Water Policy 21 (2019) 894–910

An ontology for exchanging innovation in water management

Francisco J. Lopez-Pellicer, Javier Lacasta*, Rubén Béjar, Javier Nogueras-Iso and F. Javier Zarazaga-Soria

Universidad de Zaragoza, Zaragoza, Spain

**Corresponding author. E-mail: jlacasta@unizar.es*

Abstract

As the new technological developments become increasingly complex, the creation of partnerships between companies and research centres becomes essential. Nowadays, there are several platforms trying to offer a stable innovation market that can be used for the transfer of innovation in water management. However, they neither allow a complete description of the features of innovation proposals nor are capable of describing the specific requirements of the different research fields. This work describes OntoInnova, an ontology that provides a more complete model of the different elements related to research, development and innovation exchange in water management. We have applied this ontology for the modelling of the innovation data collected in the European WE@EU project for water management in urban environments.

Keywords: Innovation technologies; Ontology; Water management

Introduction

Innovation is an urgent need for the water-related domain. Challenges such as population growth (Hunter *et al.*, 2010) and global climate change (Delpla *et al.*, 2009) make innovations related to the use of water especially relevant to society. Usually, infrastructure sectors invest important resources (time and money) in innovation to develop better products, processes, services, technologies, or ideas that give an advantage in market competition (Hall, 2004; Frankelius, 2009). However, there is a significant lack of investment in research and development in water management compared to other sectors due to the recent economic crisis, the dimension of water projects, and risk aversion from the management when the existing solutions are satisfactory (Ipektsidis *et al.*, 2016). Other causes that make innovation in water management complex are the specificity or multidisciplinarity of the work, the difficulty in assessing the innovation impact, and the uncertainty of the cost recovery of research tasks. Recent years have seen public funding schemes for improving the performance of water management innovation. In Europe, programmes such as Horizon 2020 or LIFE 2014–2020 provide access to

doi: 10.2166/wp.2019.224

funding that can be applied to water innovations. However, a full understanding of how to transform these funds into innovation in the water sector is still limited (Wehn & Montalvo, 2018).

There is a shared agreement that partnerships developed in fairs, congresses, and networking, in general, are facilitators of research and innovation development (Egger, 2006). The same happens in the water sector. An example is the Water Market Europe, whose first edition was held in 2017 organized by the European Technology Platform for water (WssTP, 2017). In this meeting, leading water actors (problem owners or 'clients' and solution providers or 'sellers') show their ideas, innovations and problems and try to foster networking and matchmaking. These meetings are useful, but they are often too focused on exhibiting ongoing local projects and top-notch technologies. Additionally, they are often organized as one-off meetings without guarantee of continuity. Hence, they do not develop a critical mass or provide a stable market for the exchange of research, development and innovation in the water domain.

The term innovation market can also be applied to describe the purpose of some initiatives supported by web platforms. An example is the European Innovation Partnership on Water (EIP Water), which aims to speed up innovations on water management by creating an innovation-friendly environment that facilitates turning ideas into products and services (Schmidt *et al*., 2018). Similarly, WaterInnEU is a Horizon 2020 project that tries to offer a stable innovation market to enhance the exploitation of models, tools, protocols and policy briefs related to water. The main drawback of these approaches is their bet for a generic and simple model to manage innovation offers and demands, which makes difficult the creation of intelligent search and matching systems.

Based on the above experiences, we believe that facilitating the exchange of knowledge through a system capable of exposing the needs and experience of the agents involved in water management innovation could help in the creation of partnership agreements and new opportunities related to innovation. However, none of the above approaches has a suitable model able to represent the main scenarios related to innovation exchange in water management. To fill this gap, this paper describes the OntoInnova ontology, an ontology that allows the conceptualization of innovation needs/expertise and the description of the available technologies (applications, models, methods and tools) and intellectual property rights (copyright, patents and industrial design rights) in this field. The use of ontologies for describing offers and demands of products is not new. They have already been successfully used in contexts such as e-commerce markets. Ding *et al*. (2003) show how ontologies can be used for integration of e-commerce information. The best example is the GoodRelations ontology, which was created to cover the representational needs of typical e-commerce scenarios in a semantic web-based e-commerce infrastructure, which is used in a broad set of e-commerce contexts (Hepp, 2008). However, the application of these kinds of ontology to the water management is a novelty because ontologies in the water domain are usually used for representing domain knowledge (Hahmann & Stephen, 2018; Wang *et al*., 2017; Meng *et al*., 2018).

OntoInnova has been used to model the data collected in the European WE@EU project for water management in urban environments (WE@EU, 2016a), an EU 7PM project funded by 'Regions of Knowledge' programme. One of the key points to facilitate the sustainable development of cities is the efficient management of water. In 2011, the Council of the European Union concluded that 'while water availability and water quality are essential for sustainable development and green economy, waters face many threats including increasing trends of global population growth, urbanization, pollution, over-exploitation, desertification and climate change' (Council of the European Union, 2011). Numerous international frameworks, policies and agreements have been created to face these challenges (e.g., the EU Water Framework Directive). However, water scarcity and droughts still threaten society, and scientific and technological advances are required to ensure improved water management. In this context, WE@EU project identified groups of interest in the water management domain and collected their research expertise and lines of work. Modelling this information with OntoInnova has facilitated the automatic identification of common interests and compatible areas of expertise between groups.

State of the art

Recently, Wehn & Montalvo (2018) had pointed out that, in general, there is an absence of academic studies on the specific dynamics of water innovation. Nevertheless, we can review the literature on innovation management as a starting point. Some works focus on how to improve the management of the processes that generate innovations. Some of them discuss the theoretical aspects of innovation management. Marinova & McAleer (2003) remark how innovation management makes it possible to anticipate industry policies in relation to emerging technologies. They analyse the trends and volatility of innovation in the US ecological field and show how this analysis can help for industrial decision-making. Mitasiunas (2007) presents different approaches found in the literature for classifying innovation: by type, by degree of novelty and by nature. With respect to types, he distinguishes innovation in products or services, processes, marketing and organizational issues. The novelty is graded as new to the firm, new to the market and new to the world. Finally, nature is organized into incremental, radical, and disruptive. Porter-Lynch (2006) remarks that organizations still lack a coherent strategic management system that supports the transformation of the innovation process into a system that can be replicated, communicated, and transmitted between professionals. He suggests the need for a systematic approach to innovation that allows the integration of functions with customers, suppliers and allies, and the configuration of innovation for production, utility and service.

