

## Semantic Location Models for Bioenergy and Biofuel Projects

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**Abstract** — The five fundamentals for a successful bioenergy project are feedstock, technology, off-take, finance and help from experts. In order to realize the essence of these fundamentals, recently, many governments and organizations are providing Decision Support Tools (DST) to the experts and project developers. One of such tools is Location Model, which helps the developers to identify the prime location for a project. The model comprises the concepts, relations, logics, constants and equations related to bioenergy and location. The model is currently represented in non-semantic means, such as spreadsheets and programming code. Representing the knowledge in non-semantic format will make the model less reusable and extendable. In order to alleviate the issues, in this paper, we present semantic location models. In particular, we have leveraged the Semantic Web technologies to represent the knowledge about the bioenergy and biofuel plant location and inferred the equations and other values required for location related calculations. The results, observed in two INTERREG IVB projects, have been found encouraging.

**Keywords**- *bioenergy ontology; location model; semantic location model; ontology-based location model; biomass; bioenergy; renewable energy*

### I. INTRODUCTION

Bioenergy is one of the most dynamic and the fastest growing renewable energy and promises sustainable solutions to the depleting fossils fuels. Biomass, the solar energy stored in the materials derived from biological sources, is treated with some conversion technologies, and bioenergy is generated. Some examples of biomass are wood fuel, waste wood, energy crops, straw, waste and agricultural waste. Biomass is used as an input while generating bioenergy; therefore, in this paper, biomass is also called feedstock.

Many governments and organizations have recently shown efforts to realize the principle of five fundamentals in bioenergy projects. An example of such efforts is the development of Decision Support Tools (DST), which provides essential information to plant developers efficiently. One of such organizations is INTERREG IVB, which has funded two projects: BioenNW and EnAlgae.

The ongoing North West European projects: BioenNW [1] and EnAlgae [2] aim to facilitate the project developers to start a new bioenergy plant in the region and develop sustainable technologies for algal biomass production respectively. These projects aspire to increase the global share of renewable energy sources by 20% within the EU by

2020. In order to achieve this, they have to consider the steps towards the five fundamentals. One of the crucial step is to provide the farmers in the region with DSTs, which will help them make decisions [3]–[11]. The DSTs provide the answers to various decision-making queries, such as:

1. What is the best place to start a new bioenergy plant?
2. What kind and how much amount of biomass are available in a region?
3. What kind of technology is suitable for a plant in a region?
4. How much investment is needed and how long will it take to return the investment?
5. What are the logistic and other related costs involved?

Location Model is one of the DSTs in these two projects, which helps the developers to identify the prime location for a project. It is represented by considering various factors, such as the concepts, relations, logics, constants, and equations. It helps project developers to analyze the viability of a project by providing them with location information. In particular, it will provide a mechanism to calculate the equations related to the costs, incentives and distance associated with a project or a cultivation technology in a location. The equations and the calculations (evaluation of the equations) in the model are affected by various attributes, such as capacity of the project, incentives in the region, bioenergy conversion technologies used and the quality of the biomass. Providing the necessary information regarding a location to developers prior to the start of a project will help them to make an informed and confident decision about starting the project.

Previous studies have primarily concentrated on implementing non-semantic models, such as hard-coded programming languages or Excel spreadsheets. That is to say, the concepts, relationships, logics, constants and equations are all embedded in some native programming language. For example, in the BioenNW project, the model was represented in MATLAB functions; whereas, in EnAlgae, the spreadsheets have been equally used to represent the model. Representing the model in such a way poses some issues, such as the model being less shareable, less reusable and less extendable, and the data being

inconsistent. To alleviate the issues, we propose semantic models for the location determination.

