, and NUTS 3 areas to small regions for specific diagnoses. Representation of spatial geometry types is also under consideration within SustainGraph.

4.2. Development Process and Status

SustainGraph is developed based on the Neo4j graph database platform that is deployed in computing infrastructure provided by ICCS. The development is based on the community edition, while the official release is based on the enterprise edition, considering the support provided by Neo4j to the ARSINOE project. The data population mechanisms are implemented through Python scripts by using the Py2neo client library and toolkit that supports working with Neo4j from within Python applications. For the data analysis pipelines, the Neo4j Graph Data Science data analytics and machine learning platform is used. Visualisations are produced based on the usage of the NeoDash dashboard builder for the Neo4j graph database, the Neo4j Bloom visualisation tool and SemSpect as a scalable graphical exploration interface for knowledge graphs. For the proper documentation of SustainGraph and for drawing pictures of graphs, the arrows-app web-based tool is used.

4.3. Interoperability with the Data Hub and the Dashboard

SustainGraph is part of the overall ICT infrastructure for knowledge management that is built within the framework of the WP4 activities in ARSINOE. The Data Hub consists of a knowledge repository, where various datasets are going to be hosted and made available to the data population mechanisms supported by SustainGraph. Such datasets are provided through the implementation of the case studies in ARSINOE. The development of data population mechanisms is in progress, where data hosted in the Data Hub in processed and provided to SustainGraph in an interoperable format. In parallel, a design is evolving regarding the visualisation outcomes of SustainGraph that will be introduced in the ARSINOE Dashboard. A set of web-based visualisation tools are considered that will enable end users to navigate in SustainGraph, submit queries and view the produced results. Access to such tools will be provided through proper user interfaces within the Dashboard.

5.0 SustainGraph Ontology

As mentioned in the introductory part of this document, SustainGraph is modelled in the form of a property graph model, as well as in the form of an ontology. The labelled property graph (LPG) model is one of the core technologies for KG representation. The LPG model includes a set of attributes to nodes and edges. By having specified a LPG model, the development of an associated ontology is very helpful to incorporate semantic metadata to make the graph model smarter and to support data alignment with existing ontologies.

The SustainGraph ontology is developed based on the W3C Web Ontology Language (OWL), which is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. Overall, the ontological description of the main concepts introduced in SustainGraph ontology can be considered as accompanying information of the structure introduced in the LPG model. An important difference between the LPG model and the ontology regards the way that properties of relationships are represented. In the LPG model, the edges (relationships) can have properties in contrast with the RDF model, in which properties cannot be directly associated with edges. A common approach to model this in an ontology is called Reification approach. As a result, edges with properties are represented as intermediate classes with their own data properties. Figure 5.1 shows the classes in the SustainGraph ontology, their hierarchy, and the relation among them.

The SustainGraph ontology includes a set of classes that are highly relevant with the entities in the LPG model. It consists of two major classes, the Policy Framework and the Concept. The Policy Framework superclass contains the subclasses regarding the emerging policies related to the Sustainable Development Goals (6T subclass, EGD subclass, CSR subclass, NDC subclass). Each of the Policy Framework subclasses is linked to other classes within their policy framework. Furthermore, the Concept super class includes a set of subclasses for representing the SDGs. Within SustainGraph ontology and in accordance with the LPG model, a Goal has a set of Targets or Indicators. Each Indicator is measured based on a Series of data which is accompanied by Observations that refer to specific geographical Area (GeoArea class). The indicator class is associated with an intermediate class that represents the association between the EU and the UN SDG indicator. Each EU SDG Indicator can contribute to a specific Policy Target defined at EU level. Another important set of entities represented in the SustainGraph ontology is related to the implementation of Case Studies across Europe to develop climate-resilient regions through the adoption of systemic solutions and innovations.

The documentation of the SustainGraph ontology is available at https://netmode.gitlab.io/sustaingraph-ontology/, while the source code is available at https://gitlab.com/netmode/sustaingraph-ontology.