Regarding innovation management modelling, literature has proposed the use of specialized ontologies as a supporting tool for the modelling of innovation management and its lifecycle. Riedl *et al.* (2009) propose the Idea Ontology, a lightweight ontology that allows the description and classification of ideas and their sources. Their goal is to support the innovation life cycle management in open innovation scenarios. Zhang *et al.* (2011) introduce the Science and Technology Innovation Concept Knowledge-Base (STICK) ontology to model innovation and to show its relationships with industry and academia. This ontology distinguishes the concept of innovation from the materialization of innovation, allowing modelling organizations and people in charge of each innovation. An alternative approach is the use of a more general business-related ontology. For example, the GoodRelations ontology (Hepp, 2008) can also be used for describing innovation as goods and services. In fact, this is the official e-commerce data model of schema.org for describing goods and services offered on the Web. However, this approach is less expressive than innovation application ontologies.

Patent applications and granted patents have also been formalized using models that have some similarities with those used for innovation management. For example, Bermudez *et al.* (2013) describe a methodological approach for the definition of relationships and reasoning tasks for patent analysis by using patent ontologies. The work of Taduri *et al.* (2011) proposes an ontology to integrate information from the patent and court case domains. It extends the innovation elements provided in a patent with additional elements related to the patent law and its enforcement. Finally, Marinova & McAleer (2006) propose some innovation indicators that include the correspondence between patents and final innovation products.

From a conceptual point of view, the OntoInnova ontology described in this paper is close to the STICK ontology, as it distinguishes the concept of innovation from its materialization. However, the OntoInnova ontology allows a more complete description of innovation features, such as innovation needs, offers, agreements and patents. To facilitate reusability and integration, the model incorporates terms and definitions drawn from other vocabularies, and it is compatible with the GoodRelations ontology. Comparing our work with Idea ontology, Idea falls behind in terms of expressivity. It proposes simpler innovation management models focused on the describing ideas, but it neither deals with the management of innovation exchanges and the organizations involved nor is adapted to the specific characteristics of the water management domain. Our work fills the gaps identified in Porter-Lynch (2006) related to communication and transmission of innovation among professionals, providing a model that allows the automatic identification of possible collaborators. The focus of OntoInnova in the water management domain also implies the use of specific terminology and vocabularies for thematic and spatial data classification.

The OntoInnova ontology

This section describes the main classes and relations of the OntoInnova ontology. We have followed the Methontology methodology (Gómez-Pérez *et al*., 2004) for the definition of the conceptual model of the ontology and its implementation as a formal model in OWL. The ontology contains a small core, which is the basis for four additional modules that cover the different aspects of innovation (agents, assets, offerings and funding).

Ontoinnova core

The core of the ontology consists of a small set of classes, properties and relations that can be used to create simple descriptions and to provide a basis for many parts of the conceptual model (see Figure 1). The classes are named *entity*, *activity* and *agent*. An *entity* is something that exists as itself, physically, digitally or conceptually, with some fixed aspects that can be used in an *activity*. An *activity* is something that occurs over a period. An *agent* is something that bears some form of responsibility for an

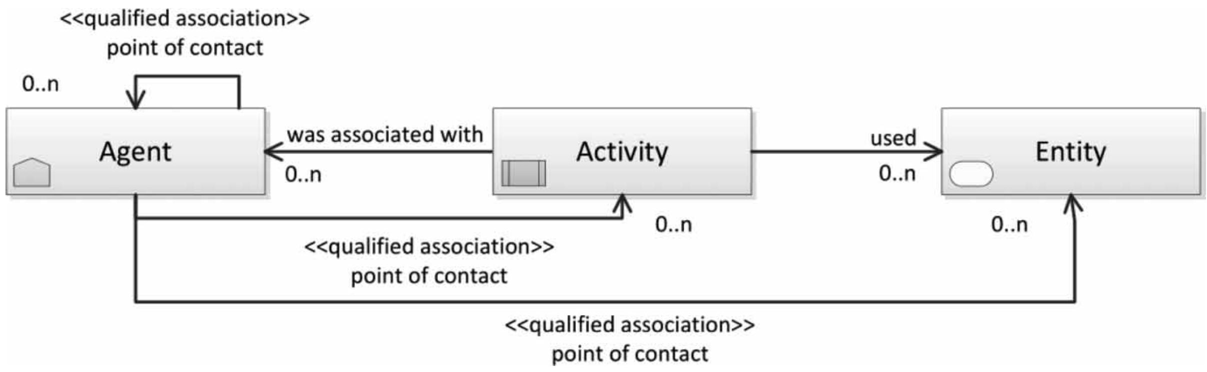

Fig. 1. Core of the model.

activity taking place. We use the Qualified Relation pattern (Dodds & Davis, 2012) to model relations that imply some *activity*. Since the use of this pattern in the paper figures may reduce the understanding of the model, these relations are tagged with the stereotype ‘qualified association’. For example, when modelling the relation *point of contact* between *agents*, the application of the stereotype ‘qualified association’ to the relation indicates an *activity* that describes the work of being the *point of contact* over a period.

Agents module

This module of the ontology provides the basis for describing relevant agents that are involved in innovation processes. The ontology distinguishes between *persons*, *organizations* and *business entities* (see Figure 2). Each class has its own properties to indicate names, addresses, websites, emails, telephones, and roles. For querying and analysis, the spatial location of the *agents* is especially relevant. For example, the address may be expressed by means of a reference to a semantic gazetteer such as GeoNames[1] and the spatial coordinates.

