Ma *Energy Informatics* (2019) 2:35
https://doi.org/10.1186/s42162-019-0100-4

Energy Informatics

RESEARCH

Open Access

Business ecosystem modeling- the hybrid of system modeling and ecological modeling: an application of the smart grid

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Abstract

Business ecosystem is popularly used to investigate a complex social system with the business perspective, and particularly contributes to the understanding of actors and their relations in the innovation research. However, the aspect of business ecosystem modeling is limited discussed in the literature, although the importance has emerged significantly in recent years due to the emphasis on cross-disciplinary research and digitalization with artificial intelligence. Therefore, this paper proposes a framework for business ecosystem modeling with the discussion of system engineering and ecological modeling. The domain of smart grid is selected to demonstrate how system engineering, especially standards and ontologies contribute to the business ecosystem modeling. The proposed framework of the business ecosystem modeling includes three parts and nine stages that combines theories from system engineering, ecology, and business ecosystem. Part I-Business ecosystem architecture development includes four stages which aims to identify a target business ecosystem and its elements (actors, roles, and interactions). Part II-Factor analysis includes two stages to identify potential changes (and the dimensions of the changes) in the ecosystem. Part III- Ecosystem simulation and reconfiguration aims to use simulations to investigate the transition of an ecosystem and the re-configurated ecosystem. The framework not only provides a systematic approach for modeling a business ecosystem but also provides a methodological foundation for research on the aspect of complex systems in the business ecosystem field.

Keywords: Business ecosystem, System modeling, System engineering, Ecological modeling, Standards, Architecture design, Simulation

Introduction

System modeling is the process of developing abstract models of a system (Sommerville 2015). System modeling is popularly used in software engineering, especially during requirement engineering to help derive the requirements for a system. System modeling can visualize a system, specify the structure or behavior of a system, provide a template for system construction, etc. System modeling represents a system by either graphical notation, e.g. the popular used Unified Modeling Language (UML) or develops mathematical models of a system that are usually used as a detailed system specification. System modeling has been used in different domains, e.g. manufacturing system (Baines and Harrison 1999), organization

(Dietz 1994), enterprise information system (Shen et al. 2004), market (Gebremedhin and Moshfegh 2004), etc. The application of system modeling in business mainly focuses on business process modeling (Greasley 2003) or strategic modeling (Cosenz and Noto 2016), which is the lack of a holistic view of the business world.

The term of the business ecosystem was introduced in 1993, by J. R. Moore (1993) to describe how the economic community works. Business ecosystem is defined as a large number of loosely interconnected participants who depend on each other for their mutual effectiveness and survival (Iansiti and Levien 2002). Business ecosystem has been popularly discussed since the 2000s, especially by the boost of the internet. Along with the internet, the term digital ecosystem was introduced, a digital business ecosystem is defined as 'constructed when the adoption of internet-based technologies for business is on such a level that business services and the software components are supported by a pervasive software environment, which shows an evolutionary and self-organizing behavior' (Peltoniemi and Vuori 2004a). The digital ecosystem has been applied to present the IT infrastructure (Iansiti and Richards 2006) or the software platform (Ceccagnoli et al. 2012).

However, there is little literature on the modeling aspect of the business ecosystem. For instance, (Manning et al. 2002) propose a 6-step approach to building a business ecosystem, but the approach is more like a guideline, not system modeling. Without system modeling, the investigation of the business ecosystem will be lack of visualization, clear structure of behaviors and specification that system modeling in software engineering can provide.

Therefore, this paper proposes an approach for systematic modeling of a business ecosystem. To develop and present this business ecosystem modeling approach, this paper chooses the smart grid business ecosystem as a case study. The reason for choosing the smart grid domain is because the smart grid is a well-defined and structured domain with a series of matured standards. Therefore, the investigation of system modeling in the smart grid can support the business ecosystem modeling development in this paper.

The proposed business ecosystem modeling approach includes three parts (Part I-Business ecosystem architecture development, Part II-Factor analysis, and Part III- Ecosystem simulation and reconfiguration). This paper mainly focuses on the introduction of the propose framework, and the three parts will be introduced in the future work.

This paper is organized as: Section II introduces the theory of system engineering with three aspects (system modeling process, domain ontology and system modeling languages). Section III presents the ecological modeling with the discussion of the biological ecosystem, ecosystem mapping and modeling. Section IV discusses the smart grid including smart grid architecture, smart grid actors and roles and value flows in the smart grid. Section V introduces the proposed framework for the business ecosystem modeling followed by conclusion in Section VI.

System Engineering

System Modeling Process

A system is a construct or collection of different elements that together produce results not obtainable by the elements alone (Rechtin 2017), and:

- *'The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results'.*
- *'The results include system-level qualities, properties, characteristics, functions, behavior, and performance'.*
- *'The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected'.*

Systems are complex, and system modeling approaches are different based on the aspects/layers of the systems required to be modeled. In system engineering, there are several well-known system modeling processes, e.g. the ISO 15288 (Industrial automation systems and integration- Integration of life-cycle data for process plants including oil and gas production facilities) (ISO 2013) and the system engineering formula by NASA (2007). In the ISO 15288, there are 25 processes defined to realize a system, starting from a statement of purpose (objective) and a set of top-level (stakeholder) requirements ending in operating and maintaining the system (Ruijven 2012). Meanwhile, NASA creates the single systems engineering formula (NASA n.d.) as:

SE (System Engineering) = Vee (the V shape diagram, shown in Fig. 1) + 11 SE Functions (shown in Fig. 2) + Tools.

Architecture development is an important part of system engineering because a system architecture is a conceptual model that defines the structure, behavior, and multiple views of a system (Jaakkola and Thalheim 2011). Among a number of the architecture development approaches, the TOGAF (The Open Group Architecture Framework) (The Open Group n.d.-a) and DoDAF (the Department of Defence Architecture Framework) (Chief Information Officer n.d.) are popularly used as the standards for the enterprise architecture (Tao et al. 2017).

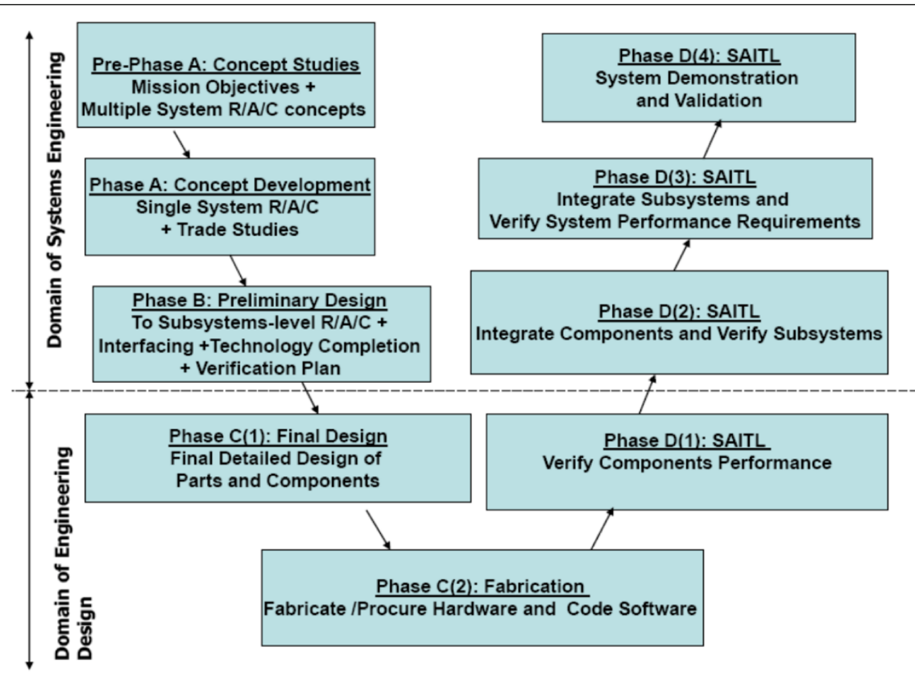

Fig. 1 Vee diagram in the single systems engineering formula by NASA (NASA n.d.)