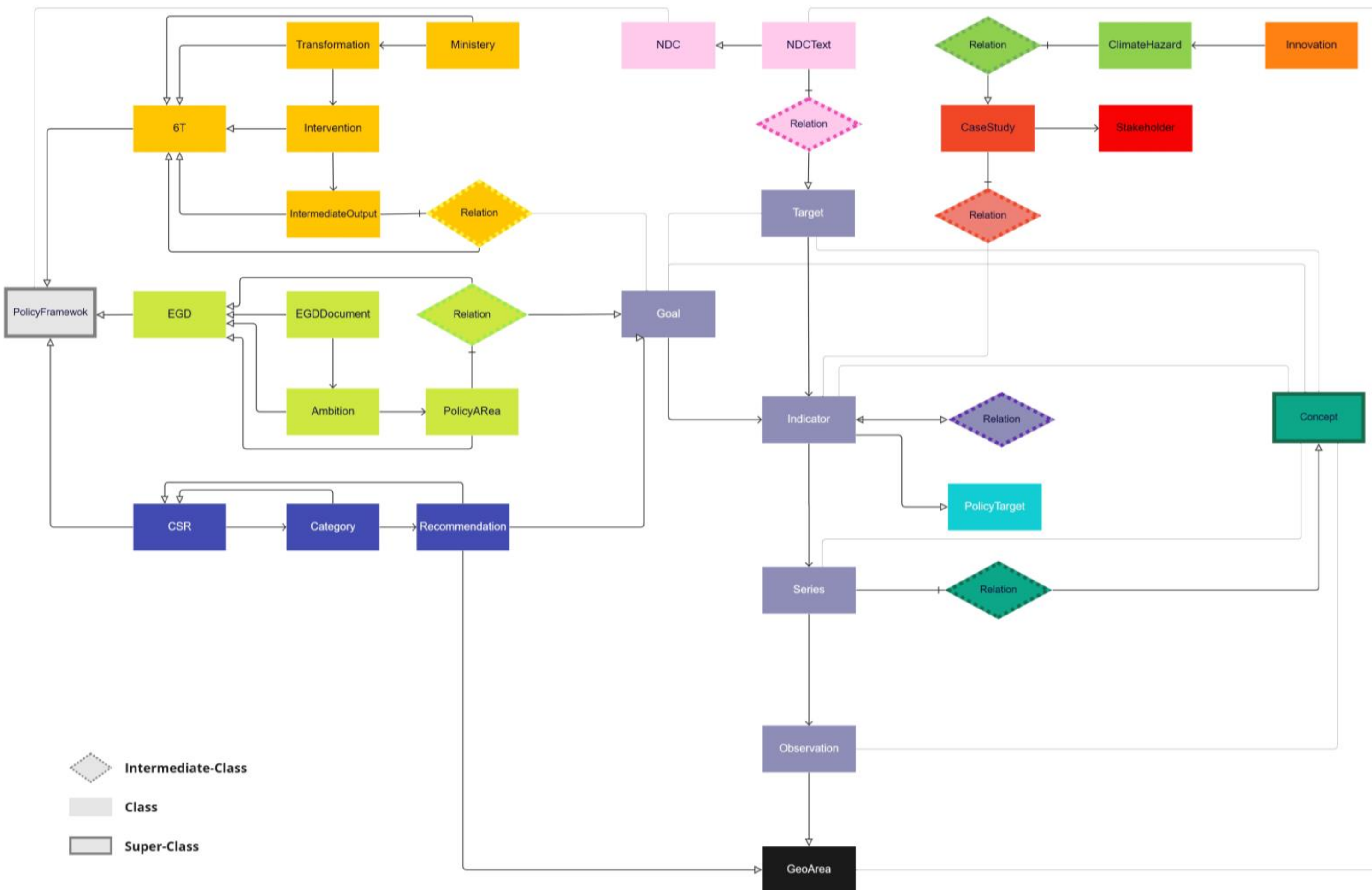

Figure 5.1: SustainGraph Ontology.

6.0 SustainGraph Data Management Mechanisms

6.1. Data Population

Based on the conceptualization of SustainGraph, a set of data population mechanisms are implemented to support knowledge acquisition processes. Through the data population mechanisms, existing data provided by various sources and different formats can be transformed to knowledge within SustainGraph. The data population process is a dynamic process, where fresh data is continuously fed into the KG, enriching the available information, and enabling further knowledge production and management. The main challenge faced here has to do with the development of custom scripts for automating or semi-automating the data ingestion to the KG. By making available such scripts, new releases of the considered datasets can be easily incorporated in the KG, significantly reducing the overhead posed to data scientists for continuously processing the available data to bring them into a homogeneous and interoperable format.

A wide set of data sources is considered. This set includes open data provided by international organisations, statistics authorities, and public bodies in the form of tabular datasets (e.g., files in csv format) or through open Application Programming Interfaces (APIs), data coming from the monitoring infrastructure that is implemented within case studies in various regions, and data coming from the processing of policy documents and reports. For the latter, machine learning (ML) techniques are applied to support the knowledge acquisition process. The main considered ML technique is related to Natural Language Processing (NLP) mechanisms that help understanding the content of the documents and extract information and insights from them. Data cleaning mechanisms are applied for improving data quality, while considering bias detection in terms of fairness. Data cleaning may regard -among others-removal of outliers, removal, or completion of entries with missing values, and deletion of content that is not considered for inclusion in the KG.

A list of the main data sources used for populating with data SustainGraph is provided in Table 3. As already mentioned, this list should be considered as indicative, since the list of data sources is continuously evolving given the availability of further data and the emergence of new concepts within SustainGraph.

Table 6.1 Indicative Data sources for SustainGraph data population.