A *person* is a *member* of an *organization* (in the sense of membership) with a role in the structure of the organization. An *organization* represents a collection of people organized into a community or other social, commercial or political structure that has some common purpose (or reason for existence) which goes beyond the set of people belonging to it. Therefore, an organization can act as an *agent*. *Organizations* are often divided into hierarchical structures that are modelled as *organizational units*. Finally, the *business entity* class is used to describe the legal *agent* that makes or seeks a particular innovation offer. A *business entity* has the legal capability of making contracts. Therefore, persons and organizations can also be considered as *business entities*. For example, when a business is owned and run by one individual, there is no legal distinction. Thus, the *agent* has to be classified as both *person* and *business entity*. This differs from a department or support unit, which is part of a larger organization.

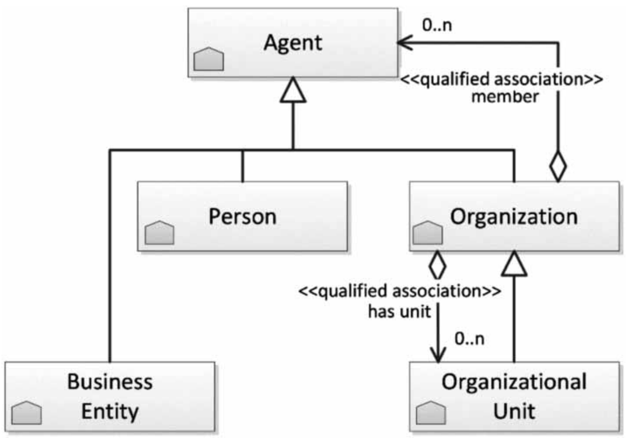

Fig. 2. Model of agents.

[1] http://www.geonames.org/.

As they only have recognition within the context of such an organization, they would not be regarded as a legal entity.

Assets module

This module allows the description of the innovation assets owned by the agents, i.e. useful or valuable things controlled by agents and available for research, development or innovation efforts. This concept includes the intangible innovation core of a product or service (concepts and ideas), the materialization of ideas in the broadest sense (innovation products) and their intellectual property rights, collaborative or individual undertaking related to innovation (projects) and ways to classify conducted research effort (research lines). All of them are modelled as specialized entities (Figure 3).

The *research line* concept identifies efforts conducted by or within a single agent in researching, developing or innovating on a research topic. A *research topic* comprises a substantial body of related works about a research field that has been conducted by a network of agents. *Innovation* is represented as a set of *innovation concepts* (the ideological/intangible core of the innovation) and *innovation products* (including new products and services invented based on the innovation concept). The *innovation* concept specializes in the *product or service* concept because innovation can be a service, a product, or both. Finally, a *document* is any physical or digital representation of information.

Figure 4 shows the relations of the *entities* with other classes in the model. The *work* relation allows the indication of the *product or service* on which the *intellectual property rights* are granted. The *included in* relation is the one used to indicate the theme of a project, product, service or research line. *Documents* have topics that can be *research topics* that describe their content or references to the *entities* the *document* is about. Finally, the *includes asset* property is used to identify a valuable element in a research line or project.

To be able to describe the purpose of the *entities* in the water management context, the instances of the *research topics* must be properly selected from adequate vocabularies. This includes the necessity of providing environmental-related terminology to use as keywords of the entities and the requirement

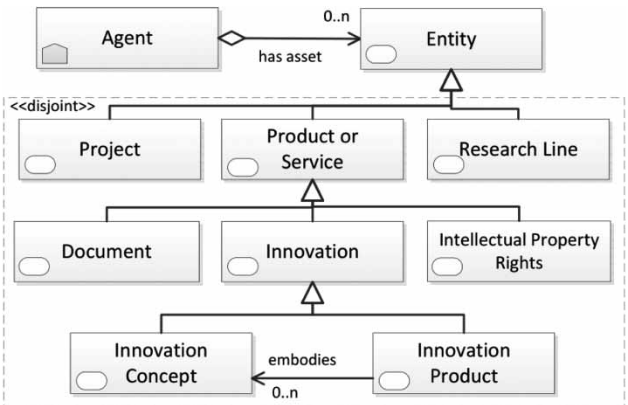

Fig. 3. Classification of innovation assets.

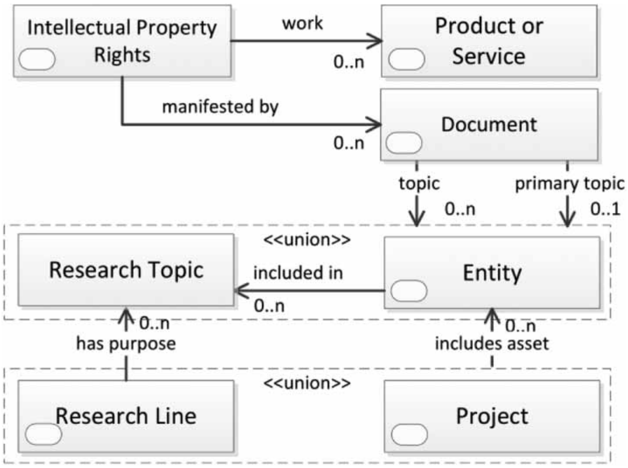

Fig. 4. Relations of entities.

of being able to describe the spatial features of the described elements. Figure 5 shows an example of the use of thematic and spatial terminologies to describe an *entity* of an *agent*. It shows the description of a *project* of the 'Guadiana River Basing Authority' from Spain about the analysis of 'water salination' in the 'Guadiana' river estuary. For thematic concepts, it uses the 'water salination' concept of GEMET thesaurus[2], but other environmental-related models such as the Water Resources Thesaurus (WRT)[3] or AGROVOC[4] may provide the terminology needed to describe an *entity*. With respect to spatial information, it shows how the *agent* addresses can be described using GeoNames, and that GeoNames can be used to indicate specific areas of interests that constrain the spatial scope of the described 'project'. Any other gazetteer including geographical features or places could be used as an alternative or complement to GeoNames if required.