The semantic location model exploits Semantic Web technologies. Ontology can be used to represent the domain knowledge and check the consistency of the model. Since the vocabularies in the ontologies are reusable, and they are explicitly defined, this approach makes the model extensible. In other words, the ontology not only holds the data but also explicitly defines the concepts used for a particular purpose [12]. Using the existing definition of the concept in an ontology, engineers can extend the ontology by creating new concepts that conform to the existing knowledge. In the proposed approach, the ontological axioms and rules are used to define the entities, such as biomass, technology, incentive, tariff, capacity and project. The following are the key benefits of using the proposed approach:

1. **Explicit concept definition:** It defines the key concepts used in the economic model explicitly, which will make the ontology re-useable and extensible.
2. **Consistent data:** It provides a mechanism to check the consistency of the data in the model.
3. **Inference:** It identifies the implicit knowledge in the model by means of ontological inference mechanism.

The rest of the paper is organized as follows. Section II provides the detailed description of the ontology-based location model in a case study. Section III and IV provide the ontology based calculation and discussion respectively. The finding of this research is concluded in Section V.

## II. THE ONTLOGY-BASED LOCATION MODEL

One of the objectives of the INTERREG IVB supported two projects BioenNW and EnAlgae is to provide DSTs to the developers in the North West of Europe. The BioenNW project aims to facilitate the farmers in the selected regions to start a new bioenergy plant. The regions have been selected in five countries: the United Kingdom, the Netherlands, Germany, Belgium and France. It has Business Support Centers (BSC) in each country for the regions in the country, where farmers get advice from bioenergy experts. These regions contain a unit of area called a cell, which is a square area, for example, 1KM square area is a cell. The DSTs provide the information about each cell, such as

1. how much it yields in a year,
2. what kind of biomass is available,
3. what regulatory guidelines are applicable in the region,
4. what incentives are being offered in the region.

The EnAlgae project aims to develop sustainable technologies for algal biomass production. The microalgae economic models are developed for various cultivation technologies, such as open pond, flat panel and tubular reactors while the economics of downstream processing is calculated for biodiesel, bioethanol dry milling and methane production.

The DSTs are Web-based tools, which can be accessed remotely by farmers, and encourage them to start a new plant. The DSTs in EnAlgae helps in making decisions about algae biomass production, from understanding the algae growth, cultivation, economics and life-cycle analysis to setting up plants and operating procedures. Some of the DSTs are map-based information tools, while others are dashboards and conversion pathways. Map-based information tools allow users to click on a map to see whether a location is suitable for a particular type of the bioenergy or algae plant. Dashboards provide calculations related costs and economics, such as how much investment is needed and how long it will take to return the investment back. One of the DSTs is the locations model.

The location model either identifies a best location for a plant (location unknown) or provides information about a selected location (location known). The model is presented in a map based web interface, where users interact with various input variables and analyze the output. The input variables in the interface are longitude and latitude of a geographic location, region in a country, amount of biomass needed in tons per annum, biomass type and biomass scenario. Based on these variables, the user is able to see whether there is sufficient biomass around the location. The biomass availability is displayed in a list of cells around the location with different density of the colors. A snapshot and description of the webpage is provided in Figure 7 in a latter section.

The location model is now represented in SW technologies. There are axioms and SWRL rules that define and infer various knowledge about the model. In particular, the reusable knowledge is separated from the calculations and queried with DL-Query and SPARQL in order to make the implicit facts explicit. Figure 1 shows an overall idea of the ontology based location model. The ontology represents the knowledge of the model; the axioms define the concepts and assert constraints; SWRL rules assert new knowledge in the ontology. The reasoners, such as Pellet help to deduce the implicit knowledge and make them explicit. The query engine with the DL-Query and SPARQL will identify the entities required for the location related calculations.