Data Provider	Description	Data Type
United Nations SDG API	UN SDG Indicators[4] (SDG data reported by the United Nations Statistics Division).	Tabular (data retrieved through an API)
Eurostat Sustainable Development Indicators	EU SDG Indicators[5] (SDG data reported by Eurostat).	Tabular (CSV data processing)
National Determined Contributions	NDC data based on the Paris Agreement[6] (time series data for specific indicators, as well as data related to the linkage between	Tabular and Classification (linkage) data (data retrieved through an API)

[4] https://unstats.un.org/sdgapi/swagger/
[5] https://ec.europa.eu/eurostat/web/sdi/indicators
[6] https://www.climatewatchdata.org/data-explorer/ndc-content

Data Provider	Description	Data Type
	NDCs and SDGs).	
World Happiness Report	World Happiness Index[7] (survey data reporting how people evaluate their own lives).	Tabular (CSV data processing)
Transparency International	Corruption Perceptions Index[8] (time series data for the perception of corruption levels worldwide).	Tabular (CSV data processing)
European Environmental Agency	Climate Hazards Classification (data for the classification of climate hazards and the associated indicators) (Crespi et al., 2020).	Tabular and Text (data import based on a script)
Climate Innovation Window	Innovations[9] (reference portal for innovations on climate change adaptation).	Tabular (data import based on a script)
European Union	European Green Deal Documents (policy documents).	Text (processing based on NLP)
National Data	CountrySpecific Recommendations (documents with recommendations per country).	Text (manual data processing and NLP)
Research and Innovation Projects	Case Study Data[10] (e.g., data provided in the ARSINOE project).	Tabular and Text (csv data processing, text processing based on NLP)
6Transformation	Data from 6Transformations Report (mapping between transformations and SDGs) (Sachs et al., 2019, 2021)	Tabular (csv file produced from the report)

6.2. Knowledge Production, Exploration and Evolution

By having access to a data-populated version of SustainGraph, a set of services can be offered upon it. These services include data exploration and visualisation, data analysis, participatory modelling and analysis, knowledge production and KG completion. Following, we provide a short description of these services, while usage examples are provided in Section 4.3.

As already stated, SustainGraph can be considered as a knowledge repository related to the evolution of SDG indicators at national and regional level. Data exploration can take place through the submission of queries by end users. Each query is related to an open question, while the query result may provide an

[7] https://worldhappiness.report/
[8] https://www.transparency.org/en/cpi
[9] https://climateinnovationwindow.eu/
[10] https://arsinoe-project.eu/

answer on it. Data exploration can be provided also through web-based navigation in the entities and relationships of SustainGraph. Various visualisations can be produced for depicting trends in the available data, comparing metrics based on their temporal and/or spatial resolution, and highlighting the weight of the existing relationships in the graph. In this way, end users can explore the existing knowledge in the KG, achieve common understanding, get answers to specific questions and easily grasp trends and insights through visualisations.

Moving one step further, through the submission of queries to SustainGraph, the retrieved data can be fed as input to analysis pipelines. Such analysis pipelines may regard algorithms applied over tabular data or graph algorithms applied over SustainGraph or a part of SustainGraph. In the case of tabular data, algorithms such as correlation analysis, regression, descriptive statistics, and classification may be applied. Tabular data can be also fed as input to developed participatory socio-environmental systems' models (e.g., based on agent-based modelling, system dynamics modelling) (Zafeiropoulos et al., 2021). Graph algorithms can be applied to support pattern identification within the KG and to evaluate the structure of the KG (e.g., examine the graph density, identify clusters, community detection). Graph ML techniques can be adopted to support link prediction and to evolve the KG with the introduction of new relationships, similarity analysis based on node embeddings, and classification analysis based on the application of node classification models. The outcomes produced by analysis pipelines can be used for the development of recommendation engines, providing insights for the design of efficient solutions (e.g., to improve the climate resilience of the considered areas within a case study).

It should be noted that the analysis results may be also fed back as information to the KG. In this way, further knowledge may be produced and made available, while results produced by different models can be compared.

6.3. Indicative Use Cases

To demonstrate the applicability of SustainGraph to guide the co-design of innovative solutions for managing the impact of climate change, we detail a set of short and simple use cases. Knowledge exploration for these use cases takes place in the form of providing answers to questions, or through navigation in the information visually depicted in SustainGraph. Given the conceptualization of SustainGraph, the objective is to provide some highlights on its potential usage. The provided examples can be considered as the basis for the development of advanced analysis processes in the future, bound to the development and validation of socio-environmental or socio-ecological models. Following, we briefly describe these use cases.

Use case #1: For a specific UN SDG indicator, compare its evolution per country in the last 20 years for countries in the Mediterranean.

