GIMA

Geographical Information Management and Applications

Conceptual model of the application and exchange of geodata within the smart power grid in the Netherlands

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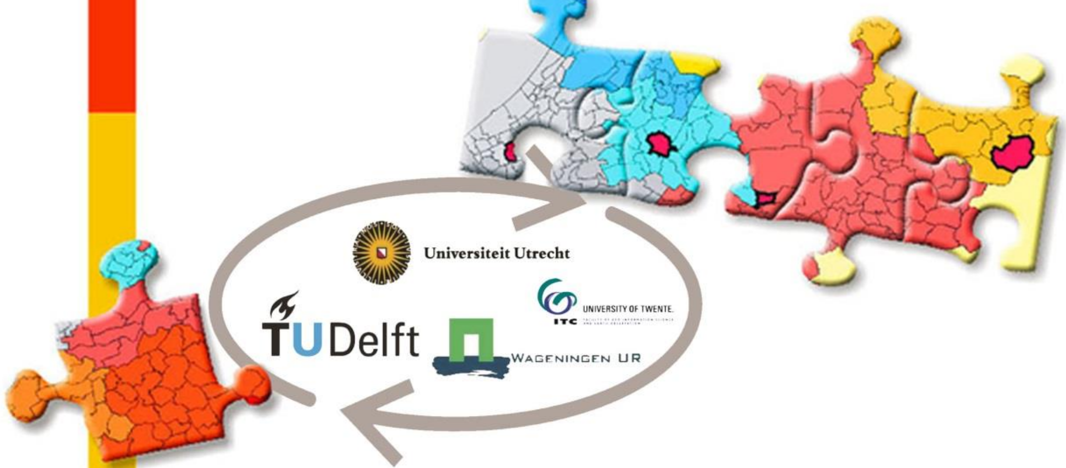

Content

Summary

The energy sector in the Netherlands is undergoing dramatic changes, often referred to as the energy transition. This energy transition is driven by environmental challenges, market changes, infrastructural challenges and innovative technologies. From these developments the smart grid is emerging. The smart grid involves a grid in which energy is produced increasingly at a local level. As a result, imbalances and congestion occur increasingly local and thus the decentralised grid places high demands on geodata.

There is not yet a model which guides owners of geographic information systems (GISs) or geodata. The objective of this research is to develop such a model in order to support owners over GISs and geodata. The conceptual model supports the energy sector to address the use and origin of geodata within the smart grid for the purpose of energy balancing and congestion management and thereby identify the exchange between domains and roles.

In outline the research identifies three steps:

1. Identify players in the smart grid;
2. Determine interaction between players in the smart grid;
3. Define the geodata used in the interaction.

The players in the smart grid are described with a role model. The most common role model in the power grid is adopted: the harmonised role model of the European network of transmission system operators for electricity (ENTSO-E). In the changing market causes shifting roles, but also a new role emerges: the aggregator. With regard to energy balancing and congestion management especially the role of the DSO is changing, because the decentralisation implies that the energy balancing and especially congestion management shifts from the transport grid towards the distribution grid. The current European and Dutch role model does not seem to fit the new relations which arise from the emerging of the smart grid. Tasks, responsibilities and power need to be redefined. The aggregator could be a part of the solution to the changing market roles. An aggregator is basically a collection of other roles from the role model. The aggregator can bridge responsibilities on one hand and the powers on the other. Still the privacy legislation is restricting the freedom of movement any role in the energy market and further research on the changing market roles is required.

The interactions of the players on the market are described by using use cases. These describe the application and exchange of geodata for the purpose of energy balancing and congestion management within the smart grid. These use cases are plotted in the ENTSO-E market role model in order to gain insight.

Next the geodata used in the interaction is elaborated on. The geodata is modelled and visualised in a conceptual class diagram and it is implemented.

The parties in the energy market have developed their own praxis to refer to an area of imbalance or congestion: the locational data is expressed as a collection of affected objects. There is no exchange of geographic and topological data when balancing energy and managing congestion. The geographical data is obtained in advance from public open data sources and the market roles add these geographical characteristics themselves for their own needs. The grid managers are holders of the topological data and keep these topological data for themselves. The fact that geographical and topological data is not exchanged when balancing energy and managing congestion, does not mean that the geographical and especially topological data is less relevant. The correct geographical and especially the correct topological data is of the utmost importance to exchange the right collection of affected objects. Otherwise interventions are made on the wrong location, causing an even greater imbalance or congestion.

A common vocabulary is required then to assure all parties involved have a shared understanding of the affected objects, so the just locational reference is assigned to the objects. Part of that common vocabulary should also be the definition of time intervals. The development of a common vocabulary would be a logical next step in order to support energy balancing and congestion management within the smart grid.

0. Introduction

The energy sector is facing major changes with enormous influence on the energy grid and the way it is managed. The use of renewable energy sources (RESs) like solar power and wind energy is increasing as a result of the growing attention for the environment: the exhausting of fossil energy sources and the concern for climate change. These RESs are often not owned by the utility company, but by consumers, farmers and cooperations. These RESs also imply a decentralised production of energy and a change of the roles within the energy sector: the consumers, farmers and cooperations not only consume energy, but also deliver energy back to the grid. Both the physical grid as the relationship between actors in the sector are changing. There is no longer one utility company that centrally produces energy, but there are many decentralised energy producers and thousands or even millions of customers consuming energy. As a result, imbalances or even congestion occur at a local level. Imbalances are differences between contracted and actual sum of supply and demand, while congestion concerns the exceeding of the capacity of the grid.

In reaction to this changes, the smart grid is emerging. The EU Commission Task Force for Smart Grids defines a smart grid as ‘an electricity infrastructure that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety’(CENELEC, 2014) . In other words: a smart grid balances demand and supply by using a two-way communication between producers and consumers of energy and thereby levelling peaks and troughs. Historically the grid capacity is determined based on the peak. That is no longer viable, while costly as decentralisation implies an increase of the variation between peaks and troughs.

In the literature regarding smart grid a lot of attention is paid to the information and telecommunication (ICT) requirements and impact of smart grids on the physical infrastructure, but relatively low attention is paid to the requirements regarding spatial data. The spatial data is becoming more important as the energy balance needs to be preserved at a more decentralised level. Only just recently, in 2012, the open geospatial consortium (OGC) has chartered a working group which examines standards regarding to geodata within the smart grid: the Energy & Utilities domain working group (E&U DWG) (OGC, 2014). In that same year the Dutch government has initiated a national program which aims at improvement of the interoperability of geo-information within the smart grid. This program, CERISE-SG (‘Combineren van Energie- en Ruimtelijke Informatie Standaarden als Enabler – Smart Grids’) focusses on the combining of energy and geo-information standards as an enabler for smart grids. CERISE-SG focusses on four use cases:

1. The EBIF: Energy Balancing Information Facility;[1]
2. Crisis management;
3. The energy map of the Netherlands; and
4. The 3D city model and solar power.

Furthermore the program describes a fifth use case: the basic infrastructure for geo-information which underpins the four use cases. The use case of the basic infrastructure for geo-information focusses on the connection between the smart grid and geo-information, but does not address the actual application of geo-information (Verhoosel, Janssen, & De Vries, 2013).

The EBIF aims to manage information of the local supply and demand of energy to ensure the local administrative balance. The objective of the EBIF is to facilitate the information to manage the local supply and demand of energy to ensure the local administrative balance. The administrative balancing is about levelling supply and demand in the grid. Within CERISE-SG an information model has been developed for the EBIF: the information model smart grid – energy balancing information facility (IMSG-EBIF) (Quak & Janssen, 2014).

[1] Initially referred to as Local Control Room, but later changed to Energy Balancing Information Facility (EBIF).

This research focusses on the development of a conceptual model of the application and exchange of geodata for the purpose of energy balancing and congestion management within the smart power grid in the Netherlands. The conceptual model supports grid managers in the Netherlands to recognise the geodata flows in the smart grid and thereby enable them to interconnect assets and actors within the smart grid.

1. Research definition

This research is positioned in between the use case of EBIF and the use case of the basic infrastructure for geo-information of CERISE-SG. As the smart grid can be seen as interconnected (micro) grids of many stakeholders the seamless exchange of geodata is of great importance in order to balance energy and manage congestion.

1.1 Problem statement

The actors in the smart grid are confronted with many viewpoints, domains, standards and standardisation organisations, and there are many initiatives to participate in. The smart grid is a comprehensive concept which is studied from various point of views and therefore many models are available. With the more decentralised energy production and reduced hierarchy of a smart grid as opposed to the traditional grid, the spatial distribution of supply and demand within the smart grid places high demands on information management regarding geodata. Existing models do not address information flows and standards which apply, nor does it give insight which geodata is needed where in the smart grid for energy balancing purposes.

As the application and exchange of geodata is underexposed in the existing models regarding energy balancing and congestion management within the smart grid, the owners of geographic information systems (GISs) or geodata have no model to guide them.

1.2 Research objective

The research objective is: "to develop a conceptual model of the application and exchange of geodata for the purpose of energy balancing and congestion management within the smart grid in the Netherlands."

The conceptual model visualises geodata application on one hand and on the geodata sources at the other. Information flows bridge the sources and the application of geodata. The result is a model which visualises domains, roles, applications, and interfaces.

The conceptual model supports the energy sector to address the use and origin of geodata within the smart grid for the purpose of energy balancing and congestion management and thereby identify the exchange between domains and roles.

1.3 Research questions

To achieve the research objective, the next research questions are formulated:

- What are the drivers of the emerging of the smart grid?
- Who are the users of geodata for the purpose of energy balancing and congestion management within the smart grid?
- What are the applications of geodata for the purpose of energy balancing and congestion management within the smart grid?
- What are the requirements regarding the geodata used for energy balancing and congestion management within the smart grid?

1.4 Research scope

The scope of the research is the smart power grid within the Netherlands. Power grid refers to the electricity infrastructure.

Furthermore the research focusses on geodata, i.e. data that has or should have a reference to the surface of the earth.

The research focusses on the application and exchange of geodata for the purpose of energy balancing and congestion management within the smart power grid in the Netherlands. The research does not aim to determine which technologies should be used. Neither does it focus on actual services.

The research is done within Stedin, one of the three biggest regional grid managers of the Netherlands.

1.5 Research approach

The core of the approach are three steps:

1. Identify players in the smart grid;
2. Determine interaction between players in the smart grid;
3. Define the geodata used in the interaction.

The development of the conceptual model takes place in four stages:

1. A literature review;
2. The setup of the methodology;
3. The development of a conceptual model; and
4. The implementation of the model.

In the literature review starts with identifying the driving forces of the emerging of the smart grid for a general understanding. Next the players within the smart grid which exchange geodata are determined. From the general understanding of the players within the smart grid, the applications of geodata with regard to energy balancing and congestion management are determined. As a result the information flows emerge. As the geodata requirements are clear then, the sources of geodata can be determined. The exchange of geodata requires a shared understanding of definitions, i.e. standards.

After the literature review, the methodology is setup. This comprises the methodology to define the use case, and the methodology to develop, assess, implement and validate the conceptual model.

Next the actual use cases are described. The use cases describe the information flow which bridge the application and sources of geodata. The use cases are the reference for validating the model. The conceptual model is developed and assessed. The development and assessment of the model is a iterative process.

Finally the conceptual model is implemented: data is collected and brought together in a system in which geodata exchange is simulated.

2. Literature review

In this chapter the drivers of the emerging of the smart grid are researched. From the understanding of the drivers of the smart grid, the applications of geodata within the EBIF of the smart grid can be derived. Next the sources of the geodata are determined. Within a smart grid geodata needs to exchanged and that calls for the data and the data exchange to be standardised. Therefore standards that are applicable are reviewed. Finally the possible information architectures underpinning the EBIF of the smart grid are studied.

2.1 Drivers of smart grid

The energy sector is confronted with great challenges. Besides the growing demand and changing demographics, the energy sector is faced with (F. X. Li et al., 2010):

1. Environmental challenges;
2. The changing market;
3. Infrastructural challenges; and
4. Innovative technologies.

The environmental challenges refer to the attention for the climate change and the exhaustion of fossil energy resources. Over 40% of the man-made CO2 emissions are caused by electricity (IRENA, 2014). The society becomes more and more aware that this is finite. But the care for the environment also include the availability and suitability of space for expansion of the grid (F. X. Li et al., 2010). The emphasise on the public space is getting more attention with the increase of RESs like solar panels and especially wind turbines, which generally are prominent in the landscape.

The second challenge is the changing market: the liberalisation and the growing transparency. Traditionally the energy sector comprised geographical monopolists with a fixed hierarchy consisting of one large provider, a grid manager and millions of end users. The energy grid is becoming more and more decentralised: any stakeholder can consume and produce energy and is free to trade it in an open market. This is often referred to with the term 'prosumer' (Pagani & Aiello, 2011). As a result the value chain is no longer controlled by one utility company, but consists of many actors. There is a paradigm shift as the energy sector was once dominated by large centralised utility companies, but is increasingly a decentralised, diverse and distributed sector (IRENA, 2014).

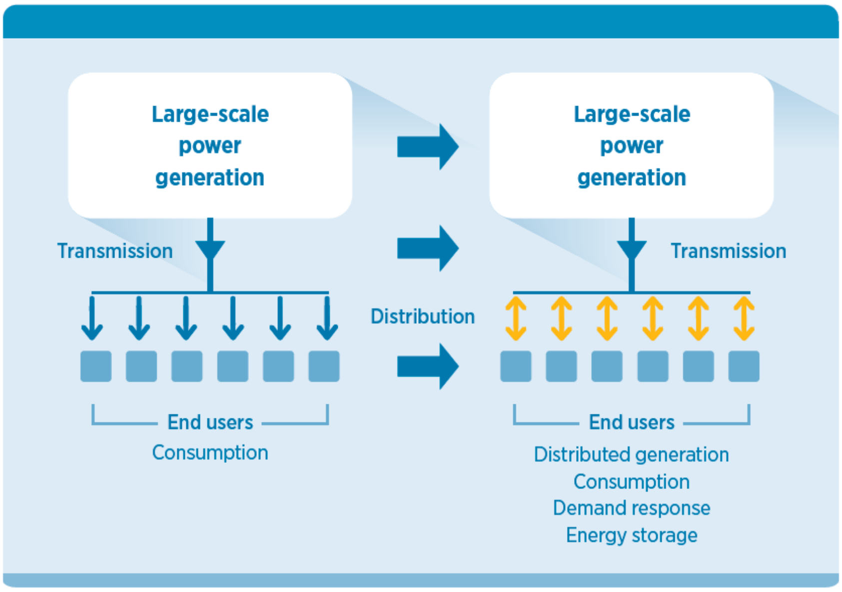

Figure 1: Paradigm shift from centralised to decentralised and from top-down to bottom-up (IRENA, 2014)

The infrastructural challenges come forth from the market changes. The traditional energy sector resembles the physical infrastructure which are mainly based on a large central power station which is connected to a transmission infrastructure. This transmission infrastructure is, in turn, connected to a distribution infrastructure which delivers energy to consumers (EU, 2006). With the changing sector, the energy grid changes, especially the distribution grid. The top-down distribution is evolves towards a bottom-up supply and the market is moving towards a user-centric approach (EU, 2006; Sonnenschein, Lünsdorf, Bremer, & Tröschel, 2014). The market change and infrastructural change is visualised in figure 1.

Electrification is also considered as an infrastructural change. The increase of heat pumps, cooking on electricity and electric vehicles (EVs) lead to an increase of consumption of electricity (Gerdes, Marbus, & Boelhouwer, 2014; F. X. Li et al., 2010; Van der Welle & Dijkstra, 2012).
The final challenge is to incorporate innovative technologies in the existing energy grid. Technologies within the grid are often not compatible (F. X. Li et al., 2010). For example communication technologies, operational technologies to manage the grid and RES technologies need to be bridged. There is a pursue for a higher quality of service (QoS) and more efficient way to manage the energy grid (EU, 2006). That pursue requires investments and innovations in the energy grid like energy storage and two-way real time communications.

The energy sector needs to reinvent itself to deal with these changes and modernise its grids. The shift towards more intelligent grids is known as 'smart grid' (F. X. Li et al., 2010). Smart grid is a term referring to the next generation of power grid in which the electricity distribution and management is facilitated by two-way communications and extensive applications of computing capabilities to improve control, efficiency, reliability and safety (Yan, Qian, Sharif, & Tipper, 2013). Or, as the European committee for electro technical standardisation (CENELEC) defines it: 'A smart grid is an electricity infrastructure that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety' (CENELEC, 2014).

2.2 Energy market roles

This paragraph is not only based on literature, but also on interviews conducted with experts. See appendix 5 for the interviews conducted.

Data exchange is an interaction between two actors. In order to determine the interaction, i.e. the data exchange, first these actors need to be known. Often such actors are referred to at a higher level, i.e. domains or roles. A well know and internationally often used model, is the conceptual domain model of the American national institute of standards and technology (NIST) (NIST, 2014). In Europe another model is used: the European transmission system operators (TSOs) joined forces in the ENTSO-E: the European network of transmission system operators for electricity. One of the results of the collaboration, is the harmonised role model (ENTSO-E, 2014b). The ENTSO-E role model is a harmonised vision on the roles within the power grid. The objective of the common terminology is to ease data exchange within the power grid. See figure 2 for the conceptual domain model of the ENTSO-E and the roles mapped in it. See appendix 2 for a detailed description of the market roles.

Energy is traded before and after 'gate closure'. The energy trade before gate closure is referred to as portfolio management. The energy trade after gate closure is referred to as energy balancing. The ENTSO-E role 'balancing responsible party' (BRP), is responsible for the portfolio management. In the Netherlands the gate closure is at noon (i.e. 12.00 o'clock) (Polak, March 2015). The energy buyers submit their demand program to the TSO. In case of imbalances, i.e. a difference between the contracted volumes and actuals, the balancing responsible party in question is fined.

The balancing responsibility (in the Netherlands also known as ‘program responsibility’) is the responsibility of grid users and licensees to draw up programs for production, transmission and consumption and act accordingly . Before gate-closure these plans need to be submitted to the system operator (Polak, March 2015). In principle every party connected to the grid is a BRP, but the responsibility can be transferred. In case of consumers the balancing responsibility is automatically transferred to the energy supplier (Mathijssen, April 2015). Do not be misled by the word ‘balancing’ in BRP: the BRP is responsible for portfolio management, but not responsible for balancing.

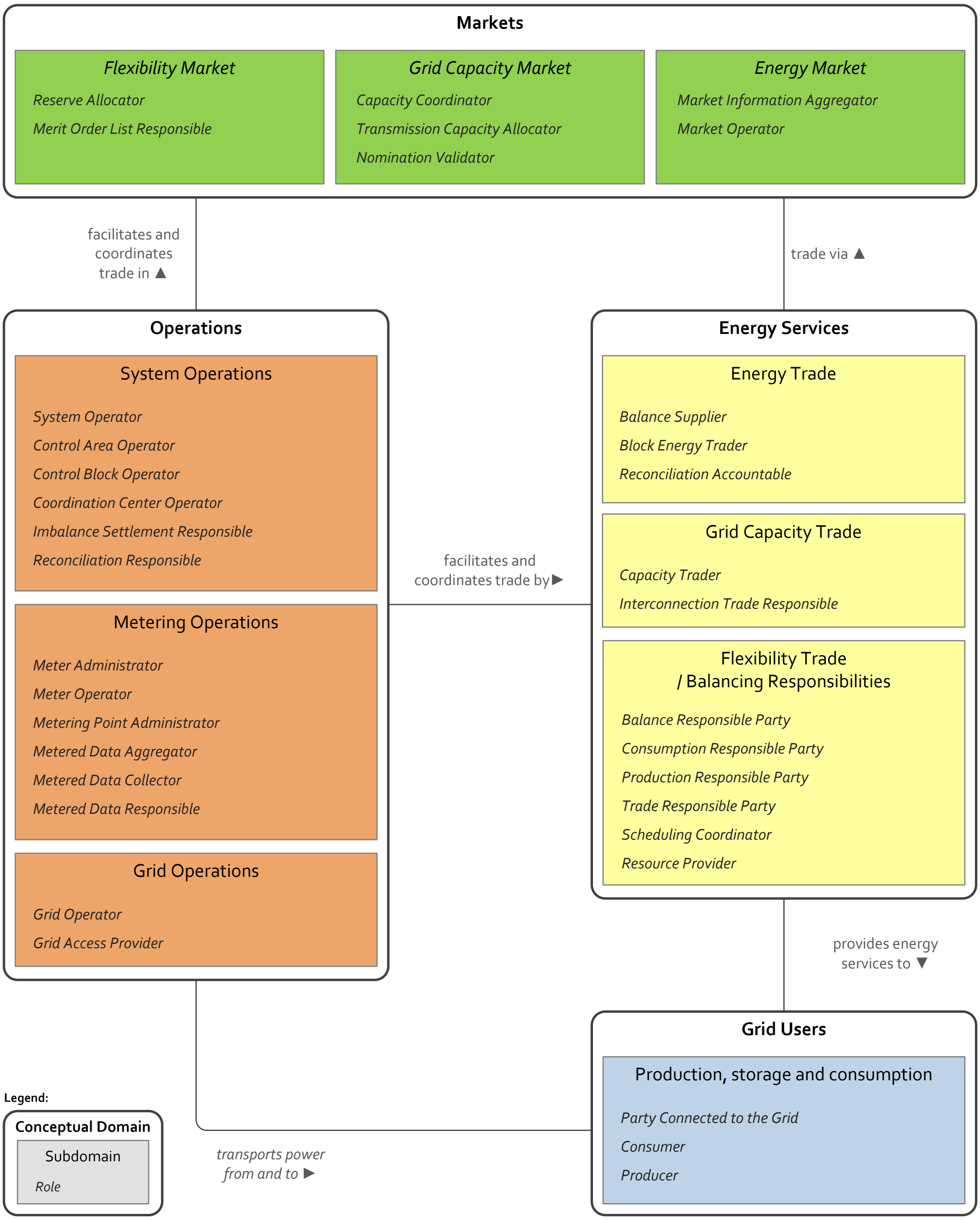

Figure 2: Conceptual domain model and market roles (CEN-CENELEC-ETSI, 2014b)

There is a distinction between the system operator role and the transmission operator role:

- The system operator role manages balance before and after gate closure, which means that the sum of supply and demand is 0;
- The transmission operator role is a role of the grid manager. It's focus is to manage congestion, i.e. prevent the overcharging of the grid capacity.