Offering module

This module focuses on the identification of the innovation offerings of each business entity. The classes indicated in Figure 6 allow the description of the innovation products and services owned, granted and affected innovations, the description of the particular details of each offering, such as the eligible customers (i.e. who is allowed to know the offering), and the type of activity or offered access. An offering represents the public, not necessarily binding, not necessarily exclusive, announcement by a business entity to provide (or seek) a certain business function for a certain product or service to a specified target audience.

An offering is specified by the type of product or service it refers to; what business function is being offered (sales, rental, etc.); and a set of commercial properties. It can refer to a clearly specified

[2] https://www.eionet.europa.eu/gemet/en/themes/.
[3] https://pubs.er.usgs.gov/publication/70039475.
[4] http://aims.fao.org/es/agrovoc.

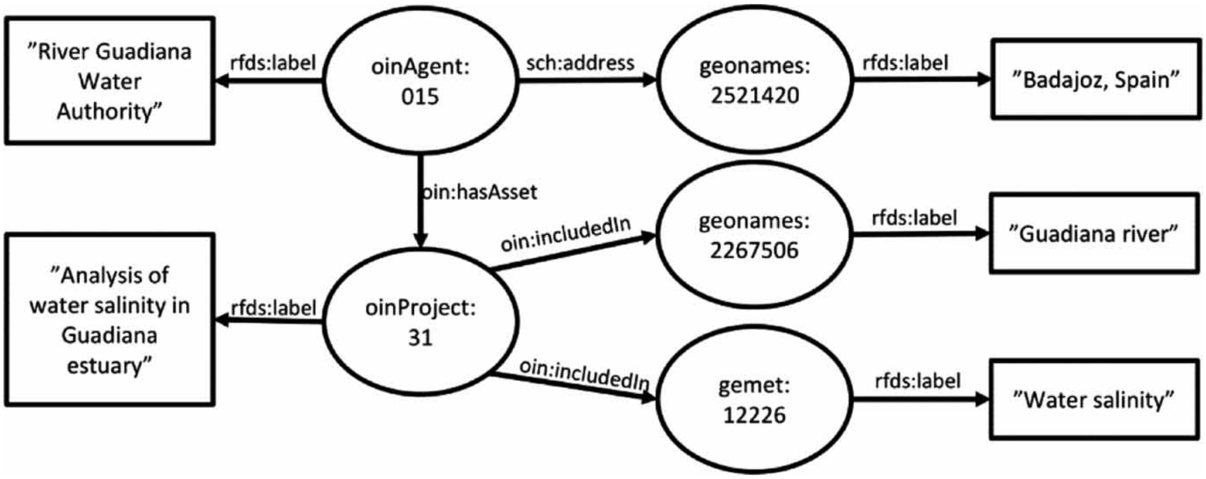

Fig. 5. Example of use of thematic and spatial terminologies.

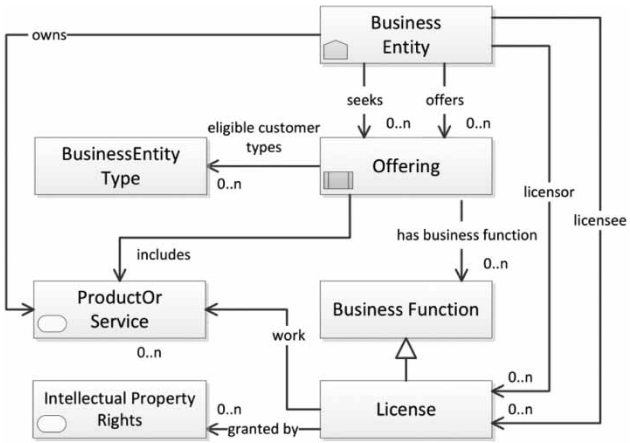

Fig. 6. Model of offerings.

individual, some anonymous items of a given type, or a product model specification. An offering may be constrained in terms of the eligible type of business partner, countries, quantities, and other commercial properties. A license is the specification of a bundle of intellectual property rights that determine the type of activity or access offered by the business entity on the product or service through the offering. The business function specifies the type of activity or access (i.e., the bundle of rights) offered by the business entity on the product or service through the offering. Finally, a business entity type is a conceptual entity representing the legal form of a business entity, its size, its main line of business, its position in the value chain, or any combination thereof. Business entity types classify business entities in the market. They are important for specifying eligible customers because, for example, an offering may be valid only for business entities that meet certain size, legal structure, or role in the value chain.

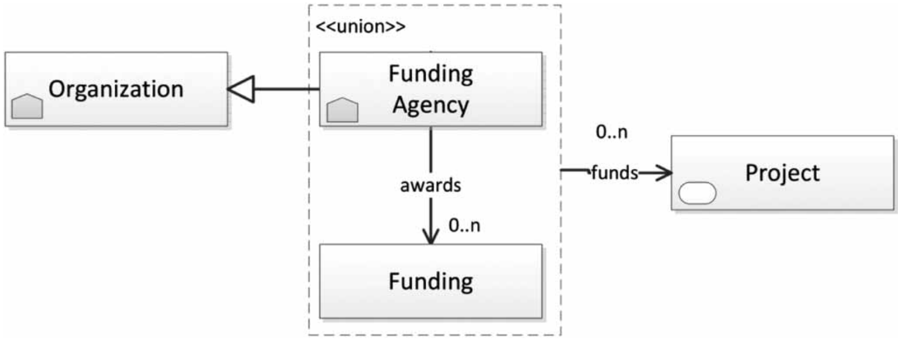

Fig. 7. Model of funding.