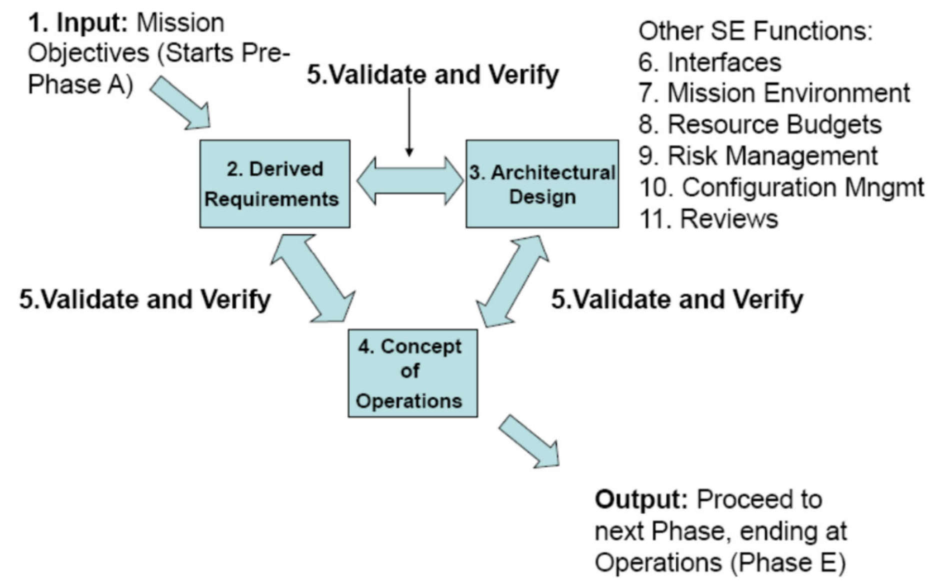

Fig. 2 11 SE Functions in the single systems engineering formula by NASA (NASA n.d.)

The process of system engineering and realization is complex due to the large number of parties involved and the many different interpretations of system engineering. To solve the challenges, e.g. lack of interoperability, the fragmentation of the total system life cycle and the need to handle a wide variety of types of system objects, one solution would be the availability of a common ontology (Ruijven 2012). To take advantage of the benefits of ontology management methods and tools in system engineering, ontology-based system engineering is recommended. For instance, (Benjamin et al. 2006) presents the role of ontologies in facilitating simulation modeling (shown in Table 1).

Domain Ontology

An ontology is an inventory of the kinds of entities that exist in a domain, their salient properties, and the salient relationships that can hold between them (Benjamin et al. 1995). In a domain ontology, various kinds of objects (e.g., tools and employees), properties (e.g., being made of metal or professional expertice), and relations between tools and employees (e.g., produced by or working with) are defined (Benjamin et al. 2006).

Ontologies are important in intelligent system development for modeling interoperability, composition, and information exchange at the semantic level. Ontologies addresses four challenges at the semantic level: semantic inaccessibility, logical disconnectedness, consistency maintenance, and modeling at multiple levels of abstraction (Benjamin and Graul 2006). However, not all ontologies represent domains in the same way and at the same level of detail. In addition, ontologies use different vocabularies to describe the same concepts. Therefore, there is the need for a unified ontology as a standard that can be used for a specific domain, e.g. smart grid (Cuenca et al. 2017).

There is no one correct way or methodology for developing ontologies (Noy and McGuinness 2001). One possible process for developing an ontology proposed by (Noy and McGuinness 2001) is:

Table 1 How Ontologies Enable the Simulation Model Development Process (Benjamin et al. 2006)

Simulation Modeling Activity	Activity Description	Role of Ontologies
Establish purpose & scope	Capture needs, questions, objectives. Integrate across multiple perspectives. Map organization /mission goals to simulation goals.	Terminology harmonization to enable shared and clear understanding.
Formulate conceptual model	Validate system descriptions. Identify model boundaries. Identify the level of modeling abstraction. Identify model objects and roles. Determine model structure and logic.	Ontology knowledge is used to determine the unambiguously differentiated abstraction levels. The ontological analysis helps to map system objects to model objects and to identify appropriate object roles. The ontological analysis helps reason with system constraints to facilitate determination of model logic.
Acquire and analyze data	Identify data sources and data dictionaries. Perform data and text mining. Perform statistical analyses, data reduction (distribution fitting, etc.).	Ontologies play an important role in detailed data analysis, especially in disambiguating terminology and interpreting text data descriptions.
Design detailed model	Refine, detail, and validate model objects. Refine, detail, and validate model structure and model logic.	Ontologies will facilitate detailed analysis of objects and constraints including mapping the simulation model constraints to evidence/ specifications of real-world constraints in the domain descriptions.

Step 1. Determine the domain and scope of the ontology
Step 2. Consider reusing existing ontologies
Step 3. Enumerate important terms in the ontology
Step 4. Define the classes and the class hierarchy
Step 5. Define the properties of classes—slots
Step 7. Create instances

For a domain ontology development, Step 1 is very important that determines the accuracy and detail of domain analysis and description. For instance, (Cuenca et al. 2017) investigates the ontologies of the energy data domain, and finds that none of these ontologies represents all types of energy performance and contextual data that should be taken into account for energy management and the data are also represented at different levels of detail (e.g. Table 2). To reuse existing ontologies, it is necessary to have a clear picture of the ontology network for the interconnected domains that related to the domain determined at Step 1 (e.g. Fig. 3). Then which parts of the existing ontologies and what concepts should be selected and reused can be decided (e.g. Table 3).

Ontologies are well discussed in the engineering domain, especially in IT & software engineering. Although there are ontologies in the business domain, the business ontology development is not popular. One of the best known business ontologies is the business model canvas, an ontology for business models (Osterwalder 2004). Another business ontology that is popularly applied in enterprise architecture modeling is the SOA (Service-Oriented Architecture) ontology (The Open Group 2014) that is part of TOGAF (The Open Group n.d.-a). The class hierarchy is shown in Fig. 4, and shows that the SOA ontology can contribute to the information flow, improve alignment

Table 2 Energy Domains Representation Level of Detail (Cuenca et al. 2017)

Energy domain	Ontology			
	Think Home	SAREF4EE	BOnSAI	ProSGV3
Infrastructure technical data	H	L	M	M
Energy consumption systems data	H	M	L	H
Energy performance data	H	H	H	H
Sensors/actuators data	H	M	M	M
Energy stakeholders' data	M	–	L	L
Weather/climate data	H	L	L	M
Geographical data	–	–	–	L
Environmental data	M	–	M	–
Distributed energy sources data	M	L	L	M
Energy DR operations	–	M	–	L

(H=High/M = Medium/L = Low)

between the business and information technology communities, and facilitate SOA adoption (The Open Group 2014).