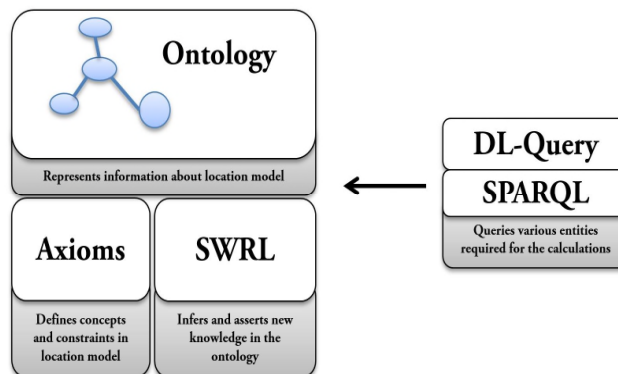


Figure 1. Semantic Web technologies used in the location model

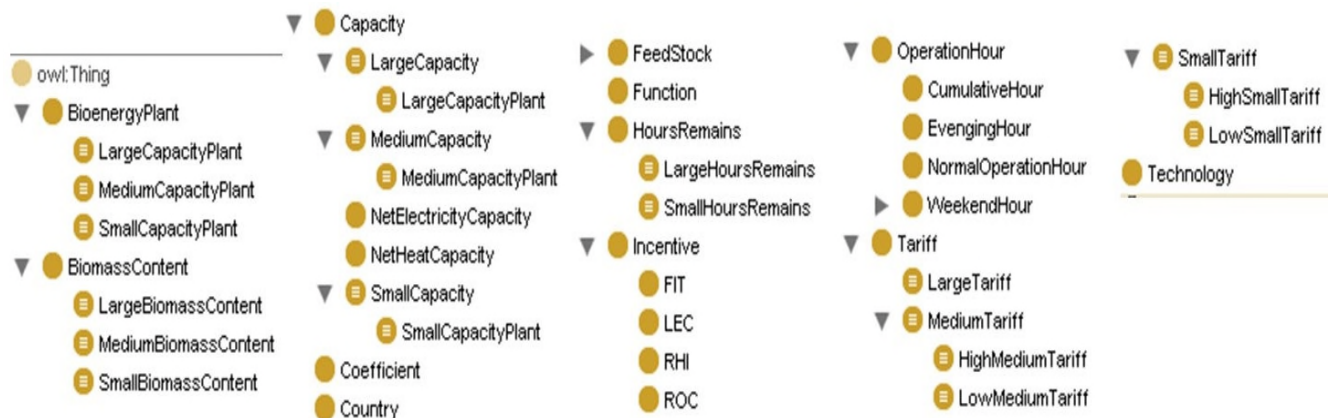


Figure 2. The classes in the location model ontology

Various tools and technologies have been deployed in order to realize the location model. Some of them are Protégé 4, Pellet [17], OWLAPI [18] with Pellet, and Jena [19] with Pellet. Protégé 4 is an ontology editor, and Pellet is a reasoner and is used as a plug-in in Protégé. OWL API with Pellet helps us to run DL-Queries in Java. In addition, Jena API with Pellet reasoner has also been used to run SPARQL queries.

Some classes of the location model ontology are depicted in Figure 2. The important constituents of the ontology are described in the following sections.

### A. The Ontology

The location model ontology is created in Protégé 4 and OWL-DL. The experts in the domain have been consulted in order to understand the concepts and the relations. The consultation went through several iteration in order to verify the understanding and representation. The classes, properties, axioms, rule and queries involved in the ontology are described separately in the following sections.

#### 1) Classes

The key classes of the ontology are Feedstock, BioenergyPlant, Technology, Country, Tariff, and Incentive. The Feedstock is a biomass that will be used as an input for heat and power generation. Technology is a process through which a Feedstock is treated in order to generate bioenergy. Depending upon BiomassContent, a feedstock can be treated with different technologies in order to generate energy efficiently. The Incentive and Tariff in a project are affected by other concepts, such as Technology, Country and Capacity of a BioenergyPlant. The other concepts are BiomassContent, Capacity, Coefficient, Function, HourRemains, and OperationHours.

#### 2) Properties

The model exploits the properties and the values for the representation and inference. The important object properties are relate the classes mentioned above, such as

BioenergyPlant, Capacity, Country and Technology with each other. For example, a BioenergyPlant is related with Country, Technology and Feedstock with properties locatedIn, hasTechnology and hasFeedstock respectfully. Figure 3 displays some properties in the ontology for the location model.

The values of the data-type properties are mostly double and play the key role in defining concepts and computing simple equations. One of the important data-type properties is hasDataValue, which is associated with many concepts, such as Capacity, BiomassContent and Coefficient. Some data-type properties are used to hold the results of the calculations. For example, hasQaQiValue holds the computed value of the quality assurance calculation.

