An Energy Ontology for Global City Indicators (ISO37120)

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1. Introduction

To create tomorrow's smarter cities, today's initiatives will need to create measurable improvements. However, a city is a complex system and measuring its performance generates a breadth of issues including;

1. What criteria shall be measured and how would these indicators be defined?
2. How shall the identified indicators be derived?

In 2014, the ISO 37120 "Sustainable development of communities – Indicators of city services and quality of life" is an international standard published. With 100 defined indicators across 17 different themes, participating cites have consistent data to measure and compare their performance over time and against other municipalities.

To maintain consistency, the reported data is validated through a certification process organised by the World Council on City Data[1]. Although the certification process validates that the data has been collected in accordance with ISO37120, the process itself is closed from public view. A recent study shows that cities do not publish the data required for the public to verify the indicators (Fox & Pettit). Without the information on the indicators' derivation, the indicators will not provide enough information to understand the root causes of a city's performance.

This working paper is one in a series that addresses the creation of a Semantic Web-based representation of the 17 different themes of ISO37120 Indicators as part of the larger PolisGnosis Project (Fox, 2017; 2015). The objective of the PolisGnosis Project is to automate the longitudinal analysis (i.e. how and why a city's indicators change over time) and the transversal analysis (i.e. how and why the cities differ from each other at the same time), in order to discover the root causes of differences. A necessary condition for analysis is that both an indicator's definition and the data used to derive the indicator's value have to be represented using a standard representation and published on the semantic web. In this

[1] http://www.dataforcities.org/global-cities-registry/

paper we define a standard representation/ontology for representing general knowledge for the Energy Theme indicators, and for representing both the definition and data used to derive the Energy indicators.

In the following we first specify a set of competency questions that the ontology must be able to answer. We then review the literature of energy indicators and ontologies. Followed by a review of the Global City Indicator Ontology that is part of the PolisGnosis project. We then define the GCI Energy Ontologies, followed the representation of the ISO37120 Energy Theme indicators definitions using these ontologies. We finish by evaluating the Energy ontologies using the competency questions.

2. Indicators and their competency requirements

2.1. ISO 37120 Energy Themed Indicators

Based on the methodology defined by Gruninger & Fox (1995), competency questions will be used to identify the types of information that the Energy ontology will need to represent in order define the Energy indicators and the data used to derive them. The following classifications will be used to organize the competency questions (Fox, 2015):

- **Factual (F):** Questions that ask what the value of some property is.
- **Consistency - Definitional (CD):** Questions that determine whether the instantiation of an indicator by a city is consistent with the ISO 37120 definition.
- **Consistency - Internal (CI):** Questions that determine whether different parts of the instantiation are consistent with each other.
- **Deduced (D):** A value or relationship that can be deduced from the instantiation.

The following meta-data related question apply to all indicators:

1. (F) What are the units of measure for the numerical value?
2. (F) When was the numerical value measured?
3. (F) Who or what agency measured the numerical value?
4. (F) What process was used to measure the value?
5. (CD) Is the indicator's supporting data consistent with the ISO37120 definition?

In the remainder of this section we provide a portion of the definition of each Energy theme indicator as found in the ISO 37120 standard. We then define a set of competency questions that the Energy ontology must support the answering of. These questions identify the various types of information the ontology must represent.

7.1 Total residential electrical energy use per capita (kWh/year) (Core Indicator)

Indicator: “Total residential electrical energy use per capita shall be calculated as the total residential electrical usage of a city in kilowatt hours (numerator) divided by the total population of the city (denominator). The result shall be expressed as the total residential electrical use per capita in kilowatt hours/year. Data should be gathered from electricity providers. Electricity consumption statistics are typically collected in three categories, residential, commercial and industrial.”

Competency Questions:

1.) (F) What city is the indicator for?
2.) (F) What is the total population of the city?
3.) (F) Is “Toronto Building 01” a residential building?
4.) (CD) Who are the owners of “Toronto Building 01”? What sector owns this building?
5.) (F) What percentage of the floor space is used for residential purposes?
6.) (F) How much energy was used per year in residential buildings?
7.) (F) What organizations provide electrical service in Toronto?
8.) (F) What addresses does “Service Provider A” service?
9.) (F) How many service accounts are there in “Toronto Building 01”?

7.2 Percentage of city population with authorized electrical service (Core Indicator)

Indicator: “The percentage of city population with authorized electrical service shall be calculated as the number of persons in the city with lawful connection to the electrical supply system (numerator) divided by the total population of the city (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

The number of city households lawfully connected to the electricity grid shall be multiplied by the current average city household size to determine the number of city residents with lawful connection to the electricity supply system (the electricity grid)”

Competency Questions:

1.) (F) How many electrical service accounts are there in the city?
2.) (F) How many households does service account x provide energy to?
3.) (F)How many households are in the city?
4.) (F) How many households in total are legally serviced by these electrical accounts?
5.) (F) What is the average number of people living in each household?
6.) (F) How many households does “Toronto Building 01” have?
7.) (D) How many individual electrical service account holders hold more than one account?

7.3 Energy consumption of public buildings per year (kWh/m²) (Core Indicator)

Indicator: “Energy consumption of public buildings shall be calculated per year as the total use of electricity at final consumption stage by public buildings (kWh) within a city (numerator) divided by total floor space of these buildings in square meters (m²) (denominator). The result shall be expressed as the total energy consumption of public buildings per year in kilowatt hours per square meter. Note that public buildings are government owned buildings such as government offices, hospitals and schools.”

Competency Questions:

1.) (F) Which buildings in Toronto are owned by the government?
2.) (F) How many public buildings are in the city?

3.) (F) What is the floor area of all the public buildings?
4.) (F) How many kWh are being consumed by public buildings?

7.4 The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption (Core Indicator)

Indicator: "The share of a city's total energy consumption derived from renewable sources shall be calculated as the total consumption of electricity generated from renewable sources (numerator) divided by total energy consumption (denominator). The result shall then be multiplied by 100 and expressed as a percentage. Consumption of renewable sources should include geothermal, solar, wind, hydro, tide and wave energy, and combustibles, such as biomass.

Data available from local utility provider, city energy or environment office, and from various international sources, such as the International Energy Agency (IEA), and the World Bank.

Renewable energy shall include both combustible and non-combustible renewables. Non-combustible renewables include geothermal, solar, wind, hydro, tide and wave energy. For geothermal energy, the energy quantity is the enthalpy of the geothermal heat entering the process. For solar, wind, hydro, tide and wave energy, the quantities entering electricity generation are equal to the electrical energy generated. The combustible renewables and waste (CRW) consist of biomass (fuel wood, vegetal waste, ethanol) and animal products (animal materials/waste and sulphite lyes), municipal waste (waste produced by the residential, commercial and public service sectors that are collected by local authorities for disposal in a central location for the production of heat and/or power) and industrial waste."

Competency Questions:

1.) (F) What is the total electrical usage of the city?
2.) (F) Who are the electrical service providers for the city?
3.) (F) What is the electrical mixture distributed for each provider?
4.) (F) What are the different sources of electricity generation?
5.) (F) Which sources are renewable? Non-renewable?
6.) (F) Which sources are combustible renewable?
7.) (F) What is the total enthalpy for all geothermal heat?
8.) (F) What % of the usage is fossil fuels?
9.) (F) Who provided the information on the renewable energy mixture production?

7.5 Total electrical energy use per capita (kWh/year) (supporting indicator)

Indicator: "Total electrical energy use per capita shall be calculated as the total electrical usage of a city in kilowatt hours including residential and non-residential use (numerator) divided by the total population of the city (denominator). The result shall be expressed as the total electrical use per capita in kilowatt hours/year.

Data shall be gathered from electricity providers. Electricity consumption statistics are typically collected in three categories: residential, commercial and industrial.
Compilation of the sources used to generate energy based on fossil and renewable energy sources; types of renewable energy already in use; identification of locally existing renewable energy sources; compilation of the energy required for heating and cooling processes; completed and planned measures to save energy and to improve energy efficiency; completed and planned activities for the environmentally friendly insulation and cooling of buildings, if available should be noted."

Competency Questions:

1.) (F) What is the total electrical usage per year?
2.) (F) Who reported the total electrical usage?
3.) (CI) What is the total non-residential energy usage per year?
4.) (CI) What is the total residential energy usage per year?

7.6 Average number of electrical interruptions per customer per year (supporting indicator)

Indicator: "The average number of electrical interruptions per customer per year shall be calculated as the total number of customer interruptions (numerator) divided by the total number of customers served (denominator). The result shall be expressed as the average number of electrical interruptions per customer per year.

Electrical interruptions shall include both residential and non-residential. It is normal to expect interruptions in service for a number of reasons including scheduled maintenance and equipment breakdown. To establish the opportunity to have a reasonable comparison between energy providers, major storms and weather events should be excluded due to their unpredictability and randomness since they are difficult to predict, prevent or mitigate against. This indicator is affected by the age, standard of maintenance and reliability of the infrastructure that constitutes the electricity grid and the electricity transmission capacity that services the grid. The ability of both the grid and its electricity transmission capacity to provide supply on demand and to cope with peak loads is also an important consideration."

Competency Questions:

1.) (CD) How do you define customers? Is that number of households or as the number of individuals under assumed impact?
2.) (CD) If an individual's home and office gets an electrical interruption, will they be counted twice?
3.) (F) How many Households have electrical interruptions?
4.) (F) How many non-residential electricity users were impacted by the electrical interruption?
5.) (F) How many service interruptions were caused by extreme weather events?
6.) (F) How many interruptions were there in the city total?
7.) (F) Which account holders total were impacted by the interruption?
8.) (F) Which electrical providers experiences the most interruptions?

9.) (F) How many interruptions were counted due to extreme weather events?

7.7 Average Length of electrical interruption (hours) (supporting indicator)

Indicator: "The average length of electrical interruptions shall be calculated as the sum of the duration of all customer interruptions in hours (numerator) divided by the total number of customer interruptions (denominator). The result shall be expressed as the average length of electrical interruptions in hours. Electrical interruptions shall include both residential and non-residential. It is normal to expect interruptions in service for a number of reasons including scheduled maintenance and equipment breakdown. To establish the opportunity to have a reasonable comparison between energy providers, major storms and weather events shall be excluded due to their unpredictability as they are difficult to prevent or mitigate against.

This indicator is affected by the age, standard of maintenance and reliability of the infrastructure that constitutes the electricity grid and the electricity transmission capacity that services the grid. The ability of both the grid and its electricity transmission capacity to provide supply on demand and to cope with peak loads is also an important consideration."

Competency Questions:

1.) (F) What is the total duration of all electrical interruptions?
2.) (F) What is the total number of interruptions?

3. Background

This section reviews the ontologies that were investigated and re-used in the development in the GCI Energy ontology. The ontologies evaluated broadly fit into two classes; ontologies that pertain to energy usage and ontologies that have terminology that could be reused to structure where and how energy is used in a city.

3.1. Energy Ontologies and Resources

Although there are many ontologies and resources on the topic of "Energy" available, the existing choices did not satisfy the competency questions specified for the GCI Energy Themed Ontology. Most existing energy ontologies are developed to facilitate improving energy efficiency on a specific building level or for smart grid infrastructure rather than total energy usage at a municipal level. These ontologies will be discussed later in this section

Concepts for the sources of energy generation were drawn from the Semanco Urban Energy Ontology (sc) (Sicillia et al., 2014). Semanco is based on existing knowledge standards on building energy efficiency and it has concepts for economic, climate, and social factors that impact energy usage. Semanco was constructed to describe the following knowledge standards:

- ISO/ICE CD 13273 –Energy Efficiency and Renewable Energy Sources
- ISO/DTR 16344 – Common Terms, Definitions and Symbols for the overall Energy Performance Rating and Certification of Buildings
- ISO/CD 16346 – Assessment of Overall Energy Performance of Buildings
- ISO/DIS 12655 – Presentation of real energy use of buildings

- ISO/CD 16343 – Methods for expressing energy performance and for energy certification of buildings
- ISO 5001:2011 – Energy Management Systems – Requirements with Guidance for Use

However, ISO 37120 was not one of the knowledge standards included in this list. Semanco represents buildings on a single building level rather than at a municipality level. It also does not have information on electrical interruptions. From this ontology, terminology on both renewable and non-renewable energy sources is reused in the GCI energy ontology, such terms include “Not-Renewable_Energy_Source,” “Nuclear,” “Fossil_Fuels,” “Renewable_Energy_Source,” “Solar_Energy,” “Wind_Energy,” “Geothermal_Energy,” “Biomass,” and “Hydro_Energy.”