There are several ontology building and management tools, e.g. Protégé, Apollo, IsaViz and SWOOP (W3C 2015). Each tool provides different functionalities, however, most users only use one, because they are not able to exchange ontology specifications between tools (Kapoor and Sharma 2010). The development comparison of the four ontology tools (shown in Table 4) shows that Protégé and Apollo are continuously updated. However, Apollo is only updated by individuals via GitHub, whereas Protégé is developed and supported by an organization-Stanford University. Protégé is popularly used in different domains, e.g. (Buitelaar et al. 2004; Knublauch 2004). Meanwhile, there are some derived software tools that use the RDF (Resource Description

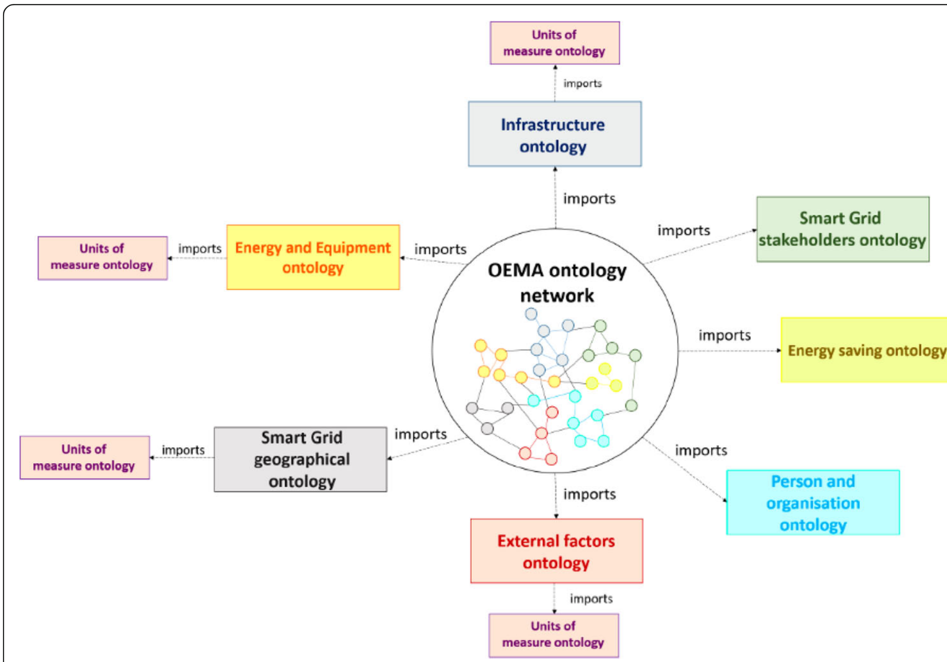

Fig. 3 OEMA (Ontology for Energy Management Applications) ontology network structure (Cuenca et al. 2017)

Table 3 Example of Reused Ontologies and Concepts (Cuenca et al. 2017)

Energy domain	Ontology	Reused concepts
Energy consumption systems data	ThinkHome ontology	HVAC systems, communication appliances, entertainment appliances, oce automation devices, lighting systems, white goods, acoustic systems, domotic network components, energy facilities, device state, device commands, equipment manufacturer, external and internal equipment
	SAREF4EE ontology	Appliances working modes and power proles, device manufacturer and device model.
	EnergyUse ontology	Wearable devices.
	ProSGV3 ontology	Body care devices, pressing devices, water heating devices, charging devices, lighting systems, entertainment devices, cleaning devices and electrical appliance category.

Framework) format to export files into the ontology tools, e.g. e[3]value editor, a value network design tool (Wieringa et al. 2019).

System Modeling Languages and Tools

The UML class diagramming has been popularly used for the system modeling. It has been used in the smart grid system modeling for modeling the electricity market (e.g. the harmonized role model (E. a. e. ENTSO-E 2018)), IT infrastructure and multi-layer architecture (in the SGAM (Smart Grids Architecture Model) framework (CEN-CENELEC-ETSI Smart Grid Coordination Group 2012)). The use case diagram is also used in the SGAM framework to present the design of the smart grid in an architectural viewpoint that allows both- specific but also neutral regarding solution and technology. SGAM

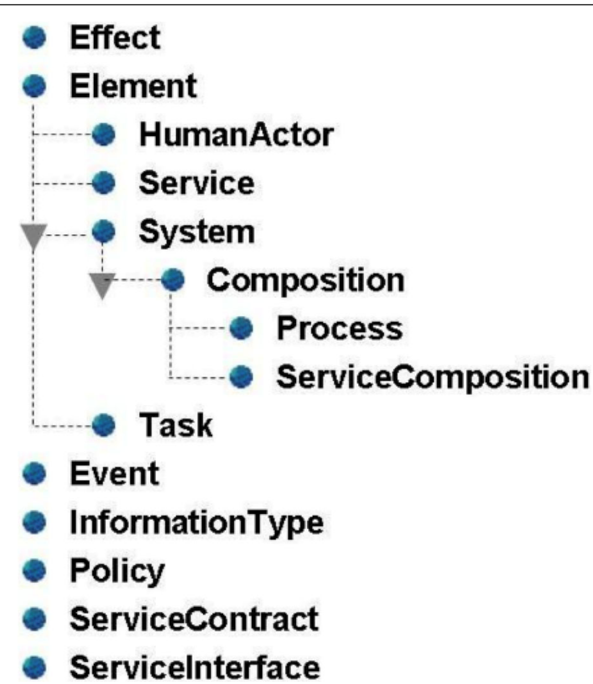

Fig. 4 SOA ontology – class hierarchy (The Open Group 2014)

Table 4 Ontology Tools, Latest Version, and Release Date

Ontology tool	Latest version	Release date	Reference
IsaViz	IsaViz 3.0-alpha	May 2007	(W3C 2007)
Apollo	Apollo-SV version 4.1.1	July, 2018	(hoganwr 2018)
SWOOP	SWOOP v2.3 beta 3	January, 2006	(W3C 2019)
Protégé	Protégé 5.5.0	Sept 2018	(Horridge 2018)

framework also uses the sequence diagrams to describe the information objects which are exchanged between actors.

The SGAM framework provides a guide for the smart grid architecture, and it does not directly apply the SysML (Systems Modeling Language) for the architecture design. SysML is well known as a general-purpose architecture modeling language for system engineering applications (shown in Fig. 5) that is adopted by the Object Management Group (OMG) in 2006 (SysML.org 2019). SysML is defined as an extension of a subset of the UML using UML's profile mechanism (SysML Forum n.d.) (shown in Fig. 6). There are a number of SysML Modeling Tools for the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems (SysML-tools.com n.d.).

Ecological modeling

Biological Ecosystem

The term ecosystem was firstly used by A. G. Tansley in 1935, and he defined an ecosystem as *'a particular category of physical systems, consisting of organisms and inorganic components in a relatively stable equilibrium, open and of various sizes and kinds'* (Tansley 1935). Later, the definitions of ecosystem emphasize more on 'interaction'. For instance, the ecosystem is defined as the joint functioning and interaction (large quantities of matter, energy and information) of these two compartments (populations and environment) in a functional unit of variable size (Garcia, and Food, and A. O. o. t. U. Nations 2003).