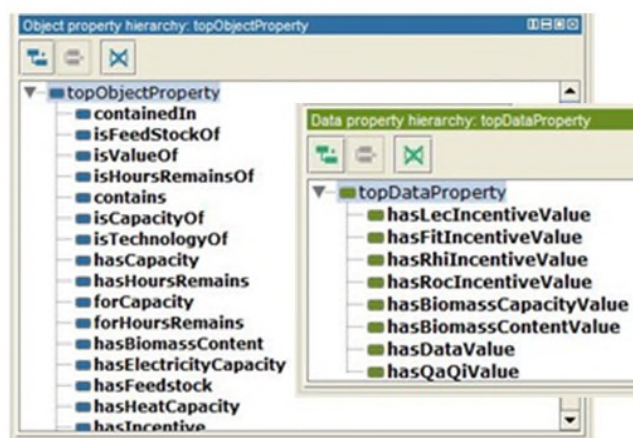


Figure 3. Snapshot showing properties in the location model ontology

#### 3) Axioms

The axioms in the ontology are essential to define the concepts and constraints. In the ontology, most of the axioms contain data-type properties, particularly with double. For example, small medium and large capacity are defined as follows:

**SmallCapacity:**

Capacity and hasDataValue some double[&lt;200]

**MediumCapacity:**

Capacity and hasDataValue some double[&gt;=200.0, &lt;1000.0]

**LargeCapacity:**

Capacity and hasDataValue some double[&gt;= 1000.0]

In these axioms, the small capacity is defined as a capacity with value less than 200, the medium capacity is a capacity with value greater than equal to 200 and less than 1000, and the large capacity is a capacity with value 1000 and more.

**4) Rules**

In location model ontology, the SWRL rules are used to assert more knowledge. There are some caveats using the rules. Since OWL and SWRL both do not support non-monotonicity, we cannot change the existing value in the ontology. However, if the value of a property is empty or not filled, it can assert a new value. If we add a new value to a property, it will not replace the existing one, but the property will have two values instead. In this ontology, most of the data-type properties are functional; therefore, any attempt to add a new value to a property that already has a value, will make the ontology inconsistent. Some rules used in the ontology are depicted in Figure 4.



Figure 4. Some SWRL rules in Protégé to assert new knowledge and calculate the quality assurance

**5) SPARQL Queries**

One of the query languages used to query the knowledge represented in the ontology is SPARQL. It will provide a mechanism to answer the queries related to the location calculations. For example, provided a set of conditions, such as technology and country, we can search for the suitable incentives applicable in a country. Figure 5 illustrates a SPARQL query for applicable incentives for AD plants in the UK. The result of this query will be RHI, LEC and FIT.