Although the Semanco was the primary ontology where energy related terms were derived from, numerous other energy related ontologies that investigated but not used for the construction of the GCI Energy Ontology for two reasons; many required concepts existed in Semanco; and second, the GCI Energy ontology explores macro level trends and concepts of a city whereas many of these ontologies explored micro-level data such as the energy output of individual home automation devices or solar panels. These ontologies include:

- OntoEnergy - Energy Efficiency for Manufacturing Plant Automation - (Linnenberg, Christiansen, & Seitz, 2013)
- DNAS - Behavioural Psychology of Energy Usage in Buildings – (Hong et al., 2015)
- A Generic Ontology for Prosumer Oriented Smart Grids- (Gillani, Laforest, & Picard, 2014)
- Smart Grid Energy Management Systems (Zeiler & Boxem, 2013)
- Critical Infrastructure Ontology – (Masucci, Adiolfi, Servillo, & Tofani, 2009)
- OpenWatt Renewable Energy Data Sources (Lamanna, Davide, Maccioni, 2012)
- DEHEMs - Digital Environment Home Energy Management System DEHEMs (Tommis, 2011)

3.2 Non-Energy Related Ontologies and Resources

3.2.1 Service

Additional non-energy related ontologies were used to build the GCI Energy Ontology to structure the classifications of buildings, how a building interacts with its electrical service, and general information about city populations.

The framework of the GCI Energy Sub-Ontologies was based off of the structure created in the GCI Telecommunications and Innovation Ontology (Forde & Fox, 2015). The ontology contains two sub-ontologies; “Service” and “Residency.” These ontologies provided the basic framework for the energy ontology because electrical services have similarities to telecommunications on how they are purchased and distributed. Although the GCI Telecommunications and Innovation Ontology provides many necessary terms, to answer the competency questions for GCI Energy, the “Service” and “Residency” ontologies do not

include electricity related terms, building classes (beyond residential), nor track service interruptions.

Most of the service related concepts used in the Telecommunications and Innovation Ontology came from Service Micro-Ontology (Voß, 2013) such as “Service,” “ServiceProvider,” and “ServiceConsumer,” “ProvidedBy” and “ConsumedBy.”

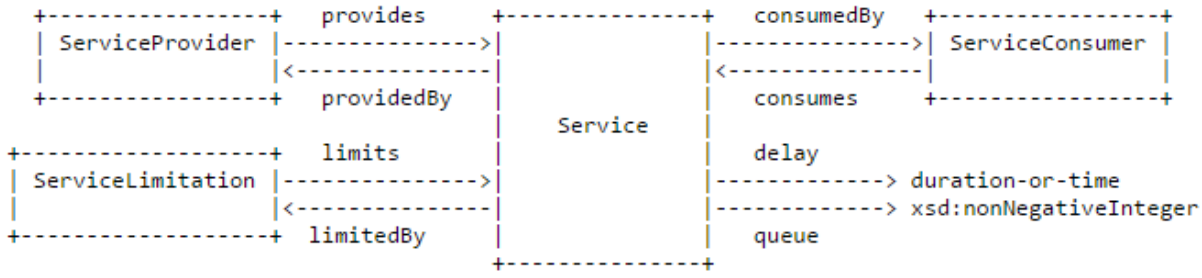

Figure 1 SO Service Ontology

Beyond the terms found in the Service Ontology by Voß, the term “APurchase” was imported directly from the GCI Innovation and Telecommunication ontology to define a legal transaction between a service consumer and service provider that would authorize a legal connection to the services.

3.2.2 Populations and Households

The classes that define people and users and electrical services were drawn from the Organization Ontology (Fox, 1998), The GCI Shelter Ontology (Wang & Fox, 2015), the FOAF Ontology (Miller, 2014).

From the Organization Ontology, the terms “Organization,” “Division,” “Government Organization,” and “Non-Government Organization” were imported to describe the service user groups living in the city and owning the services and buildings.

The residential population in the ISO 37120 indicators is described as a function of the average household size for the city. The terms for “household,” “household_size,” “average_household,” and “average_household_size” were imported from the GCI Shelter Ontology.

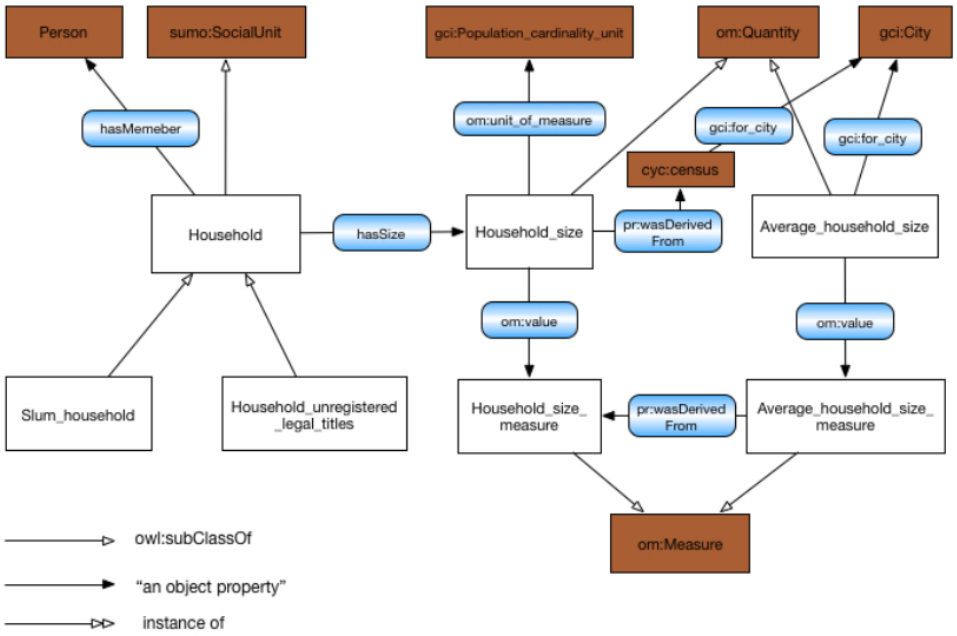

Figure 2 GCI Shelter Ontology Household Definition

3.3 GCI Foundational Ontology

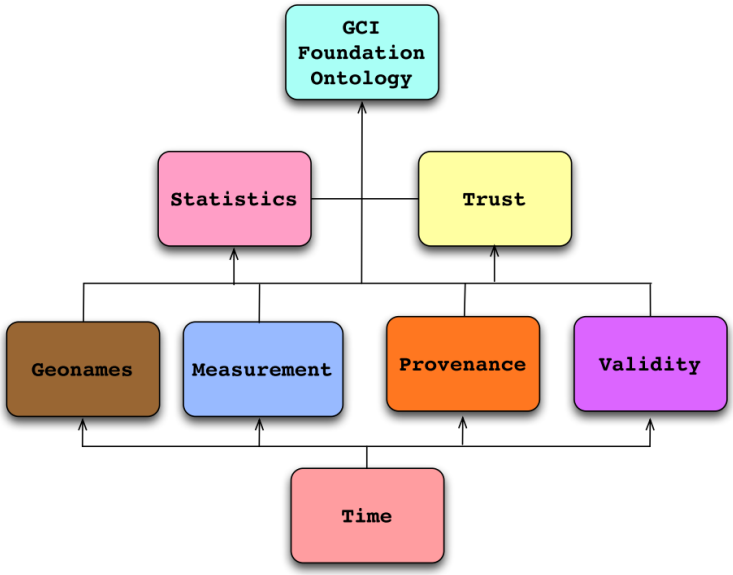

Figure 3 GCI Foundational Ontology

The GCI Foundation Ontology (Fox, 2013) provides concepts and properties that are necessary to represent all ISO 37120 indicators. It defines the representation of meta-information associated with a single indicator number, including: place names, units, time, provenance, validity and trust.

It also defines the classes and properties for representing the definition of an indicator, including populations, how they are measured and how they are analytically combined within an indicator. The foundation ontology integrates and extends the following ontologies:

- Time (Pan & Hobbs, 2004)
- Measurement (H. Rijgersberg, 2011)
- Statistics (Pattuelli, 2009)
- Geonames Ontology (www.geoname.org)
- Provenance (Belhajjame et al., 2012)
- Validity (Fox & Huang, 2005)
- Trust (Huang & Fox, 2006)

4. Architecture of the Global City Indicator Ontology

As explained in the introduction of this paper, ISO 37120 defines 100 city indicators. The following diagram (Fox, 2013) depicts the modules that are used to represent the definitions of the 37120 indicators. The ISO37120 module provides the IRIs for uniquely identifying all 100 indicators. For example, the IRI for the Total Electricity Usage Per Capita indicator is: http://ontology.eil.utoronto.ca/ISO37120.owl#7.5.

Each ISO37120 theme's indicators are defined in separate files. The OWL representation of the definitions of all seven of the GCI Energy indicators can be found in Energy.owl.

The GCI Ontology level provides specific ontologies required to define each theme's indicators. The Energy indicators are defined with concepts such as service, buildings, service interruptions, etc. These concepts are captured in GCIBuildingOccupancy.owl and GCIService.owl and are used in Energy.owl.

All of the ontologies specifics to individual themes are built on base on GCI Foundation ontology, which defines generic concepts such as energy units, meta-information, etc.

The Enterprise Ontology level contains the TOVE Enterprise Modelling ontologies (Grüninger, 1998). In this figure, only the Organization Ontology File[2] (Fox et al., 1998), one of the TOVE Enterprise Modelling ontologies, is shown.

Lastly, the Foundation Ontology level contains the very basic ontologies which serve as the foundation for everything above.

[2] The Organization ontology can be found at http://ontology.eil.utoronto.ca/organization.owl along with its documentation at http://ontology.eil.utoronto.ca/organization.html. The prefix "org" is used for this ontology where needed.