Imbalance is managed by energy trade. However energy trade can also be the tool for managing congestion. It can be less expensive for a transmission system operator to buy energy from local resellers, instead of transporting it from elsewhere (Mathijssen, April 2015).

In figure 3 the roles and responsibility are visualised.

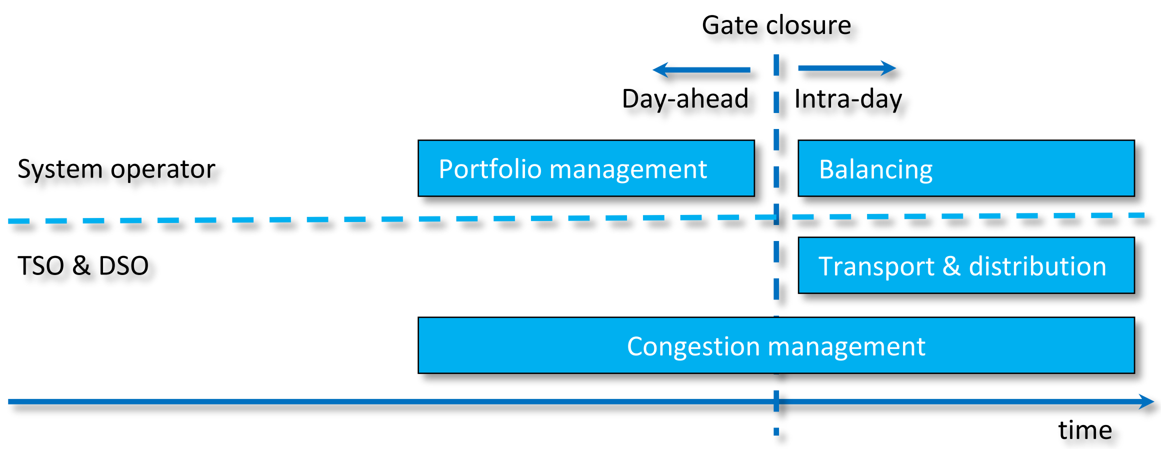

Figure 3: Dutch energy market roles day-ahead and intra-day

Currently only the TSO in the Netherlands, TenneT, is balancing energy (Knook & Cornelissen, March 2015; Mathijssen, April 2015). Congestion is managed by both the TSO as the DSO, but eventually the TSO is accountable. As a result of this accountability, the TSO has the right to overrule all other parties in order to assure grid continuity, i.e. to prevent black outs.

As the TSO and DSO are not in control of the demand and diminishingly owner of the DERs, it is harder manage congestion. The deviations in the power grid are more likely to occur locally, i.e. in the distribution gird, and thus the DSO is confronted with this challenge of energy balancing and congestion management. The DSO manages the connection, i.e. the smart meter, but it has limited access to the measurement values of smart meters. The DSO and energy provider are allowed to read the energy consumption from a smart meter at fixed moments:

- Once a year for the yearly energy invoice;
- Six times a year for the two monthly overviews;
- In case the prosumer moves or changes energy provider;
- In case it is necessary for the management or maintenance of the grid.

The DSO and energy provider, or a by the prosumer commissioned meter operator is allowed to read the energy consumption more frequently with explicit consent of the prosumer. Based on the data protection act, the DSO and energy provider are prohibited to transfer the measurement data to third parties, unless the prosumer gives explicit consent (Affairs, 2015).

In the Netherlands the TSO balances the supply and demand by financial incentives. BRPs can do regulating and reserve biddings on the IGCC'.[2] The balance responsible parties can do a bid either to reduce consumption or to increase production (Mathijssen, April 2015; Polak, March 2015). The DSOs do not have such a mechanism as the prosumer is paying a fixed fee for the connection to the DSO. The DSO does not manage the consumption and has no incentives to influence the behaviour of the prosumers and thereby manage congestion.

The changing energy market calls for a new mechanism to manage demand and supply. A mechanism that enables to shift energy demand in time, by a more (near) real time energy management. This is the demand response (DR) system. The need for the DR system increases as a result of the increase of local deviation and uncertainty of energy generation and the resulting increase of price fluctuations. The existing physical grid is limited in its ability to cope with this uncertainty and peak and troughs in energy generation. As a result the demand has to be adapted to the supply. The DR system does not only support the energy balancing in the changing energy market, but also the congestion management (Van der Welle & Dijkstra, 2012).

In figure 4 the DR scheduling process is visualised. The figure is based on the basic viewpoint on the DR scheduling process (Medina, Muller, & Roytelman, 2010), but extended with the system operator role (EG3, 2015).

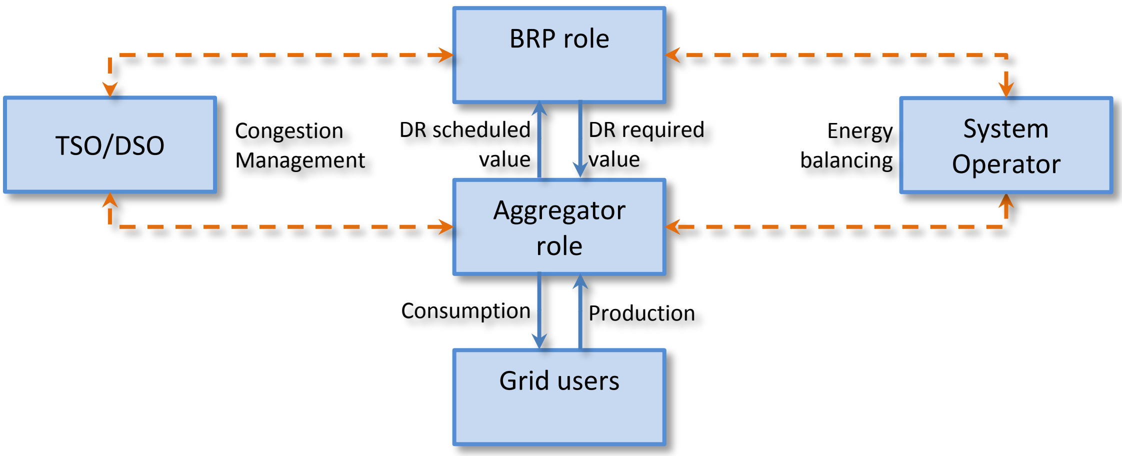

Figure 4: The DR scheduling process

The aggregator is an important role in the DR system. The aggregator role is a relatively new role within the power grid and still subject of discussion: what is the aggregator's position in the market role model? The aggregator's tasks, rights and responsibilities are subject of the expert group 3 (EG3) of the Smart Grids Task Force (SGTF) of the European Commission. EG3's focus is on regulatory recommendations for smart grid deployment (Commission, 2015). Aggregation concerns the clustering of information of prosumers in order to trade flexibility, either to increase or decrease energy production, or to increase or decrease demand (i.e. to shift energy consumption). EG3 refers to energy balancing and congestion management with the collective term 'flexibility management' (CEN-CENELEC-ETSI, 2014a).

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[2] IGCC: International Grid Control Coordination. IGGC is a collaboration of TSOs of, among others Belgium, Germany and the Netherlands. Balance Delta IGCC website: http://www.tennet.org/bedrijfsvoering/Systeemgegevens_uitvoering/Systeembalans_informatie/balansdeltaIGCC.aspx

The discussions with regard to the aggregator role revolve in outline around the following subjects (Broekmans, March 2015; Hermans, January 2015; Mathijssen, April 2015):

- Does the aggregator have a direct relation with the system operator and with the TSO/DSO for respectively the purpose of flexibility management and congestion management, or are those relations between the balancing responsible party (BRP) and the system operator and TSO/DSO. The discussion is visualised in figure 4 by the orange dashed lines;
- What is the aggregator's role with regard to congestion management?
- Is the aggregator allowed to fulfil the BRP role. The aggregator role and BRP would merge and as a result the orange dashed lines would merge. An aggregator could be considered to be a collector of BRP-roles.

2.3 Applications of geodata and interactions between market roles

The clustering of information by the aggregator can be based on location and/or based on similarity. Clustering of information based on location is obvious: the imbalance or congestion emerges on a certain location and thus a local group of grid users can contribute to the energy balancing and congestion management. The geographic location is relevant as local geographic circumstances can influence the energy generating potential. For example the local weather circumstances determine the energy generation of DERs. But more important is the location of grid users in the grid: the orthogonal location. Not the geographic location needs to be exchanged, but the connection points affected. The grid manager can then determine the relative location of the connection points in the grid. In the Netherlands, power grid connection points have an unique identifier: the eighteen digit EAN-code. EAN stands for European Article Number. The universal smart grids energy framework (USEF[3]) uses the EAN-codes to express an area of imbalance or congestion (Broekmans, March 2015).

In case of similarity, information of households, industries and businesses are distinguished. This might also be urged by the fact that the current domains have different standards, which causes problems regarding the interoperability. For example, the home energy managing system (HEMS) and building energy managing system (BEMS) used different networking standards, which hinders data-exchange (Galli, Scaglione, & Wang, 2011). Clustering information based on similarity is likely to be the result of specialisation of an aggregator. For example: if a reseller of climate control systems for office buildings fulfils an aggregator role, or a lease company its electronic vehicles.

This research focusses on the use of geodata for the purpose of energy balancing and congestion management within the smart grid. The national CERISE-SG project introduces the energy balancing information facility (EBIF) to support the information services to manage the local supply and demand in such a way that the local balance is kept. CERISE-SG identifies four main functions of the EBIF: (1) to give insight in the location and potential of energy generating and energy consuming actors on a local level; (2) to predict the supply and demand on a spatial temporal level; (3) to support the trade market; and (4) to support financial settlement by reconciliation (Quak & Janssen, 2014). The relevance of the location seems obvious, but it is not elaborated on. The most obvious functionality of geodata within the EBIF of the smart grid is to determine the location of energy generating and consuming objects and actors.

The smart grid is expected to develop towards a wide-area GIS: a virtual infrastructure in which different grid managers exchange geographic data (F. X. Li et al., 2010). The smart grid is the result of interconnected (micro) grids. So in the end, a smart grid can be considered a spatial data infrastructure (SDI). The concept of a SDI is 'to create an environment in which all stakeholders can cooperate with each other and interact with technology, to better achieve their objectives at

[3] USEF is a collaboration of parties within the energy sector. The objective is to develop a framework which supports smart energy product and services, among others an energy balancing trade market (USEF, 2015).

different levels' (Rajabifard, Binns, Masser, & Williamson, 2006). As the smart grid can be considered a SDI, it urges standardisation of the geodata exchange and the use of open data.

In the literature on smart grid supervisory control and data acquisition (SCADA) systems, energy management systems (EMSs) and distribution management systems (DMSs) are discussed. These systems focus primarily on the operational aspects of the smart grid. GISs are positioned as supportive to the maintenance services, see figure 5 (Chen, Ghenniwa, & Shen, 2006). Although closely related, the worlds of SCADA and geographic information systems (GISs) are often segregated. However, nowadays even self-healing grids are available which implies that based on operational information, the grid is maintaining itself. And so the world of smart grid and the world of GIS are further merging.

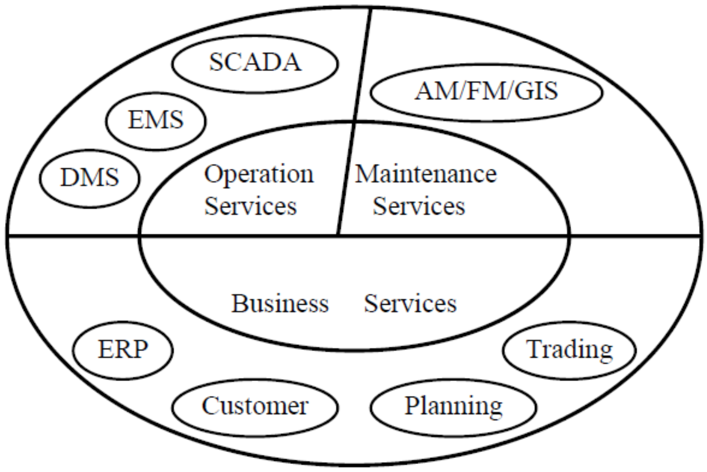


Figure 5: Traditional service classification of SCADA/DMS/EMS versus GIS (Chen et al., 2006).

The geodata can be used just for referencing, but the geo*data* can also be processed and thereby upgraded to geo-*information*. The latter three functions described by the CERISE-SG in use case 2.1 are all examples of geo-information: the prediction of the supply and demand on a spatial temporal level; the application of geodata to support the trade market; and the application of geodata to support the financial settlement by reconciliation. These latter three functions are all covered by the principle 'Demand Response' (DR).

DR is about the flattening of the peak of energy demand in time with the aim to reduce costs (Van der Welle & Dijkstra, 2012). DR values can be calculated on a zonal and nodal level. DR aims to balance or solving congestion within a zone or a node (Medina et al., 2010; Van der Welle & Dijkstra, 2012). An example of the DR on a nodal level is the neighbourhood analysis on the level of substations to determine the load spread (Sonnenschein et al., 2014). An algorithm is used which adapts to the changes of demand. Energy consuming devices are clustered iteratively and the algorithm is continuously trying to improve the rating of the neighbouring clusters. The algorithm aims to find the best rate in accordance tot the Coalition Structure Generation (CSG). CSG is a generic mathematical problem which aims to create clusters with maximum benefits as a whole (Aziz & Keijzer, 2014). The clusters are dynamic, on other words: depending on the consumption, energy consuming devices are fed by different power stations.

Eventually there is a desire to visualise the results: the location of production and consumption in time. The geodata and –information can be expressed geographically and schematically in a orthogonal map. For example, the energy consumption can be visualised at the level of a zip code, like is done at the website 'Energie in Beeld' ('energy visualised'). The website is a collaboration of three distribution grid managers in the Netherlands (Enexis, Liander and Stedin) and visualises geographically the energy production and consumption (Enexis, Liander, & Stedin, 2014). However, more relevant for the energy balancing is the way nodes are connected to each other, the topology. The topology is expressed in an orthogonal map. Historically the geographical visualisation is supported by a GIS, while the orthogonal visualisation is supported by EMSs/DMSs. As these worlds are further merging, also the visualisations, or geodata underpinning them, are merging.

So in short, the applications of geodata within the EBIF of the smart grid are: (1) georeferencing energy production and consumption in time, (2) neighbourhood analysis for aggregation purposes for DR; and (3) visualisation of the results in a geographic or orthogonal map.

2.4 Geodata within the smart grid

The source of energy production and consumption data are the community energy management systems (CEMS) which comprise of the home energy management systems (HEMS), building energy management systems (BEMS) and factory energy management system (FEMS), see figure 6. CEMS manages energy supply and demand in a certain community (Mercurio, Di Giorgio, & Quaresima, 2012). Traditionally the CEMs focus on the demand side of the smart grid. On the energy producing side, traditionally aggregations of distributed energy resources (DERs) are referred to as microgrids, or virtual power plants (VPPs). These VPPs, can concern both the integration of the physical DERs as the integration of information of the DERs for the trade market (EU, 2006; NIST, 2014).

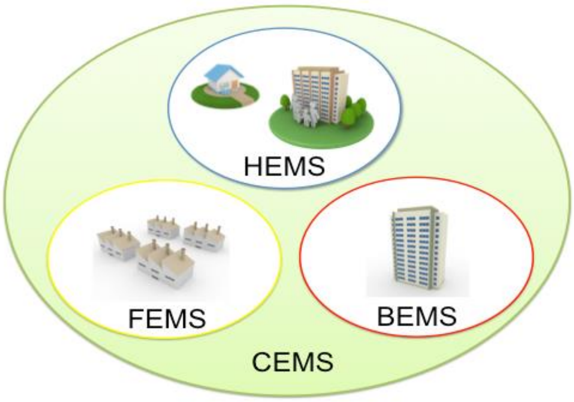


Figure 6: Energy management systems
(figure taken from: http://tocos-wireless.com/jp/tech/HEMS.html)

The energy production and consumption are less and less segregated. Within the CEMSs energy is often not only consumed, but also produced. The world of CEMSs and VPPs further merge. CEMSs incorporate the VPPs, see figure 7. This is how the CEMS is considered in this research: as an energy management system which manages both the energy production as the energy consumption. It is not only withdrawing energy from the grid, but also delivers energy back to the grid.

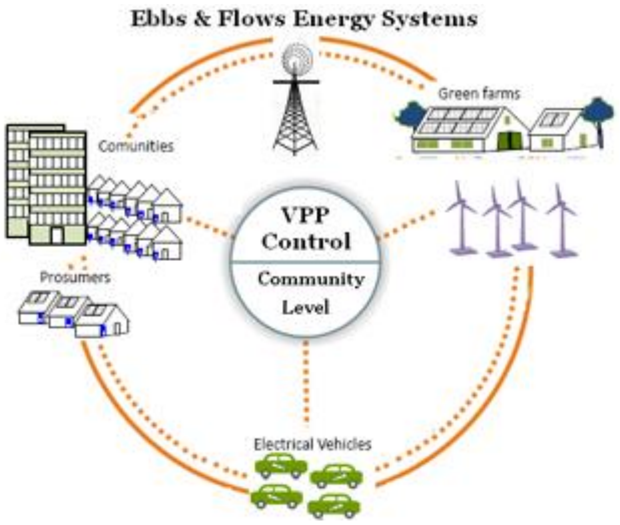


Figure 7: Virtual Power Plants
(figure taken from: http://www.eandfes.co.uk/virtual-power-plants.html *)*

The locations of the energy management systems are georeferenced. Historically topographic data is used, like the GBKN (Grootschalige Basis Kaart Nederland), the large scale base map of the Netherlands. The playing field is undergoing big changes: the costly GBKN is replaced by the free of charge BGT (Basisregistratie Grootschalige Topografie), the key register great scale topology.

The INSPIRE[4] directive is aiming at the realisation of a spatial data infrastructure (SDI) within the European Union. Utility companies are obliged to implement the INSPIRE directive. The INSPIRE directive oblige utility companies to publish their information on a national access point which is enabled for viewing services WMS and or WTM, or download services WFS and or ATOM-feeds. The national access point in the Netherlands is the National Geo Register www.nationaalgeoregister.nl (Kadaster, 2013b). This national access point is an important source for geodata for referential purposes within the smart grid. The National Geo Register contains open data of the PDOK (Publieke Dienstverlening Op Kaart): public services visualised in a map.

In order to predict the supply and demand on a spatial temporal level, other locational information is needed. So far the static locational data is discussed, but for the prediction more dynamic locational information is required. The most common is weather information. To predict the energy demand, the forecasts regarding temperature are relevant. The forecast of wind force and solar power are relevant for the prediction of the energy generation respectively by wind turbines and solar panels. Finally the forecasts of precipitation are relevant. Precipitation and the number of outages are correlated.

2.5 Standards regarding geodata

As the smart grid is a comprehensive concept, many standards apply. Figure 8 gives an overview of formal standardisation organisations, their relations and areas of interest. Besides the standardisation organisations mentioned in figure 8, there are also the open geospatial consortium (OGC) and the organisation for the advancement of structured information standards (OASIS) which issue standards regarding respectively geodata and webservices.

[4] INSPIRE: Infrastructure for Spatial Information in the European Community. The objective of the INSPIRE directive is to create a spatial data infrastructure in the European Union, to enable the sharing of geodata (INSPIRE, 2014).