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1 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
2 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4 PREFIX owl: <http://www.w3.org/2002/07/owl#>
5 PREFIX kbe: <http://www.bcu.ac.uk/kbe/bioen/economic-model.owl#>
6
7 SELECT ?Incentives
8 WHERE {
9   ?plant kbe:hasTechnology kbe:AD;
10         kbe:locatedIn kbe:UK;
11         kbe:hasIncentive ?Incentives.
12 }

```

Figure 5. A SPARQL query in the location model ontology to find the applicable incentives for a bioenergy plant in the UK



6) DL – Queries

The DL-Queries identify the appropriate category of biomass content, tariff and incentives. For example, in Figure 6, the query asks, “what kind of biomass content is it if it has biomass content value 0.9?”, and the query returns **LargeBiomassContent** as the answer.

In another example, the query asks, “What kind of tariff is applicable to a bioenergy plant if it has a capacity of 150.00?”, and **MediumTariff** is returned as the answer.

Likewise, **SmallCapacity** is the answer to the query “what category of capacity does my bioenergy plant have if the capacity value is 150.00?”.

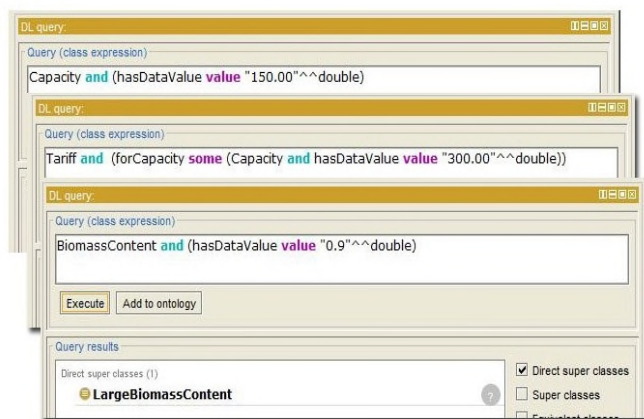


Figure 6. Three DL-Queries in the location model ontology to determine small, medium and large biomass content

III. ONTOLOGY BASED CALCULATION

The idea of ontology based location model is to separate the domain knowledge of the model from the programming code and calculations. The knowledge is represented in the ontology for the model, and the ontology will provide the crucial information to carry out the actual calculations. Once

the answers or values are obtained, there will be further queries to obtain detailed information; in particular, many numerical values, required for the calculations, are generated by the ontology. Hence, it will allow separating the logics from calculations, and the calculations will be the only tasks carried out in the programming code.

In the ontology, we can apply sequential inference rules to deduce the values required for the calculation. For example, in the rules in Figure 4, identify the QaQi values are identified by using a sequence of inferences. The values obtained from the ontology are computed in Java methods, and the values are sent to clients as RESTful services. The clients request the output, in this case in JSON format, to the server, and when they receive the output, they imbibe it in their implementation and provide the information – the output variables, in particular – to the users in a web page.

Figure 7 shows the map of Cologne region in Germany. The polygons around the pin in the region represent the cells containing the required biomass for the following requested input variables:

- Latitude = 6.336535
- Longitude = 51.056189
- Region Name = Cologne
- Needed Biomass = 1000 tons per annum
- Biomass Type = Root crops residue
- Biomass Scenario = Basis

