Supplementary Material to Universal Digital Twin – Land use

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A.1. Land Use and Biomass

The following sections review other data and ontologies that describe biomass availability, land cover and land use, and assesses their suitability for inclusion in a digital twin of the UK.

A.1.1. Biomass Availability Data

Biomass is material derived from living, or recently living organisms (Forest Research, Forestry Commission, UK, 2021). The Forest Research agency defines five categories of biomass: virgin wood, energy crops, agricultural residues, food waste, and industrial waste and co-products (Forest Research, Forestry Commission, UK, 2021). A number of reports attempt to quantify the biomass resources available to the UK.

The Forestry Commission (FC) produces a National Inventory of Woodland and Trees (Forest Research, Forestry Commission, UK, 2003) every 15 to 20 years, providing statistics by forest type, species and ownership. A mapped distribution of woodland that is over two hectares in area is included, however quantitative data are only reported regionally ('South West', 'South East' and so on). In 2003, the Forestry Contracting Association (FCA) and FC (Bijlsma et al., 2003) provided statistics about woody biomass production with greater resolution, but it was restricted to Forest Districts that were predefined by the FC. Despite the quantity of data offered, the data are only updated infrequently, which does not align with the ambition of a dynamic digital twin.

In 2013 a model was published that sought to predict the future availability of lignocellulosic biomass in the UK to 2050 (Hastings et al., 2014). The model is based on variables that could in the future be provided via a digital twin, including soil composition and weather conditions as well as constraints on where biomass can be grown. The types of biomass considered in the model are miscanthus, short rotation coppice willow, short rotation coppice poplar, and short rotation forest poplar. Calculations were performed on land areas of 1 km^2 and the results reported by region. A subsequent report by the NNFCC consultancy also assessed the availability of lignocellulosic materials in the UK (Maio and Turley, 2014). Data was presented for the availability of forest harvest residues, energy crops, agricultural straw residues and green wastes including paper. Although information was provided for the whole UK, the geographical resolution of data was again only by region.

In 2014 the National Forest Inventory produced a 50-year forecast for the availability of softwood timber in the UK (Forestry Commission, 2014). The forecast considered the area of woodland, wood characteristics, growth rate and when trees are harvested. The data include the volume of wood available by region and whether the wood is located on public or private land. However, the report necessarily caveats that the forecast is subject to unpredictable external factors that have the potential to cause significant disparity from the forecast results.

Contemporary data about the quantities of different wastes and methods of disposal are available through annual government reports in the UK (Department for Environment, Food & Rural Affairs (United Kingdom), 2019; Ystadegau ar gyfer Cymru – Statistics for Wales, 2019; Scottish Environment Protection Agency, 2018). However, the data are only resolved to a regional level, for example 'South West', 'North West' and so on, so are not able to provide a geographically precise description of biomass availability. The Digest of Waste and Resource Statistics (Department for Environment, Food & Rural Affairs (United Kingdom), 2015) also publishes data about waste streams, including some biomass, and waste treatment facilities in the UK. The Waste and Resources Action Programme (WRAP) charity reported bulk figures of household food and drink waste for the UK, separated into different categories and by possible end uses (Waste and Resources Action Programme (WRAP), 2012).

The data surveyed in this section are limited by their geospatial resolution and accuracy, and are mainly provided via text-based documents which reduces the accessibility of the data. They will not be pursued further in this iteration of the digital twin.

A.1.2. Land Cover and Land Use Data

Land Cover is the observed cover of the surface of the earth (Gregorio and Jansen, 1998), whereas Land Use is the socio-economic function of the land (EuroStat, Office for Official Publications of the European Communities, 2001). The UK Government publishes annual data about land use in England (Ministry of Housing, Communities & Local Government (United Kingdom), 2018). Developed land use categories include residential, transport and industry, while non-developed land uses include agriculture, forestry and undeveloped land. Data for the percentage of developed and non-developed land is provided by region, and higher resolution data is available on request for smaller land areas. The land use is classified using products from Ordnance Survey (Ordnance Survey, 2021), and the resulting data are subject to quality assurance tests so are of known quality. However, the data are published in the form of infographics which are not readily machine-readable.