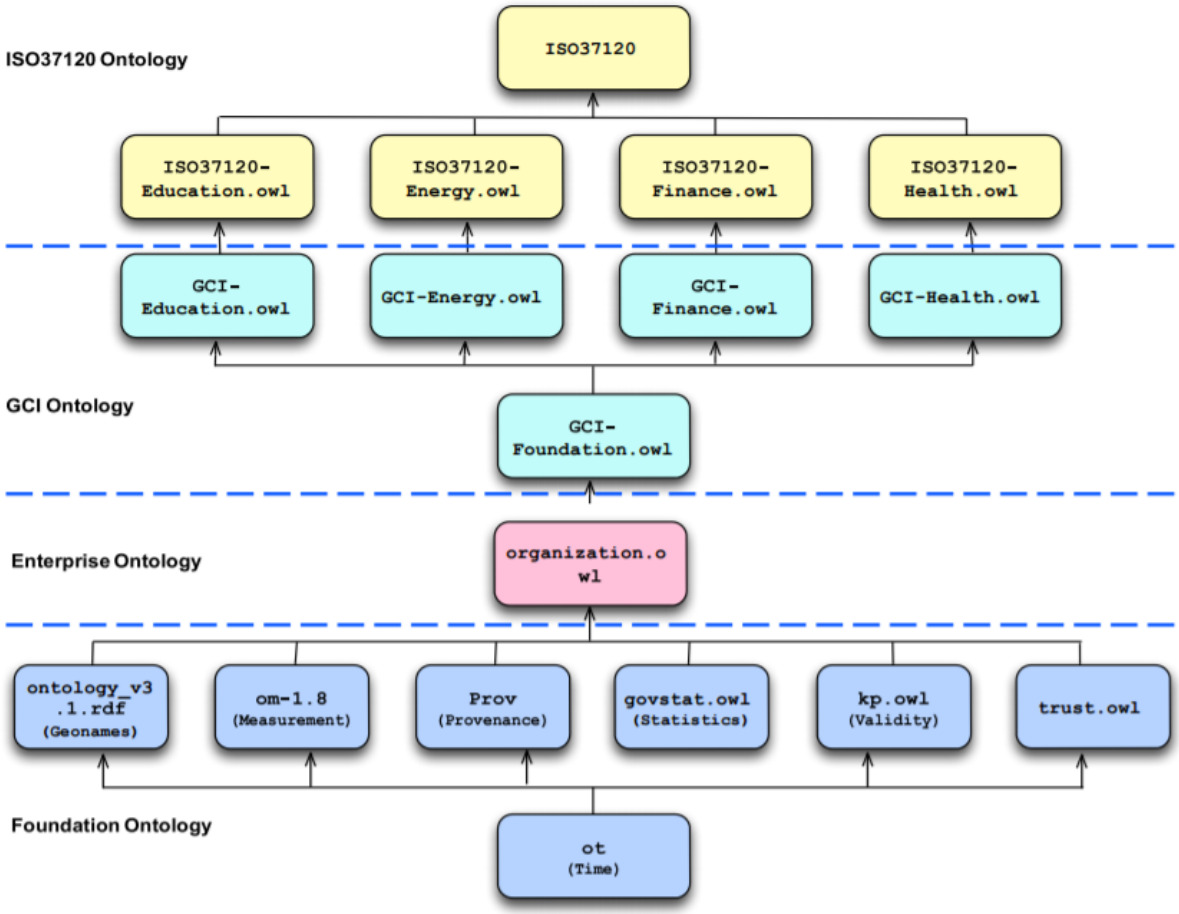

Figure 4 GCI Foundational Ontology Architecture

5. GCI Energy Sub-Ontologies

5.1 GCI - Service

Electricity is distributed as a service in cities, so in order to construct an ontology for ISO37120 energy indicators, a service ontology is needed. To satisfy the ISO37120 energy indicators competency questions, information on the quantity of the service used, the number of people with access to the service, frequency and duration on interruptions, and source of the services will need to be constructed. Some of the competency questions that relate to service include:

1. (F) How much electricity was used per year in residential buildings?
2. (F) What organizations provide electrical service in Toronto?
3. What addresses does “Service Provider A” service?
4. (F) How many service accounts are there in “residential building 01”?
5. (F) How many electrical service accounts are there in the city?
6. (F) How many households does service account x provide energy to?
7. (D) How many individual electrical service account holders hold more than one account?
8. (F) How many kWh are being consumed by public buildings?
9. (F) What is the total electrical usage of the city?

10. (F) What percentage of the electricity distributed comes from renewables by service provider?
11. (F) Who provided the information on the renewable energy mixture production?
12. (F) How many Households have electrical interruptions?
13. (F) How many interruptions were counted due to extreme weather events?
14. (F) What is the total duration of all electrical interruptions?
15. (F) What is the total number of interruptions?

This service ontology extends the Document Service Ontology (prefix so) (Voß, 2013) and the GCI's Innovation Ontology (prefix gcii) (Forde & Fox, 2015) to include information about the total volume of service used, views at the account and building level, service interruptions, and accounts that service multiple tenants.

Class	Property	Value Restriction
Service	owl:subclassOf	so:Service
	distributedBy	min 1 so:ServiceProvider
Service_Measure	rdf:subclassOf	gci:GCI_measure

Authorized Service Connections

A service consumer is an individual who has an authorized service connection. In the case of many different types of services, a single service account will benefit a group who lives or works at the address that it is servicing. This is described by ServiceConsumerGroup, where this can be defined as a household, organization, or a division of a greater organization.

Class	Property	Value Restriction
ServiceConsumer	owl:subclassOf	so:ServiceConsumer
	owl:subclassOf	foaf:agent
	experienceService Interruptions	only ServiceInterruption
	so:consumes	min 1 Service
	connectedthrough	min 1 ServiceAccount
	authorizedBy	min 1 ServiceProvider
ServiceConsumerGroup	consist_of	min 1 ServiceConsumer
	experienceService Interruption	only ServiceInterruption
	authorizedBy	min 1 ServiceProvider
	so:consumes	min 1 Service
	using	min 1 serviceAccount
	legallyAuthorizedBy	min 1 gcii:APurchase
	represents_a	some (org:Division or gcis:Household or org:Organization)
ServiceProvider	owl:subclassOf	so:ServiceProvider
	owl:subclassOf	org:Organization
	authorizes	min 1 ServiceAccount
	so:provides	min 1 Service
	ic:hasAddress	some ic:Address

The class ‘APurchase’ is from gcii. It includes properties from schema.org and so. From schema.org the class ‘Offers’ is used in which ‘APurchase’ is a subclass. An ‘Offer’ is defined as, “the transfer of some rights to an item or to provide a service.” ‘APurchase’ is a member of the Offer class since it forms a transaction between the ‘ServiceProvider’ and ‘ServiceConsumer’. As in the GCI Innovation Ontology, if a consumer has access to “APurchase” it defines that a legally authorized connection has been made.

Class	Property	Value Restriction
gcii:APurchase	owl:subclassOf	sch:Offer
	gcii:consumedBy	some so:ServiceConsumer
	gcii:providedBy	exactly 1 so:ServiceProvider
	gcii:servicetype	exactly 1 so:Service
	gcii: ‘price currency’	some xsd:decimal
	gcii:certification_Date	exactly 1 xsd:dateTime
	gcii:expiry_Date	exactly 1 xsd:dateTime

The term ServiceAccount is introduced as a subclass of APurchase. It authorizes a legal connection between a service provider and a consumer. The definition was extended to indicate whether the account is currently active and also provide measurement of the total amount of the service that is consumed. It also addresses that a single transaction can be connected to multiple addresses.

Class	Property	Value Restriction
ServiceAccount	owl:subclassOf	gcii:APurchase
	accountActive	exactly 1 xsd:boolean
	authorizedBy	exactly 1 ServiceProvider
	providedBy	exactly 1 ServiceProvider
	hasServiceAddress	min 1 ic:Address
	hasServiceArea	only gcis:ServiceAreaMeasure
	hasServiceType	only Service
	consumedBy	min 1 ServiceConsumer
	owned_by	min 1 foaf:Agent
	hasConsumption	min 1 gci:GCI_quantity
	hasServiceInterruption	only ServiceInterruption

Service Consumption

To measure the total amount of service consumed by sectors, accounts, consumers, and individual buildings, Service_Measure and Service_Consumption_Quantity were created. Service_Consumption_Quantity defines the numerical value of service consumed by either a service consumer or a service consumer group.

Class	Property	Value Restriction
Service_Consumption_Quantity	owl:sublclassof	gci:GCI_quantity
	om:value	only Service_Measure
	forService	only Service min 1 Service

	gcii:consumedBy	only (serv:ServiceConsumer or serv:ServiceConsumerGroup)

Consumers

The following classes from the GCI Shelter Ontology (Wang & Fox, 2015) define households for residential service consumers.

Class	Property	Value Restriction
gcis:Household_size	owl:subclassOf	gci:GCI_quantity
	om:value	only Household_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	prov:wasDerivedFrom	some cyc:census
gcis:Household_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
gcis:Average_houshold_size	owl:subclassOf	gci:GCI_quantity
	gci:for_city	only gci:City
	om:value	only Household_size_measure
gcis:Average_household_size_ Measure	owl:subclassOf	gci:GCI_measure
	pr:wasDerivedFrom	some Household_size_measure
	om:unit_of_measure	value gci:population_cardinality _unit
	om:numeric_value	exactly 1 xsd:string

Similarly, information is required to describe non-residential service consumers. Note that these terms were created in (and then duplicated from) the building occupany ontology that will be discussed later in this section.

Class	Property	Value Restriction
gcibo:Organization_size	owl:subclassOf	gci:GCI_quantity
	om:value	only Organization_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
gcibo: Organization_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
gcibo: Organization_Division_size	owl:subclassOf	gci:GCI_quantity
	om:value	only Organization_Division _size_measure
gcibo: Organization_Division_size_ Measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality _unit
	om:numeric_value	exactly 1 xsd:string

With the above we can now define various types of consumers and households to capture energy consumption for the indicators:

ResidentialElectricalConsumer Household	owl:subclassOf	gcis:Household
	connectedthrough	some ElectricalServiceAccount
	consist_of	only ResidentialElectricalConsumer
ElectricalServiceAccount	owl:subclassOf	ServiceAccount
	hasServiceType	only ElectricalService
ResidentialElectricalConsumer	owl:subclassOf	ElectricalConsumer
	connectedthrough	some ElectricalServiceAccount
	consumes	only ElectricalService
	authorizedby	only ElectricalServiceProvider

Service Interruptions

We extend our Service ontology to include Service Interruption events as required for Energy indicators 7.6 and 7.7.

The ServiceInterruption class specifies both the service accounts and service consumers impacted by an interruption. ISO37120 excludes all interruptions caused by extreme weather events so “causedbyWeather” was added so that extreme weather events can be filtered out. The num_accounts property identifies the number of ServiceAccount's affected by the interruption. These accounts may be listed in the impactAccount property.

Class	**Property**	**Value Restriction**
ServiceInterruption	owl:subclassOf	lode:Event
	causedByWeather	only xsd:Boolean
	ot: HasDurationDescription	exactly 1 ot:DurationDescription
	impactAccount	only ServiceAccount
	num_accounts	exactly 1 xsd:nonNegativeInteger
	impactProvider	only ServiceProvider
ServiceInterruptionMeasure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:interruption
serviceInterruptionVar	rdf:type	gs:Variable
	gs:has_Name	value ”num_accounts”
ServiceDurationMeasure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value om:hour
serviceDurationVar	rdf:type	gs:Variable
	gs:has_Name	value "HasDurationDescription"

Within the service ontology, electricity specific concepts have been added as subclasses of the more general service classes. Specific units such as om:kilowatt_hour hours were imported from the measurement ontology.

Class	**Property**	**Value Restriction**
ElectricalService	owl:subclassOf	Service
ElectricalConsumerGroup	owl:subclassOf	ServiceConsumerGroup
	gcii:consumes	some ElectricalService
ElectricalConsumer	owl:subclassOf	ServiceConsumer
	gcii:consumes	some ElectricalService
ElectricalServiceAccount	owl:subclassOf	ServiceAccount
	hasServiceType	only ElectricalService

ElectricalService ConsumptionMeasure	owl:subclassOf	ServiceConsumption Measure
	om:unit_of_measure	value om:kilowatt_hour
ElectricalService ConsumptionQuantity	owl:subclassOf	ServiceConsumption Quantity
	om:unit_of_measure	value om:kilowatt_hour
	forService	only ElectricalService
electricalConsumptionVar	rdf:type	gs:Variable
	gs:has_Name	value ”hasElectricalConsumption”
ElectricalServiceProvider	owl:subclassOf	ServiceProvider
	distributes	some ElectricalService
ElectricalServiceInterruption	owl:SubclassOf	ServiceInterruption
	forService	only ElectricalService

Service Production

The following classes enable the representation of the different resources used to generate the electricity that it is distributing.

Class	**Property**	**Value Restriction**
ServiceProduction	forService	some Service
Electrical_Service_Measure	owl:subclassOf	ServiceProductionMeasure
	om:unit_of_measure	value om:kilowatt_hour
Service_Production_Quantity	owl:sublclassof	gci:GCI_quantity
	forService	only Service
ElectricalServiceProduction Quantity	owl:subclassOf	Service_Production_Quantity
	unit_of_measure	value om:kilowatt_hour
	om:value	only ElectricalServiceProduction Measure
	forService	only ElectricalService
electricalProductionVar	rdf:type	gs:Variable
		value quantityOfProduction

The sources for electrical generation are defined as either renewables or non-renewable sources. Most terms are subclasses of Semanco (prefix sc) however, there are a few terms that were not defined such as “Tide” and “Wave.” The vocabulary was extended to add the property “QuantityOfProduction” to define what a grid mixture would look like for a city.