Funding module

This module describes the funding of innovation projects, i.e. the information about the awarded funding, the funded projects and the funding agencies. Figure 7 shows the main classes and relations. In the model, a *funding agency* is an organization that provides *funding* for projects, often in the form of grants awarded with the competitive application. The *funding* class contains fields to describe the kind of funding provided, amount, and conditions. The model allows expressing the founding source of a *project* in a general way through a reference to the *funding agency* that funds the *project*, or in detail, by indicating the details of the *funding* of the *project*.

Application in the water management domain

The FP7-REGIONS project 'WE@EU Water Efficiency in European Urban Areas' was a project developed in 2016 by a consortium integrated by nine partners from France, Israel, Malta, United Kingdom and Spain to bring together knowledge and potential innovation in the water management domain by collaborating and mutually learning in a transnational basis. They compiled the information of 106 companies, 43 research centres, 13 public administrations, 8 non-governmental organizations, 122 research lines, 70 research offers and 35 research demands related to water management.

The formalization of the concepts managed in this project led us to the development of the OntoInnova ontology and a management tool for the WE@EU data that makes use of the ontology. Figure 8 shows the architecture of the system (WE@EU, 2016b). It provides a simple editor to fill the ontology fields, a query system, and a report generator component. The search system provides a keyword-based information retrieval system able to locate offers that match the query themes and the area of interest. The report generator facilitates the aggregation of selected data to determine the state of innovation in the water management domain. All knowledge is stored in a semantic repository that is consulted with SPARQL[5].

This system is comparable to the market provided by the EIP Water, but with additional features. Our ontology not only represents people/organizations, projects and products, but also allows a finer grain

[5] https://www.w3.org/TR/2013/REC-sparql11-query-20130321/.

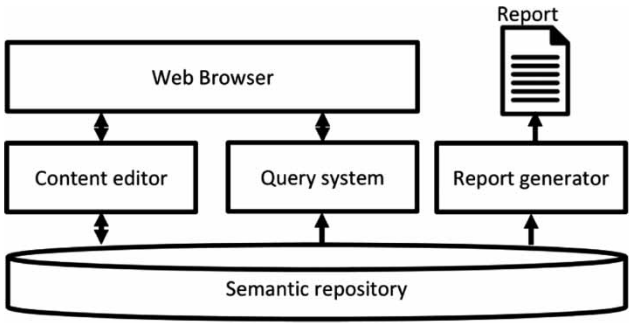

Fig. 8. WE@EU platform architecture.

description of user typologies, offerings and needs of innovation. In addition to this, semantic representation and access to the information increase the search and analysis functionality, making it simpler by the identification of collaboration areas for users and the generation of data reports for the system administrators.

Query system

The purpose of the query system is to identify matches of innovation interests between users that want to collaborate and users that need expertise in some field. The system considers two types of users: agents with experience in some field that want to find other agents for general collaboration (innovation sellers) and agents that have a need of expertise in some field and are looking for someone to fill the gap (innovation clients). Figure 9 shows the search flows designed for each user type. In the general collaboration case, the agents do not have any specific collaboration idea in mind and just want to see if there is some project or line on which they would like to work. With this aim, the user performs a query with the keywords that describe their area of interest and the system matches them with suitable offerings that seek for agents working in the queried subjects. After an inspection of the results, if the agents find some interesting proposal, they can get in contact with the publisher to discuss the possibilities of collaboration. In case there is no match, they can publish an offering describing their areas of interest and wait