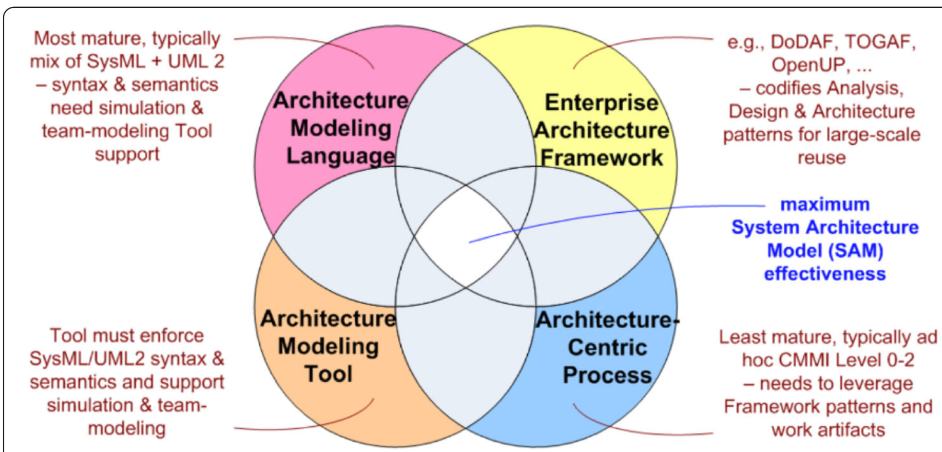

Fig. 5 MBSE (Model-Based Systems Engineering) architecture (SysML.org n.d.)

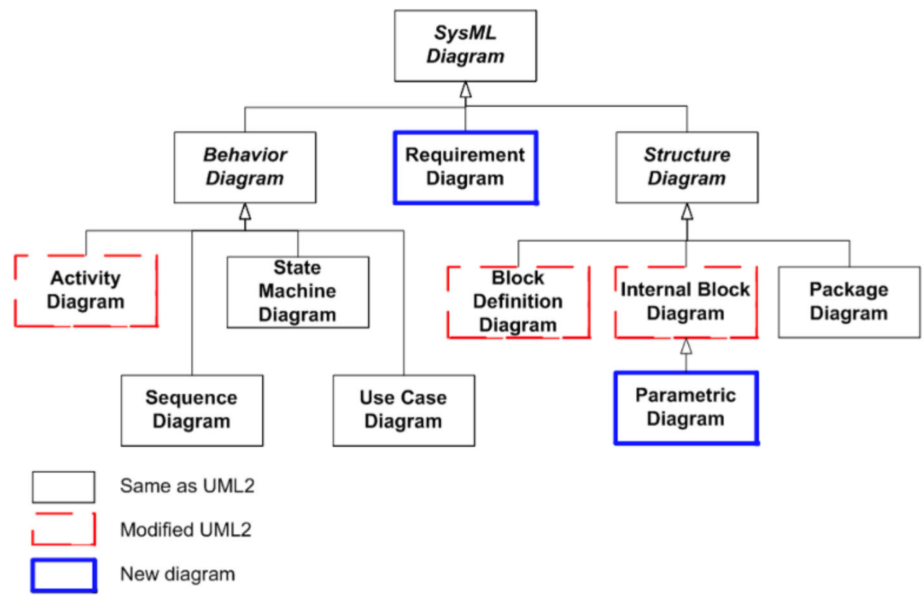

Fig. 6 SysML diagram taxonomy (SysML.org 2019)

According to (Ricard 2014), '*the "species" is the ecosystem basis and refers to all organisms of the same kind. The members of a species living in a given area at the same time constitute a population. All the populations living and interacting within a particular geographic area make up a biological (or biotic) community. The living organisms in a community together with their non-living or abiotic environment make up an ecosystem*'.

Based on the scale of ecological dynamics, ecosystems hierarchy includes ecozone, biome, ecosystem (ecological community, population, habitat/biotope), ecotone and niche (Ricard 2014).

Ecological interactions between individual organisms and entire species are often difficult to define and measure and are frequently due to the scale and context of the interactions (Harrison and Cornell 2008). Nonetheless, there are several classes of interactions among organisms that are found throughout many habitats and ecosystems, and at the coarsest level, ecological interactions can be defined as either intra-specific or inter-specific (Lang and Benbow 2013). Intra-specific interactions occur between individuals of the same species, and inter-specific interactions occur between two or more species. The main types of interspecies interactions in ecological communities are shown in Table 5.

Ecosystems are controlled both by external and internal factors, e.g. climate, soil, topography. External factors control the overall structure of an ecosystem and the way things work within it. Internal factors control ecosystem processes and are controlled by the feedback loops. Internal factors include decomposition, competition or shading, disturbance, succession and the types of species present.

Ecosystem science is the study of inter-relationships among the living organisms, physical features, biochemical processes, natural phenomena, and human activities in ecological communities (NOAA 2018). Ecosystem science investigates the areas (not limited to) of ecosystem processes, population ecology and population dynamics, disturbance and resilience, nutrient cycle, decomposition and mineralization, ecological amplitude, ecology, environmental influences, biological interactions, biodiversity, and environmental degradation. According to (Gorham and Kelly 2018), types of ecosystems, environmental factors, levels of complexity, major plants and animals, and interspecific associations have been popularly discussed in the ecosystem science.

The theories of the biological ecosystem demonstrate that the terminologies, principles and methodologies in the biological ecosystem science can be modified and applied in other disciplines, e.g. system engineering and business ecosystem research.

Ecosystem Mapping

Ecosystem mapping is the spatial delineation of ecosystems following an agreed ecosystem typology (ecosystem types), which strongly depends on mapping purpose and scale (European Union 2013). The ecosystem mapping may also include mapping of status (e.g. functioning and health) for monitoring and assessment of the ecosystem's quality.

According to a coherent analytical framework proposed by EU (2013), the ecosystem classification and mapping apply two basic principles: typological (divides nature into ecosystem types – classes that can occur at more geographical locations, e.g., temperate broadleaf and mixed forests) and regional (describes ecosystems from a regional perspective e.g., Dinaric mixed forests) or their combination.

Ecosystem services are an important part of the ecosystem mapping that describe the ways that humans are linked to and depend on nature. There are different definitions of ecosystem services ((La Notte et al. 2017) summarizes the definitions provided in recent ecosystem services studies). For instance, MA (The Millennium Ecosystem Assessment) defines ecosystem services as "the benefits people obtain from ecosystems" (Millenium Ecosystem Assesment 2005), and ecosystem services are defined as the contributions that ecosystems make to human well-being by CICES (the Common International Classification for Ecosystem Services) (European Union 2013). The conceptions of ecosystem services have been discussed in different domains, e.g. natural science, economics and policy (Danley and Widmark 2016).

There are three international classification systems available to classify ecosystem services: MA (Millennium Ecosystem Assessment 2005), TEEB (The Economics of

Table 5 The Main Types of Interspecies Interactions in Ecological Communities (Khan Academy 2016)

Name	Description	Effect
Competition	Organisms of two species use the same limited resource and have a negative impact on each other.	- / -
Predation	A member of one species, predator, eats all or part of the body of a member of another species, prey.	+ / -
Herbivory	A special case of predation in which the prey species is a plant.	+ / -
Mutualism	A long-term, close association between two species in which both partners benefit.	+ / +
Commensalism	A long-term, close association between two species in which one benefits and the other is unaffected.	+ / 0
Parasitism	A long-term, close association between two species in which one benefits and the other is harmed.	+ / -

Different types of interspecific interactions have different effects on the two participants, which may be positive (+), negative (–), or neutral (0)

Ecosystems and Biodiversity n.d.) and CICES (n.d.). Ecosystem services categories in CICES are provisioning services, regulating and maintenance services, and cultural services (Haines-Young and Potschin 2018). CICES does not include the 'supporting services' in MA, but merges the 'habitat services' from TEEB with regulating services, in a category called 'regulating and maintenance services' (La Notte et al. 2017).