Class	**Property**	**Value Restriction**
ElectricalPowerGenerationSource	owl:sublclassOf	ServiceProduction
	quantityOfProduction	Exactly 1 ElectricalService ProductionQuantity
NonRenewableSource	owl:sublcassOf	sem:Not_Renewable_Energy_Source
	owl:subclassOf	ElectricalPowerGenerationSource
NonRenewableSource	owl:subclassOf	sem:Renewable_Energy_Source
	owl:subclassOf	ElectricalPowerGenerationSource
Oil	owl:subclassOf	sem:Oil
	owl:subclassOf	NonRenewableSource
Natural_Gas	owl:subclassOf	sem:Natural_Gas
	owl:subclassOf	NonRenewableSource

Coal	owl:subclassOf	sem:Coal
	owl:subclassOf	NonRenewableSource
Nuclear	owl:subclassOf	sem:Nuclear
	owl:subclassOf	NonRenewableSource
Biomass	owl:subclassOf	sem:Biomass
	owl:subclassOf	RenewableSource
Hydro_Energy	owl:subclassOf	sem:Hydro_Energy
	owl:subclassOf	RenewableSource
Geothermal_Energy	owl:subclassOf	sem:Geotherhmal_Energy
	owl:subclassOf	RenewableSource
Solar_Energy	owl:subclassOf	sem:Solar
	owl:subclassOf	RenewableSource
Tide	owl:subclassOf	RenewableSource
Wave	owl:subclassOf	RenewableSource

5.2 GCI Building Occupancy Ontology

The building occupancy ontology is designed to describe building types and the people who are residing in them. The GCI Building Occupancy ontology draws upon the GCI Shelter ontology (Wang & Fox, 2015) and the GCI Innovation ontology (Forde & Fox, 2015).

Some of the competency questions include:

1. (F) Is “Toronto Building 01” a residential building?
2. (F) What percentage of the floor space is used for residential purposes?
3. (F) How many households are in the city?
4. (F) What is the average number of people living in each household?
5. (F) How many households does “Toronto Building 01” have?
6. (F) What is the total population of residents the city?
7. (F) Which buildings in Toronto are owned by the government?
8. (F) How many public buildings are in the city?
9. (F) What is the floor area of all the public buildings?

dbepdia (prefix db) defines a building as a free standing structure that comprises of one or more rooms and spaces, covered by a roof, and enclosed with external walls or dividing walls that extend from the foundation to the roof. A Building has one main BuildingAddress. However, within the building may be multiple units that host different households and organizations. These tenants may have different services and accounts.

The definition of a “ResidentialBuilding” is regionally specific. The OECD (Residential Building, 2002) defines buildings with more than half of their floor space allocated to residential usage as residential buildings. The ResidentialBuilding class has specified the amount of Residental_FloorArea to ensure that the definitions match across data sets.

ISO37120 also states that PublicBuildings are defined as buildings that are owned by the government. By this logic, social housing would fit under the classes of ResidentialBuilding and PublicBuilding.

Class	Property	Value Restriction
Building	owl:subclassOf	db:Building
	ic:hasAddress	exactly 1 ic:Address
	hasUnitAddress	some TenantSpace
	hasFloorArea	exactly 1 FloorArea_Quantity
	hasResFloorArea	exactly 1 FloorArea_Quantity
	occupied_by	some (gcis:Household or org:Division or org:Organization)
	hasElectricalConsumption	gcise:ElectricalServiceConsumption Quantity
	hasTenantSpace	only TenantSpace
	hasTenancy	only Tenant
	org:has_Ownership	exactly 1 org:Ownership
	owned_by	min 1 foaf:agent
CommericalBuilding	owl:subclassOf	Building
IndustrialBuilding	owl:subclassOf	Building
PublicBuilding	owl:subclassOf	Building
	has_Ownership	only org:GovernmentOrganization
ResidentialBuilding	owl:subclassOf	Building
	gcibo:hasHouseholds	min 1 gcis:Household

Furthermore, the building occupancy ontology introduces the concept of TenantSpace to help capture that some buildings can be used by multiple sectors (residential buildings may have commercial store fronts.)

Class	Property	Value Restriction
Tenant	owl:subclassOf	foaf:Agent
	occupies	min 1 TenantSpace
	represents	only (org:Organization or gcis:Household or org:Division)
gcis:Household	gcis:hasSize	only gcis:HouseHold_Size
	gcis:hasMember	only sch:Person
org:Organization	gcis:hasSize	only Organization_size
	consistsOf	only org:Division
	has_Ownership	only Ownership
	hasLegalName	1 xsd:string
org:Division	divisionOf	some org:Organization
	gcis:hasSize	only Organization_division_size
TenantSpace	hasUnitIndicator	some rdfs:Literal
	insideBuilding	exactly 1 Building
	occupied_by	min 1 Tenant
	connectedServiceAccounts	min 1 ServiceAccount

The energy indicators based on the number of residential users bases their information on household and average household size. These definitions were imported from the GCI Shelter Ontology (prefix gcis).

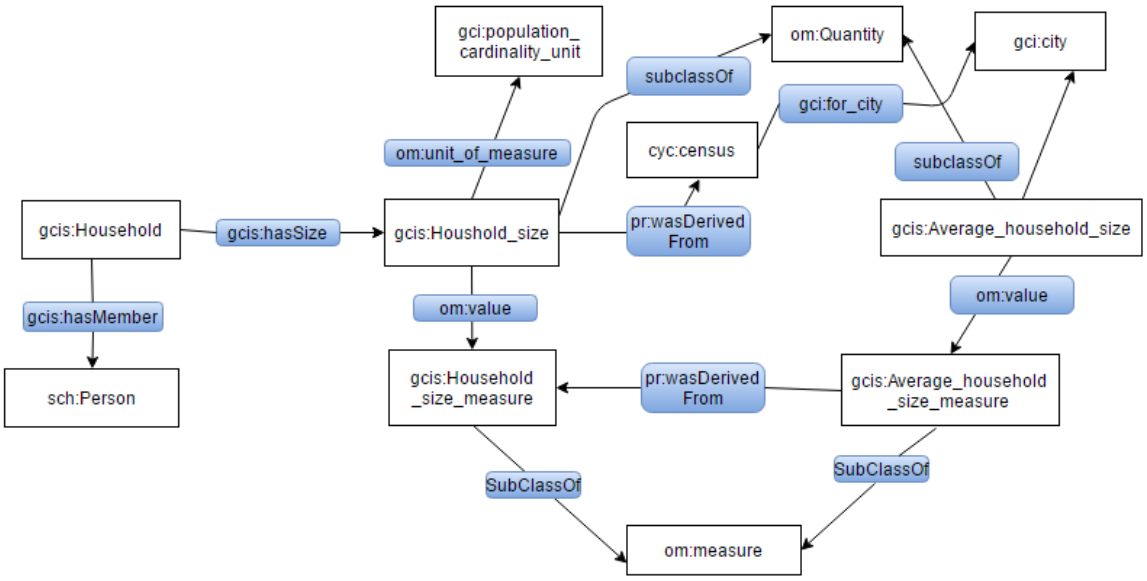

Figure 5 Household Definition

Class	Property	Value Restriction
gcis:Household_size	owl:subclassOf	gci:GCI_quantity
	om:value	exactly 1 Household_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	pr:wasDerivedFrom	some cyc:census
gcis:Household_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
gcis:Average_houshold_size	owl:subclassOf	gci:GCI_quantity
	gci:for_city	exactly 1 gci:City
	om:value	exactly 1 Household_size_measure
	unit_of_measure	value gci:population_cardinality_unit
gcis:Average_household_size_ Measure	owl:subclassOf	gci:GCI_measure
	pr:wasDervicedFrom	exactly 1 Household_size_measure
	om:unit_of_measure	value gci: population_cardinality _unit
	om:numeric_value	exactly 1 xsd:string

The Organizational_size and Organizational_Division_size classes define the number of people who are occupying buildings for non-residential usage. Classes have been divided into Organization_size and Organization_division size because the full organization may or may not occupy the building.

Class	Property	Value Restriction

Organization_size	owl:subclassOf	gci:GCI_quantity
	om:value	only Organization_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
Organization_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
Organization_Division_size	owl:subclassOf	gci:GCI_quantity
	om:value	exactly 1 Organization_Division _size_measure
Organization_Division_size_ Measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci: population_cardinality _unit
	om:numeric_value	exactly 1 xsd:string

The FloorArea_Quantity represents the quantity of the area of the floor within a building. This is associated to the total FloorArea_Measure with consist of the quantity of the floor area and the unit of measurement with is om:square_metre for this ontology.

Class	**Property**	**Value Restriction**
FloorArea_Measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value om:square_metre
FloorArea_Quantity	owl:subclassOf	gci:GCI_quantity
	om:unit_of_measure	value om:metre_Square
	om:value	only FloorArea_Measure
floorAreaVar	rdf:type	gs:Variable
	gs:has_Name	"hasFloorArea"

6. GCI Foundation Ontology Infrastructure

In this section, we reviews the basic structure of a ratio indicator, its unit of measure, population and population size as defined in GCI foundational ontology (Fox, 2013), and upon which the Energy Indicators are based.

At the core of GCI Foundations Ontology is the OM measurement ontology (Rijgersberg et al. 2011). The purpose of a measurement ontology is to provide the underlying semantics of a number, such as what is being measured and the unit of measurement. The importance of grounding and indicator in a measurement ontology is to assure that the numbers are comparable, not that they are measuring the same thing, but they are measuring the same type ex. population of people with an authorized electrical connection and total city population are the same scale (ie. Thousands vs millions) and are in the same city.

Figure 6 depicts the basic classes of the OM ontology used to represent an indicator. There are three main classes in OM: a ‘Quantity’ that denotes what is being measured e.g. diameter of a ball; a ‘Unit of Measure’ that demotes how the quantity is measured, e.g., centimeters;

and a ‘Measure’ that denotes the value of the measurement which is linked to the both ‘Quantity’ and ‘Unit of Measure’. For example, a “percentage of population with authorization to electricity” is a subclass of “quantity” (gci:GCI_quantity) that has a value that is a subclass of “measure” whose units are a “percent” that is a type of “unit of measure”. The actual value measured is a property of the “measure” subclass “Population with authorization to electricity measures.”

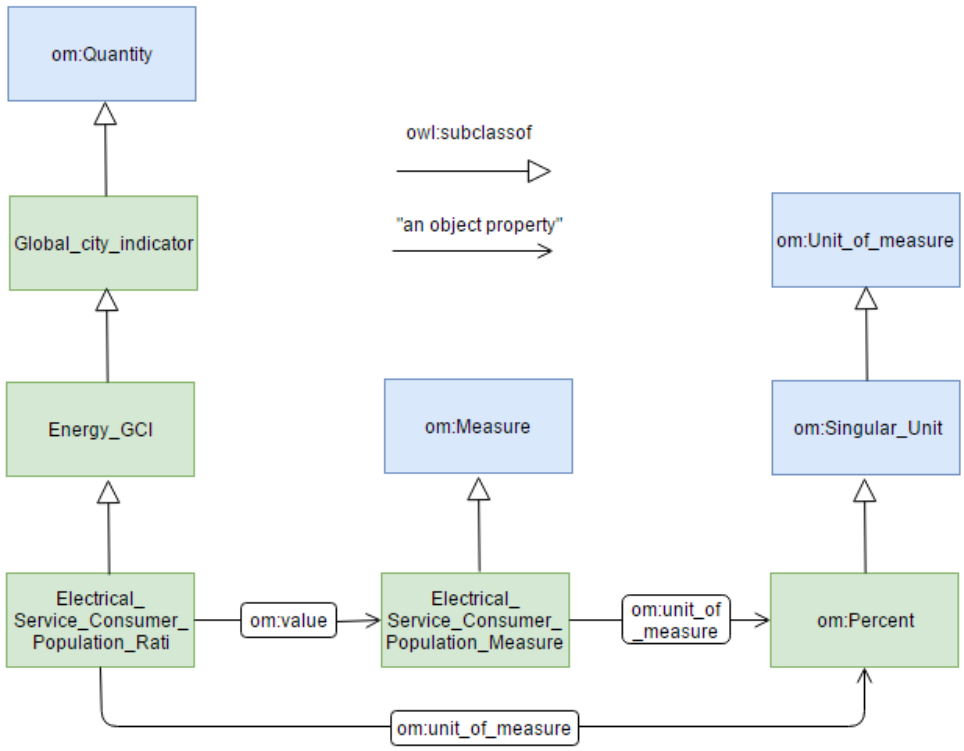

Figure 6 Electrical Consumer Definition

The number of people who are connected to electrical services is based on the population of connected households and the average size of a household in a city. One can view both as a statistical measurement in the sense that there is a population we want to perform a measurement of, a measurement being the count of the number of members that satisfy a description of an person connected to electrical service and a city resident, respectively. While the indicators require a count of members of the population, other measures may require statistics such as mean, standard deviation, etc.

