Towards A Model-Based Multi- Perspective Valuation Method for Smart Grid Initiatives: Foundations, Open Issues, and a Research Outlook

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Abstract

Information Technology (IT) is increasingly used in the electricity grid to cope with its multiple challenges, leading to its transformation into a so-called "smart grid". While there exist various technically feasible pilot smart grid initiatives, a subsequent assessment of their "value" is a non-trivial task given the notion of value in smart grid projects. The notion of value usually encompasses, among others, readily quantifiable benefits as well as qualitative ones, of different types (economic, social, environmental), which must be assessed for single actors as well as for a network of actors. To support this assessment, several smart grid valuation methods have been proposed, and subsequently adopted in practice. Although those methods are actively used, a question appears to what extent they address all important factors relevant for smart grid valuation. To answer this question, in this technical report, we carry out a literature analysis aiming at (1) identifying existing valuation methods and the steps they propose, (2) identifying important valuation considerations, and (3) confronting these considerations with artifacts proposed by the existing valuation methods to identify open issues that should be tackled. Based on the conducted analysis, we identify, among others, the following main deficiencies: (1) only a limited scope of concerns relevant to valuation is covered, particularly a systematic consideration of stakeholders goals, value exchange scenarios, and IT infrastructure is lacking; and (2) a lack of instruments dedicated to fostering accessibility of valuation, in terms of establishing a shared understanding, communicating results, or actively involving different stakeholders in the process.

The findings reported here correspond to the first stage of a larger project aiming at the development of a modeling method for the multi-perspective valuation of smart grid initiatives.

Chapter 1

Introduction

The energy sector is increasingly employing Information Technologies (IT) to monitor and manage the generation, storage, transmission, and consumption of electricity from all generation sources, in order to increase efficiency, maximize system reliability and end-user satisfaction, while minimizing costs and environmental impacts [36, 37, 49]. This leads to the transformation of the electricity grid into a "smart grid" [36]. Motivated by the liberalization of the electricity sector [77, 62], technology expectations, and substantial subsidies for private and public-private initiatives, many smart grid initiatives emerge, e.g., [58, 3, 34, 59].[1] However, despite of their demonstrated technical feasibility and promised benefits, the adoption rate of smart grid technologies is still low [14]. Among all the hindering factors, [72, 10] point to the lack of a concrete value proposition that provides benefits for all stakeholders as an exacerbating barrier.

The assessment of "value" of smart grid initiatives for all involved stakeholders is however, not a trivial task, cf. [58, 68, 43, 20, 15, 24], as it entails a wide range of aspects, among others: (1) analyzing both readily *quantifiable* smart grid benefits (e.g., lower transaction costs), as well as *qualitative* benefits (e.g., protection of the environment); (2) accounting for different *types of values*, such as economic, social, and environmental [18]; (3) for both, *individual actors* (e.g., end consumers) and *a network of actors* (e.g., the entire society); and finally, (4) considering valuation as *weighting benefits against costs* [66], whereby "costs" can be equally perceived as quantitative and qualitative, pertaining to different types of value and concerning to both an actor and a network of actors.

Considering the complexity of valuation in particular, and sense-making of a smart grid initiative in general, a valuation method is needed that guides interested parties through a valuation process. To this end, various valuation methods have been proposed [20, 15, 24]. They follow defined steps for smart grid assessment and associate each step with corresponding analysis questions and artifacts. Although those methods are actively used, a question appears to what extent they address all important factors relevant for smart grid valuation. To answer this question, in the **first part** of this technical report (Chapter 2), we carry out a literature analysis aiming at (1) identifying existing valuation methods and the steps they propose, (2) identifying important valuation considerations, and (3) confronting these considerations with artifacts proposed by the existing valuation methods to identify open issues that should be tackled. Based on the conducted analysis, we identify, among others, the following main deficiencies: (1) only a limited scope of concerns relevant to valuation is covered, particularly a systematic consideration of stakeholders goals, value exchange scenarios, and the IT infrastructure is lacking; and (2) a lack of instruments dedicated to fostering accessibility of valuation, in terms of establishing a shared understanding, communicating results, or actively involving different stakeholders in the process.