Compared to others, CICES promotes a clear distinction between ecosystem services and ecosystem benefits, and can help negotiate the different kinds of perspective that have developed around the ecosystem service concept and assist in the exchange of information about them (Haines-Young and Potschin 2012). CICES describes 'final ecosystem services' using a five-level hierarchical structure, and the way the system works can be illustrated in Fig. 7 (CICES n.d.). Meanwhile, the ecosystem service cascade also presents the relations between the environment and the social & economic system, and services can have social as well as economic value (Haines-Young and Potschin 2013).

Compared to CICES that places greater emphasis on the ecological system, FEGS-CS (Final Ecosystem Goods and Services Classification System) (United States Environmental Protection Agency (EPA) n.d.) and NESCS (the National Ecosystem Services Classification System) (Landers 2015) mainly focus on benefits and beneficiaries (described in (Landers and Nahlik 2013)). Based on the comparison between CICES and FEGS-CS (La Notte et al. 2017; Bordt 2016), this paper recommends including benefits and beneficiaries in the business ecosystem modeling because benefits and beneficiaries are an important aspect in the business ecosystem. However, there is a lack of discussion regarding whether CICES and FEGS-CS can be compatible. The Swiss Federal Office for the Environment (FOEN) proposes an 'Inventory of Final Ecosystem Goods and Services' (FEGS) and include four Benefit categories (health, security production factors and natural diversity) (Staub et al. 2011). The FEGS aims to be integrated into the MA and CICES Classifications.

Ecosystem mapping is the first step to investigate an ecosystem, it is also necessary to assess the state of ecosystems and their services. Therefore, the EU Working Group on Mapping and Assessment on Ecosystems and their Services (MAES) proposes a 4-step approach (European Union 2013) for mapping and assessment of ecosystems and their services, and proposes an integrated analytical framework and set of indicators for mapping and assessing the condition of ecosystems (Maes et al. 2018) (shown in Table 6).

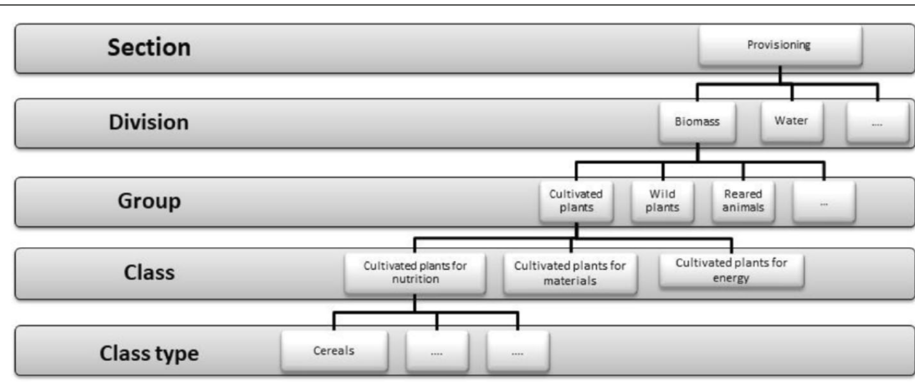

Fig. 7 The five-level hierarchical structure of the ecosystem services by CICES (CICES n.d.)

Ecosystem Modeling

Ecosystem modeling is also called ecological modeling. An ecosystem model is an abstract representation of an ecological system which is studied to better understand the real system (Hall and Day 1990). Ecological modeling can be simply categorized as conceptual models and quantitative models. Generally, conceptual models are written as diagrams with boxes (represent state variables or condition of the ecosystem components) and arrows (illustrate relationships among state variables), and a quantitative model is a set of mathematical expressions of coefficients and data attached to the boxes and arrows in the conceptual models (Jackson et al. 2000). Quantitative models are more precise and specific about a system and can make predictions when they capture the key elements for system representation (Bondavalli et al. 2009). There are three main types of ecosystem modeling and the choice of model type and detail depends on the system studied, the questions asked, and the data available (Jackson et al. 2000).

Two computational modeling approaches are popularly used for ecological modeling: agent-based models (ABM) and system dynamics models. Agent-based models are used to describe disaggregated parts of a system, system dynamics models represent the aggregated system (in the form of stocks and flows) (Martin and Schlüter 2015). The approach of agent-based modeling aims to study complex adaptive systems, and focuses on micro-level interactions to explain patterns, e.g. transient dynamics on a system level. System dynamics aims to identify the set of attractors and the properties of the system near the attractors (Bousquet and Le Page 2004), and are used to '*represent, explore and simulate the complex feedback and non-linear interactions among system elements, management actions, and performance measures*' (Elsawah et al. 2017). The characteristics of agent-based and system dynamics models are different, and (Martin and Schlüter 2015) discusses the differences and proposes a hybrid approach shown in Table 7.

Besides agent-based modeling, there is an increase in applying multi-agent simulation in ecology due to the growth in CPU power. In the field of ecosystem management, the interactions between ecological dynamics and social dynamics are examined, and modelers describe systems as a set of modules or compartments interlinked by flows (of matter, energy, or information) and controls (Bousquet and Le Page 2004). Multi-agent systems are used in ecology to investigate multiple agent interactions (Huhns and Stephens 1999). Multi-agent system originally came from the field of artificial intelligence, and is a complex system that is composed by more than one distributed agents, and these agents communicate to deal with problems which usually can't be solved by a single agent (Dam and Lukszo 2006; Merdan et al. 2011).

Table 6 Mapping and Assessment of Ecosystems, Their Services and the Condition of Ecosystems (European Union 2013; Maes et al. 2018)

MAES approach	Content
Mapping and assessment of ecosystems and their services	1) Mapping of the concerned ecosystem; 2) Assessment of the condition of the ecosystem; 3) Quantification of the services provided by the ecosystem; and 4) Compilation of these into an integrated ecosystem assessment
Indicators for mapping and assessing the condition of ecosystems	Pressures and environmental quality indicators Ecosystem attributes Composite indicators

Table 7 Characteristics of agent-based and system dynamics models, and a hybrid model (Martin and Schlüter 2015)