The UK Centre for Ecology & Hydrology produces a map of land cover across the UK (UK Centre for Ecology & Hydrology, 2021). Crops classified in this map include, field beans, grass, maize, oilseed rape, potatoes, barley (spring & winter) and wheat (spring & winter). The data is produced annually using satellite data from Sentinel-2 (European Space Agency, 2021) and is verified using land declarations produced by farmers. The data has high geospatial resolution and is reported in the form of the land cover associated with individual fields. The geospatial boundaries of the fields across the UK are obtained from the 2007 Ordnance Survey Mastermap® data (Ordnance Survey, 2021), and although this is historic data, the likelihood of field boundaries changing is considered unlikely (UK Centre for Ecology & Hydrology, 2021). However, the boundaries of the fields are highly irregular, such that this is a detailed but complex data set. In addition, the only data that is available for free for educational use dates from 2015. This data is a valuable resource, but the restrictions on accessing it limit our ability to use it in a digital twin.

The UK Government also publishes an annual Crop Map of England (CROME) (Rural Payments Agency, 2019). This is a useful source of data and is discussed in the main text. Example data is shown in **Table A.1**. A description of the CROME schema is given in **Table A.2**.

Table A.1. *Example Land Use Codes (LUCodes), their respective land cover and land use descriptions used by the CROME 2019 data set.*

Land Cover Description	LUCode	Land Use Description
Cereal Crop	AC100	Italian Ryegrass
Leguminous Crop	LG14	Clover
Energy Crop	SR01	Short Rotation Coppice
Grassland	PG01	Grass
Non-Agricultural Land	NA01	Non-vegetated or sparsely-vegetated Land
Water	WA01	Water
Trees	TC01	Perennial Crops and Isolated Trees
Unknown Vegetation Or Mixed Vegetation	AC00	Unknown or Mixed Vegetation

Table A.2. *Description of the schema used by the CROME 2019 data set.*

Envelope Type	
Property	**Description**
srsName	EPSG:27700 (coordinate system).
srsDimension	2 (2D coordinate system).
lowerCorner	Extreme south-westerly coordinate of the envelope.
upperCorner	Extreme north-easterly coordinate of the envelope.
Cell Features	
Property	**Description**
Crop_Map_of_England_2019_*EnvelopeName*	*EnvelopeName* is replaced by the name of the region to which the cell belongs, for example *Cambridgeshire*.
OBJECTID	Cells are numbered consecutively for a given envelope.
CROMEID	An identifier of the form: RPA$xxxxxxxyyyyyy$. This is a unique key associated with a cell across all survey years, where $xxxxxxxyyyyyy$ identifies the centre point of the cell using the EPSG:27700 coordinate system.
LUCode	Identifies the land use associated with the cell.
RefDate	The date the land use classification was performed (yyyymmdd format).
Shape_Length	The perimeter of the cell (m).
Shape_Area	The area of the cell (m^2).
surfaceProperty	Geospatial description of the cell.
Cell Geospatial Features	
Property	**Description**
srsName	EPSG:27700 (coordinate system).
srsDimension	2 (2D coordinate system).
posList	Series of pairs of coordinates to define a closed perimeter (the first and last pair in the series are the same). In the CROME data, each list describes a hexagonal cell so contains 7 pairs of coordinates.

A.2. Description Logic Representation of Ontologies

A.2.1. OntoLandUse

Classes

$$\begin{aligned}
\text{LandUseCode} &\sqsubseteq \top \\
\text{LandCover} &\sqsubseteq \top \\
\text{LandUseCodeType} &\sqsubseteq \top \\
\text{AgriculturalLand} &\sqsubseteq \text{LandUseCodeType} \\
\text{Non-AgriculturalLand} &\sqsubseteq \text{LandUseCodeType} \\
\text{AdministrativeDivision} &\sqsubseteq \top
\end{aligned}$$