Taking the above into consideration, in the **second part** of this technical report (Chapter 3), we argue that there is a need to extend the capabilities of existing valuation methods. We also argue that such an extension requires instruments that would help dealing with complexity, increase understanding, and enable communication between involved stakeholders. A promising instrument seems to be the application

[1] For an overview of smart grid investment programs see, e.g., [51, p. 2] [10].

of conceptual modeling, since, among others: (1) different modeling languages applied together offer a *multi-perspective* view on a smart grid initiative, thus dividing the complex notion of valuation into smaller, more manageable parts; (2) the application of a modeling language forces one to be concrete, which is especially beneficial with a fuzzy term such as valuation; (3) the use of conceptual modeling fosters communication among stakeholders. As such, it promotes a shared understanding of the value underlying a technically feasible initiative; and (4) conceptual modeling facilitates (semi-)automated reasoning, enabling the calculation of cash flows, and reasoning on goal fulfillment. Therefore, in the second part of this technical report, we analyze existing modeling approaches and their suitability to deal with the open issues identified.

Finally, in Chapter 4, the technical report provides general conclusions as well as a some ideas for future work.

Chapter 2

Valuation and Smart Grids

Valuation may be defined as an analytical process of determining the current (or projected) worth, i.e., the value, of something [32, 48, 4, 39, 5]. Various valuation methods have been proposed [32, 48, 4], to be used either when trying to decide on a future investment or when assessing the results of an investment project already carried out. Cost-benefits analysis (CBA) is a technique often used in these valuation methods, which concerns a systematic process for comparing the benefits (i.e., all gains) and costs of a given initiative [39, 5]. The gains and losses should be expressed in monetary terms irrespective to whom they accrue [39].

2.1 Literature analysis

In order to achieve an overview on the important factors of valuation for smart grids initiatives, we conduct a literature review, following the guidelines proposed by Kitchenham et al. [46], [47], and Okoli [60]. More specifically, the aim is to answer the following questions: (1) what valuation methods for smart grids exist? (2) what are the typical steps they follow? (3) what are important considerations in the steps of a valuation method, both in terms of valuation generally, and valuation for the smart grid in particular? And finally, (4) what open issues can we identify, when we confront the considerations of surveyed methods with the artifacts they provide?

We focus on the following types of literature: (1) studies proposing valuation methods for smart grids initiatives; (2) studies applying smart grid valuation methods to specific initiatives; and (3) systematic literature analyses conducted in this field. To identify relevant studies, we conducted a systematic search in the following publication databases: Google scholar, Scopus, and Ingenta connect, taking into account their reported characteristics [16]. More specifically, in addition to scholarly publications, Google scholar includes also relevant approaches outside of the scientific community, e.g., from governmental bodies or working groups. Likewise, Ingenta connect has been included for its potential to gain additional variety in the search results.

All types of documents are considered in our analysis, namely both academic peer reviewed sources and non-peer reviewed technical reports and white papers. An important reason for including non-peer reviewed material is that bodies, such as Electric Power Research Institute, International Energy Agency, and various EU groups dedicated to the electricity sector, publish material (e.g., methods, case studies, and reviews) relevant to us in both the peer-reviewed state of the art and non-peer reviewed sources. Of course care should be taken with such non-peer reviewed material that is included due to relevance. Furthermore, we have set no limit on the year of publication.

Figure 2.1 shows the steps of our literature analysis. After running a query on selected databases, and thus, identifying potentially relevant documents, we liberally scanned titles and abstracts for inclusion criteria, i.e., we checked whether a paper describes a smart grid valuation method and/or its application [46]. If so, we proceeded to check for exclusion criteria. We excluded an article (1) when the proposed method applies to a specific part of the smart grid only, e.g., electricity storage, hence as a result is not suitable for smart