	Agent-based model	System dynamics model	Hybrid model
Characteristic question	How do emergent system-level interaction (e.g. spatially, between individuals?)	How do stocks change or stabilize? (given that rates are constant) Which process/feedback is dominating?	How do changing process rates (impacted by decisions) affect dynamics? How do changing stocks affect agent states/the distribution of traits?
Purposes in general for all: improve system understanding rather than prediction or forecasting	To identify mechanisms (specific interactions) that are responsible for emerging system-level patterns (disaggregated) Generate hypotheses, exploration of micro-level behavior.	Investigate system-level dynamics (aggregated), stability properties of the system, loop dominance, explaining temporal dynamics, projection into the future.	Investigating different micro- or system-level mechanisms that drive certain dynamics. Generate hypotheses of system state-change (when does dominance of feedbacks change?) or structural development over time (when does an average trait of agents change?)
Focus	Micro-level interactions between entities, network structure (heterogeneous characteristics of individuals/actors, temporal discrete behavior), transient dynamics.	Processes driving accumulation in stocks at (sub-)system level, stable-states, feedbacks (balancing, amplifying), non-linearities.	Process of restructuring in a system which can focus either on a structure affecting the processes, or processes affecting the structure.
Tests for model calibration	Statistical pattern matching-can the model grow patterns that are found in reality?	Stability analysis-under which parameter setting can fixed points/equilibria occur? How stable are they?	Separate sub-system test (paradigm specific) and qualitative check for the coupled version.
Suitable and traditional analysis tools, typical experiments	Only through simulations, often with multiple repetitions because of stochastic elements: plotting group/system-level characteristics over time (average), evaluation a limited parameter range, describing transient dynamics.	Simple models through analytical tools (basins of attraction, bifurcation analysis, overall stability), and more complex through simulations (state space plots from simulations, evaluating stable-states, equilibria.)	Through simulations with a focus on either 1. change in structure/ parameters: how does it affect the dynamics? 2. Change in dynamics: how does it affect the structure?
Type of outcome	Emerging spatial/agent patterns, scenario comparison between structurally different model versions, system properties such as the average state of a population.	Aggregated system properties in terms of stability, loop dominance.	Time series of merging state-transitions.

Smart grid

Smart Grid Architecture

The concept of the smart grid is built upon the intersection of technology, people and infrastructure for intelligent generation, transmission, distribution and consumption of electricity (Geelen et al. 2013). A smart grid can be defined in terms of the socio-technical network with enhanced two-way communication and active management of information and energy flows that allow controlling the practices of distributed generation, storage, consumption and flexible demand (Wolsink 2012).

There are many different definitions of a smart grid that emphasizes different aspects (Ma et al. 2015). To have a holistic view of the smart grid with multiple stakeholders, multiple applications, multiple networks, it is necessary to investigate the smart grid architecture. There are several smart grid models have been proposed and discussed, e.g. the smart grid conceptual model introduced by The National Institute of Standards and Technology (NIST) (2018) and SGAM Framework developed by CEN (the European Committee for Standardization), CENELEC (the European Committee for Electrotechnical Standardization), and ETSI (the European Telecommunications Standards Institute) (CEN-CENELEC-ETSI Smart Grid Coordination Group 2012).

Compared to other smart grid models or framework, the SGAM Framework can give an overall picture of the smart grid with the description of the major elements, integrate other models and architectural frameworks, e.g. GWAC (GridWise Transactive Energy Framework) (The GridWise Architecture Council 2015) and TOGAF (The Open Group n.d.-a), etc. The SGAM framework spans three dimensions: domain, interoperability (layer) and zone (shown in Fig. 8, and explained in Table 8), and it visualizes the relations among these three dimensions with multi-layers.

Smart Grid Actors and Roles

Actors and roles have been emphasized in the SGAM framework, especially in the business layer. The main actors of the smart grid and their main interactions are described in the smart grid conceptual model (The National Institute of Standards and Technology (NIST) 2010). The smart grid conceptual model provides an overall high-level view of the smart grid system, and actors and roles are introduced in each domain (shown in Table 9).

Meanwhile (The National Institute of Standards and Technology (NIST) 2010), also gives clear definitions of the domain and actors:

- Smart Grid domain: '*is a high-level grouping of organizations, buildings, individuals, systems, devices or other actors that have similar objectives and that rely on—or participate in—similar types of applications. Communications among actors in the same domain may have similar characteristics and requirements. Domains may contain sub-domains. Moreover, domains have much overlapping functionality, as in the case of the transmission and distribution domains. Transmission and distribution often share networks and, therefore, are represented as overlapping domains*'.
- Actor: '*a device, computer system, software program, or the individual or organization that participates in the smart grid. Actors have the capability to make decisions and to exchange information with other actors. Organizations may have actors in more than one domain. The actors illustrated here are representative examples but are by no means all of the actors in the smart grid. Each actor may exist in several different varieties and may actually contain other actors within them*'.

The SG-CG/SP SG-CG (Sustainable Processes Work Group) defines the actors into system actors and business actors (CEN-CENELEC-ETSI Smart Grid Coordination Group 2012.):

- System actors: cover functions or devices, for example, defined in the Interface Reference Model (IEC 61968–1) (IEC 2012). A system actor performs a task under a specific role.

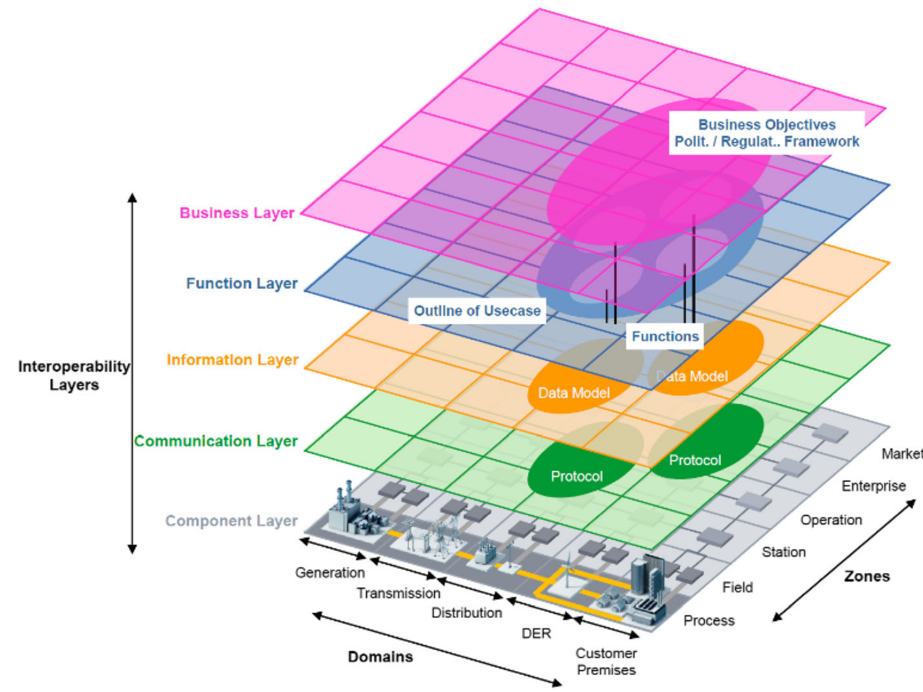

Fig. 8 SGAM framework (CEN-CENELEC-ETSI Smart Grid Coordination Group 2012)

- A business actor: '*specifies, in fact, a « Role » and will correspond 1:1 with roles defined in the eBIX harmonized role model (possibly some new roles will be required and added to the eBIX model)*'.

The harmonized role model (E. a. e. ENTSO-E 2018) proposed by ebIX, EFET and ENTSO-E define each market role related to all the different electricity markets in Europe. An example of the roles and description in the harmonized role model is shown in Table 10. UML class diagramming is used in the harmonized role model, that the "actor" symbol is used to represent a role and the "class" symbol is used to define a domain (shown in Fig. 9).