In this use case, we examine the evolution of the UN SDG indicator 1.1.1 in part of the Mediterranean countries. The indicator depicts the proportion of the population living below the international poverty line and is used for evaluating the target 1.1 (by 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day) of SDG #1. A query is submitted to SustainGraph to get time series data for a set of data series associated with this indicator for a set of countries. The produced output is visualised in Figure 6.1.

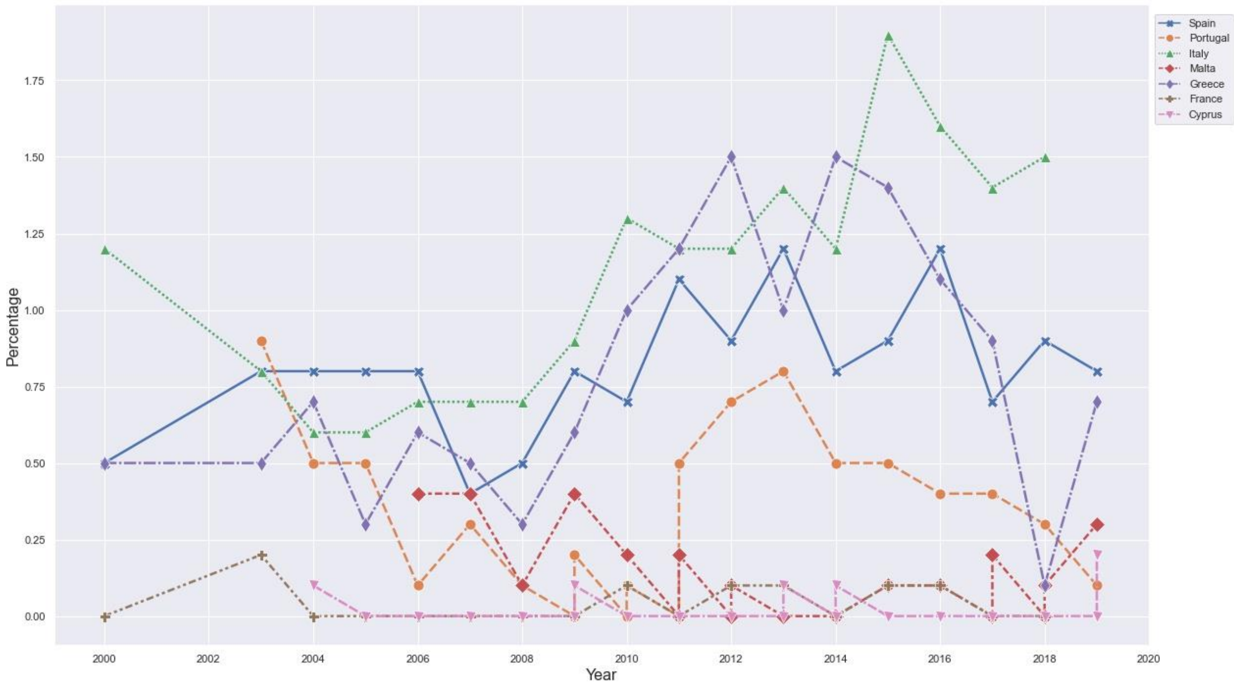

Figure 6.1: Monitoring of an UN SDG indicator across countries in the Mediterranean.

Use case #2: For a specific EU SDG indicator, compare the current status of the indicator across the EU countries, considering also the EU policy target to be achieved by 2030.

In this use case, we examine the current status of a specific EU SDG indicator, namely sdg_04_70 that tracks the ”Share of individuals having at least basic digital skills” across the EU countries. The current status of the indicator is compared to the posed target at EU level for 2030 that is 80%. Upon getting the relevant data through a query in SustainGraph, the visualisation depicted in Figure 6.2 is produced. A digital gap is noticed among the EU countries, since the indicator values range from 24% (e.g., countries in Southeastern Europe) to 81% (e.g., Scandinavian countries).