Object Properties

$$\begin{aligned}
\text{LandUseCode} &\sqsubseteq \leq 1\ \text{isConnectedTo.LandCover} \sqcap \\
&\quad \geq 1\ \text{isConnectedTo.LandCover} \\
\text{LandUseCode} &\sqsubseteq \leq 1\ \text{hasLandUseType.LandUseCodeType} \sqcap \\
&\quad \geq 1\ \text{hasLandUseType.LandUseCodeType} \\
(\text{LandUseCode} \sqcup \text{LandUseCodeType}) &\sqsubseteq \forall\ \text{usedIn.AdministrativeDivision}
\end{aligned}$$

A.2.2. OntoCropMapGML

Classes

$$\begin{aligned}
\text{OntoCityGML:EnvelopeType} &\sqsubseteq \top \\
\text{CropMap} &\sqsubseteq \top
\end{aligned}$$

Object Properties

$$\begin{aligned}
\text{CropMap} &\sqsubseteq \leq 1\ \text{OntoCityGML:boundedBy.EnvelopeType} \sqcap \\
&\quad \geq 1\ \text{OntoCityGML:boundedBy.EnvelopeType} \\
\text{CropMap} &\sqsubseteq \leq 1\ \text{hasLandUseCode.OntoLandUse:LandUseCode} \sqcap \\
&\quad \geq 1\ \text{hasLandUseCode.OntoLandUse:LandUseCode}
\end{aligned}$$

Data Properties

$$\begin{aligned}
\exists\ \text{OntoCityGML:lowerCornerPoint}.\top &\sqsubseteq \text{OntoCityGML:EnvelopeType} \\
\top &\sqsubseteq \forall\ \text{OntoCityGML:lowerCornerPoint.BigData:lat-lon} \\
\exists\ \text{OntoCityGML:upperCornerPoint}.\top &\sqsubseteq \text{OntoCityGML:EnvelopeType} \\
\top &\sqsubseteq \forall\ \text{OntoCityGML:upperCornerPoint.BigData:lat-lon} \\
\exists\ \text{OntoCityGML:srsname}.\top &\sqsubseteq \text{OntoCityGML:EnvelopeType} \\
\top &\sqsubseteq \forall\ \text{OntoCityGML:srsname.String} \\
\exists\ \text{srsDimension}.\top &\sqsubseteq \text{OntoCityGML:EnvelopeType} \\
\top &\sqsubseteq \forall\ \text{srsDimension.Integer} \\
\exists\ \text{sql:ObjectIdentifier}.\top &\sqsubseteq \text{CropMap} \\
\top &\sqsubseteq \forall\ \text{sql:ObjectIdentifier.Integer} \\
\exists\ \text{hasCromeID}.\top &\sqsubseteq \text{CropMap} \\
\top &\sqsubseteq \forall\ \text{hasCromeID.String} \\
\exists\ \text{dbo:area}.\top &\sqsubseteq \text{CropMap} \\
\top &\sqsubseteq \forall\ \text{dbo:area.Double} \\
\exists\ \text{vocab:length}.\top &\sqsubseteq \text{CropMap}
\end{aligned}$$

$$\top \sqsubseteq \forall \text{ vocab:length.Double}$$
$$\exists \text{ hasRefDate.}\top \sqsubseteq \text{CropMap}$$
$$\top \sqsubseteq \forall \text{ hasRefDate.Integer}$$
$$\exists \text{ hasGeometry.}\top \sqsubseteq \text{CropMap}$$
$$\top \sqsubseteq \forall \text{ hasGeometry.WA:POLYGON-2-14}$$
$$\exists \text{ datex:centrePoint.}\top \sqsubseteq \text{CropMap}$$
$$\top \sqsubseteq \forall \text{ datex:centrePoint.BigData:lat-lon}$$