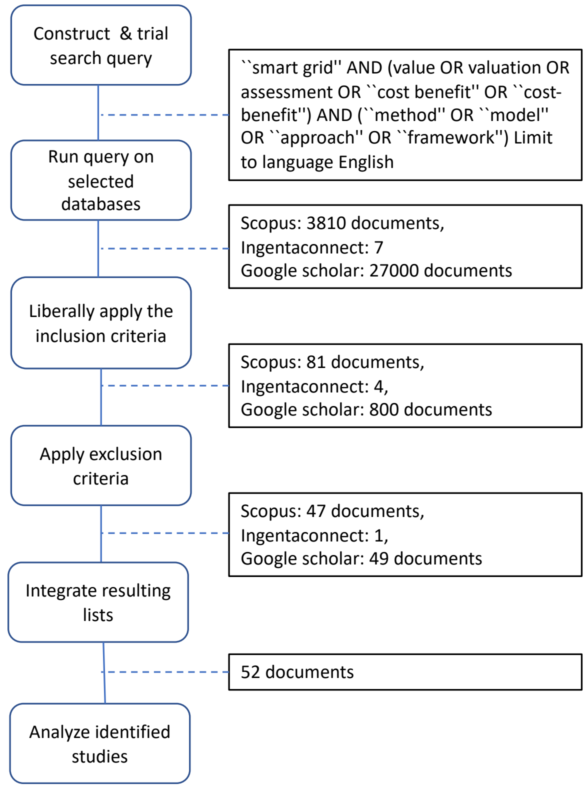

Figure 2.1: Literature Analysis

grid initiatives generally; (2) if the paper did not focus on smart grid valuation per se, but only on loosely associated aspects like electricity price forecasting; (3) when the report provided only an abstract description of its valuation method considerations, lacking substantial details; and (4) when the study possessed a notable overlap with already included work. In the case of overlaps, the paper with the most complete description of the approach was selected and used for the analysis. As the exclusion criteria require interpretation, two authors independently conducted the literature assessment. They discussed the results afterwards and found no significant disagreements. Then, the resulting lists coming from different databases have been integrated and the analysis of identified studies has been conducted.

2.2 Identified Valuation Methods

Overall, the surveyed valuation methods aim at assessing whether benefits exceed the costs of a particular smart grid initiative [11, 56, 59], such as the roll out of smart meters [79] or smart distribution system with intelligent electric vehicle charging [81]. Three main types of valuation methods have been identified: (1) methods that adapt conventional CBA for smart grid considerations and mainly focus on monetary analyses; (2) methods combining CBA with stochastic or multi-objective optimization models so as to cover both monetary and non-monetary analyses; and (3) methods that apply conceptual modeling to support CBA in terms of additional scenario exploration capabilities.

When it comes to the **first group** of approaches, in line with [56, 59, 54], our literature analysis discovered two central methods that employ conventional cost-benefits analysis for the valuation of smart grids: (i) a cost-benefit method from the Electric Power Research Institute (EPRI) of the USA, hereafter referred to as the EPRI method, and (ii) its European counterpart, a method from the European Commission's Joint

Research Centre, hereafter referred to as the JRC method.

The EPRI method [15] provides a step-wise method for evaluating costs and benefits of smart grid initiatives. It allows for business case assessment by identifying and evaluating: (1) different categories of benefits, such as economic, environmental, reliability, safety, and security; and (2) associated costs, particularly those associated with the assets required for carrying out the smart grid initiative. The EPRI method is a dominating reference and has been employed in many smart grid initiatives, e.g., [9, 55, 52, 1, 6, 51, 44]. Nevertheless, the EPRI method has several shortcomings. Among others, the EPRI method emphasizes the (in part) outdated electricity infrastructure of the USA [75], as apparent in the prevalence of benefit types that focus on grid stability, reduction of power outages, and energy security.

The JRC method, meanwhile, has adapted the proposed EPRI method to the European context [59, p. 32]. All in all, the JRC method, compared to EPRI, places more emphasis on (1) non-monetary quantification considering, e.g., environmental impacts such as CO_2 reduction, and on (2) sensitivity analysis [20].

The **second group** of smart grid valuation methods rely on multi-attribute decision strategies [54, 64, 59]. As opposed to JRC/EPRI, which rely heavily on extensive data sets and on monetization, such multi-attribute valuation methods emphasize also non-monetary assessment in terms of the satisfaction of stakeholder objectives [59, p. 32] [64, pp. 26–28]. As such, these methods are often considered as a complement to the conventional CBA methods mentioned in the first group. For example, [78] employ the Analytic Hierarchy Process (AHP), a particular multi-criteria decision making approach, in tandem with a conventional cost-benefit analysis by means of the JRC method, so as to enable both monetary and non-monetary assessment of the smart grid initiative at hand.