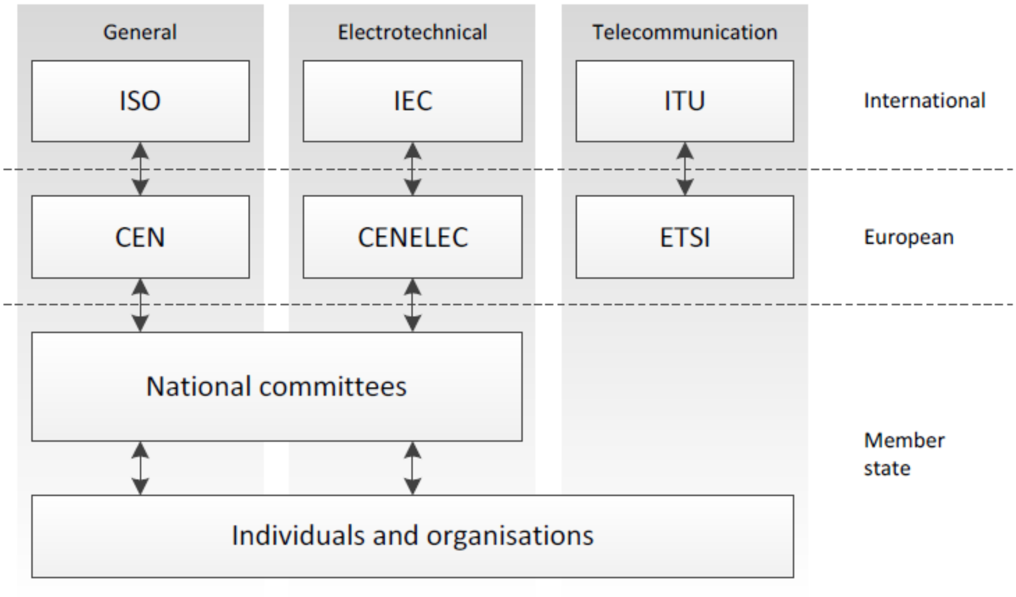


Figure 8: Overview of standardisation organisations (Verhoosel et al., 2013)

Some standards explicitly apply to the smart grid, while other apply implicitly. Explicit standards regarding the smart grid standards are:

- IEC61850: Substation Automation – Communication networks and systems in substations and for power utility automation;
- IEC61968: Distribution Management – Application integration at electric utilities – System interfaces for distribution management;
- IEC61970: management system application program interface (EMS-API);
- eMIX (OASIS): Energy Market Information Exchange (eMIX) – Exchanging price information and product definitions in energy markets and to those following markets;
- ebIX: energy Business Information eXchange – an information exchange standard with the aim to advance, develop and standardise information exchange in the energy industry;
- WS-Calendar (OASIS): WS-Calendar Common Schedule Communication Mechanism for Energy Transactions.

The IEC61970 is part of the common information model (CIM). The CIM is an open standard that a common set of objects and relationships between them. The CIM is maintained by the distributed management task force (DMTF) (DMTF, 2014).

So far, little attention is specifically paid to geodata. Although geodata is part of the CIM it still gets relatively little attention. This is surprising, since the smart grid can be seen as a spatial data infrastructure and/or to some extend as a wide area GIS (see paragraph 2.2). Geodata standards apply, of which the most common are:

- ISO/TC211 (ISO 19000): a set of standards regarding geographic information;
- WFS (OGC): Web Feature Service;
- WMS (OGC): Web Map Service; and
- NEN3610: a common geo-information model within the Netherlands.

The national committee for standardisation in the Netherlands is the NEN. One of the most common standards within the field of geo-information in the Netherlands issues by the NEN, is the NEN3610. The NEN3610 is a common geo-information model which facilitates the exchange of geo-information between parties and geo-information systems in a unambiguous and meaningful way.

The NEN3610 contains the common geo-information model of various underlying sectorial information models, see figure 9 (Geonovum, 2014a). The NEN3610 is closely related to European generic conceptual model (GCM) of Inspire and the international ISO 19000 (INSPIRE, 2013; NEN, 2011).

The Netherlands have a regulation which directs mechanical excavation. It obliges excavators to notify grid managers, and grid managers are obligated to send information to the excavators about the location of the grid (Kadaster, 2013b). The regulation has created a national SDI for grid information and is now catalyst for expansion of application of the SDI. It has standardised the data exchange by implementing a standardised information model (IMKL) and messaging protocol (BMKL). In a research under commission of the Kadaster about the future of the WION (Kadaster, 2013b), the sector has formulated a business requirements which aim to ease the interoperability and use of location information in the organisation's information systems and which ask for a wider use of the SDI. The SDI could be used to bring together information regarding supply and demand and thereby be catalyst for the EBIF.

Besides the before mentioned standards, many other standards apply implicitly. One can think of standards regarding information security, photo voltaic devices, smart meters, information exchange in general, etc. In appendix 3 an overview of standards is given. Completeness is not pretended, but the appendix gives an insight in the many standards which are or can be applicable.

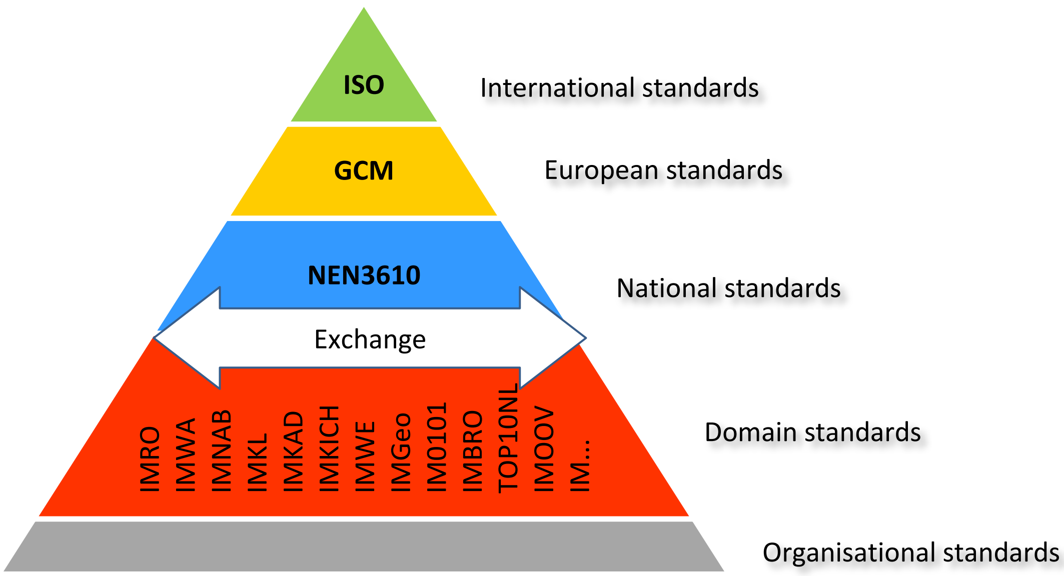


Figure 9: NEN3610 – basic model of geo-information (Geonovum, 2014a), edited

2.6 Smart grid architecture models

The energy grid is managed with SCADA. It is built upon the premise of centralised monitoring and historically devices use asynchronous communication (Galli et al., 2011). The underlying information and communication technology (ICT) of the current energy sector is predominantly supported by a client-server architecture (Pagani & Aiello, 2011).

Traditional SCADA systems use the one-way communicating automatic meter reading (AMR), while the smart grids demands a two-way communicating advanced meter infrastructure (AMI) (Galli et al., 2011). The increase of actors in the value chain and the bidirectional communication place high demands on the information exchange within the smart grid and requires a revisiting of the ICT architecture of the energy grid.

Many authors point to a service oriented architecture (SOA) as the obvious ICT architecture to underpin the smart grid (Chen et al., 2006; Considine, 2008; D. R. Li & Shao, 2009; Pagani & Aiello, 2011). Considine refers to the contraction of the SOA and smart grid with the term 'service oriented grid' (SOG) (Considine, 2008). The standardisation organisations mentioned in figure 8, have joined forces in order to 'develop a framework to enable European standardisation organisations to perform continuous standard enhancement and development in the field of Smart Grids, while maintaining transverse consistency and promote continuous innovation'(CEN-CENELEC-ETSI, 2012). The framework is referred to as the smart grid architecture model (SGAM) and is a comprehensive visualisation of the interoperability layers, zones and domains (see figure 10). See appendix 4 for a description of the dimensions used in the SGAM: the interoperability layers, domains and zones.

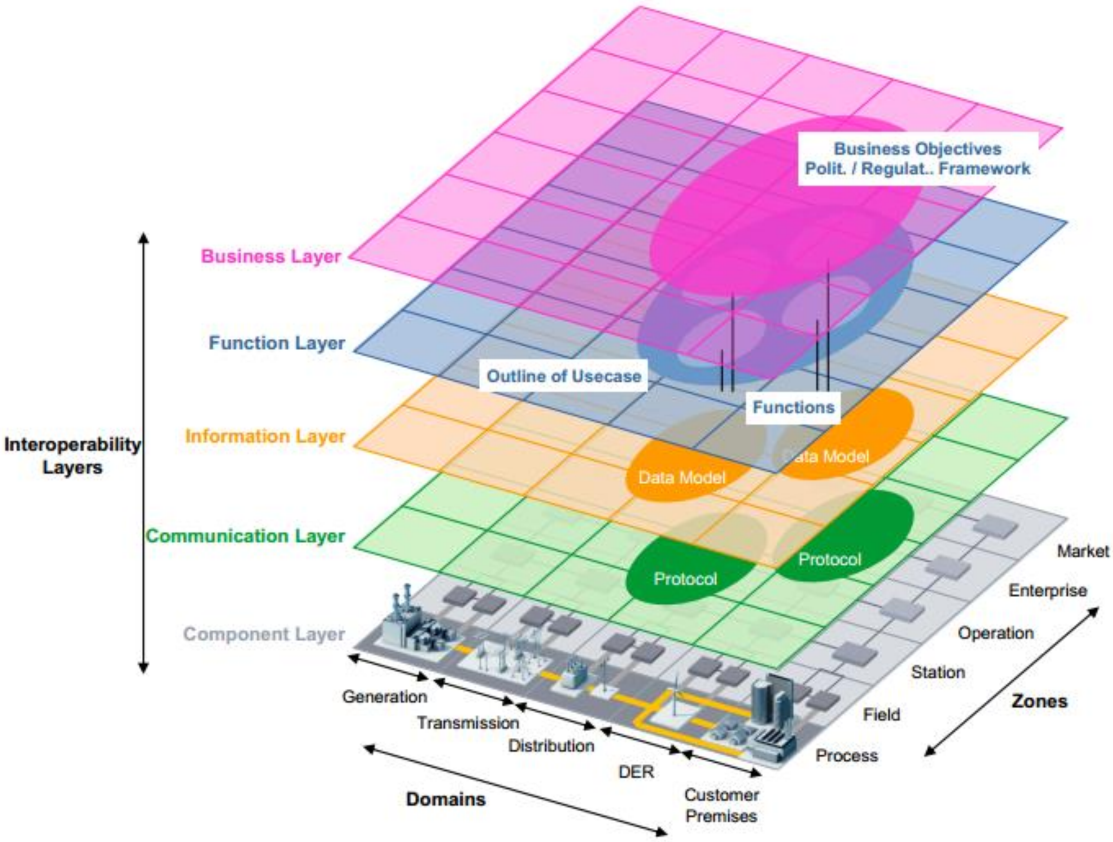


Figure 10: Smart Grid Architecture Model (CEN-CENELEC-ETSI, 2012).

3. Methodology

For the development of the conceptual model, the SGAM (see figure 10) is taken as reference model. The research focusses on the first three levels of the SGAM model: the business layer, the functional layer and the information layer. These layers are operationalised by respectively the literature review, use cases and the class model. See figure 11 for an overview of the SGAM reference layer, the applied method, instrument and software.

SGAM reference	Method	Technique	Software
Business layer	Literature review	-	-
Functional layer	Use cases	UML domain model	Enterprise Architect
Information layer	Conceptual class model	UML Class model	Enterprise Architect
	Implementation	GIS modelling	ArcGIS

Figure 11: Methodology

For modelling Enterprise Architect is used. Enterprise Architect is a product of Sparx Systems. Enterprise Architect supports most modelling methodologies. In this research the unified modelling language (UML) is used, because it the common used modelling methodology among in the market (Geonovum[5] and INSPIRE amongst others) and it includes the use case diagram.

ArcGIS is used, because it handles all above mentioned data formats: WMS, WFS, XML and GML. ArcGIS is a product of ESRI. ArcGIS is a geography platform which enables the user to create, share, and manage geographic data, maps, and analytical models using desktop and server applications (ESRI, 2014). For this research ArcGIS version 10 or higher is used. With ArcGIS geodata provided by WMS and WFS is easy to add to the model. Furthermore ArcGIS supports most common standards.

3.1 Approach to set up the use case

A use case describes an event or a series of events which contribute to a single goal, and who or what initiates those events (Miller, 2003). In this case facilitate information exchange in order to optimally balance energy and manage congestion. A use case does not focus on how the system does that. A use case consists of actors, scenarios and communication associations, visualised by respectively stick figures, ovals and lines. Basically, a use case is a collection of scenarios which all revolve around the same objective. An actor is someone or something whom or which triggers the scenario. They are generally expressed in roles. A scenario is description of a process which is triggered by an actor and generates output which contributes (or should contribute) to the objective. A use case can, and generally does, comprise of more than one scenario. Actors and scenarios are connected by communication associations (Miller, 2003). The communication associations in a use case are straightforward lines. Specific characteristics of the associations are assigned in a next step, in this case when the conceptual model is developed.

[5] Geonovum is the organisation which is governed by the Ministry of Infrastructure and Environment and is assigned the task to make public information accessible, develop standards for that purpose and to exploit public information better (Geonovum, 2014b).

The use case is chosen as starting point, because it urges to analyse the subject of modelling and it is an effective tool to determine the requirements (Miller, 2003). These requirements are necessary for validation: the conceptual model needs a baseline to compare its functionalities to.

3.2 Approach to develop and assess the conceptual model

A model is an abstract representation of a problem in the real world. A domain is the real world in which the problem occurs. Obviously there is not one single definition of the real world. It matters if one looks at the smart grid from a electro technical or telecommunication point of view (see figure 8). The SGAM model (figure 10) tries to comprise the complex world in three dimensions. However, as the SCADAs, EMS and GIS merge and as a wide area smart grid emerges, the challenge is to define the domains (Yan et al., 2013). To avoid a dissertation on defining domains, the aim is to adopt parts of existing models and enrich it with the specific needs for this research, i.e. geodata.

A conceptual model comprises of the components: classes; associations; inheritance relationships; composition associations; and vocabularies. Only the class name is given in the class and not the attributes and methods, like is done in case of a class diagram. Including attributes and methods would imply design decisions, which do not belong to a conceptual model. Therefore only the responsibilities are mentioned (Ambler, 2003). Including responsibilities is also a smooth proceeding after the use case. See table 1 for an overview of the components.

Component	Description
Classes	Classes are the 'blueprints' of objects. An object can be many things: an actor like used in the use case, a person, a device, an event, etc. Instance: one single object in a class is called an instance.
Responsibilities	The role or 'function' of the object.
Associations	Associations represent the relationship between instances of classes. Navigability: is the direction of the association. Multiplicity: is the number of possible instances of the class associated with one single instance at the other end of the association.
Inheritance relationships	Inheritance relationship implies similarities. It enables to reuse data of one class in another class. Composition: is a strong association in which the part can belong to only one whole – the part cannot exist without the whole. Generalisation: implies that one class is a sub class of, or superclass over another class. Example: if A inherits from B, than A is the subclass of B, while B is the superclass of A.
Composition associations	Composition associations mean that an object consists of other objects. Aggregation means that a class belongs to another class. Composition is the same as an aggregation, but in this case the object cannot exist without the whole. Example: a province cannot exist without a country.
Vocabularies	In vocabularies the semantics, taxonomies and ontologies of objects are defined. Semantics: the meaning of objects. Taxonomy: the hierarchy of objects. Ontology: the definition of the characteristics and relations of objects within a certain domain.

Table 1: Components of a conceptual model (Ambler, 2003; Miller, 2003)

Classes are the main components of an object-oriented modelling approach (Ambler, 2003). In this research the object-oriented approach is applied, first because it is common used in the sector: most existing data models follow the object-oriented approach. But second because it identifies domains and domains are considered to be ideal to address and structure the comprehensive context of the smart grid. The alternative would be the data-oriented approach. The differences are trivial at a higher level. Both approaches differ particularly on the level of system design, i.e. technical level (Kranenburg & Van Riel, 2007). An overview of both approaches in a three-tier architecture is given in table 2.

Tiers	Data-oriented approach	Object-oriented approach
Conceptual	Information	Business domains
Logical	Data-model	Object model
Physical	Database schema	Classes/database schema

Table 2: Comparison of data-oriented approach and object-oriented approach based on a three tier-architecture (Kranenburg & Van Riel, 2007).

Another architecture model in the field of information science is the Zachman framework. The Zachman framework is in line with the object-oriented approach and can be seen as an extension of the three-tier architecture. Zachman identifies six perspectives: the contextual, conceptual, logical, physical, data definition, and the enterprise functioning perspective (Fatolahi & Shams, 2006; Frankel et al., 2003). The relation between the Zachman framework, object-oriented modelling and UML and the applied data modelling method UML is given in figure 12.

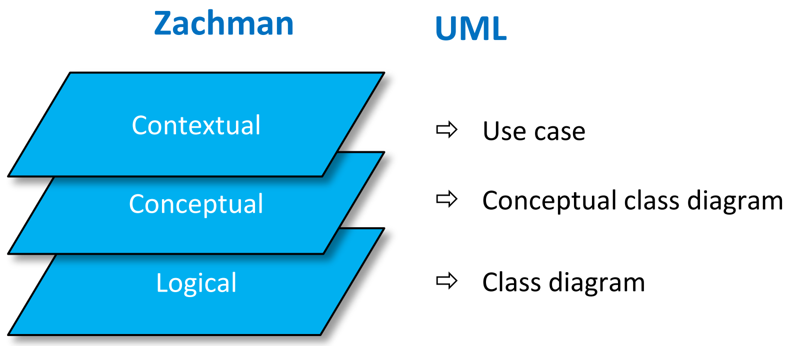


Figure 12: Relation between architecture perspectives and UML as applied in this research

The conceptual model is assessed by interviews with stakeholders both within Stedin as outside of Stedin. Stakeholders outside Eneco are other distribution grid managers like Liander and Enexis or their parent companies: respectively Alliander and Essent. TenneT is also invited to contribute to this research. TenneT is the transmission system operator (TSO) for the Netherlands. TenneT has mostly regulated activities and is charged with the objective to manage the transmission gird and to balance the energy across the grid (Pagani & Aiello, 2011; TenneT, 2014). Based on the interviews, the conceptual model will be further developed, and adjusted in case of flaws.

3.3 Approach to implement and validate the conceptual model

The conceptual model is implemented by setting up a SOA. Practically the conceptual class diagram is enhanced towards a class diagram. This model is implemented in ArcGIS. In ArcGIS open data layers are included by means of WMS and WFS.

The model is validated by simulating geodata exchange. Preferably with real data to maximise the data to be representative for the real world. Should that not be possible, than 'virtual' data is used. Virtual data can either be data from another area, or dummy data (i.e. of a non-existing actor or device). De results of the simulations are compared to the use case which is the baseline for the geodata exchange. The comparison is judged qualitatively.

4. Conceptual model

This chapter starts with the scope definition of the conceptual model. Next the definitions are elaborated on, followed by the description of the use cases. After that a domain-model is presented. The domain-model is made for better understanding, to bridge the role-models and to bridge the use cases and conceptual data model.

4.1 Scope of the conceptual model

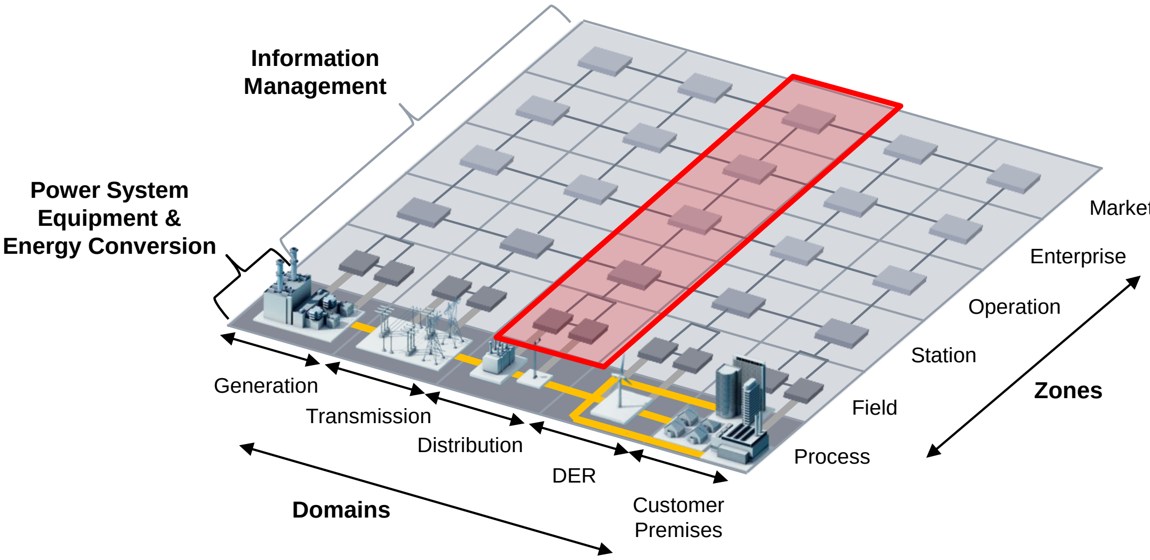


Figure 13: Research scope (red shaded area) projected on the domain and zone axes of the SGAM (figure taken from: (CEN-CENELEC-ETSI, 2014c))

Looking at the SGAM (see figure 10), the conceptual model focusses on the function and information layer. The function layer is defined in a use case (i.e. this chapter). The information layer is defined in a class diagram (i.e. chapter 5). The SGAM has two other axes: the domains and the zones. The conceptual model focusses on the distribution domain and its relations to the adjacent domains: transmission and parties connected to the grid (i.e. DER and customer premises of the SGAM). Energy balancing and congestion management thus the conceptual model comprises to a greater or lesser extent almost all zones. Only the process zone is discarded, because the conceptual model aims at describing the geodata exchange, not geodata processing. For example: the weather forecasts are based on data from weather stations. These values need to be extrapolated. This research does not address the most suitable extrapolation methods. See the red shaded area in figure 13 for the scope of the conceptual model on the level of the information level.