A.2.3. OntoCropEnergy

Classes

$$\text{Crop} \sqsubseteq \top$$
$$\text{Barley} \sqsubseteq \text{Crop}$$
$$\text{Beet} \sqsubseteq \text{Crop}$$
$$\text{Carrot} \sqsubseteq \text{Crop}$$
$$\text{Chicory} \sqsubseteq \text{Crop}$$
$$\text{Lettuce} \sqsubseteq \text{Crop}$$
$$\text{Linseed} \sqsubseteq \text{Crop}$$
$$\text{Maize} \sqsubseteq \text{Crop}$$
$$\text{Oats} \sqsubseteq \text{Crop}$$
$$\text{Onions} \sqsubseteq \text{Crop}$$
$$\text{Rye} \sqsubseteq \text{Crop}$$
$$\text{Strawberry} \sqsubseteq \text{Crop}$$
$$\text{Triticale} \sqsubseteq \text{Crop}$$
$$\text{Wheat} \sqsubseteq \text{Crop}$$
$$\text{Cabbage} \sqsubseteq \text{Crop}$$
$$\text{Turnip} \sqsubseteq \text{Crop}$$
$$\text{Oilseed} \sqsubseteq \text{Crop}$$
$$\text{Potato} \sqsubseteq \text{Crop}$$
$$\text{Tomato} \sqsubseteq \text{Crop}$$
$$\text{Sunflower} \sqsubseteq \text{Crop}$$
$$\text{Field Beans} \sqsubseteq \text{Crop}$$
$$\text{Green Beans} \sqsubseteq \text{Crop}$$
$$\text{Peas} \sqsubseteq \text{Crop}$$
$$\text{Miscanthus} \sqsubseteq \text{Crop}$$
$$\text{GrossCalorificValue} \sqsubseteq \top$$
$$\text{NetCalorificValue} \sqsubseteq \top$$
$$\text{CropYield} \sqsubseteq \top$$
$$\text{SurfacePowerDensity} \sqsubseteq \top$$
$$\text{CropSurfacePowerDensity} \sqsubseteq \text{SurfacePowerDensity}$$

Object Properties

$$\text{Crop} \sqsubseteq \forall \text{ OntoCropMapGML:hasLandUseCode.}\ \text{OntoLandUse:LandUseCode}$$
$$\text{Crop} \sqsubseteq \leq 1 \text{ hasGrossCalorificValue.GrossCalorificValue} \sqcap \geq 1 \text{ hasGrossCalorificValue.GrossCalorificValue}$$

$$\begin{aligned}
\text{Crop} &\sqsubseteq \leq 1\ \text{hasNetCalorificValue.NetCalorificValue} \sqcap \\
&\quad \geq 1\ \text{hasNetCalorificValue.NetCalorificValue} \\
\text{Crop} &\sqsubseteq \leq 1\ \text{hasCropYield.CropYield} \sqcap \\
&\quad \geq 1\ \text{hasCropYield.CropYield} \\
\text{Crop} &\sqsubseteq \leq 1\ \text{hasCropSurfacePowerDensity.CropSurfacePowerDensity} \sqcap \\
&\quad \geq 1\ \text{hasCropSurfacePowerDensity.CropSurfacePowerDensity} \\
\exists\ \text{OM:hasValue}.\top &\sqsubseteq \text{GrossCalorificValue} \sqcup \text{NetCalorificValue} \sqcup \\
&\quad \text{CropYield} \sqcup \text{CropSurfacePowerDensity} \\
\top &\sqsubseteq \forall\ \text{OM:hasValue.OM:Measure} \\
\exists\ \text{OM:hasUnit}.\top &\sqsubseteq \text{OM:Measure} \\
\top &\sqsubseteq \forall\ \text{OM:hasUnit.OM:UnitDivision} \\
(\text{CropYield} \sqcup \text{NetCalorificValue} \sqcup & \\
\text{GrossCalorificValue}) &\sqsubseteq \leq 1\ \text{OntoSpecies:hasWeblink.OntoSpecies:Weblink} \sqcap \\
&\quad \geq 1\ \text{OntoSpecies:hasWeblink.OntoSpecies:Weblink}
\end{aligned}$$