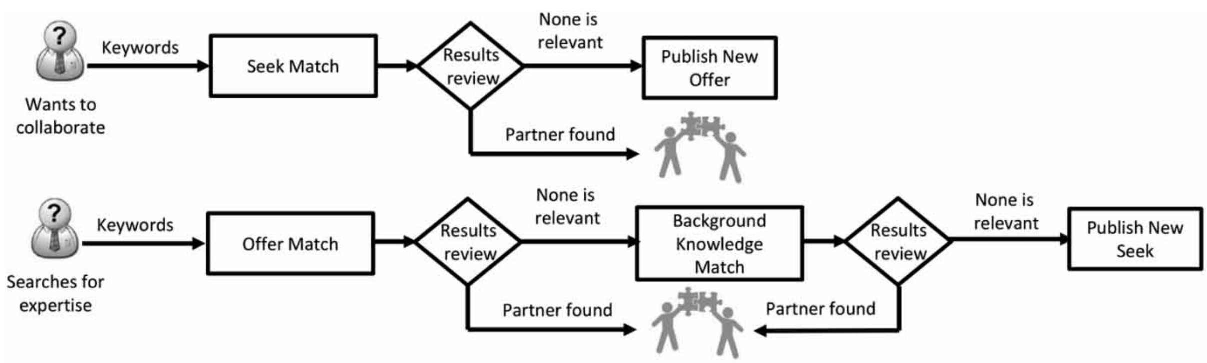

Fig. 9. Search flows for agents interested in establishing collaborations.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX oin: <http://www.weateu.eu/ontology/ontoInnova#>
PREFIX sch: <http://schema.org/>
PREFIX geo: <http://sws.geonames.org/>/
SELECT DISTINCT ?agName ?type ?resName  WHERE {
    ?agentID rdf:type ?type.
    ?agentID sch:address geo:3038354. #Provence-Alpes identifier in GeoNames
    ?agentID oin:hasName ?agName.
    ?agentID oin:hasAsset ?asset.
    {?asset rdf:type oin:researchLine}
       UNION {?asset rdf:type oin:project}
       UNION {?asset rdf:type oin:intellectualPropertyRights}.
    ?asset oin:hasName ?resName.
}
```

Fig. 10. Example of the query to obtain the research lines of agents in Provence-Alpes-Côte d'Azur region.

until another agent has that need. The other search flow is used for agents looking for expertise in some knowledge area to create a tool, system, project or analysis.

The first step for this search is to locate offerings that indicate interest in working in the areas defined in the query. A revision of the returned agents may lead to contact with mutual interests. If none of the active proposals are found relevant, the system allows querying to the background expertise of the agents. This may lead to identify agents that, even if they do not have an explicit current interest in some fields, have worked in the fields in the past. Therefore, contacting them is a good approach to find possible partners. In this case, none of the previously found agents are relevant or have interest. That is to say, the solution is to create a new offering indicating what the agent seeks. Additionally, the system provides a browsing functionality that lists the registered agents, their expertise and interest, so a faceted search can be performed.

The search flow described in Figure 9 is implemented with simple SPARQL queries. This makes the system easy to implement and to extend. For example, Figure 10 shows the SPARQL query required to obtain the participating organizations located in Provence-Alpes-Côte d'Azur (France) and their research lines. Since administrative divisions are hierarchically organized, the organizations in the selected region are inferred from the cities they are located in.

Figure 11 shows the results of the queries, focusing on the area around the city of Marseille. Each mark describes the companies or institutions in the area that desire to collaborate and the projects, research lines and intellectual property rights of these companies. At the level of zoom in the figure, information is summarized and cannot be distinguished which agents provide the 'Drug molecules treatment in water' research line. With a higher zoom level in the map, it is possible to distinguish that it corresponds to the 'Société des eaux de Marseille'.

Report generator

To use OntoInnova for data analysis, we have developed a component for the generation of statistics about the repository content. It allows defining data aggregation processes using SPARQL queries such as identifying areas of interest in which many agents are working on, or showing divergences in the research interests between the different types of agents involved in the market.

This report component stores previously defined queries and executes them when required. We have defined queries to identify thematic interests at the region, at country and at the European level. For example, SPARQL queries shown in Figure 12 generate data reports that summarize the current

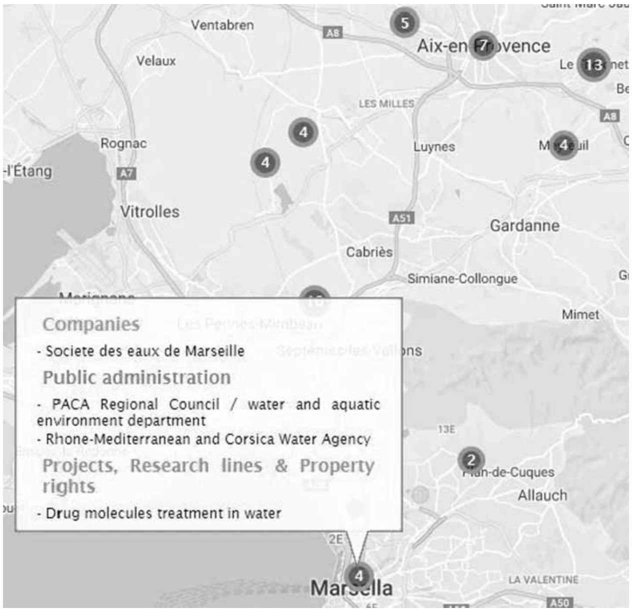

Fig. 11. Presentation of query results.

(a)
```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
    PREFIX oin: <http://www.weateu.eu/ontology/ontoInnova#>
    PREFIX gr: <http://purl.org/goodrelations/v1#>
PREFIX dct: <http://purl.org/dc/terms/>
SELECT ?type ?keyword (count(?keyword) as ?occurrences) WHERE {
    {?asset rdf:type oin:Project} UNION
       {?asset rdf:type oin:ResearchLine} UNION
       {?asset rdf:type oin:IntellectualPropertyRigths}.
    ?agent oin:hasAsset ?asset.
    ?agent gr:category ?type.
    ?asset oin:includedIn ?keyword.
}GROUP BY ?type ?keyword
```

(b)
```
PREFIX oin: <http://www.weateu.eu/ontology/ontoInnova#>
PREFIX gr: <http://purl.org/goodrelations/v1#>
SELECT ?type ?keyword (count(?keyword) as ?occurences) WHERE {
    {?agent gr:seeks ?offer} UNION
       {?agent gr:offers ?offer}.
    ?offer gr:includes ?asset.
    ?agent gr:category ?type.
    ?asset oin:includedIn ?keyword.
}GROUP BY ?type ?keyword
```

Fig. 12. SPARQL queries used to obtain current expertise and future research interests. (a) SPARQL query for current expertise. (b) SPARQL query for future interests.

expertise and future research interests between companies and research institutions at the European level. For visualization and analysis purpose, the thematic concepts used in the resources have been aligned with the vocabulary used by the EIP Water. This vocabulary is used to describe priority areas and relations between the areas in the water management domain, and it includes water reuse and recycling, water and wastewater treatment, water-energy nexus, flood and drought risk management, ecosystem services water governance, decision support systems and monitoring, and financing for innovation. The concepts that did not fit into these categories have been classified as 'others'.