4.2 Definition of concepts, domains and roles

In the conceptual model, some concepts are used. These concepts are described in table 3.

Concept	Description
Actor	An actor represents a party that fulfils a certain role or group of roles.
Domain	A domain is a group of roles and actors.
Role	A role represents a responsibility of a party, an interaction with other roles with a certain goal. A role can only be fulfilled by one party

Table 3: Concepts as described by CEN-CENELEC-ETSI (CEN-CENELEC-ETSI, 2014b)

The actors are not considered in this research. This is where this research differs from the CERISE-SG use cases. CERISE-SG uses actors, like the KNMI, RDW and Kadaster. This research respectively uses the roles weather forecast, vehicle administrator and key-registers. Not only to make the model more flexible, i.e. more generic and thereby broader applicable, but also because data can be obtained from more than one source. The Kadaster for example disseminates key register data, but the source holder are the higher and lower levels of the government like municipalities. Furthermore the data can be obtained from different sources, for example both from the official websites www.nationaalgeoregister.nl and www.pdok.nl, which is better covered by using roles instead of actors. The relationship between domains, roles and actors is visualised in figure 14.

Figure 14: Relationship domains, roles and actors (CEN-CENELEC-ETSI, 2014b)

There is a large amount of consensus about the domains, subdomains and roles within the energy market (CEN-CENELEC-ETSI, 2014b; ENTSO-E, 2014a; NIST, 2014). From these reputable institutions the domains and roles are adopted which are used in this research. From this research perspective a domain is missing: the information services domain: the energy market uses generic and centralised, often open, data sources. For instance for topographic information, registers of energy devices like EVs and solar panels. See table 4 for the definition of domains.

Domain	Description	
Energy services	Description: Origin:	The energy services domain describes the provisioning of energy services to the grid users. The domain facilitates the trade of generated or stored electricity of the grid users (so after gate-closure) and thereby hosts the balancing mechanisms, i.e. flexibility management. From this domain energy is traded on the market CEN-CENELEC-ETSI (CEN-CENELEC-ETSI, 2014b)
Grid users	Description: Origin:	The grid users domain consists of all roles which generate, consume or store electricity. The domain comprises of all parties connected to the grid: prosumers, business and also bulk generation. CEN-CENELEC-ETSI (CEN-CENELEC-ETSI, 2014b)
Information services	Description: Origin:	The Information Services domain provides information services to all roles within the smart grid.. -
Markets	Description: Origin:	Within the market domain energy is traded. CEN-CENELEC-ETSI (CEN-CENELEC-ETSI, 2014b).
Operations	Description: Origin:	The operations domain focusses on the stable and safe operations of the power grid CEN-CENELEC-ETSI (CEN-CENELEC-ETSI, 2014b).

Table 4: Definition of domains

The CEN-CENELEC-ETSI adopts the roles as defined in the harmonised electricity market role model by the ENTSO-E. Roles can be bundled. The ENTSO-E role model is embraced as starting point, but some roles are bundled to make the model more condensed and easier to read. The DSO for example is a bundled role comprising for example of the grid manager and meter data collector roles (CEN-CENELEC-ETSI, 2014b). The roles used in this research are described in table 5.

Role	Description
Aggregator	Description: A bundled role, in which roles are bundled from different (sub)domains, solely focussing on information gathering. Origin: -
Bulk Generator	Description: Represents the bulk power generation role: the power plant. Origin: ENTSO-E
CEMS	Description: Community Energy Management System, also refered to as the grid users or party connected to the grid. These can be single actors, like HEMS, BEMS and FEMS, or a group of actors like a microgrid. Looking at the CIM, this object also bundles the network point and transfer point. Origin: ENTSO-E bundled role
DSO	Description: The distribution system operator. It is a bundle of system and grid operation roles in the distribution grid. Origin: ENTSO-E bundled role
Energy Market	Description: Market where energy trade takes place: the place where demand and supply of energy meet. Origin: ENTSO-E
Energy Trade	Description: Role that trades the energy. In the Netherlands the APX is the energy trade market. Origin: ENTSO-E
Flexibility Market	Description: Market where imbalance is traded. Origin: ENTSO-E
Flexibility Trade / Balancing responsibilities	Description: Trading role in order to level consumption and production of energy and thus pursuing energy balance. Origin: ENTSO-E
Grid Capacity Market	Description: Market where capacity is traded with the aim to prevent or resolve congestion. Origin: ENTSO-E
Grid Capacity Trade	Description: Trades the grid capacity. Origin: ENTSO-E
Key DER Registers	Description: Centrally maintained registers. Relevant key DER Registers are: 1. PIR; 2. C-AR; 3. Vehicle administrator: information about EVs. Where EVs are registered. Origin: -
Meter Operations	Description: The role concerned with managing the meters of the grid users. Origin: ENTSO-E
Public Open Data	Description: Referred to by Kadaster by CERISE-SG (Verhoosel et al., 2014), but the data is offered via other channels too, like the websites www.nationaalgeoregister.nl and www.pdok.nl. Some key DER Registers are: 1. BAG (addresses and buildings); 2. BRK (cadastral information); 3. BRT (topography); 4. BGT (great scale topography). Origin: -
TSO	Description: The transmission system operator. It is a bundle of system and grid operation roles in the transport grid. In the Netherlands the role is fulfilled by TenneT. Origin: ENTSO-E bundled role
Weather Forecast	Description: Referred to as KNMI by CERISE-SG (Verhoosel et al., 2014), but weather forecasts can be obtained by other parties also, for instance the MeteoGroup. Weather data relevant to the smart grid: 1. Temperature; 2. Sun power; 3. Wind force; 4. Precipitation. Origin: -

Table 5: Role definitions

The aggregator

One specific role is added: the aggregator. There are many viewpoints on what an aggregator is or can be and in which domain it should be positioned. It is a new role emerging in the new playing field emerging from the energy transition the Netherlands is going through. In this research it is an abstract role and separate domain. It is placed outside the other domains, because this research is not aiming to interpret the position in the market. The aim of the research is to identify the data exchange. The aggregator role has not been assigned specific characteristics and no presumptions are done of an actor fulfilling the role. It can encompass several existing roles of the ENTSO-E role model. Example amongst others (see figure 2 in paragraph 2.2):

- The market information aggregator role in the energy market subdomain;
- The balancing responsible party in the flexibility trade/balancing responsibilities subdomain;
- The capacity trader in the grid capacity trade subdomain;
- The metered data aggregator in the metering operations subdomain .

Thus, the aggregator is considered a bundled role on a conceptual level in which roles are bundled from different (sub)domains. This is the reason that the aggregator role is placed in the centre of the conceptual role model and is also placed outside the domains, see paragraph 4.4. This research focusses solely on the information gathering function of the aggregator role. Therefore the aggregator is always placed in between the interactions of the operations and energy services domain.

4.3 Use cases

The use cases are based on the use cases as defined by CERISE-SG (Verhoosel et al., 2013; Verhoosel et al., 2014) and the use case repository of the CEN-CENELEC-ETSI[6]. The latter is a repository with use cases in progress. The use cases of the short term planning processes (day-ahead) and the real time planning processes (intra-day) are described in respectively table 6 and 7.

Short term planning processes (day-ahead)	Taken from
On a day-ahead energy market supply and demand is traded. Price is determined based on supply-demand. At gate-closure the supply and demand is ‘fixed’. The supply and demand and it’s price, are both time and location dependent. The energy trade provides the contracted volumes of energy, while the aggregator can provide the energy trade subdomain with information about the actuals and the contracted volume of energy and thereby facilitate the trade. Interaction: Energy trade ⇔ Aggregator	CERISE-SG & CEN-CENELEC-ETSI
After gate-closure, the aggregator offers congestion information to the grid capacity trade role in order to manage congestion and thereby mitigate overcharging the grid. Congestion has an explicit spatial temporal component. Interaction: Grid capacity trade ⇔ Aggregator	CERISE-SG edited
Information services supports the roles in the other domains by providing information: - Key Registers on DERs, like the CAR, PIR among others, provide the aggregator insight in local supply and demand capacity. These key DER registers need to be related to the CEMS for insight. These key registers are not freely available for all roles; - Weather forecast information enables the aggregator and the parties in the operations domain to predict imbalance by comparing contracted supply and demand to the local supply and demand capacity. This can be done on different timescales. On a day ahead energy market all parties involved can include the information in their biddings. And (near) real time the system operators, aggregator and flexibility trade / balancing responsibilities can take the local weather forecasts in account when trading to manage flexibility; - For each local phenomenon, a spatial reference eases to visualise and understand it. For instance by adding a geographic or topologic layer.	CERISE-SG edited & CEN-CENELEC-ETSI (WGSP-2112)

[6] https://usecases.dke.de/sandbox/editor/

Interaction: Information Services ⇨ Operations domain Interaction: Information Services ⇨ Energy services domain Interaction: Information Services ⇨ Markets domain Interaction: Information Services ⇨ Aggregator	
The smart grid offers improved or even new possibilities to monitor the balance within the energy grid. As more and decentralised information of the CEMSs can be related to the information services, and as the SCADA systems of the system operators become more advanced (i.e. able to manage voltage levels at a more decentralised level), the energy balance within the grid can be managed better. Interaction: System Operator ⇨ Aggregator	CEN-CENELEC-ETSI (WGSP-0600)

Table 6: Short term planning processes (day-ahead)

Real time planning processes (intra-day)	Reference
The actual sum of consumption and production of the CEMS are measured at the smart grid connection point (SGCP). The SGCP is the interface, the location where the CEMS is connected to the grid (CEN-CENELEC-ETSI, 2014c). In the Netherlands this connection point has an administrative unique identifier: the eighteen digit EAN-code. Interaction: CEMS ⇨ Aggregator	CERISE-SG
In order to balance the energy or manage congestion, the CEMSs can shift energy consumption, either in time or amount. It requires bidirectional information: at one hand the need for flexibility desired by a system operator on a certain location at a certain time(frame). CEMSs can be tempted by incentives (i.e. price offerings) to supply energy to the grid or to restrain the energy consumption. Interaction: CEMS ⬄ Aggregator	CERISE-SG & CEN-CENELEC-ETSI (WGSP 2128).
Mostly the consumption can be directed, but also the availability of energy can be directed to some extent. Not likely the production, because the DERs depend on weather circumstances, which are not within one's influence. However, the energy storage can be invoked. For instance, when connected to the grid, the remaining energy of EVs can be used to mitigate the energy peak at dinnertime. It requires insight in the locations (of owners) of Evs. Interaction: Flexibility trade/balancing responsibilities ⬄ Aggregator	CERISE-SG & CEN-CENELEC-ETSI (WGSP 2128).
The TSO/DSO manage load in order to manage congestion and prevent outages. This requires local information about energy supply (capacity) and consumption. Congestion can be managed by lowering consumption (time and/or load shift) or by invoking local energy storage. Interaction: TSO/DSO ⇨ Aggregator	CEN-CENELEC-ETSI (WGSP-0901)

Table 7: Real time planning processes (intra-day)

The above described use cases are visualised in a use case diagram in figure 15. The information services supports all actors and is excluded from the use case diagram to enhance readability.

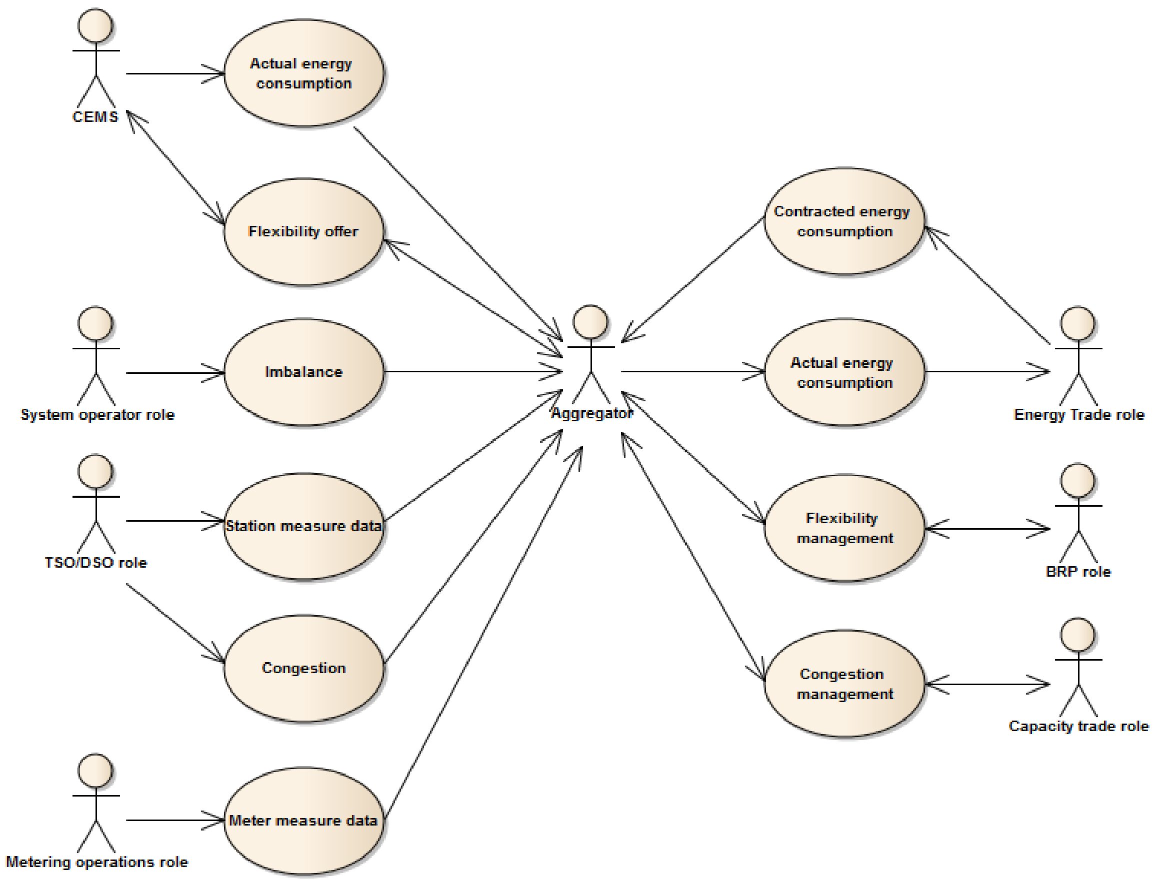


Figure 15: Use case diagram for energy balancing and congestion management

4.4 Conceptual role model

The use cases are included in the ENTSO-E role model, see figure 16. The conceptual role model emerging visualises the interactions.

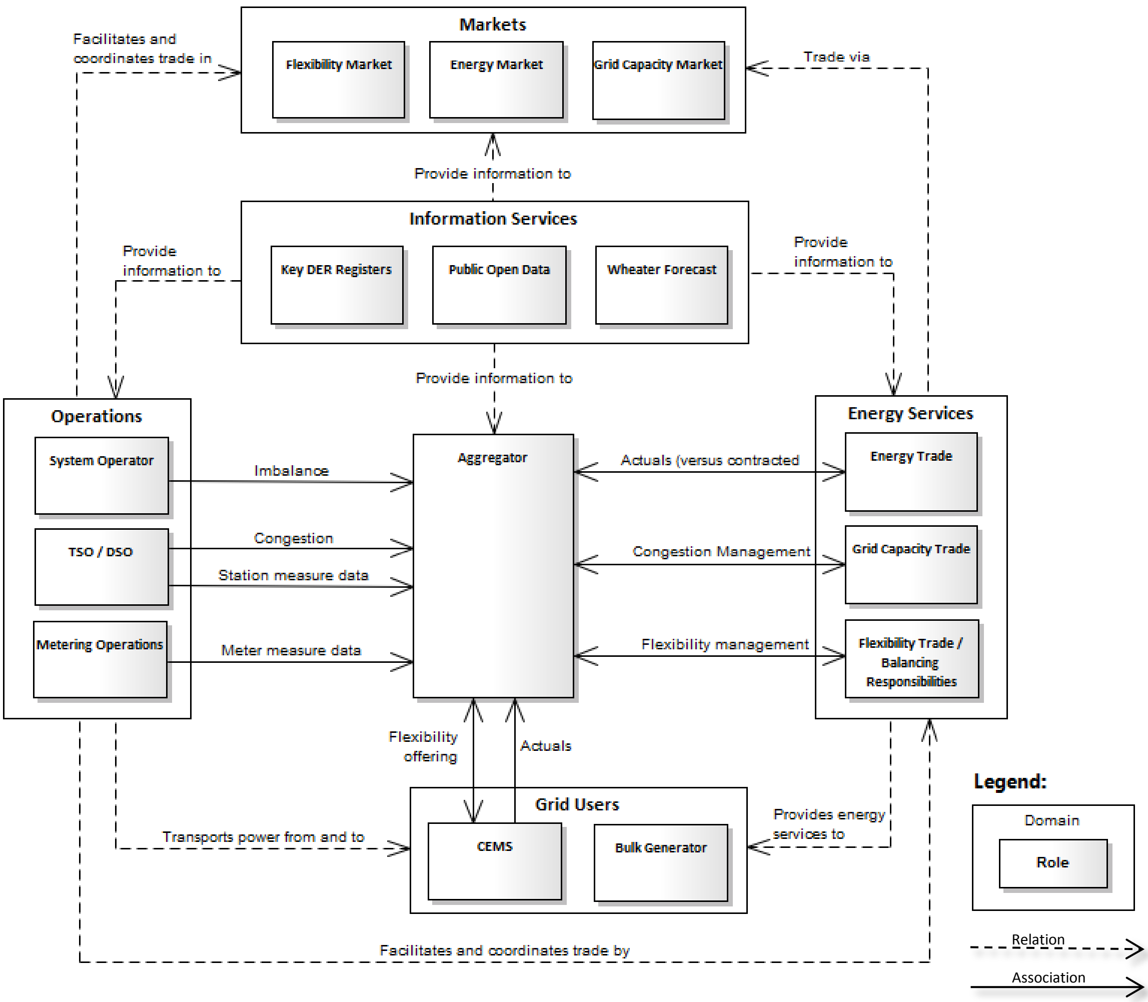


Figure 16: Conceptual UML domain-role model

4.5 Conceptual class model

The conceptual role model describes the interactions within the smart grid with regard to energy balancing and congestion management. The conceptual model is translated into a conceptual class model to identify the specific geodata required in each interaction, see figure 17. Basically three translations are able:

1. An abstract information class model in which data is modelled as objects;
2. An abstract network model in which the conceptual role model is translated to a network model with nodes and vertices; or
3. A functional class model with a clear reference to the physical world.

The first option would be appropriate if the focus would be on the telecommunication aspects of the energy balancing and congestion management within the smart grid. However, it would miss the reference to the physical world. Energy balancing and congestion management have a crisp and clear relation with the electro technical characteristics of the physical grid. The second and third option have that reference to the physical grid and are therefore preferred.

The second option would be to translate the energy balancing and congestion management use cases into a more abstract network model in which objects are either nodes or vertices. The network model is considered to be appropriate for orthogonal representations and network analysis purposes. The first, the orthogonal representation, applies to this research. The latter however, the network analysis or processing, is not in scope of this research.

The third option is chosen as viewpoint for the conceptual class model. A functional class model has a clear reference to the physical world. It serves the purpose of recognition. Moreover it does leave room to extend it with a network model, like is done in case of the information model cables and pipes (IMKL) of the Kadaster (Geonovum, 2015). Furthermore the functional class model with reference to the physical world is commonly used in national standards, like the BAG and IMKL (Geonovum, 2015; Kadaster, 2013a).

The conceptual data model is adopting objects and parts of models of three major other and common data models:

1. The information model smart grid, energy balancing information facility (IMSG-EBIF) of CERISE-SG (Quak & Janssen, 2014);
2. The information model cables and pipes (IMKL) of the Kadaster. The IMKL adopts objects and their definitions of Inspire (Geonovum, 2015); and
3. The simple feature types of geometry of the ISO/OGC (OGC, 2011).