Data Properties

$$\begin{aligned}
\exists\ \text{OM:hasNumericalValue}.\top &\sqsubseteq \text{OM:Measure} \\
\top &\sqsubseteq \forall\ \text{OM:hasNumericalValue.Double} \\
\exists\ \text{dateOfAccess}.\top &\sqsubseteq \text{Weblink} \\
\top &\sqsubseteq \forall\ \text{dateOfAccess.String} \\
\exists\ \text{hasURL}.\top &\sqsubseteq \text{Weblink} \\
\top &\sqsubseteq \forall\ \text{hasURL.String}
\end{aligned}$$

A.3. Namespaces

BigData: <http://www.bigdata.com/rdf/geospatial/literals/v1#>
Datex: <http://vocab.datex.org/terms#>
Dbo: <http://dbpedia.org/ontology/>
OM: <http://www.ontology-of-units-of-measure.org/resource/om-2/>
Geo: <http://www.bigdata.com/rdf/geospatial#>
OntoCityGML: <http://www.theworldavatar.com/ontology/ontocitygml/OntoCityGML.owl#>
OntoCropEnergy: <http://www.theworldavatar.com/ontology/ontocropenergy/OntoCropEnergy.owl#>
OntoCropEnergyKB: <http://www.theworldavatar.com/kb/ontocropenergy/>
OntoCropMapGML: <http://www.theworldavatar.com/ontology/ontocropmapgml/OntoCropMapGML.owl#>
OntoCropMapGMLKB: <http://www.theworldavatar.com/kb/ontocropmapgml/>
OntoLandUse: <http://www.theworldavatar.com/ontology/ontolanduse/OntoLandUse.owl#>
OntoLandUseKB: <http://www.theworldavatar.com/kb/ontolanduse/>
OntoSpecies: <http://www.theworldavatar.com/ontology/ontospecies/OntoSpecies.owl#>
Rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
Sql: <http://ns.inria.fr/ast/sql#>
Vocab: <http://open.vocab.org/terms/>
WA: <http://www.theworldavatar.com/ontology/datatype/>

A.4. Example Geospatial Queries

Query A.1. *Geospatial SPARQL query to count the number of land features located in a region defined by the centre point and radius of a circle. Blazegraph resolves the query by performing geospatial reasoning against the centre points of the land features.*

```
PREFIX BigData: <http://www.bigdata.com/rdf/geospatial/literals/v1#>
PREFIX geo: <http://www.bigdata.com/rdf/geospatial#>
PREFIX datex: <http://vocab.datex.org/terms#>
PREFIX OntoCropMapGML:
    <http://www.theworldavatar.com/ontology/ontocropmapgml/OntoCropMapGML.owl#>

SELECT (COUNT(?Feature) as ?FeaturesTotal)
WHERE
{
  SERVICE geo:search
  {
    ?cropMap geo:search "inCircle" .
    ?cropMap geo:predicate datex:centrePoint .
    ?cropMap geo:searchDatatype BigData:lat-lon .
    ?cropMap geo:spatialCircleCenter "52.40#0.13" .
    ?cropMap geo:spatialCircleRadius "5" . # default unit: km
  }
  ?cropMap OntoCropMapGML:hasGeometry ?Feature
}
```

Query A.2. *Geospatial SPARQL query to retrieve the location (lat#lon) and LUcode of land features located in a region defined by the centre point and radius of a circle. Blazegraph resolves the query by performing geospatial reasoning against the centre points of the land features.*

```
PREFIX BigData: <http://www.bigdata.com/rdf/geospatial/literals/v1#>
PREFIX geo: <http://www.bigdata.com/rdf/geospatial#>
PREFIX datex: <http://vocab.datex.org/terms#>
PREFIX OntoCropMapGML:
    <http://www.theworldavatar.com/ontology/ontocropmapgml/OntoCropMapGML.owl#>

SELECT ?location ?geometry ?LUCode
WHERE
{
  SERVICE geo:search
  {
    ?cropMap geo:search "inCircle" .
    ?cropMap geo:predicate datex:centrePoint .
    ?cropMap geo:searchDatatype BigData:lat-lon .
    ?cropMap geo:spatialCircleCenter "52.40#0.13" .
    ?cropMap geo:spatialCircleRadius "5" . # default unit: km
  }
  ?cropMap datex:centrePoint ?location .
  ?cropMap OntoCropMapGML:hasGeometry ?geometry .
  ?cropMap OntoCropMapGML:hasLucode ?LUCode .
}
```

A.5. Example Calculation for Elean Power Station Use Case

The following is an example calculation of the power associated with the crops grown in the vicinity of Elean Power Station. The queries and calculations were implemented in Python. All relevant SPARQL queries are provided in Section A.6.