Finally, the **third group** of valuation methods relies on conceptual modeling. We could find a couple of papers, cf. [23, 22], that actively use value modeling as part of their CBA. In particular, we found the BUSMOD method [24, 45]. BUSMOD is promising to consider, since it centers on value modeling. Such value modeling allows for systematic scenario exploration of alternative constellations of actors involved in a smart grid initiative in terms of who exchanges value with whom. BUSMOD provides a process model to develop a description of a business case as an overview of the needed actors and value exchanges, with a cash flow calculation to signal the profit or loss for each involved actor. However, despite BUSMOD hints at the relevance of other perspectives informing valuation, such as inventorying and analyzing the required technologies [45, p. 140], it focuses on value-exchange modeling only. Moreover, the BUSMOD tasks and guidelines per step are too pragmatic, being limited to, e.g., plain-text tables, to analyze complex phenomena such as actor goals or smart grid assets.

2.3 Typical Analysis Steps

In answering the second question *"what are the typical steps in analyzed valuation methods?"*, we find that despite minor differences, both conventional cost-benefit analysis methods (first group of approaches), and the conceptual modeling method BUSMOD (third group of approaches), follow similar steps. This is also in line with surveys on smart grid valuation [11, 56, 59]. These steps are: (1) business case description, in terms of, e.g., project goals, involved stakeholders, and legal setting, and a rough sketch of the involved assets; (2) technology identification, mainly as a preparation to the cost-benefit identification in the next step; (3) cost-benefit identification, in terms of quantification as a preparation for further analysis; (4) costs-benefit analysis, to compare costs and benefits, e.g., by means of Net Present Value; and finally (5) sensitivity analysis of the main parameters. Note that these steps have feedback loops between them. For example: detailing the assets during technology identification (Step 2) can sharpen the business case description (Step 1).

Multi-attribute CBA methods (second group of approaches), complementing the aforementioned cost-benefit methods, tend to follow additionally the steps of the associated decision making technique. We discuss here briefly the method proposed by [64, 78], since it is one of the few multi-attribute CBA methods whose documentation is openly available.[1] Their method, as a complement to the steps of the JRC method, follows also steps from the multi-criteria decision strategy AHP [64, pp. 19–20]. As such, it involves among others the

[1]An alternative multi-criteria CBA method, SG-MCA, is reported in the survey from [54, p. V]. However, unfortunately no clear documentation could be found.

following additional steps: (1) decision making formalization, in terms of alternatives to be considered and criteria to be assessed, and (2) a pairwise comparison, whereby roughly speaking alternatives are compared against criteria in a pairwise manner.

2.4 Considerations in Smart Grid Valuation Steps

In answering the third question *"what are important considerations in the steps of a valuation method, both in terms of valuation generally, and valuation for the smart grid in particular?"*, we build upon the typical steps summarized in the previous section, because they pertain to both conventional cost-benefit analysis methods and conceptual modeling based methods. We associate with each step the corresponding analysis questions raised in these methods in Table 2.1 and Table 2.2. Additional discussion on the considerations relevant to multi-attribute CBA methods is also provided (but not included in Table 2.1 and Table 2.2).

2.4.1 Business case description

In this step, the surveyed methods refer to considerations that are typical for a high-level project definition, such as the overall goal, and legal concerns related to the regional setting. We here zoom into two such considerations: determining the scope and conducting a goal analysis for all involved actors.

Determining the overall goals of the initiative, in line with its scoping: The methods surveyed in Tables 2.1, typically start by determining the scope of the initiative at hand in the form of a (concise) textual description of the initiative. As per the analysis questions (Q1.1 and Q1.3) we observe that, next to sketching the legal setting, for this description, outlining the overall project goals is important for both BUSMOD and JRC/EPRI.

Identifying main actors and their goals: In addition to the overall scope, as visible in the analysis questions (Q1.2 and Q1.4), both JRC/EPRI and BUSMOD recommend to identify the involved stakeholders and their goals already in an early stage, so that over the successive steps of the cost-benefit analysis both monetary and non-monetary values can be identified on a per actor basis. Moreover, BUSMOD in particular recommends to perform various goal analysis (Q1.5), such as identifying potentially conflicting and/or complementing goals between actors, and the relation between long-term project goals and short-term actor goals.