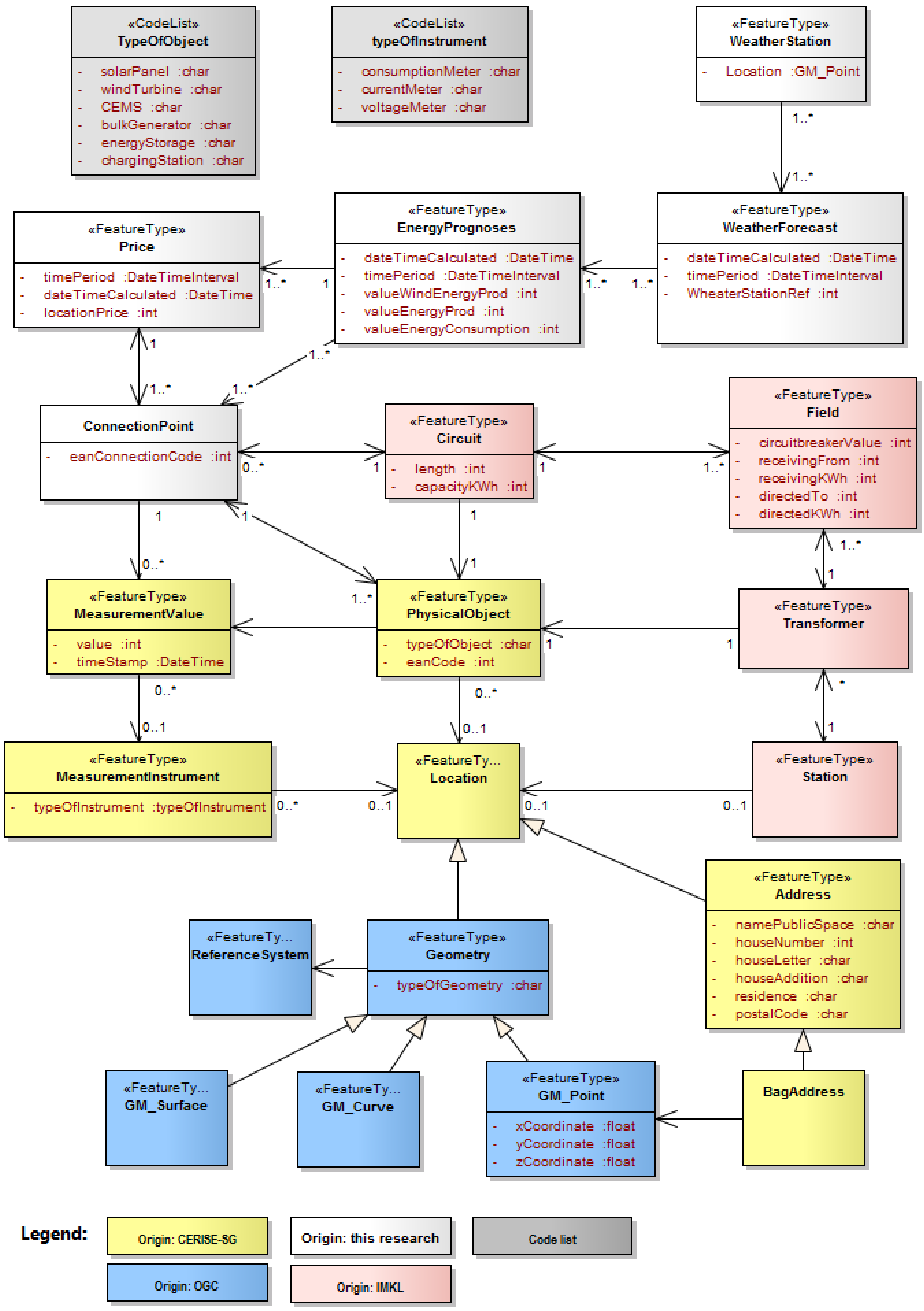


Figure 17: Conceptual UML class model

4.6 Description of the classes

Class	Description	
Address	Definition: Description: Origin:	the location of an object expressed by an address. In the Netherlands the BAG is used as standard for expressing an address. Not all databases are yet in accordance with the BAG. Therefor addresses and BAG addresses cannot be yet equated. BAG
BAG address	Definition: Description: Origin:	the standardised addresses in the Netherlands Databases do not yet contain the standardised BAG addresses. As a result most addresses need geo-referencing processes to bring address in line with the BAG. IMSG-EBIF
Circuit	Definition: Description: Origin:	the circuit is the collection of interconnected cable segments between two transformers the circuit consists of a chain of cable segments. Each segments has its own capacity. The capacity of the circuit is determined by its weakest cable segment. -
Connection Point	Definition: Description: Origin:	the point at which a CEMS is connected to the (smart) grid. The unique identifier of the connection point is the 18 digit EAN-code. In CEN-CENELEC-ETSI it is referred to as the smart grid connection point (SGCP). IMSG-EBIF recognises three objects: the information point, the transfer point and the network point. In this research these three are aggregated to the connection point. Opposite to the IMSG-EBIF the connection point is not considered a physical object, as the connection point an administrative identifier, a functional object. IMSG-EBIF, CEN-CENELEC-ETSI
Energy prognoses	Definition: Description: Origin:	forecast of generation of energy the temperature determines the energy consumption, whereas the sun power, wind force and precipitation determines energy generated by solar panels and wind turbines. It is assumed that from a weather forecast, only one energy prognoses is determined (instead of scenario planning). -
Field	Definition: Description: Origin:	the field is an object of a transformer which powers or receives from a circuit(s). a transformer in the transmission grid consists of two or more fields. More than one field can power a circuit. The capacity of the field is determined by the value of the circuit breaker. The value of the circuit breaker is lower than the capacity of the weakest cable segment of the circuit. -
Geometry	Definition: Description: Origin:	a shape with a relative position to the Earth. A geometry is associated with a spatial reference system to define the relative position to the Earth. A relative position can be expressed as a point, curve or as a surface. The representation of the relative position can depend on scale and functional application. ISO/OGC.
GM_Curve	Definition: Description: Origin:	topological one-dimensional geometry which represents a line the circuits are expressed as lines. ISO/OGC.
GM_Point	Definition: Description: Origin:	topological zero-dimensional geometry which represents a position a point object is expressed by an x and y coordinate. ISO/OGC.
GM_Surface	Definition: Description: Origin:	topological two-dimensional geometry which represents a region of a plane some objects might be geographically represented as a plane at a large scale, but in a orthogonal representation as a point object. ISO/OGC.
Location	Definition: Description: Origin:	the physical presence of an object in the real world. the physical presence of an object in the real world can be expressed as an address and/or as a geometry. IMSG-EBIF, CERISE-SG
Measurement instrument	Definition: Description: Origin:	instrument which measures the values. measurement instrument has an unique 13 digit EAN-code, which is an unique object identifier. The characteristics of the measurement instrument are recorded at this object. IMSG-EBIF, CERISE-SG

Class	Description	
Measurement value	Definition:	value of a measurement of a certain instrument measuring the production or consumption of an object which is associated with the EAN-code of the connection.
	Description:	the physical objects with their eighteen digit EAN-code are associated with the 18 digit EAN-code of the connection.
	Origin:	IMSG-EBIF, CERISE-SG
Physical object	Definition:	tangible object which produces or consumes energy.
	Description:	the physical objects are 'behind' the connection point, as the grid objects like the circuit, circuit breaker, transformer and the station do not produce or consume energy, they just transport it.
	Origin:	IMSG-EBIF, CERISE-SG
Price	Definition:	the price of energy at a certain location, determined at a certain time and applicable for a certain time period.
	Description:	the price is applicable at a certain area, which is expressed connection point. By expressing the area as a collection of EAN-codes, the area is fully flexible. It can be determined by either the geographical area or the orthogonal location: the location of an object relative to other objects.
	Origin:	-
Reference system	Definition:	the spatial reference system a geometry is associated with
	Description:	A geometry is associated with a spatial reference system to define the relative position to the Earth. In the Netherlands the RD-coordinates ('Rijksdriehoekstelsel') is the standard spatial reference system.
	Origin:	OGC
Station	Definition:	the physical object in which the transformer and the fields are located
	Description:	the transformer and the fields heritage their location from the station they are in.
	Origin:	-
Transformer	Definition:	the object that transforms the power between circuits
	Description:	the transformer transforms power levels between circuits.
	Origin:	-
Weather forecast	Definition:	prognoses of weather circumstances temperature, sun power, wind force and precipitation.
	Description:	the weather forecasts
	Origin:	HiRLAM
Weather station	Definition:	the weather station in which the weather is forecasted.
	Description:	the Netherlands has 27 weather stations. At each weather station on predefined moment in time the weather is forecasted.
	Origin:	-

Table 8: Description of classes

4.7 Assessment of the conceptual role model and the conceptual class model

The conceptual role model and the conceptual class model are assessed by interviewing stakeholders. Not only within Stedin, but also outside Stedin. See appendix 5 for an overview of interviews conducted. The assessment focussed on both the role model as on the conceptual class model. During the interviews it became clear that some basic knowledge about the operation of the grid is essential for the proper setup of the conceptual class model. For this purpose some extra interviews were conducted at the end of April 2015.

This assessment paragraph is a retrospective: the results of the assessment are already included in the conceptual role model and conceptual class model. The assessment of the conceptual models consider an assessment preliminary to the implementation of the model (see chapter 5).

Philosophy behind the model

As described in paragraph 1.5, in outline this research distinguishes three steps:

1. Identify players in the smart grid;
2. Determine interaction between players in the smart grid; and
3. Define the geodata used in the interaction.

This research does not address the specific applications of geodata, it describes the information exchange, which means that processing (see paragraph 4.1) is discarded. However, the model should not restrict but enable decentralised and distributed applications (Dietvorst March 2015). The model supports the premise of a wide area GIS.

Relationship between energy balancing and congestion management

Although energy balancing and congestion are two different processes, there is a close relation between the two. Congestion management uses to a great extend the same means as used for energy balancing. Energy balancing is about the levelling of supply and demand, while congestion is about transmission demand or supply exceeding the grid capacity. The grid capacity is the physical limit of the grid to transport or distribute energy. The relations in short (Broekmans, April 2015; Knook & Cornelissen, March 2015; Mathijssen, April 2015; Polak, March 2015):

1. When solving congestion by lowering demand, imbalance can be caused;
2. When solving imbalance by transporting energy, the grid manager is bounded by the grid (transport) capacity. It might be required to generate or invoke stored energy locally;
3. The transport distance causes energy losses. So for efficiency reasons, not because of congestion, local energy generation might be preferred over transportation. Thus, energy trade can also be the mean to manage congestion.

These examples might currently be exceptional, but will occur more frequent with the evolution towards a smart grid and DERs. Initially the model and even the scope of the research focussed solely on energy balancing. As energy balancing and congestion management are so closely related, congestion management has been included in the research. In the model the maximum capacity of objects in the grid is added, like the value of the weakest cable segment and the value of the circuit breaker.

Congestion management is a continuous process in which the load on the circuits and transformers is constantly calculated in scenario's. Continuous scenario planning implies that it is done before and after gate-closure, i.e. respectively day-ahead and intra-day. The TSO in the Netherlands, TenneT, expresses the load as a percentage of the capacity: in case of congestion, the load exceeds 100% (Mathijssen, April 2015).

Distinction between physical and administrative balancing

From the aforementioned relation between energy balancing and congestion management, it is clear that the model is travelling on a fine line between physical and administrative balancing. As the price of energy can be very low (near nil) and the costs to set up a local energy trade market can be high, the flexibility trade might not be lucrative. As a result, it might not be interesting to establish a trade market for local balancing (Dietvorst, March 2015; Knook & Cornelissen, March 2015). The physical and administrative energy balancing needs to be disengaged in the model. The physical balancing might not be left to a trade market (Dietvorst, March 2015).

The model encompasses objects which represent the physical grid. It is decided not to model information objects at an abstract level. This is decided for purpose of recognisability and to connect to existing models like the IMKL. Furthermore the information exchange, the attributes, do not solely focus on trade, but also on the physical characteristics of the power grid. Eventually the physical characteristics determine the value of energy from the DSOs perspective: when balancing energy or managing congestion, the consumer delivers a service and becomes a prosumer: a consumer is no longer only consumer of energy, but also supplier.

Positioning of the DSO and determining the level of grid control

In practise the bandwidth of balance is so small, that there is a constant imbalance and thus a continuous market for offering (over)capacity or offering to lower or shift energy consumption to the TSO. Parties can offer their (over)capacity or lowering of energy consumption on the TSO

(Mathijssen, April 2015; Polak, March 2015). The TSO is the balancing responsible party for the transport grid and has the responsibility to assure continuity: a safe and guaranteed supply of energy. This means that when congestion threatens to occur, the TSO is allowed or even obliged to overrule all other parties within the power grid to assure the safety and continuity of energy supply.

Every party connected to the grid is a balancing responsible party. This right is transferred automatically to the energy provider in case of prosumers. There is also a transmission right, this is the right to close an energy connection to the grid. This right can be obtained by any party in the energy market, thus including the DSO. However, the DSO has not got the means to exercise that right (Mathijssen, April 2015). For the DSO energy balancing is a new phenomenon. Opposite to the TSO, the DSO has to balance energy on a local level and it has to develop means for it.

In a substation the transport voltage is transformed into a distribution voltage. In this medium voltage grid measurements take place (Broekmans, April 2015; Knook & Cornelissen, March 2015). Besides the end users connection points, no measurements take place in the low voltage grid. It is costly to equip low voltage cabinets with measurement instruments, especially since the revenues are doubtful: relatively few connection points are involved. The value of the investments in smartening the grid, are likely to exceed the potential savings on imbalance and congestion (Dietvorst, March 2015; Knook & Cornelissen, March 2015). So from both the energy balancing perspective as from the congestion management perspective the grid managers are facing high risk investments decisions.

The challenge is to determine the breakeven point where the investments to smarten the grid are lower than the costs associated with the enhancement of the grid. Estimates differ, but for the change towards a smart grid seems to be a business case when 20 to 30% of the electricity is generated with DERs (Knook & Cornelissen, March 2015). In order to make the right decision, the challenge is to foretell the technological future. The developments on energy storage will have a mitigating effect on the need for enhancement of the grid, i.e. for investments in technologies to cope with peaks (Knook & Cornelissen, March 2015; Mathijssen, April 2015).

Thus, when smartening the grid, it is recommendable to work from the top down: first create a smart medium voltage grid, before considering the smartening of the low voltage grid. The scope of the implementation of the model in this research will therefore be the medium voltage grid.

Reliability of data of key registers

The DERs are known, since the prosumer is obliged to notify the installation of the DER. But be aware: only the initial installation is properly registered. The first wave of replacements has begun and new placements are not registered accurately. Often the enhancement of the grid or higher efficiency as a result of technical improvement are unknown (Knook & Cornelissen 2015).

This data quality of key registers has implications on the reliability of the outcomes of the model, not so much on the correctness of the model itself. Individually the DERs capacity might not have a big influence on the delivery of energy back to the grid, but as the sum of parts it can have a significant influence on the balance or congestion.

Timescale

Technically the grid is managed near real time. The SCADA systems use measurement values within minutes. The data needs to be processed, so the information from it is gained with some delay. For operational purposes quarter hour values are used. This is sufficient, because the deviations within that time periods are limited. The actuals are used for a rolling forecast and the deltas are balanced on the market (Polak, March 2015). Imbalance up to 15 minutes is managed by control capacity of other system operators, while imbalance from 15 minutes is solved by reserve capacity (Mathijssen, April 2015). Both are traded on the balance-delta market.

Objects do not only have a spatial dimension, but also a temporal dimension (Huisman & By, 2009). Two temporal attributes are distinguished in the objects weather forecast, energy prognoses and price: the time stamp of the moment on which data is obtained and a time interval to which an observation applies. In order to be able to compare the data, the timestamp of measurements need to be comparable.

Identifying objects in the grid by EAN-codes

Since August 2013 consumers have only one connection point to the grid, as a result of a legislation known as ‘Upstream’ (‘Stroomopwaarts’ in Dutch). This connection point is an administrative unique eighteen digit EAN code. EAN stands for European article numbering. For each EAN is known if other EANs, like solar panels, are connected to it (Knook & Cornelissen, March 2015). Beware that there are two types of EAN codes: besides a eighteen digit article code for products, the Dutch energy sector has its application of EAN-codes. All objects in the power grid are assigned unique eighteen digit EAN-code, so not only the connection point, but also the transformer, a circuit and the measurement instruments in the grid: current meters (ampere), voltage (volt) meters and consumption meters. Not only the physical objects, but also the market roles are assigned a EAN-code. However, in case of market roles the EAN-codes consist of thirteen digits (Polak, March 2015; Stufkens, May 2015).

In the conceptual data model the code list of the type of measurement instrument is based on this distinction of the before mentioned types of meters. Furthermore a distinction is made between the two EAN-codes. The eighteen digit EAN-code of the connection is an attribute of the connection point and other objects in the power grid.

Defining scope of EAN-codes affected by imbalance or congestion

An imbalance or congestion area is the collection of EAN-codes affected. The imbalance or congestion is not further limited to grid components. In other words: it is not reported on either a transformer, or a circuit, or otherwise. An imbalance and congestion area can be expressed on the level of virtually any object, that is up to the grid manager. This is also how the universal smart grids energy framework (USEF) handles imbalance and congestion areas (Broekmans, April 2015; Mathijssen, April 2015). From the viewpoint of USEF, a congestion area is a collection of connection points associated with a congestion point and vice versa. A congestion point is a location in the power grid where congestion can occur. In practise this congestion point is often a transformer. For each congestion point also the DSO is known and for each connection point the aggregator is known. Connection points without aggregator are neglected. The DSO can do a flexibility request and the concerning aggregators can meet the request with a flexibility offer. In the system of USEF the aggregator knows for which congestion points they can offer flexibility, while the DSO knows how many connection points an aggregator represents, but not which ones (Broekmans, April 2015).

The model should not direct or limit the level and objects on which congestion is registered. The model needs to be flexible and support any collection of EAN-codes involved in an imbalance or congestion. The determination of EAN-codes affected should be captured in services to keep the model robust. Therefore the affected ‘area’ is not included in the model itself. By including it in services, it also stays dynamic: the definition of ‘local’ can be different. The impact in terms of location of imbalance of congestion in case one affected circuit is smaller than in case of an affected transformer. The latter implies that more circuits are affected.

Mobility of objects and actors

When modelling local energy balance, the model assumes the fixed location of the energy consumption, generation and storage. In practise the consumer or even the physical object, for instance an EV, is not bound to one location (Dietvorst, March 2015). However, the EV eventually can only connect to the grid via a charging station. This location is fixed, the EV using it is not.

The natural or legal persons are discarded from this model, as they are irrelevant for energy balancing and congestion management. Eventually any energy generating or consuming object needs to connect to the grid at a fixed location. The code list van the type of physical object is extended with the attribute charging station.

The mobility of actors and objects like an EV has impact on the predictability of the consumption or the invoking of energy. Data analysis could enhance the predictability, but this is neglected as data processing is out of scope.

Positioning of weather forecasts

In the energy trade role within the energy services domain in the conceptual role model, see figure 15, weather forecasts are already taken into account. These weather forecasts are used for the technical balancing of the grid (Knook & Cornelissen, March 2015).

Since the weather forecasts are used for broader purposes and the weather data will be provided as open data in the Netherlands from July 1st of 2015, the weather forecast role is explicated in the information services domain. More in general the information services domain is related to the other domains, since the information services can support any domain.

Exclusion of the development plans

The grid development plans are less relevant for energy balancing and congestion management. The grid might need to be enhanced to ensure sufficient capacity, but balancing and congestion management is primarily about short and medium term processes (i.e. < 1 year). Moreover grid development plans appeal to other procedures, like license management and engineering (Knook & Cornelissen, March2015).

The grid development plans role is not included in the model, as the relationship is indirect.

Basic principles of the physical configuration of the grid

Some basic understanding of the physical configuration of the grid is required to model it.

A power station is only a building or can even be considered as a functional object. A station generally contains several transformers. A transformer, in turn, has several fields: incoming fields and outgoing fields which power a certain circuit. A circuit can be powered by more than one field. The circuit is not a single cable, but a string of cable segments, cabinets and sockets. In a medium voltage orthogonal circuit diagram the cable segment with the lowest capacity is reported on the circuit diagram as the capacity of the circuit. Each field is equipped with a circuit breaker to prevent the circuit from overcharging (Broekmans, April 2015; Minnaar, April 2015). As the circuit is not only powered by a transformer, but also locally by DERs, the circuit breaker is not a sufficient precautionary measure in the future. That is to say: it is probably a sufficient precautionary measure to prevent a station to blackout, but not for the concerning circuit.

The low voltage grid is meshed: a connection point is not always powered by only one station. Therefore it is hard to balance energy. This physical grid configuration is altered, it is desired that a connection is only powered by only one transformer. The physical grid configuration is subject of changes as a result of the energy transition (Minnaar, April 2015).

A distinction is required between the maximum capacity of the circuit and the maximum power of the supplying field. The maximum capacity of the circuit is determined by the weakest link, i.e. line segment, while the maximum power of the supplying field is determined by the concerning circuit breaker. Both are added to the model.

5. Implementation of the conceptual model

The model of chapter 4 is validated by implementing it: the model is setup to simulate geodata exchange. This chapter starts with the decisions and assumptions that have been made in advance, see paragraph 5.1. The subsequent paragraph 5.2 describes the data used. Finally the model is validated by simulating the (geo)data exchange.

5.1 Decisions and assumptions

The first decision to take, is which pilot area is taken into account. The following criteria are applied:

1. The aim is to limit the size for performance reasons, i.e. to prevent big data issues;
2. To avoid boundary issues, for instance with regard to the weather forecasts, the pilot area should be in the middle of the Netherlands;
3. The grid in the pilot area should be of the highest available data quality.