Figure 13(a) shows the results of the query in Figure 12(a) (background knowledge comparison). It contains the percentage of research assets (research lines, research projects and intellectual property rights) about each theme in the collection divided between companies and research centres. Since a research item can focus on multiple subjects, it is counted in all the categories of the keywords it contains. In the figure, it can be observed that companies have deeper knowledge in water treatment, recycling and energy, while research centres are more focused on ecosystem services and other areas outside this classification. However, the differences are not extreme (10%). It is also relevant that water treatment has almost the double of expertise than the other fields.

Figure 13(b) shows the results of the query in Figure 12(b) (offers and demands of research comparison). It can be observed that there is a clear correlation between the desired future work and the previous knowledge of the institutions shown in Figure 13(a). It can also be observed how the future objectives between companies and research institutions differ. For example, companies are far more interested in water reuse and treatment than research institutions. This indicates that there is a gap between the interests of companies and research institutions across all the regions.

Figure 14(a) and 14(b) show the results of a query equivalent to the previously described ones that groups the current assets and future interests by country instead of distinguishing between companies and research groups. The bubble sizes indicate the percentage of assets or research lines of each country classified according to the EIP Water vocabulary. In this case, it can be observed how all the countries focus on the water treatment field, both at accumulated expertise and future interests. This indicates how important water quality has become for the different countries and remarks it as a promising area of research in the next years. It is also important to note the expertise and interest of Malta and Israel in water reuse. This is normal in an island such as Malta, but the growing interest in Israel denotes an increase in the water demand or a reduction of the natural water sources. The bigger size of 'others' classification in the future interests denotes a problem in the terminology used to aggregate the data. The EIP Water vocabulary is mostly valid for past works, but many future areas of water research do not fit in any of the categories. This problem could be solved with a reclassification of the data with an extended set of categories focused on the elements currently described as 'others'.

Lessons learned

This system requires companies and institutions to participate in the WE@EU consortium to publicly expose their projects and research interests. Participants were free to decide the amount of their own information published and shared with other partners in the platform. Studies such as Ipektsidis *et al.* (2016) report limited openness towards knowledge transfer in the water sector. However, experience has shown that the minimum information required by OntoInnova to facilitate contact and exchange matches with that considered by participants as information that can be made public without risk. This minimum information corresponds to the description of each *agent* and to the list of *entities* offered and searched by the agent alongside a brief description of each one. Therefore, it could be feasible to apply OntoInnova to develop innovation markets in other regional areas such as middle-income and developing world regions. Note that other implementations based on OntoInnova may lack reporting

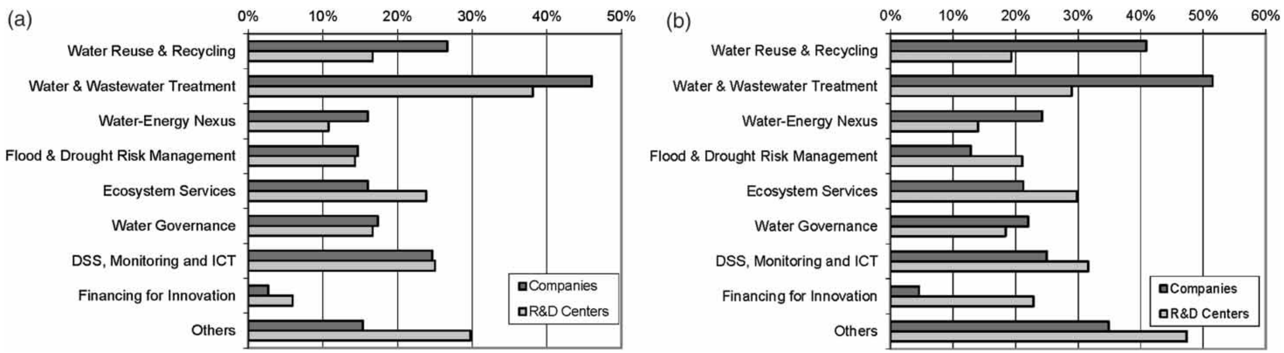

Fig. 13. Assets and future interests in research activities from companies and research entities. (a) Assets. (b) Future interests.

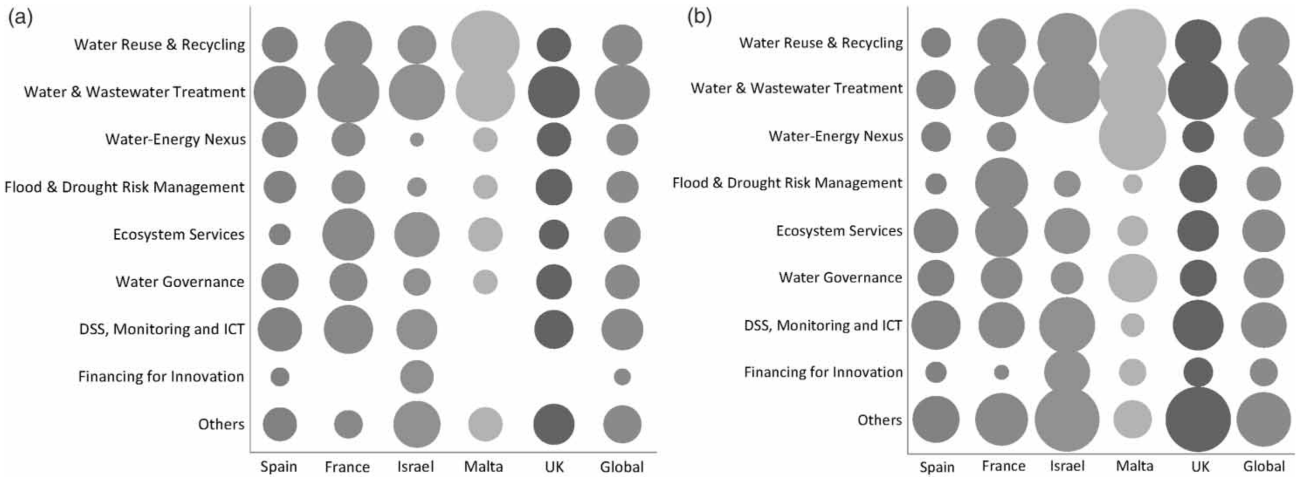

Fig. 14. Assets and future interests in research activities in each country. (a) Assets. (b) Future interests.

facilities due to reluctance to provide detailed information related to entities in the *offerings* and *funding* modules (in particular with economic or licensing aspects).

Conclusions

OntoInnova ontology has been created to facilitate the description of the research, development and innovation exchange by providing a way to model agents, assets, offerings, and funding of innovation in the water management domain. The use of an ontology to model innovation exchange harmonizes its description, and the available query languages facilitate the analysis of the contained data. This makes it possible to define automatic tasks such as identifying groups of entities interested in the same themes or summarizing the state of innovation in a domain. In these cases, the ontology inference capabilities can be used to simplify the matching tasks.

OntoInnova ontology has been used to describe each research-driven cluster involved in the WE@EU project and to create an innovation map of every business and public administration in the cluster. The information system constructed on top of this ontology has allowed defining the background knowledge of the agents, the identification of matches between innovation interests and the generation of reports about the participant interests. This system can be directly used in other regions to define their own clusters to promote collaboration and analyse the state of innovation in the water management domain.