1. Query data for biomass-fired power stations in the UK. **Table A.3** shows the result for Elean Power Station.
2. Query the land use codes of the crops (wheat, miscanthus and oilseed) that are able to be used by Elean Power Station (Engineering Timelines, 2000). **Table A.4** shows the results of the query.
3. Query the yield and net calorific value of wheat, miscanthus and oilseed crops. **Table A.5** shows the results of the query.
4. Perform a geospatial *inCircle* query centred on Elean Power Station to count the number of occurrences of the land use codes for wheat, miscanthus and oilseed as a function of radius around the power station. **Table A.6** shows the results of the query.
5. Estimate the total power that could be generated using all the wheat, miscanthus and oilseed crops grown within a given radius of Elean Power Station.

$$P = N\,A\,Y\,E, \tag{A.1}$$

where P is the power available for a crop (W), N is the number of occurrences of the land use code for the crop within the search radius (-), A is the area of corresponding to each occurrence of a land use code, Y is the yield (kg m^{-2} s^{-1}) and E is the net calorific value of the crop (J kg^{-1}).

Table A.7 shows the results of the calculation. The area A could have been retrieved via another query. However, in this case it was known *a priori* that $A \approx 4156$ m^2, corresponding to the area of the hexagonal cells used by the CROME data (Rural Payments Agency, 2019).

6. Estimate the electricity that could be generated from crops in the search radius.

$$G = P_{\text{total}}\,\eta, \tag{A.2}$$

where G is the power generated by Elean Power Station, P_{total} is the total power available and $\eta = 32.5\%$ is the assumed efficiency of Elean Power Station (Select Committee on Science & Technology, House of Lords, 2004).

Table A.3. *Results of a query to retrieve data for Elean Power Station.*[1]

Name	Ely
Capacity	40 MW
Built	2001
Fuel	Biomass
Technology	Conventional Steam
Latitude	52.3955987
Longitude	0.1640088

[1] The data in the knowledge graph returned by this query originate from the Digest of UK Energy Statistics (DUKES) (Department for Business, Energy & Industrial Strategy (United Kingdom), 2020). The discrepancy in the value of the capacity, which is reported elsewhere as 38 MW is noted.

Table A.4. *Results of a query to retrieve the LUCodes of crops consumed by Elean Power Station.*

Crop Name	**LUCode**
Winter Wheat	AC66
Winter Oilseed	AC67
Miscanthus	TC01
Spring Wheat	AC32
Spring Oilseed	AC36

Table A.5. *Results of queries to retrieve the yield and net calorific value of crops consumed by Elean Power Station.*

Crop Name	Yield / te ha $^{-1}$ yr^{-1}	Net Calorific Value / MJ kg^{-1}
Winter Wheat	8.9345	14.70
Winter Oilseed	3.3057	15.73
Miscanthus	14.0000	10.12
Spring Wheat	8.9345	14.70
Spring Oilseed	3.3057	15.73

Table A.6. *Results of a geospatial query to count the LUCode occurrences within 17.1 km of Elean Power Station.*

Crop Name	LUCode	Occurrences / -
Winter Wheat	AC66	58, 510
Winter Oilseed	AC67	7, 656
Miscanthus	TC01	3, 186
Spring Wheat	AC32	2, 511
Spring Oilseed	AC36	0

Table A.7. *Power associated with crops within 17.1 km of Elean Power Station.*

Crop	Power / MW
Winter Wheat	101.2
Winter Oilseed	5.2
Miscanthus	5.9
Spring Wheat	4.3
Spring Oilseed	0.0
Total	116.7

A.6. Queries Performed by the Elean Power Station Use Case

Query A.3 is levied against a part of the knowledge graph that is not currently public. However, a previous iteration of this part of the knowledge graph can be viewed online. See https://kg.cmclinnovations.com/explore/digital-twin/power-system.