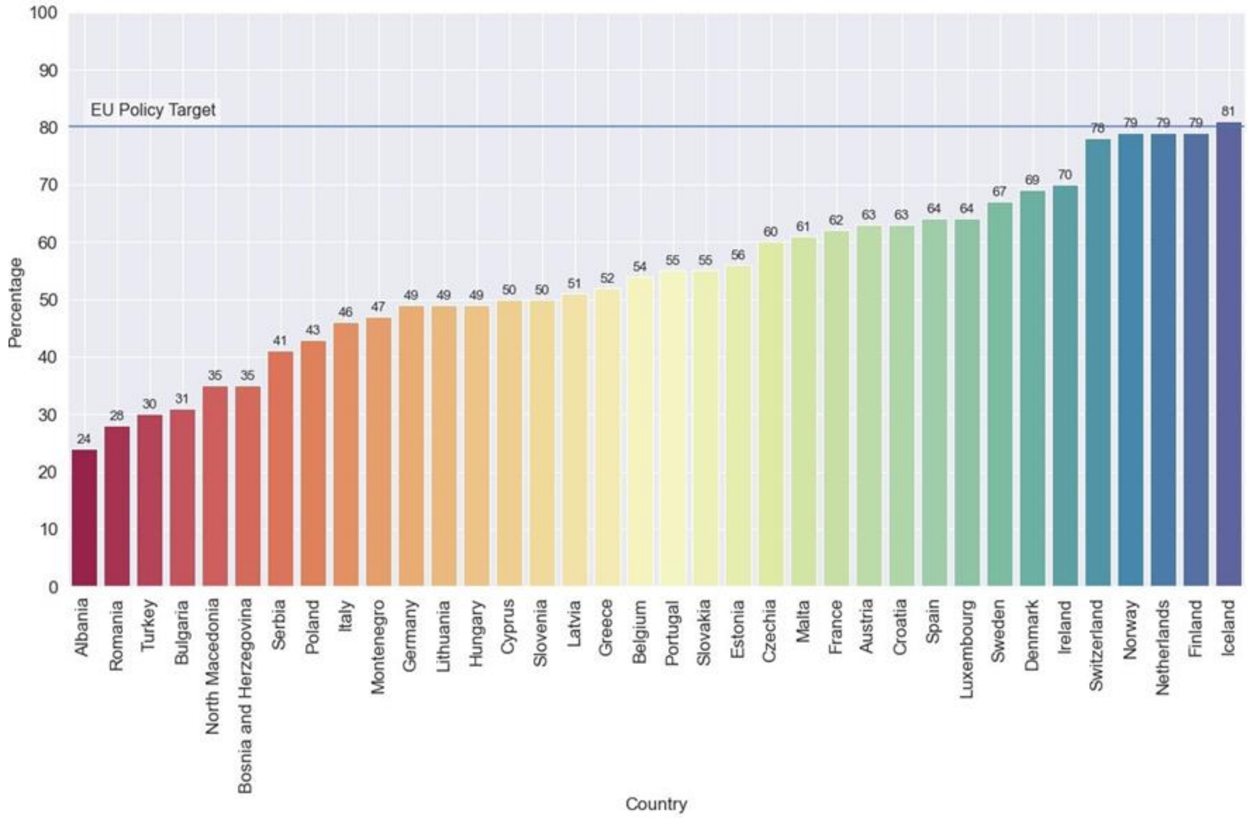

Figure 6.2: Monitoring of an EU SDG indicator across EU countries.

Use case #3: Which SDG targets are mostly considered in the plans for the Nationally Determined Contributions (NDCs)?

In this use case, we consider the G8 countries, and we examine the importance posed in their Nationally Determined Contributions (NDCs) towards the achievement of the SDGs. The objective is to get a high-level view of the priorities set by these countries, as well as identify any differences. Through a query in SustainGraph, the produced visualisation is depicted in Figure 6.3. For the EU countries (Italy, Germany, and France) the produced distribution is identical, since the NDCs of these countries are based on the overall direction provided by the EU. The most considered SDGs regard SDGs # 7, 12 and 15. SDGs # 7 and 15 seem to be considered in the NDCs of all G8 countries with rates varying from 8-50% for SDG #7 and 13-50% for SDG #15. In the case of Russia, only these two SDGs are considered with a rate of 50% each. The most prioritised SDG is SDG #12 (with rate 23%) for Japan, SDG #7 (with rate 31%) for Canada, SDG #12 (with rate 17%) for United Kingdom, and SDGs #2 and 7 (with rate 19% each) for the United States of America.