Future work will be oriented towards applying the proposed innovation ontology to other contexts different from the WE@EU project. We think that it can be directly used to facilitate innovation exchange in clusters of other thematic domains, or even in interdisciplinary areas.

Acknowledgements

This work has been partially supported by the European Commission (project WE@EU, FP7REGIONS-2012-2013-1, reference: 320007), the Spanish Government (project TIN2017-88002-R), and the Aragon Regional Government (project T59_17R).

References

Bermudez, M., Noguera, M., Hurtado, N., Hurtado, M. V. & Garrido, J. L. (2013). Analyzing a firm's international portfolio of technological knowledge: a declarative ontology based OWL approach for patent documents. *Advanced Engineering Informatics 27*(3), 358–365.

Council of the European Union (2011). Protection of water resources and integrated sustainable water management in the European Union and beyond Council conclusions 3103rd ENVIRONMENT Council meeting. Luxembourg, 21 June 2011.

Delpla, I., Jung, A. V., Baures, E., Clement, M. & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International 35*(8), 1225–1233.

Ding, Y., Fensel, D., Klein, M., Omelayenko, B. & Schulten, E. (2003). The role of ontologies in ecommerce. In: *Staab and Studer*. Springer, Berlin, Heidelberg, pp. 593–616.

Dodds, L. & Davis, I. (2012). *Qualified Relation, in Linked Data Patterns*. Technical Report, Modelling Patterns, patterns.dataincubator.org.

Egger, S. (2006). Determining a sustainable city model. *Environmental Modelling & Software 21*(9), 1235–1246.

Frankelius, P. (2009). Questioning two myths in innovation literature. *Journal of High Technology Management Research 20*(1), 40–51.
Gómez-Pérez, A., Fernández-López, M. & Corcho, O. (2004). Ontological Engineering. In: *Advanced Information and Knowledge Processing*. Springer-Verlag, London, Berlin, Heidelberg, pp. 125–142.
Hahmann, T. & Stephen, S. (2018). Using a hydro-reference ontology to provide improved computer-interpretable semantics for the groundwater markup language (GWML2). *International Journal of Geographical Information Science 32*(6), 1138–1171.
Hall, B. H. (2004). Exploring the patent explosion. *The Journal of Technology Transfer 30*, 35–48.
Hepp, M. (2008). GoodRelations: an ontology for describing products and services offers on the web. In: *Proceedings of the 16th International Conference on Knowledge Engineering: Practice and Patterns*. Acitrezza, Italy, pp. 329–346.
Hunter, P. R., MacDonald, A. M. & Carter, R. C. (2010). Water supply and health. *PLoS Medicine 7*(11), e1000361.
Ipektsidis, B., Remotti, L. A., Rumpf, G., Spanos, Y., Soderquist, K., Vonortas, N., Damvakeraki, T., Montalvo, C., Bulavskaya, T., Dröes, M., Moghayer, S., Hu, J., Koops, O., Leijten, J., Derbyshire, J., Passi, H., Burge, P., María Lázaro, J. & Fisher, R. (2016). *R&D Investments and Structural Change in Sectors, Report to the General Directorate of Research and Innovation*. European Commission, Brussels.
Marinova, D. & McAleer, M. (2003). Modelling trends and volatility in ecological patents in the USA. *Environmental Modelling & Software 18*(3), 195–203.
Marinova, D. & McAleer, M. (2006). Anti-pollution technology strengths indicators: international rankings. *Environmental Modelling & Software 21*(9), 1257–1263.
Meng, X., Xu, C., Liu, X., Bai, J., Zheng, W., Chang, H. & Chen, Z. (2018). An ontology-underpinned emergency response system for water pollution accidents. *Sustainability 10*(2), 546.
Mitasiunas, J. (2007). *Innovation and Technology Transfer (Bonita Project)*. Technical Report, Vilnius University.
Porter-Lynch, R. (2006). *Collaborative Innovation*. Creating a School of Thought. Technical Report, Warren Company.
Riedl, C., May, N., Finzen, J., Stathel, S., Kaufman, V. & Krcmar, H. (2009). An idea ontology for innovation management. *IJSWIS 5*(4), 1–18.
Schmidt, G., Bauer, S., Baur, T., Fleischmann, N., Kaltenböck, M., Leeuw, E., Matauschek, C., Matauschek, M., Nanu, C., Thurner, T., Misiga, P., Capitao, J. & Schroeder, R. (2018). The European innovation partnership on water (EIP water): approach and results to date (2012–2015). *Journal of Cleaner Production 171*, S147–S148.
Taduri, S., Lau, G. T., Law, K. H., Yu, H. & Kesan, J. P. (2011). An ontology to integrate multiple information domains in the patent system. In: *IEEE International Symposium on Technology and Society ISTAS*. IEEE, New York, pp. 23–25.
Wang, C., Wang, W. & Chen, N. (2017). Building an ontology for hydrologic monitoring. In: *Geoscience and Remote Sensing Symposium (IGARSS), 2017 IEEE International*. IEEE, New York, pp. 6232–6234.
WE@EU (2016a). *Water Efficiency in European Urban Areas*. Joint Action Plan. Technical Report, WE@EU.
WE@EU (2016b). *Water Efficiency in European Urban Areas Portal*. Available at: http://www.weateu.eu/.
Wehn, U. & Montalvo, C. (2018). Exploring the dynamics of water innovation: foundations for water innovation studies. *Journal of Cleaner Production 171*, S1–S19.
WssTP (2017). *Strategic Innovation and Research Agenda*. Technical Report.
Zhang, P., Qu, Y. & Huang, C. (2011). Designing a multi-layered ontology for the science and technology innovation concept knowledge-base. In: *System Sciences (HICSS). 44th Hawaii International Conference on IS*. Kauai, HI, pp. 1–10.

Received 15 November 2018; accepted in revised form 8 April 2019. Available online 29 April 2019