Query A.3. *Query power station coordinates.*

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX ontopowsys_PowSysRealization:
  <http://www.theworldavatar.com/ontology/ontopowsys/PowSysRealization.owl#>
PREFIX ontopowsys_PowSysPerformance:
  <http://www.theworldavatar.com/ontology/ontopowsys/PowSysPerformance.owl#>
PREFIX upper_level_system:
  <http://www.theworldavatar.com/ontology/ontocape/upper_level/system.owl#>
PREFIX ontoeip_powerplant:
  <http://www.theworldavatar.com/ontology/ontoeip/powerplants/PowerPlant.owl#>
PREFIX technical_system:
  <http://www.theworldavatar.com/ontology/ontocape/upper_level/technical_system.owl#>
PREFIX meta_model_topology:
  <http://www.theworldavatar.com/ontology/meta_model/topology/topology.owl#>
PREFIX space_and_time_extended:
  <http://www.theworldavatar.com/ontology/ontocape/supporting_concepts/space_and_time/
      space_and_time_extended.owl#>
PREFIX power_plant:
  <http://www.theworldavatar.com/ontology/ontoeip/powerplants/PowerPlant.owl#>

SELECT ?PowerPlant ?Built ?Capacity ?Unit ?Fuel ?Technology ?Latitude ?Longitude
WHERE
{
  ?PowerPlant ontoeip_powerplant:hasYearOfBuilt ?v_built.
  ?v_built upper_level_system:hasValue ?vv_built .
  ?vv_built upper_level_system:numericalValue ?Built .

  ?PowerPlant technical_system:hasRequirementsAspect/upper_level_system:hasValue ?v_capa
      .
  ?v_capa upper_level_system:numericalValue ?Capacity .
  ?v_capa upper_level_system:hasUnitOfMeasure ?Unit .

  ?PowerPlant technical_system:hasRealizationAspect ?PowerGenerator .
  ?PowerGenerator a ontoeip_powerplant:PowerGenerator .
  ?PowerGenerator technical_system:realizes/ontoeip_powerplant:consumesPrimaryFuel ?Fuel
      .
  ?PowerGenerator technical_system:realizes/ontoeip_powerplant:usesGenerationTechnology ?
      Technology .

  ?PowerPlant space_and_time_extended:hasGISCoordinateSystem ?CoordinateSystem .
  ?CoordinateSystem space_and_time_extended:hasProjectedCoordinate_x ?x_coordinate .
  ?CoordinateSystem space_and_time_extended:hasProjectedCoordinate_y ?y_coordinate .
  ?x_coordinate upper_level_system:hasValue ?GPS_x_coordinate .
  ?y_coordinate upper_level_system:hasValue ?GPS_y_coordinate .
  ?GPS_x_coordinate upper_level_system:numericalValue ?Longitude. # east/west
  ?GPS_y_coordinate upper_level_system:numericalValue ?Latitude . # north/south

  Filter(?Fuel= power_plant:Biomass) # only return data for biomass plants
}
```

The following queries are levied against https://kg.cmclinnovations.com/blazegraph_geo.

Query A.4. *Query crops and LUCodes.*

```
PREFIX OntoCropEnergyKB:<http://www.theworldavatar.com/kb/ontocropenergy/>
PREFIX OntoCropMapGML:
  <http://www.theworldavatar.com/ontology/ontocropmapgml/OntoCropMapGML.owl#>
SELECT ?Crop ?LUCode
WHERE
{
  ?Crop OntoCropMapGML:hasLucode ?LUCode .
  Filter(?Crop= OntoCropEnergyKB:SpringWheat||
    ?Crop= OntoCropEnergyKB:WinterWheat
      ||?Crop= OntoCropEnergyKB:SpringOilseed
        ||?Crop= OntoCropEnergyKB:WinterOilseed
          ||?Crop= OntoCropEnergyKB:Miscanthus)
}
```

Query A.5. *Query yield.*