However, the definition of a business actor corresponds 1:1 with a role (E. a. e. ENTSO-E 2018; IEC 2012) does not comply in all smart grid system. Unbundling is defined by EU (European Commission n.d.) as 'the separation of energy supply and generation from the operation of transmission networks'. Comparatively, in the bundling electricity market structure, the energy supply and generation might not be separated from the operation of transmission network, and one actor can hold one or more than

Table 8 Table Styles Terms and Definitions in the SGAM Framework (CEN-CENELEC-ETSI Smart Grid Coordination Group 2012)

Terms	Definitions
SGAM Interoperability Layer	To allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GridWise Architecture model are aggregated in SGAM into five abstract interoperability layers.
SGAM Domain	One dimension of the Smart Grid Plane covers the complete electrical energy conversion chain, partitioned into 5 domains.
SGAM Zone	One dimension of the Smart Grid Plane represents the hierarchical levels of power system management, partitioned into 6 zones.

Table 9 Domains and Actors in the Smart Grid Conceptual Model (The National Institute of Standards and Technology (NIST) 2010)

Domain	Actors in the Domain
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the movement of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

one roles. For instance, the actor-utility in the Chinese electricity market corresponds to the roles of transmission operator, distribution operator, and electricity supplier.

To clarify the relations between actors and roles, the CEN-CENELEC-ETSI Smart Grid Coordination Group defines actors and roles in the smart grid as (CEN-CENELEC-ETSI Smart Grid Coordination Group 2014):

- An actor: '*represents a party that participates in a business transaction. Within a given business transaction an actor performs tasks in a specific role or a set of roles*'.
- A Role: '*represents the intended external behavior (i.e. responsibility) of a party. Parties cannot share a role. Parties carry out their activities by assuming roles, e.g. system operator, trader. Roles describe external business interactions with other parties in relation to the goal of a given business transaction*'.

These definitions can better represent the relations between actors and roles in a smart grid.

Value Flows in the Smart Grid

Besides the emphasis on actors and roles in both the business layer in the SGAM framework and in the conceptualization of the business ecosystem, interactions between actors are also important and well discussed in both the SGAM framework specification and business ecosystem litterature.

For instance, in the SGAM conceptual model, actors are connected by associations, the exchanged information is defined as business services, and actors interact through these business services. However, the description of the associations or

Table 10 An Example of the Roles and Descriptions in the Harmonized Role Model (E. a. e. ENTSO-E 2018)

Role	Description
System operator	Has overall responsibility for creating balance in the market and for handling transmission grid operation and ensuring stable electricity supply.
Grid Operator	A party that operates one or more grids
Meter Operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters.

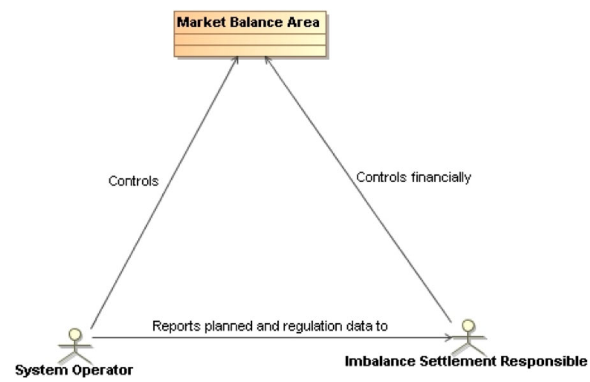

Fig. 9 An example of the role and domain relationships in harmonized role model (E. a. e. ENTSO-E 2018)

business services is not detail discussed in the SGAM framework. Meanwhile, although processes/ interactions between actors are described in the harmonized role model (E. a. e. ENTSO-E 2018) and IEC standards (e.g. 61,850) (Energinet 2019), the described interactions in (E. a. e. ENTSO-E 2018; Energinet 2019) are mainly technical related information, and there is no methodology for systemically defining and describing the interactions between actors in the smart grid.

In the theory of the business ecosystem, especially the service ecosystem, value co-creation is well discussed for the understanding of interactions between actors, e.g. (Palumbo et al. 2017). Value co-creation is driven by the collaborative efforts of and interactions between actors in the ecosystem (Pop et al. 2018). Value can be tangible and intangible (Ciasullo et al. 2017), and at different levels: micro (e.g., households, organizations, etc.), meso (e.g., industries, communities, etc.), and macro (e.g., nations, global markets, etc.) (Frow et al. 2016). However, the types of value are not defined in the ecosystem theory, but value constitutesis an important part of the ecosystem modeling to define and clarify the interactions between actors.

TOGAF® standard (The Open Group 2017) provides a definition of the three value related terms: value chains, value networks, and lean value streams:

- *The value chain takes an economic value perspective;*
- *Value networks are primarily concerned with identifying the participants involved in creating and delivering value;*
- *Lean value streams are all about optimizing business processes (primarily within a manufacturing context).*

However, TOGAF mainly focuses on the value streams that a focal organization is related to, e.g. value stream of acquiring the retail product (shown in Table 11), and the interaction between actors in an ecosystem is missing. Although value network is also mentioned in TOGAF, there is no detail, especially no definition or description of the types of value between businesses or enterprises. One of the advantages of the TOGAF value analysis is that there is a guideline for the systematic analysis and mapping not only the static value stream but also stages of a value stream. This guideline includes:

1) *Value Stream Modeling Relationships with an external stakeholder value stream mapping*
2) *Decomposing the value stream into a sequence of value-creating stages*
3) *Mapping value stream stages to business capabilities and performing a gap analysis*
4) *Heat-mapping Scenario and decision-making processes*

Business ecosystem modeling

The investigation of the system engineering and biological ecosystem modeling shows that there are similarities and differences between these two fields. For instance, ecosystem theory focuses on interaction (ecosystem services), the ecosystem itself (e.g. the types of ecosystem, the assessment of the ecosystem), and the hierarchy of the ecosystem. Ecosystem mapping is similar as the system modeling, and ecosystem modeling is more abstract (usually mathematical modeling) and focuses one/several aspects in the ecosystem, and system modeling mainly focuses on the architecture of a system with ICT (Information and Communication Technology) auxiliary.

Although ecosystem theory discusses species, it mainly focuses on the interaction between species (interspecies and inner species). Comparatively, system engineering emphasizes actors and their roles. The interactions between actors are also discussed in the system engineering, but not systematic as in the ecosystem theory, and mainly use the UML diagrams to describe the interactions.

Standards are important in both ecosystem mapping and system engineering that allow better understanding and consistency in practice. However, there are concerns about which standards should be applied and whether there is a compatibility issue between standards. Meanwhile, different domains or theoretical/practice fields have their own ontologies that raise the inconsistency issue in the interdisciplinary research, especially, if there is ontological overlap across domains (e.g., different ontologies describe the same thing in different domains).

System modeling mainly aims to visualize the static status of a system, although the system changes are also discussed in system engineering. The ecosystem modeling aims to investigate the system dynamics by establishing models or simulations (usually mathematic modeling). The static status and dynamics are both important for the business ecosystem modeling.

The biological ecosystem theory (especially the ecosystem mapping) and system engineering (especially the system modeling) can contribute to the business ecosystem modeling for different aspects. The ecosystem mapping mainly contributes to the theoretical aspects, e.g. the categories of interactions and system dynamics. There are several standards in system modeling, e.g. ISO, SGAM, TOGAF, and UML that can contribute to the practices of the business ecosystem modeling.

Table 11 An Example of Value Strem of Acquiring Retail Product in TOGAf (The Open Group 2017)

Name	Acquire Retail Product
Description	The activities involved in looking for, selecting, and obtaining a desired retail product.
Stakeholder	A retail shopper wishing to purchase a product.
Value	Customers are able to locate desired products and obtain them in a timely manner.