Based on these criteria, the city of IJsselstein is chosen. Stedin is improving the data quality and functionalities of its distribution management system (DMS). The data quality of the city of IJsselstein has recently been improved, namely the first quarter of 2015.

Next it is determined which part of the power grid is in scope of the implementation: generally the grid is divided in a high, medium and low voltage grid. In the Netherlands the high voltage concerns all power grids above 23 kV, the medium voltage power grids concern 3 up to 23 kilovolt (kV) and the low voltage power grid concerns power grids below 3 kV (in practise in the Netherlands often the 0,4 kV power grid). From the previous chapter it is concluded that the smartening of the grid should be done top down. So after the transport grid, the medium voltage distribution grid should be smarted. This choice has another advantage: it bypasses physical grid configuration challenges: the low voltage grid being meshed. It is assumed that the medium voltage grid is not meshed.

The aim of the implementation is to simulate (geo)data exchange, not to simulate energy balancing and congestion management. Therefore the implementation focusses on the characteristics of data, not on actual data from the real world. Moreover, access to actual data is restricted for privacy reasons and for reasons of public order and safety:

- For privacy reasons dummy data is used in case of consumption and production data;
- For privacy reasons locational data of connection points (customers) is aggregated; and
- For reasons of public order and safety the grid data is confidentially provided.

Therefore the visualisations of the data for the purpose of validation (paragraph 5.3) are provided in an addendum which is not publically accessible. The addendum contains confidential information and is provided only to the supervisors and examination board for examination and accreditation purposes.

The data used for the implementation concerns data of different moments in time. As a result the implementation concerns a virtual moment in time.

5.2 Data

For the implementation of the model, several datasets are combined:

1. Grid data: connection points, circuits, fields, transformers and stations;
2. Energy consumption and generation;
3. Key DER registers: PIR;
4. Public open data: geographic referential data like topography, key-register addresses; and
5. Weather forecast: HiRLAM.

The datasets are plotted on the conceptual class model (figure 17): the visualisation is included in appendix 6. The location data is often part of all datasets to some extent, mostly the address in accordance with the BAG, to be able to relate it to the geometry.

5.2.1 Grid data

Both topological and geographical grid data are required to implement the model. From the DMS system the topological data is obtained. The source for geographical data is the GIS.

The data from the DMS and GIS is already georeferenced and in accordance with the BAG and the geometries are in accordance with the Dutch standard reference system: RD-coordinates[7].

For privacy reasons the data is anonymised: natural and legal persons associated with an object are not provided. Therefore the data is aggregated on the level of a circuit

The dataset from the DMS contains all the connection points of the catchment area of the city of IJsselstein. Therefore the C-AR, in the model considered as information service, is already part of the dataset from the DMS. The eighteen digit EAN-code of the connection point is chosen as the primary key as it is the smallest entity in the grid. In table 9 the data from the DMS is described.

Column	Description
EAN connection code **(PK)**	Administrative unique eighteen digit code of the connection point
Transformer ID	Unique identifier of the transformer
Field ID	Unique identifier of the field
Station ID	Unique identifier of the station
Station reference	The name or code of the station
PC4	4-postions postal code (in accordance with the BAG)
Name public space	Name public space (in accordance with the BAG)
House number	House number (in accordance with the BAG)
House addition	House letter (in accordance with the BAG)
Residence	Residence (in accordance with the BAG)
X	X- coordinate (in accordance with the RD coordinates)
Y	Y-coordinate (in accordance with the RD coordinates)

Table 9: Content of the records of the dataset from the DMS

The GIS contains the geometries of the circuits and stations. Fields and transformers inherit their location from the station they are in. The circuit is chosen as the primary key as only one instance is associated with a connection point on one hand and a field at the other. It is also the physical interconnection between a connection point and a transformer and it's fields. In table 10 the data from GIS is described.

Column	Description
Circuit ID (**PK**)	The string of cable segments in between two stations. The circuit ID is a contraction of the unique identifiers of the two stations which are interconnected
Circuit GM_curve	The geometry of the circuit, expressed as a curve
Transformer ID	Unique identifier of the transformer, an eighteen digit EAN-code
Field ID	Unique identifier of the field
Field kWh	The kWh of the field, determined by the circuit breaker
Station ID	Unique identifier of the station
Station name	The name of the station
Station GM_point	The geometry of the station, expressed as a surface

Table 10: Content of the records of the dataset from the GIS

[7] In Dutch 'Rijksdriehoekstelsel', and in ArcGIS 'RD_new' coordinate system.

5.2.2 Energy consumption and generation

The TSO and DSO manage the grid, including the connection point. Prosumers pay the grid managers a fixed fee for their connection point. Legislation limits or even prohibits the grid manager's access to the energy consumption information. As pointed out in paragraph 2.2, the grid managers (and energy providers) are allowed to read the energy consumption from a smart meter at fixed moments. By all means every two months, for the purpose of two monthly overviews, but with the explicit consent of the prosumer the grid manager or energy provider is allowed to read the energy consumption more frequent.

As a result of this limitation and as a result of company policy regarding privacy and information security, this research has no access to the actual energy consumption and energy production measurement values. Therefore dummy data is used based. In case of the energy consumption the average energy consumption of a household is used. In case of production installations the maximum yield is expressed in kilowatt peak (kWp).

However, as the implementation does not aim to simulate energy balancing and congestion management, the actual energy consumption and generation is not required. Only the unit of measurement and unique identifiers need to be known.

Consumers have only one connection point to the grid (see paragraph 4.7 'Identifying objects in the grid by EAN-codes') , which implies that there is only one measurement value. This measurement value can be positive, but also negative in case more energy is generated than consumed. Table 11 describes the energy consumption and production data. This data is not actually provided, so virtual data (i.e. dummy data: data of a non-existing actor or device) is used.

Column	Description
EAN connection code (**PK**)	Administrative unique eighteen digit code of the connection point
Measurement value	Value of consumption or production of energy, expressed in kWh
Measurement ID	The unique identifier of the measurement instrument the consumption is associated with.

Table 11: Content of the records of the dataset for energy consumption and generation

5.2.3 Key DER registers

The most important key DER register is the production installation register (PIR) of EDSN. The PIR contains all energy generation installations of prosumers, like solar panels, high-efficiency boilers, combined heat and power units, wind turbines, biomass plants and small hydroelectric installations (energieleveren.nl, 2015). Public charging stations for EVs are regular connection points, thus are part of the C-AR.

The data of the PIR is anonymised and generalised from a six positions postal code to a four positions postal code. Each DER has a eighteen digit EAN-code a unique identifier and for each DER it is known which connection point is associated with it.

The nominal values of the DERs are known, i.e. the value of the maximum capacity of energy consuming and generating devices. These nominal values either require a lot of interpretation, or cannot be used at all:

- In case of energy balancing, the nominal values of energy consuming and generating devices serve no purpose. The focus is on levelling supply and demand, which is about the actual consumption and production;
- In case of congestion management the nominal values represent the maximum capacity. However, the nominal values require interpretation before they can be applied. The nominal values of solar panels and wind turbines say something about the potential yield, but the actual yield can differ substantially.

Column	Description
EAN_code (**PK**)	Unique eighteen digit identifier of the DER
EAN connection code	Administrative unique eighteen digit code of the connection point associated with the DER
Measurement value	Value of production of energy, expressed in kWh
PC4	4-postions postal code (in accordance with the BAG)
Residence	Residence (in accordance with the BAG)

Table 12: Content of the records of the dataset for energy generation

5.2.4 Public open data

Open data is used to visualise the other data layers geographically. Public open data is published on the National Geo Register (NGR) of the Netherlands: www.nationaalgeoregister.nl. The NGR is the open data portal as prescribed by the Inspire directive (Kadaster, 2013b). The open data on the NGR is mostly available via WMS, WFS, WCS, XML and GML standards. WMS, WFS, WCS XML and GML respectively stands for web mapping service, web feature service, web coverage service, extensible markup language, and geography markup language. The Kadaster also publishes data on its own portal: public services on map (in Dutch 'Publieke Dienstverlening Op Kaart' (PDOK)): www.pdok.nl. See table 13 for the most common cadastral referential data.

Abbreviation	Dutch	Translated in English	Description
BGT (Top10NL)	Basisregistratie Grootschalige Topografie	Key Register Great Scale Topology	Scale 1:5.000 Available as both raster and vector
BRT	Basis Registratie (kleinschalige) Topografie	Key Register Small Scale Topology	Scale 1:10.000 Available as both raster and vector
BAG	Basisregistratie Adressen en Gebouwen	Key Register Addresses and Buildings	Available as both raster and vector
BRK	Basis Registratie Kadaster	Key Register Kadaster	Available as both raster and vector
AHN	Actueel Hoogtebestand Nederland	Present Height register of the Netherlands	Available as raster

Table 13: Referential data sources of the Kadaster / National Geo Register

In this research the BGT in vector format is used as reference layer. Not all layers of the BGT are switched on as that would lead to a poor performance. Only the build-up areas, roads and waterways are included. From the layer with residences, IJsselstein is selected. The selected layers of IJsselstein and the other layers are intersected.

5.2.5 Weather forecasts

The temperature is the most influential on the energy consumption as the prosumers heat or cools their home. With the rise of DERs, other weather characteristics become of importance: the wind force determines the energy generation of wind turbines, and the sun power determines the yield of solar panels.

From July 1st 2015, the Dutch meteorological service, KNMI, will provide weather forecasts as open data. The KNMI has cooperated in this research by providing weather forecast data prior to that date. Together with other meteorological institutes, the KNMI participates in an international research programme 'HIgh Resolution Limited Area Model' (HiRLAM). One of the objectives of the HiRLAM is to develop the European weather forecast model: HARMONIE (HiRLAM, 2015). This

HARMONIE data is provided by the KNMI. See appendix 6 for a detailed description of the HARMONIE data.

The KNMI provides the weather data in grib format. The weather data is extracted using GribAE version 1.1.3. GribAE is a freeware graphical user interface (GUI) for reading grib data.

The weather forecasts are delivered on fixed moments over fixed periods: measurements take place each 6 hours and forecasts the weather for each hour, the next 48 hours. The format is provided as a rolling forecast, i.e. the forecast covers the next 48 hours and is recalibrated at each measurement.

As is clear from appendix 6, the weather forecast data of HARMONIE is complex. Not only the data itself is complex, but also its application. Grid managers need the power to be expressed in kWh. This kind of information is not available as open data, but can be obtained on the commercial market. The required weather characteristics are described in table 14.

Column	Description
Weather GM point	The geographic location of the weather station to which the weather forecast applies
Weather station ID	Unique station ID
Sun power kWh	Value of energy of sun power, expressed in kWh. The technological characteristics of the DER determine the yield from the sun power.
Wind force kWh	Value of energy of wind force, expressed in kWh. The technological characteristics of the DER determine the yield from the sun power.

Table 14: Content of the records of the dataset of weather characteristics

5.3 Validation of the model

The simulation in ArcGIS is described in this chapter. As mentioned in paragraph 5.1, the visualisations of the validation are included in an addendum which is provided only to the supervisors and examination board for examination and accreditation purposes, since it contains confidential information.

The validation is done in two steps:

1. Relating the three datasets and checking the individual interactions;
2. Simulate imbalance; and
3. Simulate congestion.
   The main purpose of the latter two is not the simulation itself, but to determine what the demands are with regard to the data exchange.

Basically three datasets are related:

1. The connection points and topological data from the DMS;
2. The geographic and circuit data from the GIS; and
3. The production installations from the PIR.

The weather data is excluded from the validation process. The data is to complex and the relationships between wind force and the yield of a wind turbine, and between solar power and the yield of a solar panel, needs to be elaborated on. The study area does not contain wind turbines. The study area does contain solar panels. Dummy data is used and based on the maximum yield of a solar panel: a solar panel's capacity is expressed in kilowatt peak (kWp), which indicates the yield under full solar radiation. The kWp is aggregated on the level of the medium voltage circuit it is connected with.

However, the data model can be validated party by the characteristics of the dataset itself. The weather forecast object is assigned a time-interval attribute. The HARMONIE weather data as provided by the KNMI does not contain a time-interval to which a forecast applies. The weather is forecasted at time points and the weather in the intermediate time can be determined by interpolation. It is safe to conclude that the same principle applies to the energy prognoses and thus the time-interval attribute should be discarded from the energy prognoses object too.

The object price is part of the model a modelled as it is determined by the weather forecasts. When simulating supply and demand, the suspicion arose that the research encountered a conflict between the current price mechanism and the expected future price mechanism. The model describes the current price mechanism in which the price is determined statically on beforehand. Demand-response suggests that price is determined dynamically. The price might not be determined on the energy prognoses, as suggested in the model, but on the actuals of supply and demand.

In the DMS it is known by which station a connection point is powered. Notice that the dataset used is preprocessed: from an electro-technical point of view, and as modelled in this research (see figure 17), the connection point is connected to a field in order to assign the maximum load value determined by the circuit breaker. In the dataset used, this value is already assigned. This is the result of the fact that the dataset is extracted from an intermediate database table which the DMS uses for circuit diagrams.

The geographic location of the circuits and stations are obtained from the GIS dataset.

The connection points and topological data from the DMS are related to the production installations from the PIR by using the eighteen digit EAN-code as unique identifier.

By relating the three datasets it can be derived which production installation belongs to which connection point, and which connection points are connected to which circuit. The result is visualised in figure A in the addendum.

Energy imbalances are determined by equations of attribute values, namely demand versus supply. The sum of the equation should be 0, as that implies that the consumption is equal to the production. The imbalance or congestion occurs at the level of an physical object in the power grid: a circuit, a field or a transformer. In this research the validation focusses on the imbalance at the level of a circuit. Due to privacy legislation, the actual consumption and production is not available. Therefore dummy data is used. The average Dutch household consumes 3.500 kWh a year[8], which is approximately 7kWh a day. The virtual consumption is based on the number of connection points related to a circuit and multiplied by 7kWh.

The datasets do not contain a bulk generator object, for instance a power plant, so there is no energy producing object other than the small production installations of the PIR. The energy production is simulated by just adding kilowatt-hours as counterbalance at the level of a circuit. The imbalance is easy to feign, see figure B in the addendum, as is solving it in a simulation: just increase the production, lower the consumption, or evoke stored energy. From this point of view the increase of production is the least desirable, since it does not solve the imbalance locally. The decentral measures concern the lowering of consumption or evoking of stored energy.

A second finding with regard to energy balancing, is that the energy consumption and production can be modelled in two ways, namely by considering the values as either positive (production) or negative (consumption), or by adding an attribute to indicate if the object 'measurement value' considers either production or consumption. In the conceptual class model, see figure 17, the object 'measurement value' is related to the object 'physical object' which contains an attribute 'type of object'. The types of objects are listed in a code list. Among these objects are energy producing objects, energy consuming objects and energy storing objects. As CEMS and energy storing objects can both consume and produce energy, the initial design of the model has proven to be correct: production and consumption is expressed by respectively positive and negative values, not by an additional attribute.

[8] Source: http://energietrends.info/wp-content/uploads/2014/09/EnergieTrends2014.pdf

Finally congestion is implemented and validated. Congestion is determined by equations of attribute values: grid load versus maximum power grid capacity. Variables are missing to translate and equalise the units of measurements in order to simulate congestion. For example: the diameter and length of the circuit, or cable segments, are of influence. The grid manager calculates its needs and communicates its need in watts. The grid manager also determines what part of the grid is affected and thereby which parties connected to the grid can do biddings. More data does not have to be exchanged.

The available data for this research is insufficient to express the grid load as an percentage of the maximum grid capacity of the circuit, while they use different units of measurement. The virtual grid load on one hand and the maximum grid capacity of the circuit on the other, are classified and visualised separately in figure C in the addendum. The visualisation can be compared: circuits with a low capacity and relatively high virtual load, are likely to get congested than circuits with high capacity and a relatively low virtual load.

In short the findings of the validation are:

- The common unit of measurement for electric energy is watt or kilowatt and is the common unit of measurement to use in the data exchange;
- Time-interval attributes should be discarded from the data model to enhance robustness;
- The model is based on some current mechanisms, but should be further developed to better fit the future mechanisms. For instance:
    - The model is based on the current price mechanism, in which the price is determined statically on beforehand. Demand-response suggests that price is determined dynamically based on the actuals of supply and demand;
    - To solve imbalance, the focus should be increasingly on lowering consumption and evoking stored energy instead of increasing the production;
- The exchange of production and consumption data can best be done as respectively positive and negative values opposite to adding an attribute to indicate if the object ‘measurement value’ considers either production or consumption.

6. Results

In this chapter the results are presented: the findings and conclusions in paragraph 6.1, the discussion and pointers for further research in paragraph 6.2.

6.1 Findings & conclusions

The energy sector in the Netherlands is undergoing dramatic changes, often referred to as the energy transition. This transition has impact on the market roles, the data exchange and the configuration of the physical grid. Although the latter is not the focus of this research, some statements can be made from the perspective of this research.

The initial focus of this research was solely on energy balancing, but as energy balancing and congestion management are strongly related, the congestion management was added to the scope of the research.

The findings and conclusions are structured as answers to the research questions.

What are the drivers of the emerging of the smart grid?

To understand the impact of the energy transition on energy balancing and congestion management, first the drivers of the emerging of the smart grid have been identified. In outline there are four drivers:

1. Environmental challenges: the attention for climate change and the exhaustion of fossil energy resources;
2. The changing market;
3. Infrastructural challenges; and
4. Innovative technologies.

The environmental challenges consist of the attention for climate change and the exhaustion of fossil energy resources. The way energy is generated and used is unsustainable. Parallel to this awareness, the energy sector is liberalised and become more transparent. With the increase of DERs both the market as power grid is decentralised. Consumers start producing energy and become prosumers, and the power grid needs to meet the requirements imposed by this change.

The interrelations between the drivers of the smart grid have not been examined, for example if the infrastructural challenges result from the technological innovations or vice versa. The interrelations between the driver of the smart grid are considered to be irrelevant for the purpose of this research.

Who are the users of geodata for the purpose of energy balancing and congestion management within the smart grid?

The users of (geo)data in the power grid are changing as a result of the changing market, infrastructural challenges and innovative technologies: the emerging of the smart grid. Market roles shift and even a new market role emerges: the aggregator.

With regard to energy balancing and congestion management especially the role of the DSO is changing. As a result of the decentralisation, the energy balancing and especially congestion management shifts from the transport grid towards the distribution grid.

The decentralisation implies an increase of the variation between peaks and troughs of energy supply and demand at a local level. As a result, the energy needs to be balanced at a more local level to assure continuity: a safe and guaranteed supply of energy.

Balancing energy refers to levelling supply and demand. It is the concern of the system operator role. The TSO in the Netherlands, TenneT, is the only party which fulfils the system operator role. As the imbalance is increasingly expected to occur at a more local level, it seems inevitable that the DSO will fulfil the system operator role too.

Congestion management concerns the physical limits of the power grid. As the local peaks of energy supply and demand increase, it is likely that the maximum capacity of the local power grid is exceeded more often. Congestion management is the concern of the TSO/DSO role.

A prosumer is paying a fixed fee for its connection to the DSO. Today the DSO has no incentives to influence the behaviour of the prosumers. Furthermore, as a result of the data protection act, the DSO also depends on the explicit consent of the prosumer to read the energy consumption from the smart meter. Without explicit consent of the prosumer, the highest frequency to obtain energy consumption data, is once each two months. Thus, the DSO cannot manage congestion (near) real time within the current legal boundaries. On the other hand, the DSO in the Netherlands has limited responsibility to assure energy supply. This responsibility rests with the TSO, which is eventually accountable.

The incentives to influence the behaviour of the prosumers for the purpose of energy balancing and congestion management is left to the market. The balancing responsible party (BRP) role can do regulating and reserve biddings to solve imbalance. Congestion is traded on a separate market with the capacity trade role. The aggregator could fulfil both roles: the BRP role and the capacity trader role. The aggregator can be considered a collection of BRP and capacity trade role , but also other roles like, amongst others, the market information aggregator role and the metered data aggregator.

The current European and Dutch role model does not seem to fit the new relations which arise from the emerging of the smart grid. In politics and in the media, the discussion is often guided towards commercial interests of the DSO, but the primary responsibility seems to be neglected: the preservation of the safety and continuity, and the efficiency of the energy supply.

One of the precepts to allow a DSO, an energy provider, or a meter operator to read the energy consumption from a smart meter, is the necessity to manage or maintain the grid. This precept should be stretched for the DSO (as the TSO already has this right): to ensure a safe and continuous energy supply, it is always necessary for the DSO to have full and constant access to the energy consumption and generation measurement values within the power grid. The commercial entanglement can be prevented by disengagement of the aggregator roles, and the system operator and TSO/DSO role.

What are the applications of geodata for the purpose of energy balancing and congestion management within the smart grid?

The applications of geodata for the purpose of energy balancing and congestion management within the smart grid are:

1. Georeferencing energy production and consumption in time, and areas of imbalance or congestion that follow from that production and consumption;
2. Neighbourhood analysis for aggregation purposes for DR; and
3. Visualisation of the results in a geographic or orthogonal map.