The system also provides a mechanism to store the consultation containing the input and output variables under a client’s name. The users, then, retrieve the saved results, compare and analyze them in order to get a better view of the potential project.

If a client chooses a place and places the pointer where there is not enough biomass of the requested type and amount, the system will suggest the client that there is not enough biomass available and displays the nearest places where the client might be interested to choose instead.

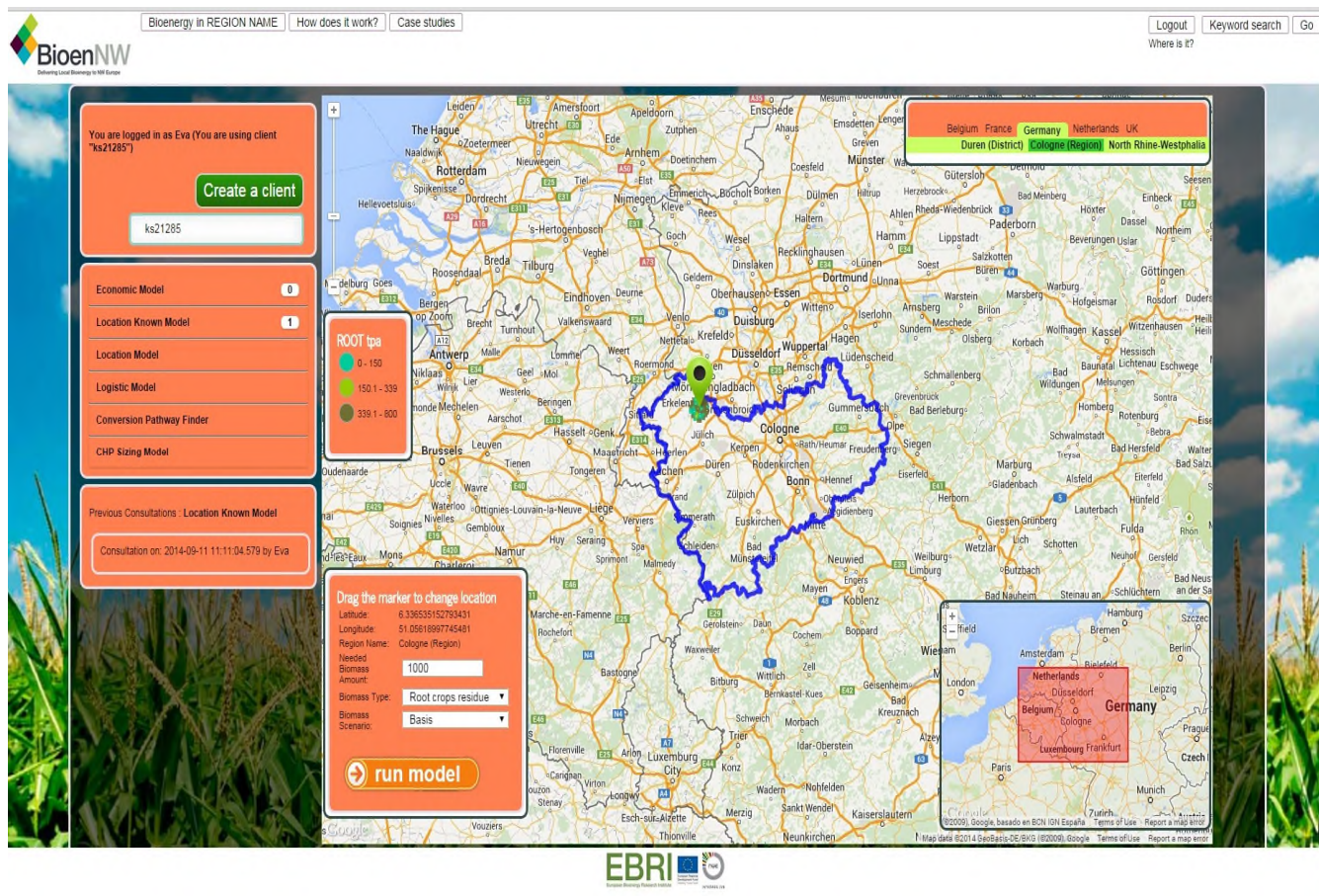


Figure 7. Google map showing 1000 tons of root crop residue around a point in Cologne region

#### IV. DISCUSSION

The results from the ontology-based location model have shown that the approach has a promising solution. The model is one of the DSTs for the bioenergy and algae plants, which helps the plant developers or the farmers to identify appropriate location for their projects. In the model, there are various incentives and tariffs based on various factors, such as location, feedstock and technology. The model needs to execute a series of calculations integrating all the information. Currently, the domain knowledge of the location model is hard coded with programming code, which entails the model with some limitations, for example the model being less explicit, less reusable, less sharable and less extendable. An alternative to these limitations is to separate the knowledge from the code and represent it in a logic based explicit format. One of such representations format is Ontology. Ontology is a part of SW technologies.

In this paper, we explained how the concepts, relations and logic behind the calculations could be represented semantically. SW technologies allow us to define the concepts, relations and their constraints, thus making the knowledge explicit, sharable, reusable and extendable.

#### V. CONCLUSION

In this paper, we described how the concepts, relationships and logics could be separated from the location model for bioenergy and biofuel projects, and represented them in an ontology, which made the model more shareable, reusable and extendible. Ontology allows an efficient mechanism to specify formal concepts with axioms and rules. Since the information in ontology is represented in description logic, there are well-known inference engines available to infer new knowledge from existing knowledge. By inferring the knowledge in the ontology for the location model, we generated the required information for calculations, such as the variables: incentives, tariffs and other attributes. This approach is useful for extending the model and checking whether the knowledge in the model is consistent.

In future work, we aim to integrate the bioenergy ontology, which is developed as part of the BioenNW project, into the ontology for the location model. If the time permits, we will also integrate MathML into our system, and infer the equations relevant to a particular scenario in such a way that they will be executed in a correct sequence.

## VI. ACKNOWLEDGEMENTS

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