All Energy indicators are ratio indicators (Fox, 2013). All ratio indicators have a numerator and denominator that are both represented by “population” class. A population is a collection of the same object such as people in a city and households. A ratio indicator has a unit of measure defined to be a “Population Ratio Unit” that specifies that the indicator is the ratio of the sizes (cardinalities) of two populations. One population size is the numerator and the other the denominator. A “Population Size” is defined as the cardinality of a “population,” and “Population” is defined by a “City” that the population is located in, and by a description of a “Person” within the “City” (Fox, 2013). For example, the “person” could be connected to

electrical services (gcise:ElectricalServiceConsumer). Hence the population size (gci:Population_size) could be a number of “gcise:ElectricalServiceConsumer” in a particular city (gci:City). This general ontology structure is used in the indicator definitions outline in Section 7.

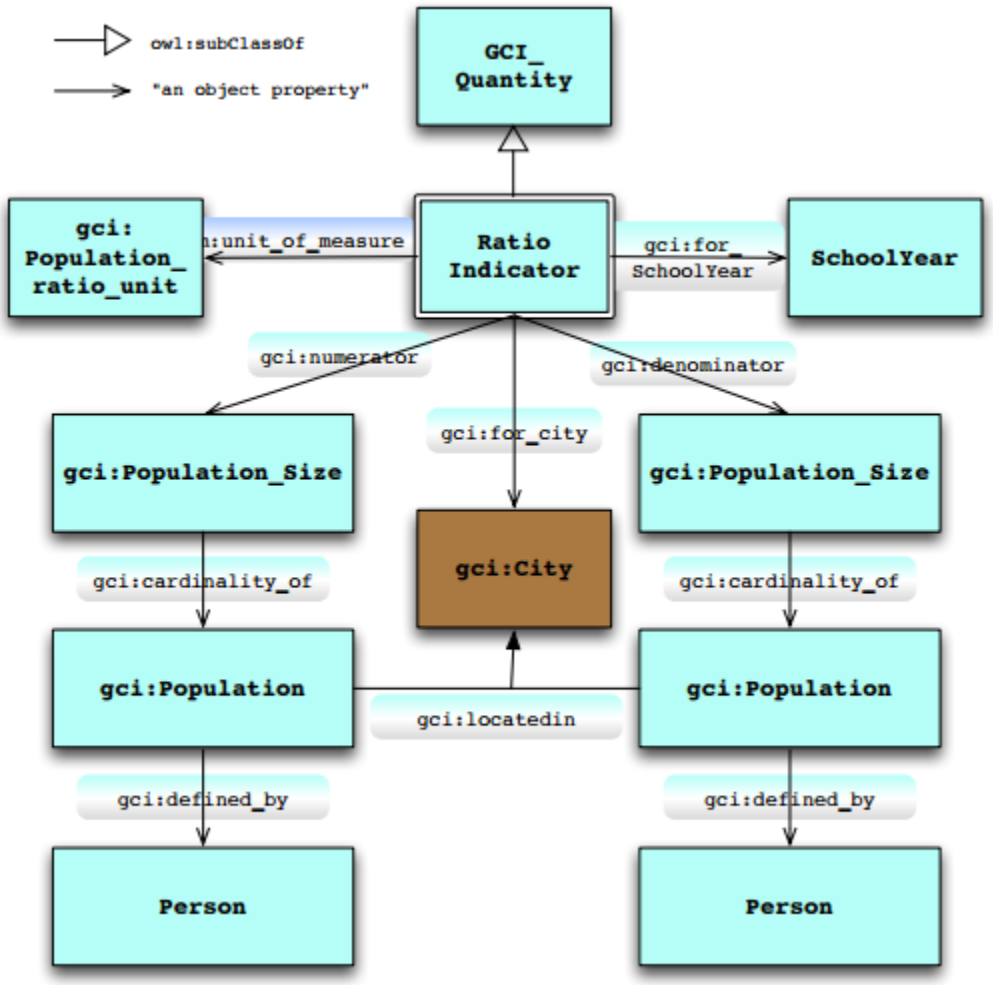

Figure 7 Foundation Ontology Ratio Definition

7. ISO 37120 Energy Indicators Definitions

The GCI Building Occupancy and GCI Service Ontologies provide the concepts needed to represent the definitions of ISO37120 Energy themed Indicators. This section provides a representation for each of the seven ISO37120 Energy Indicators' defintions. The OWL representation of the energy indicators can be found at http://ontology.eil.utoronto.ca/GCI/ISO37120/Energy.owl.

Common to multiple energy indicators such as 7.1, 7.2, and 7.5 is the city’s population. The class gci:City_Population_Size will be used as the denominator for the indicators 7.1, 7.2, and 7.5 and it is a gci:cardinality_of gci:City_Population which is a subclass of gci:Population.

Class	Property	Value Restriction
gci:City_Population_Size	owl:subclassOf	gci:Population_size
	cardinality_of	exactly 1 gci:City_Population
	om:unit_of_measure	value gci:population_cardinality_unit
gci:City_Population	owl:subclassOf	gci:Population
	defined_by	exactly 1 gci:Resident
	function_of	some gcis:Average_household_size
	located_in	exactly 1 gci:city

7.1 total residential electrical energy use per capita (kWh/year) (Core Indicator) (ISO 37120: 7.1)

This indicator is derived from the total amount of energy usage for residential buildings within city limits and divided by the city's population. The numerator is 7.1_Total_Residential_ElectricityConsumption_Quantity and the denominator is gci:City_Population_Size, as described above.

Class	Property	Value Restriction
iso37120:7.1	owl:subclassOf	iso37120:Energy
	om:denominator	exactly 1 gci:City_Population_Size
	om:numerator	exactly 1 7.1_Total_Residential_Electrical_ Consumption_Quantity
	om:unit_of_measure	value gci:kwh_per_pc

The 7.1_Total_Residential_ElectricityConsumption_Quantity is the defined as the total electrical usage in residential buildings within a city. To represent this, 7.1_Total_Residential_ElectricalConsumption_Quantity is a subclassOf gs:Sum which sums the total Residential_ElectricalConsumptionQuantities for the city's population of residential buildings. This population of residential buildings is defined by 7.1_Population_of_Residential_Buildings, which is defined by the population of residential buildings in a city.

Class	Property	Value Restriction
7.1_Total_Residential_Electrical_ Consumption_Quantity	owl:subclassOf	gcise:ElectricalService ConsumptionQuantity
	om:value	exactly 1 gcise:Electrical_Service_Measure
	owl:subclassOf	gs: Sum
	gs:sum_of	exactly 1 7.1_Population_of_Residential_Buildings
	gs:sum_of_var	value gcise:electricalConsumptionVar
7.1_Population_of_Residential_Buildi ngs	owl:subclassOf	gs:Population
	gci:defined_by	only gcibo:ResidentialBuilding

The following figure represents a tree format of the construction of iso37120:7.1.

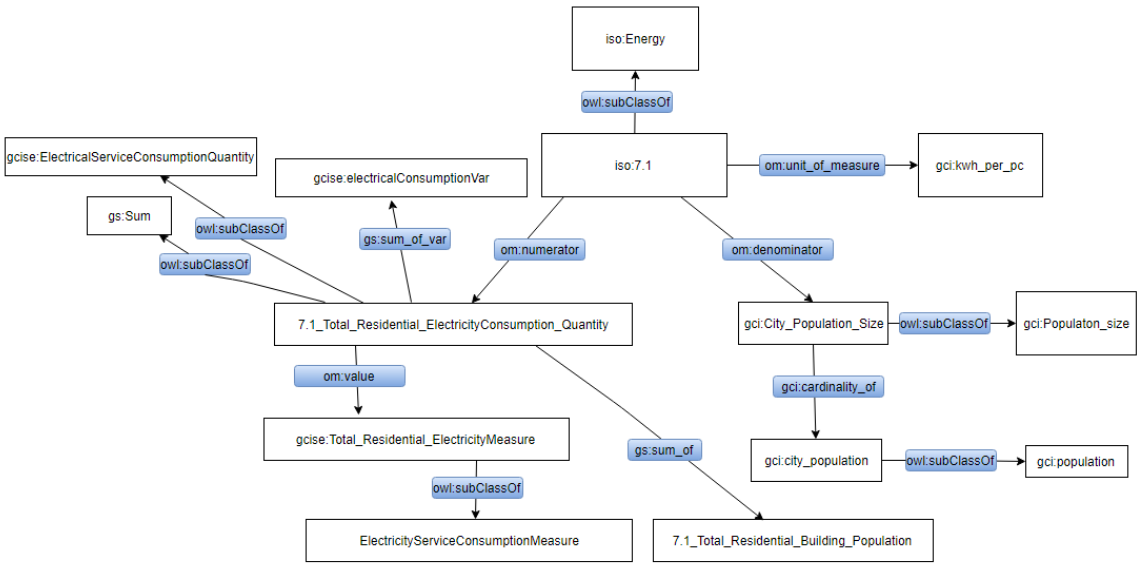

Figure 8 ISO37120 7.1 Definition

7.2 Percentage of city Population with authorized electrical service (core indicator) (ISO37120: 7.2)

This indicator describes the percentage of the total population who are legally accessing electrical services in their homes. Previously, we have defined the denominator of the indicator, which is the total population of the city. To construct the numerator of the indicator, we will define city residents who are receiving electrical services, if they are legally authorized to do so, and their total population. The numerator of the indicator is "7.2_Population_with_authorized_electrical_service."

Class	Property	Value Restriction
iso37120:7.2	owl:subclassOf	iso37120:Energy
	om:denominator	gci:City_Population_Size
	om:numerator	7.2_Population_with_authorized electrical_service_size
	om:unit_of_measure	only om:percent

The numerator shall be calculated as the number of households lawfully connected to the electrical grid multiplied by the average household size. The definitions for average household size have been imported from the GCI shelter ontology (prefix gcis). Although the calculation is done by multiplying the number of households with electrical service by the average number of average household population, the intent of the calculation to collect the total number of residential electrical consumers.

Class	Property	Value Restriction
7.2_Population_with_authorized	owl:subclassOf	gci:Product_Quantity

_electrical_service_size	om:unit_of_measure	value gci:population_cardinality_unit
	om:value	exactly 1 gci:Population_measure
	om:term_1	exactly 1 gcis:Average_household_size
	om:term_2	exactly 1 7.2_Population_of_Electrically ServicedHousehold_size
7.2_Population_of_ElectricallyServ icedHousehold_size	owl:subclassOf	gci:Population_size
	gci:cardinality_of	7.2_Population_of_Electrically ServicedHouseholds
7.2_Population_of_ElectricallyServ icedHouseholds	owl:subclassOf	gci:Population
	gci:defined_by	only ResidentialElectrical ConsumerHousehold

The definition of the numerator relies upon the definition of ResidentialElectricalConsumerHousehold in the energy service ontology (prefix gsise), defined earlier. Authorization arises from their having an account with an electrical service provider.