Georeferencing considers both geographic as topological referencing. However, eventually geographic and topological data are not exchanged, other than the geodata provided by the information services. The geographical and topological data are just like the market roles and the power grid characterised by a decentralised and distributed application. The users maintain their own geographical or topological (reference) data.

The locational data is expressed as a collection of affected objects : i.e. connection points, circuits and/or transformers. Depending on the application and information requirements, each market role assigns geographical or topological meaning themselves.

What are the requirements regarding the geodata used for energy balancing and congestion management within the smart grid?

There are spatial temporal requirements with regard to the data which is exchanged within the smart grid. The requirements cover three aspects: the spatial aspect, the temporal aspect and the object itself.

To start with the latter: the energy sector already has a clear common referencing for objects, namely the EAN-codes. These codes are managed centrally in key registers like the C-AR and the PIR.

With regard to the geodata: as concluded in answering the previous research question, there is no exchange of geodata when balancing energy and managing congestion. The geographical data is obtained in advance from public open data sources and the market roles add these geographical characteristics themselves for their own needs. The grid managers are holders of the topological data and keep these topological data for themselves. The fact that geographical and topological data is not exchanged when balancing energy and managing congestion, does not mean that the geographical and especially topological data is less relevant. On the contrary. The correct topological data is of great importance to ensure the right collection of affected objects is determined and exchanged. Otherwise interventions are made on the wrong location, i.e. at the wrong collection of objects, causing an even greater imbalance or congestion.

The determination of the ‘location’, i.e. the area that covers the collection of objects which are subject of either imbalance or congestion, is basically a matter of neighbourhood analysis for aggregation purposes for DR. As the ‘location’ is dynamic, the definition of what to consider as ‘local’ should be captured in services.

Whether the model covers the high, medium or low voltage grid, is just a matter of the objects (i.e. measurement instruments) which are included in the model.

Especially the temporal aspect needs attention. The energy market needs a shared understanding of time, especially the time intervals. Values of attributes at a certain point in time can be interpolated. The biggest challenge is to define the time intervals to which imbalance or congestion applies and thus for which time intervals an increase or decrease of supply or demand is desired. However, the time-intervals should be discarded from the model as it harms the model’s robustness. The time-intervals should be covered by services. In service definitions the time-intervals are determined based on the timestamps of the model.

The research objective was: *“to develop a conceptual model of the application and exchange of geodata for the purpose of energy balancing and congestion management within the smart grid in the Netherlands.”*

The model has been developed, but the locational data is not expressed as geodata the imbalance or congestion is translated to objects affected and the unique identifiers of these objects are exchanged. The parties involved have their own geographic or topological reference for those objects. The parties in the energy market have developed their own praxis to refer to an area of imbalance or congestion, namely by exchanging the objects affected. The objects already have unique identifier: the eighteen digit EAN-code.

This research adopts part of several existing standard data models: the IMKL (which integrates Inspire GCM), CERISE-SG and ISO/OGC, see figure 17 in paragraph 4.5. The geographic data is obtained from public open data sources for georeferential purposes, but is not exchanged when balancing energy or managing congestion. The geographic data is added by the market roles themselves. Topological data is not exchanged, but used by the grid manager to determine the collections of objects affected by the imbalance or congestion.

A common vocabulary is required then to assure all parties involved have a shared understanding of the affected objects, so the just locational reference is assigned to the objects. Part of that common vocabulary should also be the definition of time intervals.

6.2 Discussion & further research

As the imbalance and congestion is likely occur more locally in the future, it is expected that the system operator role is also fulfilled by the DSO. Furthermore it seems likely that the DSO gets more responsibilities. However, the DSO is limited empowered to balance energy and manage congestion. The DSO could be granted more power, or a part of the responsibilities might need to be transferred to other market roles. For example, the CEMs might need to be held responsible for the correct and up to date registration of their DERs. The least CEMSs can do or be forced to do, is to register their DERs. The CEN-CENELEC-ETSI suggest in one of their use cases in their repository (WGSP-2130) that DERs should be registered automatically.

The aggregator could fulfil this intermediate role, i.e.: responsibilities of the DSO and the CEMs can be transferred to the aggregator. If the aggregator fulfils all roles, it is able to determine at a local level if imbalance or congestion occurs when supply or demand is increased or decreased. The responsibility may lie with the aggregator then.

As a result of the changing market roles, the tasks, powers and responsibilities need to be reconsidered.

The research describes the temporal aspects insufficiently. The mechanisms behind determining the time intervals are unclear: if imbalance or congestion occurs at a certain moment in time, is unclear in which time period the aggregator can react. Future research is needed to determine if the current data model supports the temporal aspect sufficiently.

As concluded in the previous chapter, a common vocabulary is required to assure all parties involved to have a shared understanding of the affected objects in order to assign the just locational reference to the objects. The common understanding of time-intervals can also be captured by such a common vocabulary. The development of a common vocabulary would be a logical next step in order to support energy balancing and congestion management within the smart grid.

Finally the model is based on current mechanisms with regard to determining price and solving imbalance. The model is based on the current price mechanism, in which the price is determined statically on beforehand. Demand-response suggests that price is determined dynamically based on the actuals of supply and demand. Furthermore it should be further researched if the model sufficiently supports the balancing of energy by mechanisms of lowering consumption and evoking stored energy. The model should be further tested and developed to better fit these future mechanisms.

Appendix 1: Acronyms & abbreviations

AC	Alternate Current
ADWH	Asset Data WareHouse
AHN	Actueel Hoogtebestand Nederland (Up to date heights of the Netherlands)
AMI	Advanced Meter Infrastructure
AMR	Automatic Meter Reading
BAG	Basisregistratie Adressen en Gebouwen (Key Register Addresses and Buildings)
BEMS	Building Energy Management System
BGT	Basisregistratie Grootschalige Topografie (Key Register Great Scale Topology)
BMKL	Berichten Model Kabels en Leidingen (Messaging Model Cables and Pipes)
BRK	Basis Registratie Kadaster (Key Register Kadaster)
BRT	Basis Registratie Topografie (Key Register Topology)
C-AR	Centraal AansluitingenRegister (Central Connections Register)
CEMS	Community Energy Management System
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electro technical standardisation)
CERISE-SG	Combineren van Energie- en Ruimtelijke Informatie Standaarden als Enabler – Smart Grids' (combining of energy and geo-information standards as an enabler for smart grids)
CIM	Common Information Model
COSEM	Companion Specification for Energy Metering
CSG	Coalition Structure Generation
CWI	Centrum Wiskunde & Informatica (Centre for Mathematics and Computer Science)
DC	Direct Current
DER	Distributed Energy Resources
DMS	Distribution Management System
DMTF	Distributed Management Task Force
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EAN	European Article Numbering
EBIF	Energy Balancing Information Facility
ECMWF	European Centre for Medium-range Weather Forecasts
EDSN	Energie Data Service Nederland (Energy Data Service Netherlands)
EG3	Expert Group 3
EMS	Energy Management System
ENTSO-E	European network of transmission system operators for electricity
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
GCM	Generic Conceptual Model
GIS	Geographic Information Systems
GML	Geography Markup Language
HEMS	Home Energy Management System
HiRLAM	High Resolution Limited Area Model
IEC	International Electro-technical Commission
IETF	Internet Engineering Task Force
IMKL	Informatie Model Kabels en Leidingen (Information Model Cables and Pipes)
IMSG	Information Model Smart Grid
Inspire	Infrastructure for Spatial InfoRmation in the European community
IRENA	International Renewables Energy Agency
ISO	International Organisation for Standardisation
ITU	International Telecommunication Union
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Dutch Meteorological Institute)
NEN	Nederlandse Norm (Dutch Standard)

NGR	Nationaal Geo Register (National Geo Register)
NIST	National Institute of Standards and Technology
OASIS	Organisation for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
PDOK	Publieke Dienstverlening Op Kaart (Public Services On Map)
PHEV	Plug-in (Hybrid) Electric Vehicles
PIR	Productie Installatie Register (Production Installation Register)
PLC	Power Line Communications
PV	Photo Voltaic
QoS	Quality of Service
RDW	RijksDienst voor het Wegverkeer (Public Authority in the Mobility Chain)
RES	Renewable Energy Sources
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart Grid Architecture Model
SGCP	Smart Grid Connection Point
SGTF	Smart Grids Task Force (of the European Commission)
SOA	Service Orientated Architecture
SOG	Service Orientated Grid
TSO	Transmission System Operator
UML	Unified Modelling Language
URI	Uniform Resource Identifier
USEF	Universal Smart Grids Energy Framework
VPP	Virtual Power Plant
WAN	Wide Area Network
W3C	World Wide Web Consortium
WSDL	Web Services Description Language
XML	Extensible Markup Language

Appendix 2: Energy market role definitions

In paragraph 2.2 'market roles' the ENTSO-E market roles are discussed. This appendix consists a full overview of all roles and its descriptions as used by the European network of transmission system operators for electricity (ENTSO-E).

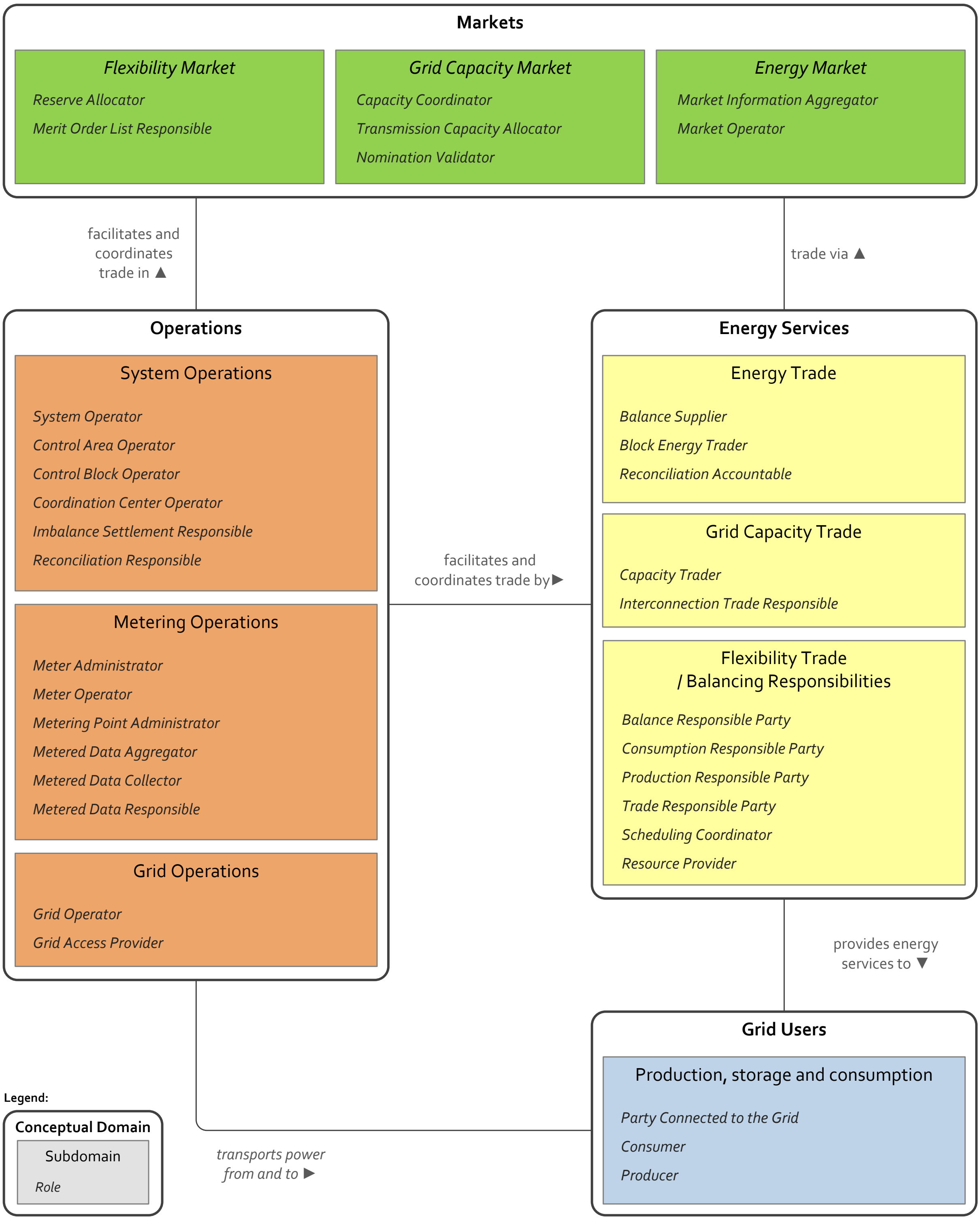
Role	Description
Balance Responsible Party	A party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Market Balance Area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level. *Additional information*: The meaning of the word "balance" in this context signifies that that the quantity contracted to provide or to consume must be equal to the quantity really provided or consumed. Equivalent to "Program responsible party" in the Netherlands. Equivalent to "Balance group manager" in Germany. Equivalent to "market agent" in Spain.
Balance Supplier	A party that markets the difference between actual metered energy consumption and the energy bought with firm energy contracts by the Party Connected to the Grid. In addition the Balance Supplier markets any difference with the firm energy contract (of the Party Connected to the Grid) and the metered production. *Additional information*: There is only one Balance Supplier for each Accounting Point.
Billing Agent	The party responsible for invoicing a concerned party.
Block Energy Trader	A party that is selling or buying energy on a firm basis (a fixed volume per market time period).
Capacity Coordinator	A party, acting on behalf of the System Operators involved, responsible for establishing a coordinated Offered Capacity and/or NTC and/or ATC between several Market Balance Areas.
Capacity Trader	A party that has a contract to participate in the Capacity Market to acquire capacity through a Transmission Capacity Allocator. NOTE: the capacity may be acquired on behalf of an Interconnection Trade Responsible or for sale on secondary capacity markets.
Consumer	A party that consumes electricity. *Additional information*: This is a Type of Party Connected to the Grid.
Consumption Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points. *Additional information*: This is a type of Balance Responsible Party.
Control Area Operator	Responsible for : 1. The coordination of exchange programs between its related Market Balance Areas and for the exchanges between its associated Control Areas. 2. The load frequency control for its own area. 3. The coordination of the correction of time deviations.
Control Block Operator	Responsible for : 1. The coordination of exchanges between its associated Control Blocks and the organization of the coordination of exchange programs between its related Control Areas. 2. The load frequency control within its own block and ensuring that its Control Areas respect their obligations in respect to load frequency control and time deviation. 3. The organization of the settlement and/or compensation between its Control Areas.

Role	Description
Coordination Center Operator	Responsible for : 1. The coordination of exchange programs between its related Control Blocks and for the exchanges between its associated Coordination Center Zones. 2. Ensuring that its Control Blocks respect their obligations in respect to load frequency control. 3. Calculating the time deviation in cooperation with the associated coordination centers. 4. Carrying out the settlement and/or compensation between its Control Blocks and against the other Coordination Center Zones.
Grid Access Provider	A party responsible for providing access to the grid through an Accounting Point and its use for energy consumption or production to the Party Connected to the Grid.
Grid Operator	A party that operates one or more grids.
Imbalance Settlement Responsible	A party that is responsible for settlement of the difference between the contracted quantities and the realised quantities of energy products for the Balance Responsible Parties in a Market Balance Area. NOTE: the Imbalance Settlement Responsible has not the responsibility to invoice. The Imbalance Settlement Responsible may delegate the invoicing responsibility to a more generic role such as a Billing Agent.
Interconnection Trade Responsible	Is a Balance Responsible Party or depends on one. He is recognised by the Nomination Validator for the nomination of already allocated capacity. *Additional information*: This is a type of Balance Responsible Party.
Market Information Aggregator	A party that provides market related information that has been compiled from the figures supplied by different actors in the market. This information may also be published or distributed for general use. NOTE: the Market Information Aggregator may receive information from any market participant that is relevant for publication or distribution.
Market Operator	The unique power exchange of trades for the actual delivery of energy that receives the bids from the Balance Responsible Parties that have a contract to bid. The Market Operator determines the market energy price for the Market Balance Area after applying technical constraints from the System Operator. It may also establish the price for the reconciliation within a Metering Grid Area.
Meter Administrator	A party responsible for keeping a database of meters.
Meter Operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters.
Metered Data Collector	A party responsible for meter reading and quality control of the reading.
Metered Data Responsible	A party responsible for the establishment and validation of metered data based on the collected data received from the Metered Data Collector. The party is responsible for the history of metered data for a Metering Point.
Metered Data Aggregator	A party responsible for the establishment and qualification of metered data from the Metered Data Responsible. This data is aggregated according to a defined set of market rules.
Metering Point Administrator	A party responsible for registering the parties linked to the metering points in a Metering Grid Area. He is also responsible for maintaining the Metering Point technical specifications. He is responsible for creating and terminating metering points.
Merit Order List (MOL) Responsible	Responsible for the management of the available tenders for all Acquiring System Operators to establish the order of the reserve capacity that can be activated.

Role	Description
Nomination Validator	Has the responsibility of ensuring that all capacity nominated is within the allowed limits and confirming all valid nominations to all involved parties. He informs the Interconnection Trade Responsible of the maximum nominated capacity allowed. Depending on market rules for a given interconnection the corresponding System Operators may appoint one Nomination Validator.
Party Connected to the Grid	A party that contracts for the right to consume or produce electricity at an Accounting Point.
Producer	A party that produces electricity. *Additional information*: This is a type of Party Connected to the Grid.
Production Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and produced for all associated Accounting Points. *Additional information*: This is a type of Balance Responsible Party.
Reconciliation Accountable	A party that is financially accountable for the reconciled volume of energy products for a profiled Accounting Point.
Reconciliation Responsible	A party that is responsible for reconciling, within a Metering Grid Area, the volumes used in the imbalance settlement process for profiled Accounting Points and the actual metered quantities. NOTE: the Reconciliation Responsible may delegate the invoicing responsibility to a more generic role such as a Billing Agent.
Reserve Allocator	Informs the market of reserve requirements, receives tenders against the requirements and in compliance with the prequalification criteria, determines what tenders meet requirements and assigns tenders.
Resource Provider	A role that manages a resource object and provides the schedules for it.
Scheduling Coordinator	A party that is responsible for the schedule information and its exchange on behalf of a Balance Responsible Party. For example in the Polish market a Scheduling Coordinator is responsible for information interchange for scheduling and settlement.
System Operator	A party that is responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area. The System Operator will also determine and be responsible for cross border capacity and exchanges. If necessary he may reduce allocated capacity to ensure operational stability. Transmission as mentioned above means "the transport of electricity on the extra high or high voltage grid with a view to its delivery to final customers or to distributors. Operation of transmission includes as well the tasks of system operation concerning its management of energy flows, reliability of the system and availability of all necessary system services". (Definition taken from the ENTSO-E RGCE Operation handbook Glossary). NOTE: additional obligations may be imposed through local market rules.
Trade Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points. NOTE: a power exchange without any privileged responsibilities acts as a Trade Responsible Party. *Additional information*: This is a type of Balance Responsible Party.
Transmission Capacity Allocator	Manages the allocation of transmission capacity for an Allocated Capacity Area. For explicit auctions: The Transmission Capacity Allocator manages, on behalf of the System Operators, the allocation of available transmission capacity for an Allocated capacity Area. He offers the available transmission capacity to the market, allocates the available transmission capacity to individual Capacity Traders and calculates the billing amount of already allocated capacities to the Capacity Traders.

(ENTSO-E, 2014a)

The figure below gives a full overview of all the above-described ENTSO-E roles plotted on the European Conceptual Model for the Smart Grid(CEN-CENELEC-ETSI, 2014b).



Appendix 3: Overview of smart grids geodata standards

In paragraph 2.5 the standards regarding geodata are studied. This appendix elaborates on the many standards. It is impossible to give a full overview of all standards applicable on smarts grids, because the applicable standards strongly depend on the context. The objective of this appendix is to give insight in the many standards which are or can be applicable.

This appendix is composed of the next sources:

- NEN3610:2011;
- INSPIRE Generic Conceptual Model;
- The website of the IEC (http://www.iec.ch/smartgrid/standards/);
- The website of OASIS (https://www.oasis-open.org/standards);
- The website of OGC (http://www.opengeospatial.org/standards);
- The website of ISO/TC211 (http://www.isotc211.org/); and
- The article 'Towards a Service-Oriented Energy Market: Current State and Trend' (Pagani & Aiello, 2011).

IEC:

Core standards of the IEC regarding smart grid:

IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
IEC 61850	Substation Automation – Communication networks and systems in substations and for power utility automation
IEC 61968	Distribution Management – Application integration at electric utilities - System interfaces for distribution management
IEC 61970	CIM – management system application program interface (EMS-API)
IEC 62325	Framework for energy market communications
IEC 62351	Security – Power systems management and associated information exchange - Data and communications security
IEC/TR 62357	SOA – Power system control and associated communications - Reference architecture for object models, services and protocols

The IEC also issues standards regarding RESs, EVs, etc.:

IEC 60364	Electrical installations of buildings (BEMS)
IEC 60904	Solar voltaic – Photovoltaic devices
IEC 61727	Solar voltaic – Photovoltaic systems – Characteristics of the utility interface
IEC 61400	Wind Turbines
ISO 81400	Wind Turbines
IEC 61851	Electrical vehicle charging
IEC 62052	Metering – Electricity metering equipment (including 11 and 21: tariff and load control)
IEC 62056	COSEM – Electricity metering - Data exchange for meter reading, tariff and load control
IEC 62600	Marine Power – Marine energy - Wave, tidal and other water current converter (*in project stage*)
ISO/IEC 14543	Information technology - Home electronic system (HES) architecture (HEMS)

ISO:

ISO/TS 15000	Electronic Business using eXtensible Markup Language, commonly known as e-business XML, or ebXML. Sponsored by OASIS
ISO12006	International Framework for dictionaries/buildingSMART Data Dictionary (BEMS)
ISO16739	datamodel of building information, including geometry (BEMS)

ISO 19119:2005	Geographic information – Services
ISO19152	Land Administration Domain Model. Cadastral information: objects (premises, cables, pipes) and rights and restrictions and responsibilities.