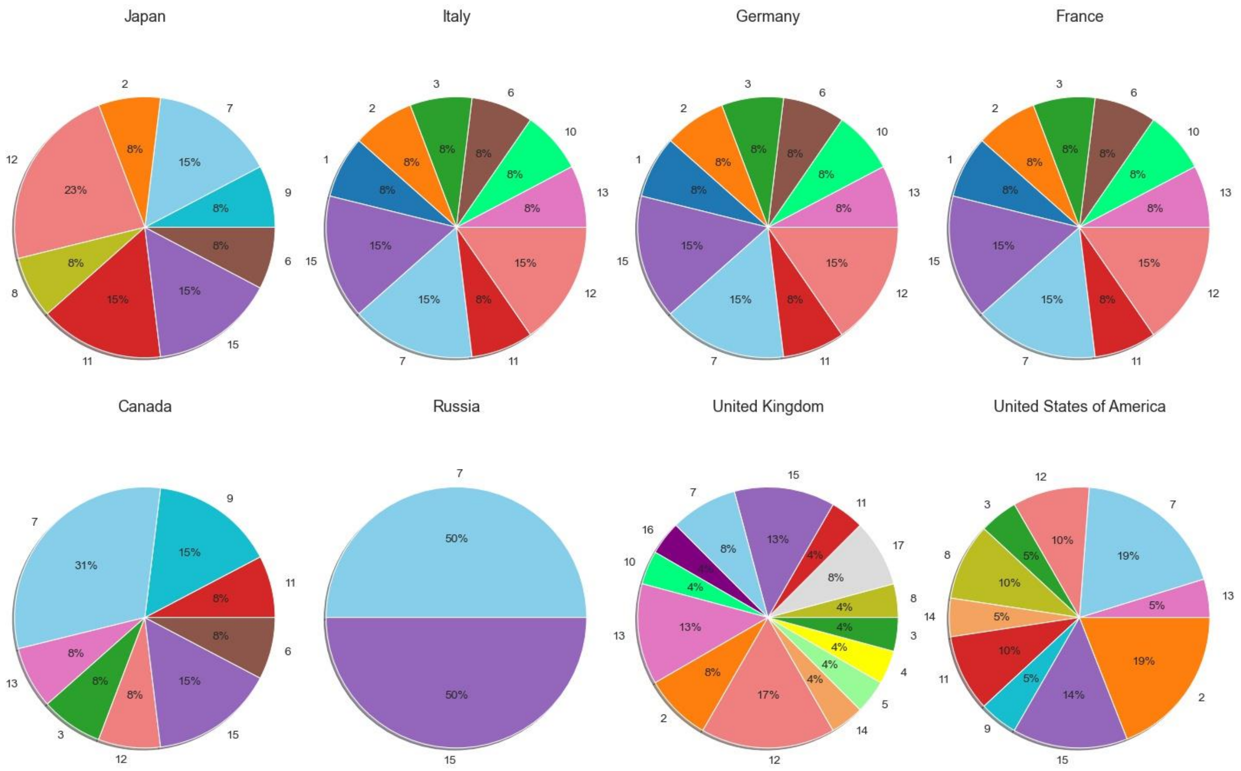

Figure 6.3: Association between NDCs and SDGs for the G8 countries.

Use case #4: What is the relationship between the Outputs expected from a specific Transformation with the SDG goals?

In this use case, we examine the association between a specific Transformation and the SDG goals, given that the Transformations are considered as modular building blocks for SDGs achievement. We have selected the "Health, Wellbeing, and Demography" Transformation (Sachs et al., 2019). Navigating in SustainGraph (see Figure 6.4), it is noticed that this Transformation is mainly implemented by the Ministries of Health, while it comprises of two Interventions (development of healthy behaviours and social determinants of health, support of universal health coverage). These interventions contribute to the Intermediate Output of providing Public Health Services that is associated with a set of SDGs (SDGs # 1, 405 2, 3, 4, 5, 8, 9, 10, 11, 12, 16).

Use case #5: For a specific case study, what are the associated climate hazards that are tackled within the considered geographical areas? Are there any innovations that can be adopted to tackle these hazards?

In this use case, we focus on a specific case study developed within the ARSINOE H2020 project (ARSINOE project, 2022). The case study focuses on tackling the impact of heat waves in the Attica area of Greece. As an initial examination of the case study, we want to identify what are the main climate hazards considered in the case study and if there are available existing technological solutions to help to mitigate their impact. By navigating through SustainGraph, we can see that "Heat and cold" is the main hazard category considered, while the associated hazard types regard the "Extreme heat" and the "Mean temperature" increase (see Figure 6.5). For tackling these hazard types, four innovations are made available through the “Climate Innovation Window” platform with Technology Readiness Level (TRL) levels ranging from 4 to 7.