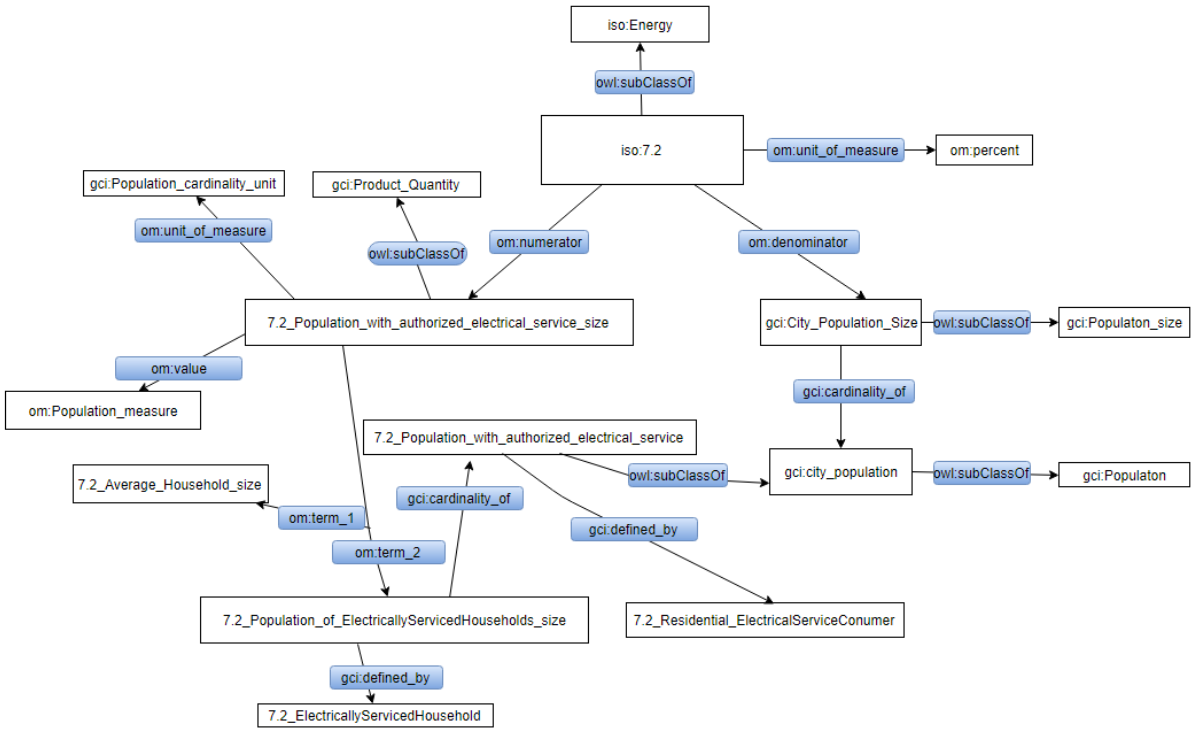

Figure 9 ISO 37120 - 7.2 Definition

7.3 Energy consumption of public buildings per year (kWh/m^2) (Core Indicator) (ISO 37120: 7.3)

The third indicator describes the total amount of electrical used in public buildings divided by the total amount of floor space in square metres. This indicator measures the energy efficiency of a city's public infrastructure. Public buildings have been defined in the Building Occupancy Ontology as buildings that are owned by government organizations.

First, we define the Iso37120:7:3 to have the numerator 7.3_Total_PublicBuilding_Electrical_Consumption_Quantity and it has the denominator of 7.3_Total_PulicBuilding_FloorSpace_Quantity.

Class	Property	Value Restriction
iso37120:7.3	owl:subclassOf	iso37120:Energy
	om:unit_of_measure	value gci:kwh_per_square_metre
	om:denominator	exactly 1 7.3_Total_PublicBuilding_ FloorSpace_Quantity
	om:numerator	exactly 1 7.3_ Total_PublicBuilding_Electrical Consumption_Quantity

The total quantity of electrical consumption in public buildings is represented as the total amount of the sum of usage from the city's entire public building population.

Class	Property	Value Restriction
7.3_Total_PublicBuilding_Electrical_ Consumption_Quantity	owl:subclassOf	ElectricalService ConsumptionQuantity
	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 7.3_Population_of_ Public_Buildings
	om:value	exactly 1 gcise:ElectricalService ConsumptionMeasure
	gs:sum_of_var	value gcise:electricalConsumptionVar
7.3_Population_of_Public_ Buildings	owl:subclassOf	gs:Population
	gci:defined_by	only gcibo:PublicBuilding

The total amount of floor space in a building is calculated similarly to the way that the total amount of electrical usage has been calculated. The amount of floor space is the sum of all of the floor space for the city's population of public buildings.

Class	Property	Value Restriction
7.3_Total_PublicBuilding_FloorSpac e_Quantity	owl:subclassOf	gcibo:FloorArea_Quantity
	owl:subclassOf	gs:Sum
	gs:sum_of	only 7.3_Population_of_Public _Buildings
	gs:sum_of_var	value gcibo:floorAreaVar

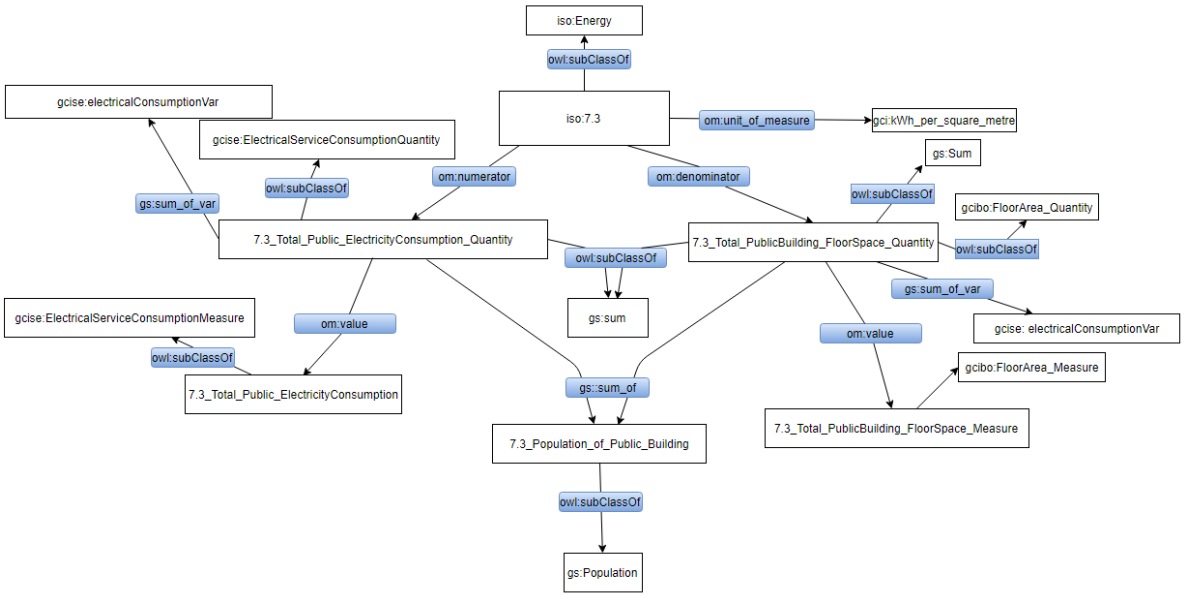

Figure 10 ISO37120 7.3 Definition

7.4 The percentage of total energy derived from renewable sources as a share of the city's total energy consumption (Core Indicator) (ISO37120:7:4)

The fourth core indicator evaluates the total amount of electricity that a city used that was initially produced by renewable energy sources. For this indicator, we estimate % of consumption by the ratio of renewable electrical production to total electrical production.

Class	Property	Value Restriction
iso37120:7.4	owl:subclassOf	iso37120:Energy
	om:denominator	exactly 1 7.4_Total_Electrical_ Production_Quantity
	om:numerator	exactly 1 7.4_Total_Electrical_ Production_From_Renewables _Quantity
	om:unit_of_measure	value om:percent

First, the total amount of electricity produced by renewables shall be calculated by the amount of electricity generated by renewable sources including biomass, tide, solar, geothermal, wave, and wind that are nested under renewable sources. 7.4_Total_Electricity_Production_Quantity takes the sum of the gcise:QuantityOfProduction from each source in the population of renewable resources.

Class	Property	Value Restriction
7.4_Total_Electrical_Production_ From_Renewables_Quantity	owl:subclassOf	ElectricalServiceProduction Quantity
	owl:subclassOf	gs:Sum
	gs:sum_of	7.4_RenewableSources
	gs:sum_of_var	value gcise:electricalProductionVar
	om:value	exactly 1 ElectricalServiceProductionMeasure
7.4_RenewableSources	owl:subclassOf	gs:Population

	gci:defined_by	only (gcise:Biomass or gcise:Geothermal or gcise:Hydro_Energy or gcise:Solar_Energy or gcise:Tide or gcise:Wave or gcise:Wind_Energy)

Next, we define the amount of electrical consumption by taking the sum of the electrical consumptions for the entire population of buildings in a city. This corresponds to the Variable "ElectricalServiceConsumption" for the data property gcise:Electricity_Consumption for each building.

Class	Property	Value Restriction
7.4_Total_Electrical_ Production_Quantity	owl:subclassOf	gcise:ElectricalServiceProductionQuantity
	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 7.4_Production _Population
	om:value	exactly 1 ElectricalServiceProductionMeasure
	gs:sum_of_var	value gcise:electricalProductionVar

The entire population of buildings in a city are summarized the loads taken from all buildings. For the ISO37120 indicators, public buildings and residential buildings are already defined.

Class	Property	Value Restriction
7.4_Total_Production_ Population	owl:subclassOf	gs:Population
	gci:defined_by	only gcise:ElectricalPowerGenerationSource

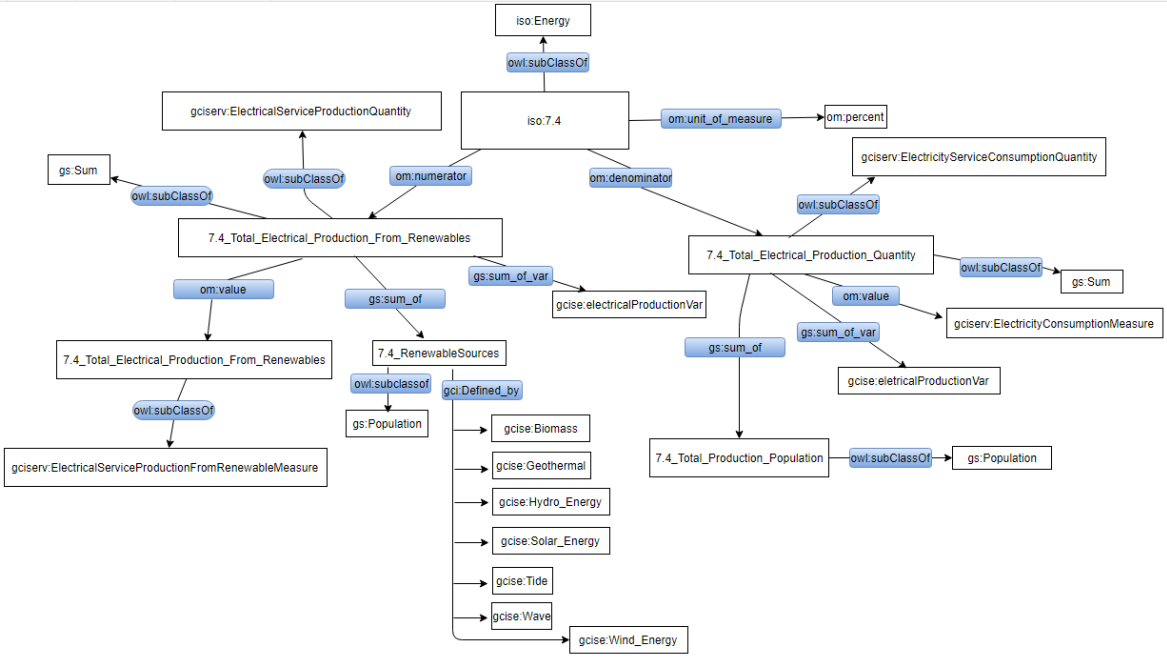

Figure 11 ISO37120 7.4 Definition

7.5 Total electrical energy use per capita (kWh/year) (Supporting Indicator) (ISO37120: 7.5)

The total amount of electrical usage per capita describes the total amount of electricity that a city would use (both residential and non-residential) per person. The numerator is similar to 7.4 and the denominator is the city population which was identified at the beginning of this section.