ISO/TC 211, Inspire CGM (*) and NEN3610:2011 (^):

Infrastructure Standards	
EN ISO 19101:2005*^	Geographic information — Reference model
ISO/TS 19103:2005*	Geographic Information — Conceptual schema language
ISO/TS 19104:2008	Geographic information — Terminology
ISO 19105:2000	Geographic information — Conformance and testing
ISO 19106:2004	Geographic information — Profiles ....
Data model standards	
EN ISO 19107:2005*^	Geographic information — Spatial schema
EN ISO 19108:2005*	Geographic information — Temporal schema
EN ISO 19109:2006*^	Geographic Information — Rules for application schemas
EN ISO 19123:2007*	Geographic information — Schema for coverage geometry and functions
ISO 19137:2007	Geographic information — Core profile of the spatial schema
ISO 19141:2008	Geographic information — Schema for moving features
Geographic information management standards	
EN ISO 19110:2006*	Geographic information — Methodology for feature cataloguing
EN ISO 19111:2007*^	Geographic Information — Spatial referencing by coordinates
ISO 19111-2:2009*	Geographic Information — Spatial referencing by coordinates — Part 2: Extension for parametric value
EN ISO 19112:2005*^	Geographic information — Spatial referencing by geographic identifiers
ISO 19112:2003	Geographic information — Spatial referencing by geographic identifiers
ISO 19113:2002	Geographic information — Quality principles
ISO 19114:2003	Geographic information — Quality evaluation procedures
EN ISO 19115:2005*^	Geographic information — Metadata
EN ISO 19115:2005/AC:2008*	Geographic information — Metadata — Technical Corrigendum 1
OGC 06-103r3*	Implementation Specification for Geographic Information - Simple feature access - Part 1: Common Architecture v1.2.0
EN ISO 19126:2009*	Geographic Information – Feature concept dictionary and registers
ISO/TS 19127:2005	Geographic information — Geodetic codes and Parameters
EN ISO 19131:2008*	Geographic Information – Data Product Specification
EN ISO 19135:2007*	Geographic information — Procedures for item registration
EN ISO 19136:2009*	Geographic Information – Geography Markup Language
ISO/ts 19138:2006	Geographic information — Data quality measures
Geographic information services standards	
ISO 19116:2004	Geographic information — Positioning services
ISO 19117:2005^	Geographic information — Portrayal
ISO 19119:2005	Geographic information — Services
ISO 19125-1:2004	Geographic information — Simple feature access — Part 1: Common architecture
ISO 19125:2004^	Geographic information — Simple feature access — Part 2: SQL option
ISO 19128:2005	Geographic information — Web map server interface
ISO 19132:2007	Geographic information — Location based services — Reference model
ISO 19133:2005	Geographic information — Location based services — Tracking and navigation
ISO 19134:2007	Geographic information — Location based services — Multimodal routing and navigation

Geographic Information encoding standards	
ISO 19118:2005**^**	Geographic information — Encoding
ISO 6709:2008	Standard representation of geographic location by coordinates
ISO 19136:2007	Geographic information — Geography Markup Language (GML
ISO/TS 19139:2007*	Geographic Information – Metadata – XML Schema implementation
Standards for specific thematic areas	
ISO/TS 19101-2:2008	Geographic information — Reference model — Part 2: Imagery
ISO/TS 19115-2:2008	Geographic information — Metadata — Part 2: Extensions for imagery and gridded data
IETF RFC 3986*	Uniform Resource Identifier (URI): Generic Syntax, 2005, http://www.ietf.org/rfc/rfc3986.txt
ISO 19156:2011*	Geographic Information – Observation and Measurements
ISO/DIS 19157*	Geographic information – Data quality
UML 2.1.2*	Unified Modelling Language (UML) Superstructure and Infrastructure, Version 2.1.2
OGC 09-146r1*	GML application schema – Coverages, version 1.0
OGC 10-129r1*	Geography Markup Language (GML) — Extended schemas and encoding rules
NEN-ISO/IEC 19757-3:2006**^**	Information technology – Document Schema Definition Languages (DSDL) – Part 3: Rule-based validation – Schematron
NEN-ISO/IEC 11404:2008**^**	Information technology – General – Purpose Datatypes (GPD)
ISO/TS 19103:2005**^**	Geographic information – Conceptual schema language

OpenGIS Symbology Encoding Implementation Specification, version 1.1.0, OGC**^**
INSPIRE D2.5: Generic Conceptual Model, Version 3.2**^**

OGC:

The latter two standards mentioned at Inspire CGM are OGC standards. Other OGC standards:

SWE	Sensor Web Enablement
SensorML	Sensor Model Language, standard for sensor measurements and processes, including methods to process and aggregate sensor observations.
CityGML	CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. CityGML offers a common definition of the basic entities, attributes, and relations of a 3D city model.
KML	Keyhole Markup Language
GeoRSS	Geo Real Dimple Sydication. To update news on a webpage.
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
CSW	Catalogue Service for the Web
WPS	Web Processing Services
LBS	Location Based Services

Other Dutch Standards (other than NEN):

Dutch profile on GML: core GML Profile for the Netherlands (under construction), Geonovum, Amersfoort
Dutch profile on NEN-EN-ISO 19115 for geography, Geonovum, Amersfoort
Information Model – Measurements, SIKB, Gouda

IMKL – Informatie Model Kabels en Leidingen (Information Model Cables and Pipes), Kadaster
BMKL – Berichten Model Kabels en Leidingen (Messaging Model Cables and Pipes), Kadaster

OASIS:

eMIX: Energy Market Information Exchange (eMIX) – Exchanging price information and product definitions in energy markets and to those following markets

Energy markets and sales have been characterised by tariffs and embedded knowledge that make decision automation difficult. Smart grids introduce rapidly changing products and product availability, with associated dynamic prices. Lack of standardised messages conveying a standardised vocabulary for market information has been a barrier to development and deployment of technology to respond to changing market circumstances.

Price and product definition are actionable information. When presented with standard messages conveying price and product, automated systems can make decisions to optimise energy and economic results. In regulated electricity markets, price and products often are defined by complex tariffs, derived through political processes. EMIX defines the information for use in messages that convey this actionable information. An essential distinction between energy and other markets is that price is strongly influenced by time of delivery. EMIX conveys time and interval by incorporating WS-Calendar into tenders, contracts, and performance calls.
Source: https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=emix
And https://www.oasis-open.org/committees/tc_cat.php?cat=smartgrid

oBIX: Open Building Information Exchange (oBIX). Enabling mechanical and electrical control systems in buildings to communicate with enterprise applications

The purpose of oBIX (open Building Information Exchange) is to enable the mechanical and electrical control systems in buildings to communicate with enterprise applications, and to provide a platform for developing new classes of applications that integrate control systems with other enterprise functions. Enterprise functions include processes such as Human Resources, Finance, Customer Relationship Management (CRM), and Manufacturing.
Source: https://www.oasis-open.org/committees/tc_cat.php?cat=smartgrid

Energy interoperation: describes an information model and a communication model to enable collaborative and transactive use of energy, service definitions consistent with the OASIS SOA Reference Model [SOA-RM], and XML vocabularies for the interoperable and standard exchange of:

- Dynamic price signals
- Reliability signals
- Emergency signals
- Communication of market participation information such as bids
- Load predictability and generation information exchange of signals for dynamic pricing, reliability, and emergencies.
- Generation information

Source: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCosSIFOASISSeries
And https://www.oasis-open.org/committees/tc_cat.php?cat=smartgrid

WS-Calendar :	WS-Calendar Common Schedule Communication Mechanism for Energy Transactions.

The anticipated use of WS-Calendar is as a component within other specifications, providing a common model for schedule to diverse interactions in different domains. WS-Calendar adapts the existing specifications for calendaring to passing schedule and event information between and within services.

A fundamental component of negotiating services is agreeing when they should occur, and in auditing when they did occur. Traditionally, short running services have been handled as if they were instantaneous. Longer running processes cannot be so handled. When multiple long-running services participate in the same business process, it may be more important to negotiate a common completion time than a common start time. Central coordination of such services reduces interoperability by requiring the coordinating agent to know the lead time of each service.
An increasing number of specifications envision synchronization of processes. The smart grid relies on coordinating processes in homes, offices, and industry with projected and actual power availability at different times. Emergency management coordinators wish to inform geographic regions of future events, such as a projected tornado touchdown, using EDXL. Building systems and industrial processes are already operated using service interactions in a number of open and proprietary specifications. These efforts will benefit from a common standard for exchanging schedule and interval.
Source: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCosSIFOASISSeries
And https://www.oasis-open.org/committees/tc_cat.php?cat=smartgrid

W3C (standards for data exchange via Internet):

XML	Extensible Markup Language
JSON	JavaScript Object Notation
RSS	Rich Site Summary
RDF	Resource Description Framework
XSLT	Extensible Stylesheet Language Transformations
XQuery	XML Query
SPARQL	SPARQL Protocol and RDF Query Language. A RDF query language

Source: CERISE-SG use-case D1.3 paragraph 3.2.5

WXXM:

WXXM:	The Weather Information Exchange Models and Schema (WXCM-WXXM-WXXS) are designed to enable a platform independent, harmonised and interoperable meteorological information exchange covering all the needs of the air transport industry.

Source: http://www.wxxm.aero/public/subsite_homepage/homepage.html

CSML :	Climate Science Modelling Language

Climate Science Modelling Language v3.0 is a data model for encoding climate, atmospheric and oceanographic data in terms of geometry-based observation classes such as Points, Profiles, Trajectories and Grids. It is a specialist profile of ISO 19156 Observations and Measurements and there is an accompanying implementation as a GML 3.2.1 Application Schema.

In Europe, the INSPIRE directive is establishing an infrastructure for spatial information in Europe to support policies or activities which may have an impact on the environment.
The CSML pattern is being used in the version 2.0 drafts of the INSPIRE Data Specifications for Atmospheric Conditions/Meteorological Features and Oceanographic Geographical Features.
Source: http://csml.badc.rl.ac.uk/

ebIX :

ebIX — energy business Information eXchange – an information exchange standard with the aim to advance, develop and standardise information exchange in the energy industry.

The main focus is on interchanging administrative data for the internal European markets for electricity and gas. ebIX shall also cover the needs both for the wholesale market (upstream) and the retail market (downstream).
ebIX will follow the rules of the European Union where applicable.
Source : http://www.ebix.org/

Appendix 4: Smart Grid Architecture Model (SGAM) definitions

In paragraph 2.6 ‘Smart grid architecture models’ the smart grid architecture model (SGAM) is introduced. This appendix contains the definitions of respectively the layers, domains and zones as used in the smart grid architecture model (SGAM) (CEN-CENELEC-ETSI, 2014c).

Definition of layers:

Layer	Description
Business	The business layer represents the business view on the information exchange related to smart grids. SGAM can be used to map regulatory and economic (market) structures (using harmonised roles and responsibilities) and policies, business models and use cases, business portfolios (products & services) of market parties involved. Also business capabilities, use cases and business processes can be represented in this layer.
Function	The function layer describes system use cases, functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components. The functions are derived by extracting the use case functionality that is independent from actors.
Information	The information layer describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services in order to allow an interoperable information exchange via communication means.
Communication	The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.
Component	The emphasis of the component layer is the physical distribution of all participating components in the smart grid context. This includes system & device actors, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers.

Definition of domains:

Domain	Description
(Bulk) Generation	Representing generation of electrical energy in bulk quantities typically connected to the transmission system, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. PV, CSP).
Transmission	Representing the infrastructure which transports electricity over long distances.
Distribution	Representing the infrastructure which distributes electricity to customers.
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation and consumption technologies (typically in the range of 3 kW to 10,000 kW). These distributed electrical resources may be directly controlled by e.g. a TSO, DSO, an aggregator or Balance Responsible Party (BRP).
Customer Premises	Hosting both end users of electricity and also local producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines.

Definition of zones:

Zone	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind …) and the physical equipment directly involved (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads, any kind of sensors and actuators which are part or directly connected to the process,…).
Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Including commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement…
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, retail market.

Appendix 5: Interviews

Interviews are conducted with stakeholders to assess the conceptual class model, see paragraph 4.7. However, the interviews contributed to a large extend to the general understanding of the energy market roles and as a result paragraph 2.2 contains references to these interviews.

In this appendix an overview is given of the interviewees and the topics of the questions asked.

Date	Interviewee(s)	Function	Company	Remarks
January 23rd 2015	Peter Hermans	Chief architect	Stedin	EG3 participator
March 5th 2015	Milo Broekmans	Sr. Enterprise architect	Stedin	Stedin participator USEF
March 23rd 2015	Ronald Knook & Joost Cornelissen	Information Manager Information Manager	Alliander	Distribution grid
March 23rd 2015	Wilco Polak	Manager Asset Information Management	TenneT	Transport grid, asset (information) management
March 29th 2015	Louis Dietvorst*	Enterprise architect	Enexis	Distribution grid
April 13th 2015	Henri Mathijssen	Manager System Operations	TenneT	Transport grid, operations
April 24th 2015	Milo Broekmans	Sr. Enterprise architect	Stedin	Stedin participator USEF
April 28th 2015	Pieter Minnaar	Sr. Designer/Developer	Realworld	Sr. Designer/Developer, operations
May 19th 2015	Dennis Stufkens*	Manager System Operations, Transmission Services	TenneT	Application of EAN-codes

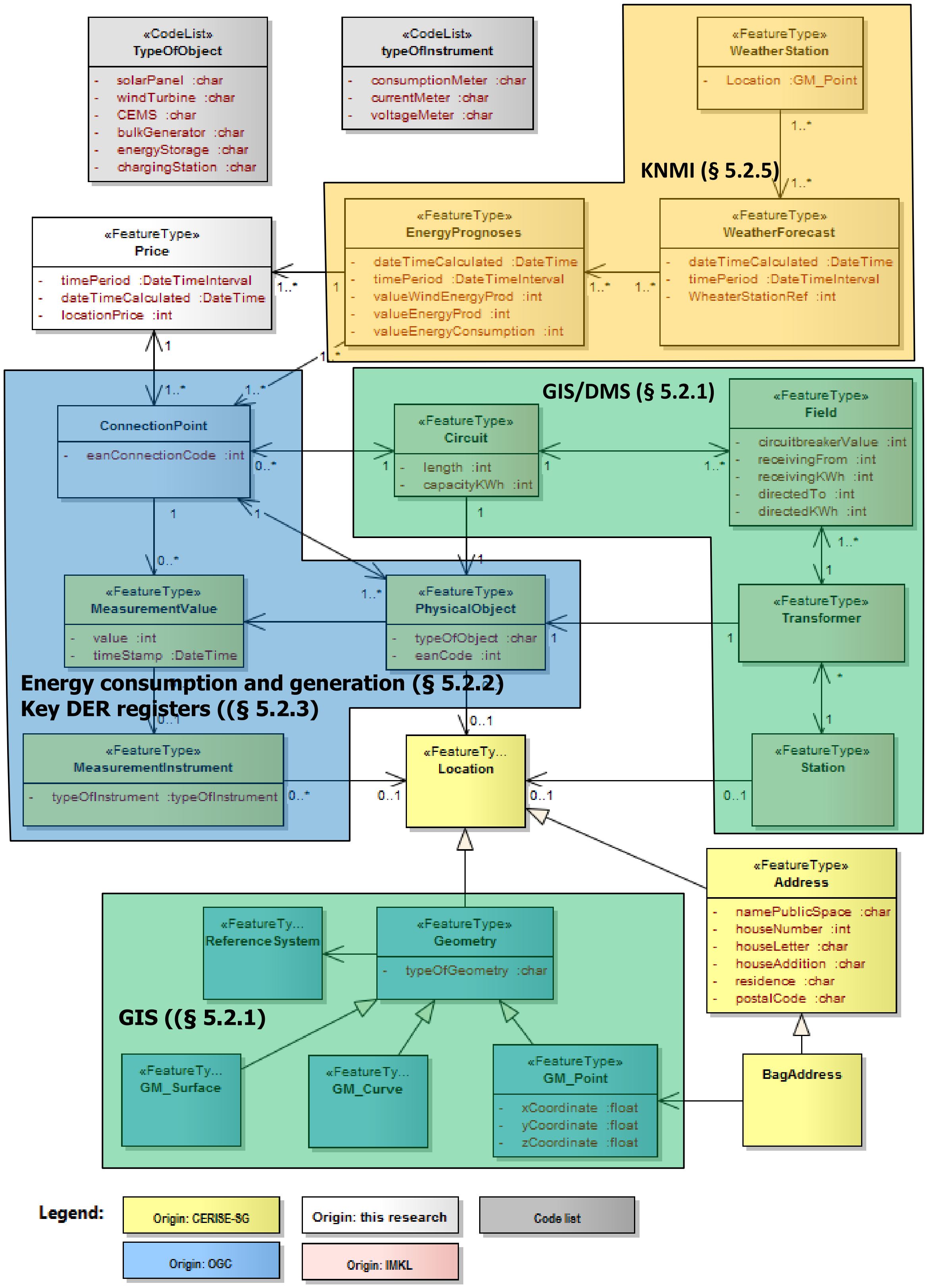
*: contribution by mail.

The assessment is a qualitative review, guided by, but not restricted to questions regarding the following topics:

- The roles;
- The energy balancing and congestion management processes;
- The technical operation of the grid; and
- The data.

Appendix 6: Mapping of the implementation data on the class model

Chapter 5 describes the datasets used at implementing the conceptual class model. The datasets are plotted on the conceptual class model (figure 17 in paragraph 4.5) and visualised in the figure below:



Appendix 7: HARMONIE model data description

The weather data is described in paragraph 5.2.5. The general information and technical specifications are included in this appendix.

The HARMONIE data of the KNMI is extracted from the data centre catalogue (KNMI, 2015).

General information

Data product:	nl/nwp/harm36/grid/p1
Content:	KNMI HARMONIE Data Package nr. 1
Description:	Current grid point information of the selected fields from the original field of computational model HARMONY KNMI.
Computational grid:	Lambert projection
Time series model runs:	+00h = 00, 06, 12, and 18 UT
Computation time:	2,5 – 3 hours
Product resolution:	0,037° West-East; and 0,023° North-South (300x300)
Grid representation:	Regular Lat/Long
Bounding box:	Northern latitude 55,877 South latitude 49,0 Eastern longitude 11.063 Western longitude 0,0
Time steps	+00u (+1u) +48u
Parameters:	Single level parameters

GRIB 1, local grib table

Abbr.	Description parameter	Code	Level	Units
PMSL	Pressure converted to sea level	001	0	Pa
U10	U-wind at 10 m	033	10	m s-1
V10	V-wind at 10 m	034	10	m s-1
2T	Air temperature at 2 m	011	2	K
2RH	Relative humidity	052	2	%
TCC	Total amount of cloud cover	071	0	%
LCC	Low Cloud Cover (surface to 748 hPa)	073	0	%
MCC	Medium Cloud Cover (748 to 424 hPa)	074	0	%
HCC	High Cloud Cover (above 424 hPa)	075	0	%
CR	Cumulative amount of rain	061	457	kg m-2
CS	Cumulative amount of snow	062	457	kg m-2
CG	Cumulative amount of graupel	063	457	kg m-2
INR	Intensity of rain	061	456	kg m-2 s-1
INS	Intensity of snow	062	456	kg m-2 s-1
ING	Intensity of graupel	063	456	kg m-2 s-1
SC	Snow cover	066	0	
BLH	Boudary layer hight	067	0	m
GR	Global Radiation	117	0	J m**-2
SWR	Net shortwave radiation	111	0	J m**-2
SWR	Net shortwave radiation	111	0	J m**-2
LWR	Net long wave radiation	112	0	J m**-2
LH	Latent heatflux	121	0	J m**-2
SH	Sensible heat flux	122	0	J m**-2
BRT	Brightness temperature	118	39680	J m-2s-1
CLB	Cloud base	135	0	M
CIG	Column integrated graupel	201	458	kg m-2

UWG	U-component max gust of wind	162	10	m s-1
VWG	V-component max gust of wind	163	10	m s-1

Time step (analysis) +00 u

Abbr.	Description parameter	Code	Level	Units
LSM	Land See Mask; L=1, Z=0	081	0	Proportional

Technical specifications

Filename: harm36_v1_ned_surface_jjjjmmddhh.tgz
File size: ca. 300 Mbytes for a 48-hours model run
Description: all files of run 1 are zipped in 1 tgz-file, data files are saved in GRIB1 file format (49 files: 0-48 time steps).

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