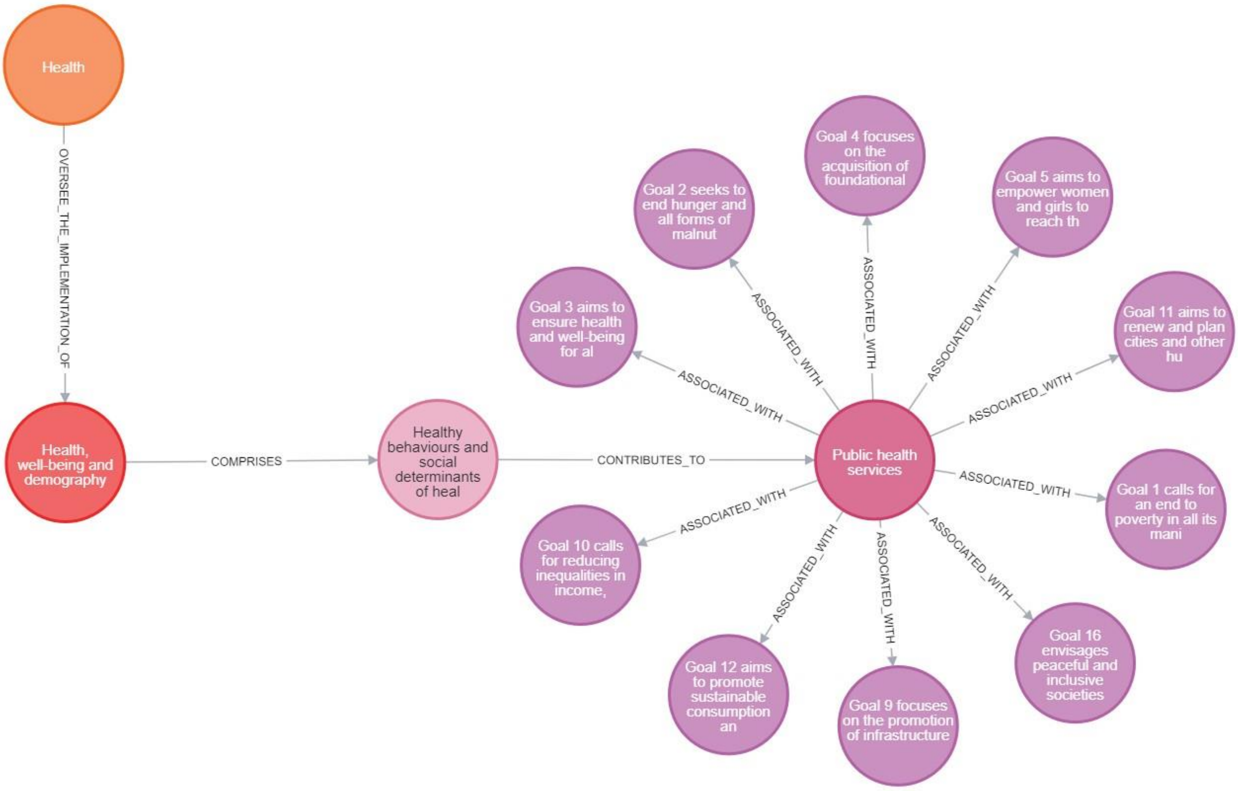

Figure 6.4: Association between a specific Transformation and the SDGs.

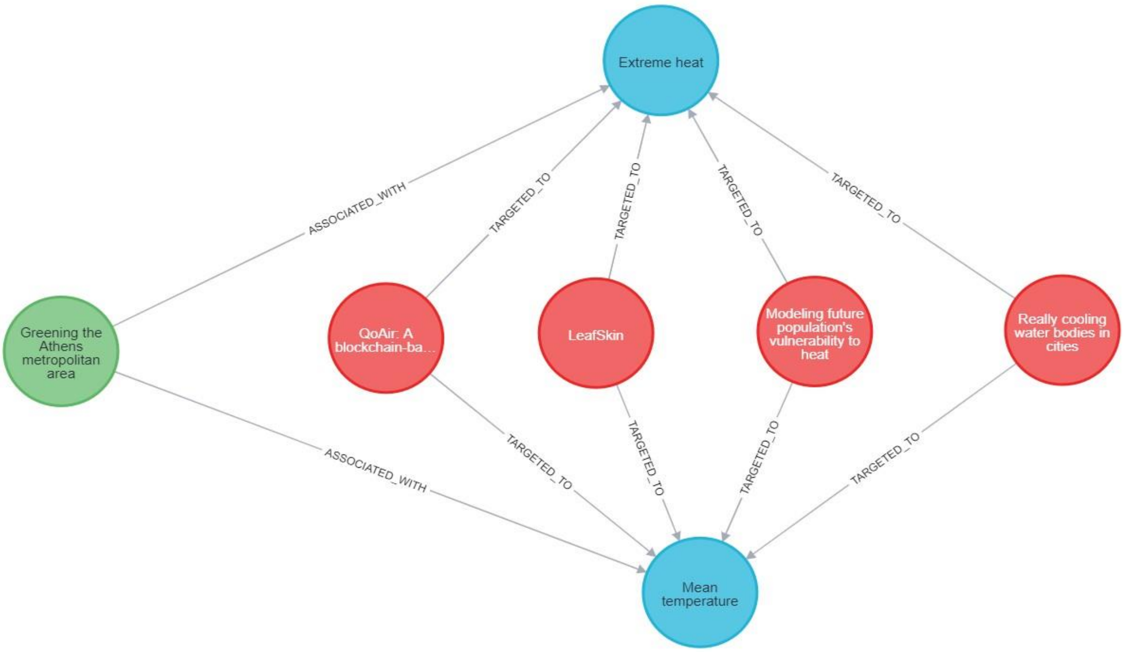

Figure 6.5: Climate hazards and innovation for a specific case study.