Based on these contributions, this paper proposes the following framework for the business ecosystem modeling including three parts and nine stages (shown in Table 12). This framework combines theories from both business ecosystem, system engineering and ecology. The corresponded theories from these three research fields are shown in Table 13.

Conclusion

The history of the business ecosystem field shows that the concepts of ecology and system engineering have been applied in the field, and especially the term and fundamental elements of the 'business ecosystem' originally came from ecology. However, the 'business' aspect is still the main focus in the business ecosystem field, not so much attention of the 'system' aspect in the research compared to the fields of system engineering and ecology. This paper proposes a framework for business ecosystem modeling to fill this gap.

The proposed framework includes three parts and nine stages that combine theories from system engineering, ecology, and business ecosystem. Part I-Business ecosystem architecture development includes four stages which aims to identify a target business ecosystem and its elements (actors, roles, and interactions). Part II-Factor analysis includes two stages to identify potential changes (and the dimensions of the changes) in the ecosystem. Part III- Ecosystem simulation and reconfiguration aims to use simulations to investigate the transition of an ecosystem and the re-configurated ecosystem.

The proposed framework not only provides a systematic approach for modeling a business ecosystem, but also provides a methodological foundation for research on the aspect of complex systems in the business ecosystem field. Meanwhile, it brings the practices of business and engineering together, therefore, provides a common language for a better understanding across the business ecosystem, system engineering and innovation management.

The application of the smart grid not only demonstrates a well-defined and structured system that was missing in the business ecosystem, but also presents the importance of standards in the system engineering. Meanwhile, the SGAM framework

Table 12 The Framework and Steps of the Business Ecosystem Modeling

Part	Stage	Business ecosystem modeling
Part I Business ecosystem architecture development	1	Identify the boundary of a selected ecosystem.
	2	Identify actors and their roles in the ecosystem.
	3	Identify actors' value propositions and business models.
	4	Identify interaction between actors (different types of interactions.)
Part II Factor analysis	1	Investigate influential factors and their impact on the elements in the ecosystem (actors, roles, and interaction.)
	2	Investigate potential changes in the ecosystem.
Part III Ecosystem simulation and reconfiguration	1	Multi-agent based ecosystem modeling to identify ecosystem reaction towards the potential changes.
	2	Ecosystem reconfiguration (including reconfiguration of actors, roles, and interaction) due to changes, system dynamics modeling might be applied at this stage.
	3	Business model reconfiguration.

Table 13 The Business Ecosystem Modeling With The Integration of System Modeling and Ecosystem Theory

Business ecosystem modeling	Business ecosystem	System engineering	Ecology
Part I- Stage 1 Identify the boundary of a selected ecosystem.	Domain oriented business ecosystem. Innovation ecosystem. Digital ecosystem.	Ontology development. System architecture .	Types of ecosystem. Ecosystem hierarchy.
Part I- Stage 2 Identify actors and their roles in the ecosystem.	Stakeholders. Business models.	Domain ontology. System standards.	Categories of organisms (Lundberg and Moberg 2003)(producers, consumers, decomposers.) Types of keystone species (Mills et al. 1993) (predators, mutualists, engineers.)
Part I- Stage 3 Identify actors' value propositions and business models.	Business model (Zott and Amit 2013). Value creation (Clarysse et al. 2014).	Business services. Value stream.	Ecosystem function and biodiversity (Duffy 2002).
Part I- Stage 4 Identify interaction between actors (different types of interactions.)	Value co-creation. Value flows (Matthies et al. 2016) (monetary, product, information and intangible.) Social network analysis (Ashton 2008).	Flows (e.g., information exchange.) Associations (in UML diagram.) Service-oriented architecture (in TOGAF.)	Intra-specific & inter-specific ecological interaction. Ecosystem services Matter, energy and information flows.
Part II- Stage 1 Investigate influential factors and their impact on the elements in the ecosystem (actors, roles, and interaction.)	–	Motivation and strategy (in ArchiMate.) System thinking (Rubenstein-Montano et al. 2001). machine logic (Polic and Jezernik 2005).	Assessment and indicator of ecosystem conditions.
Part II- Stage 2 Investigate potential changes in the ecosystem.	Emergence and co-evolution (Peltoniemi and Vuori 2004b).	Risk management/ assessment (Sage and Rouse 2014).	Ecosystem change (Elmqvist et al. 2003).
Part III- Stage 1 Multi-agent based ecosystem simulation to identify ecosystem reaction towards the potential changes.	Multi-agent-based models (Lurgi and Estanyol 2010).	System dynamics (Karnopp et al. 2012).	System dynamics Multi-agent based modeling.
Part III- Stage 2 Ecosystem reconfiguration (including reconfiguration of actors, roles, and interaction) due to changes.	Business ecosystem lifecycle (Rong et al. 2015).	System lifecycle management (Sage and Rouse 2014).	Evolution of ecosystems (Azaele et al. 2006).
Part III- Stage 3 Business model recofiguraation.	Business model innovation (Chesbrough 2010).	–	–

illustrates the complexity of the smart grid, and indicates that the business ecosystem modeling for a complex system as the smart grid should consider the layers of several interactive business ecosystems that might cross multi-domains. Therefore, the importance of ontology design is obvious in the business ecosystem modeling, and the design of the business ecosystem ontology should include both domain ontology (e.g. standards in the domain) and business ontology.

There are many subjects in the fields of ecological modeling and system engineering, and lots of them can contribute to the business ecosystem modeling. This paper does not cover all these subjects, and mainly aims to provide a prompt for an open thread. Meanwhile, although each part in the proposed framework combines theories from the fields of system engineering and ecology, detail description and examples are recommended in the future work, especially the application of multi-agent systems and system dynamics in the business ecosystem. Multi-agent systems and system dynamics have been popularly applied in the system engineering and ecological modeling for different purposes. However, the application of these two in the business ecosystem is limited, especially without a domain focus, e.g. (Lurgi and Estanyol 2010; Marín et al. 2007; Camarinha-Matos and Collaborative Business Ecosystems and Virtual Enterprises 2013).

Abbreviations

ABM: Agent-based model; CEN: The European Committee for Standardization; CENELEC: The European Committee for Electrotechnical Standardization; CICES: The Common International Classification for Ecosystem Services; DoDAF: The Department of Defence Architecture Framework; ETSI: The European Telecommunications Standards Institute; FOEN: The Swiss Federal Office for the Environment; GWAC: GridWise Transactive Energy Framework; ICT: Information and Communication Technology; MA: The Millennium Ecosystem Assessment; MAES: Mapping and Assessment on Ecosystems and their Services; NESCS: The National Ecosystem Services Classification System; NIST: The National Institute of Standards and Technology; OEMA: Ontology for Energy Management Applications; SGAM: Smart Grids Architecture Mode); SG-CG/SP SG-CG: Sustainable Processes Work Group; SOA: Service-Oriented Architecture; SysML: Systems Modeling Language; TEEB: The Economics of Ecosystems and Biodiversity; TOGAF: The Open Group Architecture Framework; UML: Unified Modeling Language

Acknowledgements

Not applicable.

Authors' contributions

ZM carried out the the paper design and writing. The author read and approved the final manuscript.

Funding

This paper is completed under no funding.

Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Ethics approval

Not applicable.

Consent for publication

Not applicable.

Competing interests

The author declares that she has no competing interests.

Received: 24 September 2019 Accepted: 26 September 2019
Published online: 21 November 2019

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