```
PREFIX OntoCropEnergy:
  <http://www.theworldavatar.com/ontology/ontocropenergy/OntoCropEnergy.owl#>
PREFIX OntoCropEnergyKB:<http://www.theworldavatar.com/kb/ontocropenergy/>
PREFIX OM: <http://www.ontology-of-units-of-measure.org/resource/om-2/>
SELECT ?Crop ?Yield
WHERE
{
  ?Crop OntoCropEnergy:hasCropYield ?YieldRef .
  ?YieldRef OM:hasValue ?Measure .
  ?Measure OM:hasNumericalValue ?Yield .
  Filter(?Crop= OntoCropEnergyKB:SpringWheat||
    ?Crop= OntoCropEnergyKB:WinterWheat
      ||?Crop= OntoCropEnergyKB:SpringOilseed
        ||?Crop= OntoCropEnergyKB:WinterOilseed
          ||?Crop= OntoCropEnergyKB:Miscanthus)
}
```

Query A.6. *Query net calorific value.*

```
PREFIX OntoCropEnergy:
  <http://www.theworldavatar.com/ontology/ontocropenergy/OntoCropEnergy.owl#>
PREFIX OntoCropEnergyKB:<http://www.theworldavatar.com/kb/ontocropenergy/>
PREFIX OM: <http://www.ontology-of-units-of-measure.org/resource/om-2/>
SELECT ?Crop ?LHV
WHERE
{
 ?Crop OntoCropEnergy:hasNetCalorificValue ?LHVRef .
  ?LHVRef OM:hasValue ?Measure .
  ?Measure OM:hasNumericalValue ?LHV .
  Filter(?Crop= OntoCropEnergyKB:SpringWheat||
    ?Crop= OntoCropEnergyKB:WinterWheat
      ||?Crop= OntoCropEnergyKB:SpringOilseed
        ||?Crop= OntoCropEnergyKB:WinterOilseed
          ||?Crop= OntoCropEnergyKB:Miscanthus)
}
```

Query A.7. *Count LUCode occurrences within 17.1 km of Elean Power Station.*

```
PREFIX BigData: <http://www.bigdata.com/rdf/geospatial/literals/v1#>
PREFIX geo: <http://www.bigdata.com/rdf/geospatial#>
PREFIX datex: <http://vocab.datex.org/terms#>
PREFIX OntoCropMapGML:
  <http://www.theworldavatar.com/ontology/ontocropmapgml/OntoCropMapGML.owl#>
PREFIX OntoLandUseKB:
  <http://www.theworldavatar.com/kb/ontolanduse/>
SELECT ?LUCode (COUNT(?LUCode) AS ?Occurrences)
WHERE
{
  SERVICE geo:search
  {
    ?cropMap geo:search "inCircle" .
    ?cropMap geo:predicate datex:centrePoint .
    ?cropMap geo:searchDatatype BigData:lat-lon .
    ?cropMap geo:spatialCircleCenter "52.3955987# 0.1640088" .
    ?cropMap geo:spatialCircleRadius "17.1" .
  }
  ?cropMap OntoCropMapGML:hasLucode ?LUCode
  Filter(?LUCode= OntoLandUseKB:AC32||
    ?LUCode= OntoLandUseKB:AC66
      ||?LUCode= OntoLandUseKB:AC36
        ||?LUCode= OntoLandUseKB:AC67
          ||?LUCode= OntoLandUseKB:TC01)
}
GROUP BY ?LUCode
ORDER BY DESC(?Occurrences)
```

Nomenclature

CROME	Crop Map of England
DUKES	Digest of UK Energy Statistics
FCA	Forestry Contracting Association
FC	Forestry Commission
LUCodes	Land Use Codes
WRAP	Waste and Resources Action Programme

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