Class	Property	Value Restriction
iso37120:7.5	owl:subclassOf	iso37120:Energy
	om:unit_of_measure	value gci:kwh_per_pc
	om:denominator	exactly 1 gci:City_Population_Size
	om:numerator	Exactly 1 7.5_Total_Electrical_Consumption_Quantity
7.5_Total_Electrical_ Consumption_Quantity	owl:subclassOf	ElectricalService ConsumptionQuantity
	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 7.5_Total_Building_Population
	om:value	exactly 1 gcise:ElectricalService ConsumptionMeasure
	gs:sum_of_var	value gcise:electricalConsumptionVar
7.5_Total_Building_Population	owl:subclassOf	gs:Population
	gci:defined_by	only gcibo:Building

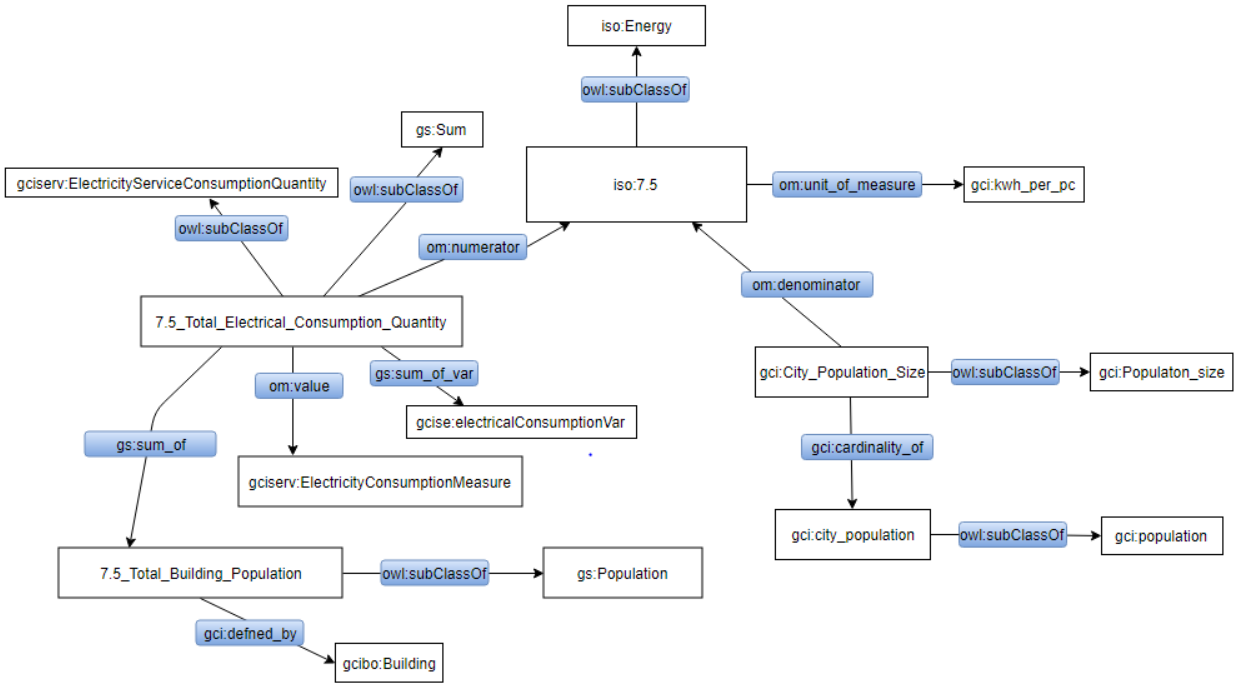

Figure 12 ISO37120 Definition for 7.5

7.6 Average number of electrical interruptions per year (Supporting Indicator) (ISO37120: 7.6)

The sixth indicator measures the consistency of a city's electrical service. The indicator seeks to derive the total number of electrical interruptions that each customer. Customer interruptions exclude service interruptions caused by extreme weather events.

Class	Property	Value Restriction
iso37120:7.6	owl:subclassOf	iso37120:Energy
	om:denominator	exactly 1 7.6_Customer_Account_Size
	om:numerator	exactly 1 7.6_Total_Count_of_Electrical_ Interruptions
	om:unit_of_measure	value gci:interruption_per_year

The numerator sums the number of accounts that have been affected over the population of all electrical interruptions. The population excludes interruptions caused by weather.

Class	Property	Value Restriction
7.6_Total_Count_of_Electrical Interruptions	owl:subclassOf	gci:GCI_quantity
	owl:subclassOf	gs:Sum
	om:unit_of_measur e	gci:interruption
	om:value	exactly 1 gcise:ServiceInterruptionMeas ure
	gs:sum_of	Only 7.6_Population_of_Electrical Service_Interruptions
	gs:sum_of_var	value serviceInterruptionVar
7.6_Population_of_ElectricalService_Interrupti ons	owl:subclassOf	gs:Population
	gci:defined_by	exactly 1 7.6_ElectricalServiceInterruptio n
7.6_ElectricalServiceInterruption	owl:subclassOf	gcise:ElectricalService Interruption
	gcise:causedBy Weather	value xsd:false

The denominator identifies the total number of customer accounts by defining a population composed of electrical service accounts.

Class	Property	Value Restriction
7.6_Customer_Account_Size	owl:subclassOf	gci:GCI_quantity
	owl:subclassOf	gs:Cardinality
	om:unit_of_measure	value gci:population_cardinality_unit
	om:value	exactly 1 gci:Population_measure
	gs:cardinality_of	exactly 1

		7.6_Customer_Account_Pop
7.6_Customer_Account_Pop	owl:subclassOf	gs:Population
	gci:defined_by	exactly 1 gcise:ElectricalServiceAccount

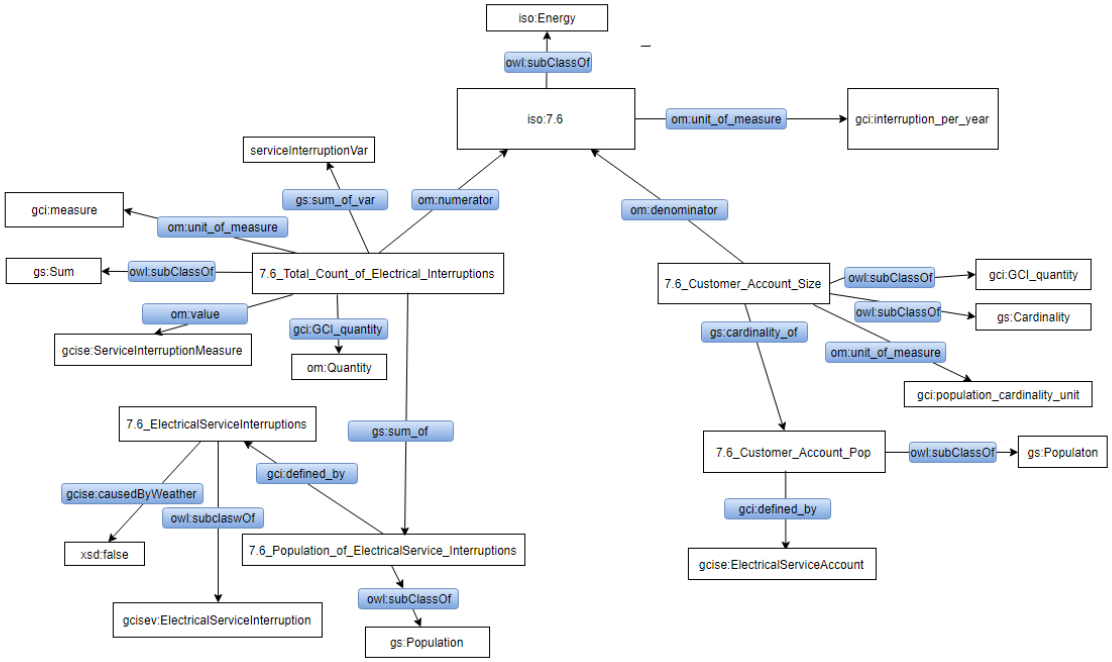

Figure 13 ISO37120 - 7.6 Definition

7.7 Average Length of Electrical Interruptions (Hours) (Supporting Indicator) (ISO37120:7.7)

The final energy theme indicator measures the average duration of the electrical interruptions. The indicator is derived dividing the sum of all the electrical interruptions divided by the total number of interruptions.

Class	Property	Value Restriction
Iso37120:7.7	owl:subclassOf	iso37120:Energy
	om:numerator	exactly 1 7.7_Sum_of_Duration_of_Electrical _Interruptions
	om:denominator	exactly 1 7.7_Total_Count_of_Electircal Interruptions
	om:unit_of_measure	om:hour

We define the total duration of the electrical outages by taking the sum of the durations for all non-weather related interruptions.

Class	Property	Value Restriction

7.7_Sum_of_Duration_of _Electrical_Interruptions	owl:subclassOf	gci:Quantity
	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 7.7_Electrical _Service_Interruption_Pop
	gs:sum_of_var	value gcise:serviceDurationVar
	om:value	exactly 1 gcise:ServiceDurationMeasure
	om:unit_of_measure	value om:hour
7.7_Electrical_Service_Interruption_ Pop	owl:subclassOf	gs:Population
	gci:defined_by	exactly 1 7.7_Electrical_Service_Interruption
7.7_Electrical_Service_Interruption	owl:subclassOf	gcise: ElectricalServiceInterruption
	gcise:causedByWeather	value xsd:false

The denominator 7.7_Total_count_of_Electrical_Interruptions is defined as all electrical interruptions that were not caused by extreme weather events. It reuses the electrical service interruption population of the numerator but counts the size of the population

Class	**Property**	**Value Restriction**
7.7_Total_Count_of_Electrical Interruptions	owl:subclassOf	gci:GCI_quantity
	owl:subclassOf	gs:Cardinality
	om:unit_of_measure	value gci:interruption
	om:value	exactly 1 ServiceInterruptionMeasure
	gs:cardinality_of	exactly 1 7.7_Electrical_Service_Interruption_Pop

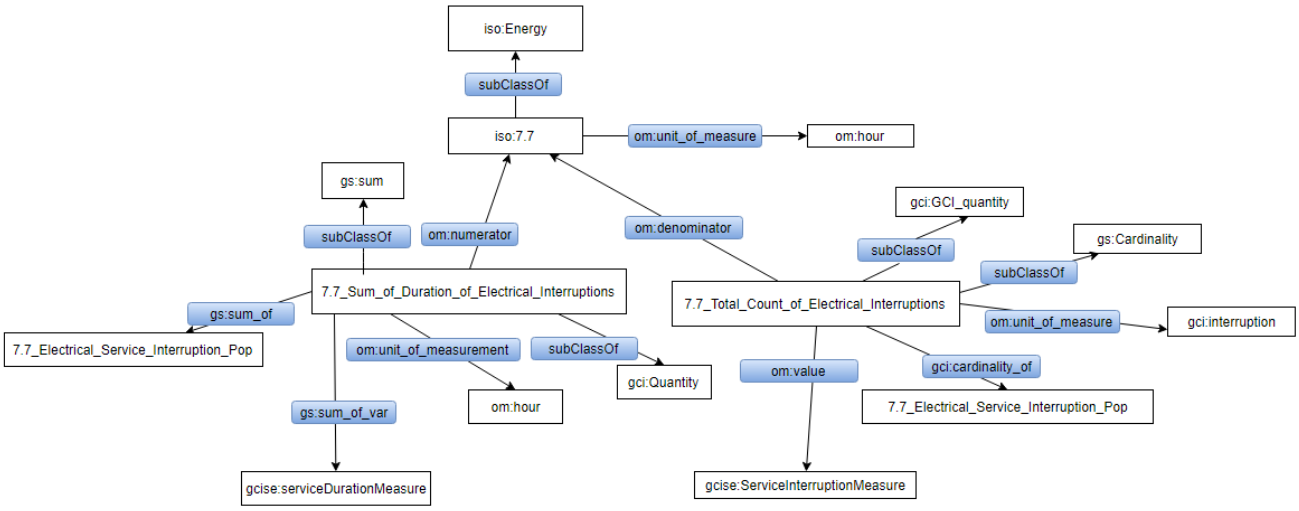

Figure 14 ISO37120 7.7 Definition

8. Evaluation

In this section we verify the Energy ontology by demonstrating that it can answer the competency questions. We use the City of Toronto in the Province of Ontario, Canada to answer the competency

questions. In the following section, we define the example from the City of Toronto, using our ontology that will used to answer the competency questions. Appendix B contains the list of all prefixes.