7.0 Conclusions and Next Steps

In the current work, we have presented SustainGraph, as the first, to our understanding, Knowledge Graph that tries to holistically represent information associated with the set of goals, targets and indicators specified by the United Nations in the 2030 Agenda for Sustainable Development. SustainGraph is conceptualized by having in mind the need to track targets and indicators provided by different data providers, considering the need to represent their association based on their exact definition (e.g., the UN SDG and the EU SDG indicators are not identical). The information collected in SustainGraph includes data related to the association between the emerging policies and the SDGs, the implementation of case studies and the release of innovative solutions to tackle climate change.

The conceptualization and development of SustainGraph is the first and basic step to serve a wide set of end users, including the scientific community, policy makers and educational organizations. To achieve so, various challenges are being considered and effort is allocated to tackle them. One of the major challenges has to do with the development of mature solutions to easily populate SustainGraph with data. As already mentioned, data quality issues along with the need for harmonization of the provided datasets by different data providers hinder the ease adoption and usage of such data. A set of data population mechanisms are already into place to support the population of SustainGraph with qualitative data, however, further mechanisms must be developed in the future, considering the volatility of the structure of the produced data and the inclusion of further data sources (e.g., data coming from initiatives related to the development of sustainable cities, data associated with the classification of activities according to the EU Taxonomy). Another challenge has to do with the development of user-friendly interfaces to make SustainGraph easily adoptable by end users without expertise in computer science. To achieve so, a set of visualisation tools are considered that make straightforward the interaction with SustainGraph, while work is in progress towards the development of user-friendly querying interfaces for submission of questions by end users.

SustainGraph aims also to promote collaboration among scientists from various domains, being aligned with the Systems Innovation Approach. Participatory modelling approaches can be applied over SustainGraph, taking advantage of the harmonization of the represented concepts in the KG and the provision of access to data that are accompanied by their meaning and can make sense to the end users. Interoperability of SustainGraph with tools that support the execution of analysis pipelines and modelling environments (e.g., multi-agent programmable modelling environments) is desirable, since it is going to further boost its usability by scientists. Furthermore, ways for ingesting the analysis results to the KG are going to be considered (e.g., the forecasting of the evolution of specific indicators can be available in the KG).

Special mention must be given to the exploitation of opportunities provided by the emergence of ML techniques and toolkits. ML techniques can be applied in SustainGraph for supporting both data population and data analysis mechanisms. Natural Language Processing (NLP) techniques are very helpful to analyse policies documents and extract information that can be embedded in the KG. In a similar way, computer vision techniques can be applied over images (e.g., from satellite infrastructure or citizen science platforms) to further populate with data the KG. In the analysis part, various ML pipelines can be developed to support KG evolution and completion processes, considering graph ML algorithms. Focus has also to be given on the development of explainable Artificial Intelligence (AI) solutions over SustainGraph, providing accurate and easily interpretable decisions, and facilitating the adoption of such solutions by scientists (Tiddi and Schlobach, 2022).

To be able to support these extensions, openness and interoperability regard characteristics that are considered by design in the conceptualization and development of SustainGraph. An open-source release of SustainGraph is made available (Fotopoulou et al., 2022), while consumption of open APIs is considered, where applicable, in the development of data population mechanisms. The latter is going to be achieved with the proper interlinking of SustainGraph with the ARSINOE Data Hub, will ongoing work targets to the interlinking of the outcomes produced through SustainGraph with the ARSINOE Dashboard.

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Systems Innovation Approach (SIA) addresses the growing complexity, interdependencies and interconnectedness of modern societies and economies, focusing on the functions of the cross-sectoral system as a whole and on the variety of actors. The Climate Innovation Window (CIW) is the EU reference innovations marketplace for climate adaptation technologies. ARSINOE shapes the pathways to resilience by bringing together SIA and CIW, to build an ecosystem for climate change adaptation solutions. Within the ARSINOE ecosystem, pathways to solutions are co-created and co-designed by stakeholders, who can then select either existing CIW technologies, or technologies by new providers (or a combination) to form an innovation package. This package may be designed for implementation to a specific region, but its building blocks are transferable and re-usable; they can be re-adapted and updated. In this way, the user (region) gets an innovation package consisting of validated technologies (expanding the market for CIW); new technologies implemented in the specific local innovation package get the opportunity to be validated and become CIW members, while the society (citizens, stakeholders) benefits as a whole. ARSINOE applies a three-tier, approach: (a) using SIA it integrates multi-faceted technological, digital, business, governance and environmental aspects with social innovation for the development of adaptation pathways to climate change for specific regions; (b) it links with CIW to form innovation packages by matching innovators with end-users/regions; (c) it fosters the ecosystem sustainability and growth with cross-fertilization and replication across regions and scales, at European level and beyond, using specific business models, exploitation and outreach actions. The ARSINOE approach is show-cased in nine widely varied demonstrators, as a proof-of-concept with regards to its applicability, replicability, potential and efficacy.

ARSINOE

CLIMATE-RESILIENT REGIONS THROUGH SYSTEMIC SOLUTIONS AND INNOVATIONS

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