Instance	Property	Value
gn:6251999	rdfs:label	Canada
	rdfs:type	gn:feature
	rdfs:type	sch:Country
gn:6093943	rdfs:label	“Ontario”
	rdfs:type	gn:Feature
	rdfs:type	sch:Province
gn:6167865	rdfs:Label	Toronto
	rdfs:type	gn:feature
	rdfs:type	sch:city

Instance	Property	Value
Toronto_Building_01	rdfs:type	iso37120en:7.1_ResidentialBuilding
	ic:Address	Address_01
	gcibo:hasFloorArea	Total_FS_TB01
	gcibo:hasResFloorArea	Res_FS_TB01
	gcibo:hasTenantSpace	gcibo:TenantSpace
	org:hasOwnerShip	org:privately_owned
	gcibo:owned_by	foaf:JohnDoe
Address_01	rdfs:type	ic:Address
	ic:HasCity	gn:6167865
	ic:hasState	gn:6093943
	ic:hasCountry	gn:6251999
	ic:Has_Street_number	123
	ic:Has_street	Fake
	ic:has_street_type	Street
	gcibo:hasBuilding	Toronto_Building_01
Address_02	rdfs:type	ic:Address
	ic:HasCity	gn:6167865
	ic:hasState	gn:6093943
	ic:hasCountry	gn:6251999
	ic:has_Street_number	14
	ic:has_street	Carlton
	ic:has_street_type	Street
JohnDoe	rdfs:label	John Doe
	rdfs:type	foaf:agent
Total_FS_TB01 *(total floor area of building)*	rdfs:type	gcibo: FloorArea_Measure
	om:value	Total_FS_TB01_value
	om:unit_of_measure	om:square_metre
Total_FS_TB01_value	rdfs:type	gci:GCI_measure
	om:numerical_value	1000
	om:unit	om:square_metre
Res_FS_TB01 (*floor area in building for residential use)*	rdfs:type	gcibo: Res_FloorArea_Measure
	om:value	Total_FS_TB01_value
	om:unit_of_measure	om:square_metre

Res_FS_TB01_value	rdfs:type	gci:GCI_measure
	om:numerical_value	900
	om:unit_of_measure	om:square_metre
Toronto_Hydro	rdfs:type	gcise: ElectricalServiceProvider
	so:hasLegalName	'Toronto Hydro'
	so:hasAddress	Address_02
	gcise:distributes	gcise:ElectricalService
	gcise:Authorizes	ServiceAccount_01
ServiceAccount_01	rdfs:type	gcise: ElectricityServiceAccount
	gcise:accountActive	True
	gcise:Authorized_by	Toronto_Hydro
	gcise:hasServiceType	gcise:ElectricalService
	hasServiceAddress	Address_01
	gcise:owned_by	JohnDoe

Instance	**Property**	**Value**
7.1_ex *(Instance of 7.1)*	rdfs:type	iso37120:7.1
	gci:numerator	7.1_ex_Res_elec_ Consumption
	gci:denominator	Toronto_city_pop_size
	gci:for_city	gn:6167865
	om:unit_of_measure	om:kwh_per_pc
	om:value	7.1_ex_value
7.1_ex_value *(value of 7.1)*	rdfs:type	gci:GCI_measure
	om:numerical_value	1830
	om:unit_of_measure	om:kwh_per_pc
7.1_ex_Res_elec_ Consumption_quant *(numerator for 7.1)*	rdfs:type	iso37120en: 7.1_ Total_Residential_ Electrical_Consumption_ Quantity
	om:value	7.1_ex_Res_elec_ Consumption
	om:unit_of_measure	om:Kilowatt_hour
	gci:for_city	gn:616765
	gs:sum_of	7.1_TO_Res_Build_Pop_ Value
	gs:sum_of_var	gcise:electricalConsumptionVar
7.1_ex_Res_elec_ Consumption *(value of the numerator of 7.1)*	rdfs:type	gci:GCI_measure
	om:numerical_value	5,073,000,000
	om:unit_of_measure	kilowatt_hour
Toronto_city_pop	rdfs:type	gci:City_Population
	gci:located_in	gn:6167865
Toronto_city_pop_size *(denominator for 7.1)*	rdfs:type	gci:City_Population_Size
	gci:cardinality_of	Toronto_city_pop
	om:value	Toronto_city_pop_size_ Value
	om:unit_of_measure	gci:population_cardinality_ unit

Toronto_city_pop_size_ Value *(value of denominator for 7.1)*	rdfs:type	gci:GCI_measure
	om:numerical_value	2615000
	om:unit_of_measure	gci:population_cardinality_ unit
7.1_TO_Res_Build_Pop_ Size	rdfs:type	iso37120en:7.1_Total_Residential Building_Population
	gci:cardinality_of	7.1_TO_Res_Build_Value
	om:unit_of_measure	gci:population_cardinality_ unit
7.1_TO_Res_Build_Pop_ Value	rdfs:type	iso37120en:7.1_Population_of _ResidentialBuilding
	gci:GCI_measure	xsd:integer
	om:unit_of_measure	gci:population_cardinality _unit

The following illustrates how the competency questions for ISO37120:7.1 are implemented in SPARQL.

1. (F) What city is the indicator for?

   SELECT ?cityname WHERE
   {7.1_ex gci:for_city ?city.
   ?city rdfs:label ?cityname}

   Answer: “Toronto”

2. (F) What is the total population of the city?

   SELECT ?city ?city_pop_value WHERE
   {?cityPop rdf:type gci:City_Population.
   ?cityPop gci:located_in ?city.
   ?cityPopSize gci:cardinality_of ?cityPop.
   ?cityPopSize om:value ?cityPopSize_measure.
   ?cityPopSize_measure om:numerical_value ?city_pop_value}

City	**City Population Size**
Toronto	“2615000” ^^ xsd:integer

3. (F) Is “Toronto_Building_01” a residential building?

   SELECT ?BuildingType WHERE
   { Toronto_Builidng_01 owl:subclassOf ?BuildingClass }

   Answer: ResidentialBuilding

4. (CD) Who is the owners of Toronto_Building_01? What sector owns these buildings?

   SELECT ?Owner ?Sector WHERE
   { Toronto_Building_01 gcibo:owned_by ?Owner.

Toronto_Building_01 org:HasOwnership ?Sector}

Owner	Sector
JonDoe	Privately_owned

5. (F) What percentage of the floor space is used for residential purposes in Toronto_Building_01?

   SELECT (?Res_FS_Value/?Tot_FS_Value) AS ?percentage WHERE
   { Toronto_Building_01 gcibo:hasFloorArea ?Tot_FS.
   ?Tot_FS Om:value ?Tot_FS_Value.
   Toronto_Building_01 gcibo:hasResFloorArea ?Res_Tot_FS.
   ?ResPTot_FS om:value ?Res_Tot_FS_Value }

   Answer: 0.90

6. (F) How much energy was used per year in residential buildings?

   SELECT ?numeric_value ?unit WHERE
   {7.1_ex_Res_elec_Consumption om:value ?value.
   ?value om:numerical_value ?numeric_value.
   ?value om:unit ?unit }

Numeric_value	Unit
5,073,000,000	Kilowatt_hour

7. (F) What organizations provide electrical service in Toronto?

   SELECT ?ServiceProvider ?ServiceAccount WHERE
   { ?ServiceAccount a gcise:ServiceAccount.
   ?ServiceAccount gcise:hasServiceProvider gcise:ServiceProvider.
   ?ServiceAccount hasServiceAddress ?Address.
   ?Address ic:hasCity ?city.
   ?City rdfs:Label ?label.
   FILTER regex (?label. “Toronto”)}

ServiceProvider	ServiceAccount
Toronto_Hydro	ServiceAccount_01

8. (CI) Which service provider does each Toronto building use?

   SELECT DISTINCT ?ServiceProvider ?Building WHERE
   {?ServiceProvider a gcise:ServiceProvider.
   ?ServiceProvider gcise:authorizes ?ServiceAccount.
   ?ServiceAccount gcise:hasServiceAddress ?Address.
   ?Building a db:Building.

?Building ic:hasAddress ?Address }

ServiceProvider	Building
Toronto_Hydro	Toronto_Building_01

9. (F) How many service accounts are there in residential_building_01?

SELECT (Count(?ServiceAccount) AS ?C) WHERE
{?ServiceAccount a gcise:ServiceAccount.
?ServiceAcccount gcise:hasServiceAddress ?Address.
?Address gcibo:hasBuilding Toronto_Building_01}

Answer: 1

9. Conclusions

The goal of this research was to define an ontology to represent the ISO37120 theme indicator definitions and the data use to derive a city's specific indicator value. In order to construct this ontology, we had to define some generic ontologies for energy related knowledge.

In summary, this research made the following contributions:

1.) Defines an Energy Ontology that covers a broader range of energy concepts related to total city level electrical usage and interruptions.
2.) Uses the above concepts to support and expand the definitions for indicators in "ISO 37120:7 Energy"
3.) Defines each of the ISO 37120: 7 Energy indicators using the foundation and GCI Service and Building Occupancy Ontology, providing a formalized computationally precise definition; and
4.) Provides a standard representation for general energy knowledge related to indicators, city specific versions of energy knowledge and the data used to derive the indicators value.

10. Acknowledgements

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Appendix A – Key Ontologies

The Global City Indicator Foundation ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Founation-v2.owl.

The Global City Indicator Service Ontologies for Service can be found in:
http://ontology.eil.utoronto.ca/GCI/Energy/GCI-Service.owl.

The Global City Indicator Service Ontologies for Building Occupancy can be found in:
http://ontology.eil.utoronto.ca/GCI/Energy/GCI-BuildingOccupancy.owl.

URIs for all of the ISO37120 indicators can be found in:
http://ontology.eil.utoronto.ca/ISO37120.owl.

Definitions of the ISO37120 Finance indicators, using the GCI Foundation and Energy ontologies can be found in:
http://ontology.eil.utoronto.ca/GCI/ISO37120/Energy.owl.

Appendix B – Prefixes of Ontologies Used

Prefix	Ontology	URL
db	dbpedia	http://dbpedia.org/ontology/

foaf	FOAF	http://xmlns.com/foaf
gci	GCI foundation	http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl
gcibo	GCI Building Occupancy	http://ontology.eil.utoronto.ca/GCI/BuildingOccupancy/GCI-BuildingOccupancy.owl
gcii	GCI Innovation	http://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl
gcis	GCI Shelter	http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl
gcise	GCI Service	http://ontology.eil.utoronto.ca/GCI/Energy/GCI-Service.owl
gn	Geonames	http://sws.geonames.org/
gs	GovStat	http://ontology.eil.utoronto.ca/govstat.owl
ic	Icontact (international address Ontology)	http://ontology.eil.utoronto.ca/icontact.owl
iso37120	iso 37120 IRIs	http://ontology.eil.utoronto.ca/ISO37120.owl
iso37120en	ISO 37120 Energy	http://ontology.eil.utoronto.ca/GCI/ISO37120/Energy.owl#
iso37120s	ISO 37120 Shelter	http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl
lode	LODE Event	http://linkedevents.org/ontology/
om	Measurement ontology	http://www.wurvoc.org/vocabularies/om-1.8
org	TOVE organization	http://ontology.eil.utoronto.ca/organization.owl
ot	Owl time	http://www.w3.org/2006/time
pr	Prov	http://www.w3.org/ns/prov
sch	Schema.org	http://schema.org/
sem	Semanco	http://semanco-tools.eu/ontology-releases/eu/semanco/ontology/SEMANCO/SEMANCO.owl
so	Service	http://purl.org/ontology/service
sumo	Suggested Upper Merged Ontology	http://www.ontologyportal.org/SUMO.owl#