The need for goal analysis is further emphasized by multi-attribute CBA methods, which explicate non-monetary motivations as a complement to conventional cost-benefit analysis methods. In particular, in using the Analytic Hierarchy Process as a complement to the JRC method, [64, p. 8] recommends to outline goals of the initiative in question, so that goals associated to non-monetary values (such as social and environmental goals) can equally be taken into consideration at a later stage.

2.4.2 Technology identification

The specific project assets are identified as a preparation to cost-benefit identification (cf. analysis questions Q2.1 and Q2.2). In the context of smart grid initiatives, technologies pertain to both electricity sector assets (such as wind turbines) and Information Technologies (IT) assets. In this paper, we focus on the consideration of IT assets in particular.

IT infrastructure to inform cost-benefit analysis: Both JRC/EPRI and BUSMOD differentiate between IT assets and electricity sector assets, but only BUSMOD offers a separate stage for IT infrastructure analysis with a set of associated analysis questions [45, p. 140]. In particular, as shown in Table 2.1, these questions establish the groundwork for estimating IT infrastructure investments (Q2.4) based upon the qualities desired from the software and hardware (Q2.3), such as estimated downtime or network latency.

2.4.3 Cost-benefit identification

In this step, both monetary and non-monetary benefits and costs are identified and associated to actors, mainly based on the assets from Step 2. Subsequently, the costs and benefits, to the extent it is possible, are

Table 2.1: Comparison of the valuation methods JRC/EPRI and BUSMOD – Part 1

Aggregate	**Analysis questions**		**Key artifacts**	
	JRC/EPRI*	BUSMOD	JRC/EPRI*	BUSMOD
Business case description	Selection (p. 18): (Q1.1) What is the overall project objective? (Q1.2) What are the relevant stakeholders? What are regional legal concerns?	Selection (see p. 102): (Q1.3) What are the main goals to be achieved by this specific idea? (Q1.4) What are the main short-term goals of each stakeholder including customers? What are the commercial offerings?; (Q1.5) Does a goal prevent or complement any strategic or other operational goals? (Q1.6) What a goal of type "Environmental", "Market development", or "Quality and efficiency"?	(A1.1) Textual description	textual description (core business idea); (A1.2) Goal hierarchy table, Goal conflict table
Technology identification	(p. 18): (Q2.1) What are the necessary assets, both electricity sector assets and IT assets?	(p. 115): (Q2.2) What technology characteristics are essential for the business case, especially for the fulfillment of goals?; (p. 142) Selection: (Q2.3) What quality parameters need to be defined? (Q2.4) What influence do these quality parameters have on price and cost?	(A2.1) textual description of assets	(A2.2) UML deployment diagram
Cost benefit identification	Excerpt: What are functionalities for the given assets? What are potential benefits for the identified functionalities? (Q3.1) What are the social, environmental, and economic benefits associated with our initiative? (Q3.2) What are capital expenditures for a given asset? (Q3.3) What are operating expenditures for a given asset? (Q3.4) What are the beneficiaries of the benefits? (Q3.5) What are KPIs for non-monetary benefits?	Selection: (Q3.6) For the customer: is every value object estimated in monetary units and included in profitability sheets?, (Q3.7)(p. 132): Is the actor really receiving the incoming value object?, (Q3.8) (p. 132): Is the actor really offering the outgoing value object?	(A3.1) assets–functionalities matrix, functionalities-benefits matrix, (A3.2) Smart Grid Computational Tool	(A3.3) the e^3*value* method, (A3.4) the e^3*value* software tool

*any exact steps here refer to the steps from the JRC. While those of the EPRI deviate, they do so only slightly and for the sake of argument, EPRI and JRC can be treated as similar.

Table 2.2: Comparison of the valuation methods JRC/EPRI and BUSMOD – Part 2

Aggregate	Analysis questions		Key artifacts	
	JRC/EPRI*	BUSMOD	JRC/EPRI*	BUSMOD
Cost Benefit Analysis	Excerpt (p. 28) (Q4.1) What is the Benefit Cost Ratio for each of the involved actors? (Q4.2) What is the Net Present Value for each of the involved actors? (Q4.3) For JRC: for a given benefit, how does an asset perform in terms of associated KPIs?	Excerpt: (p. 150) (Q4.4) Are the profitability numbers of each actor positive? - (Q4.5) Do you have at least one profitability sheet for each actor? -Are all the in-going and outgoing objects present in profitability sheets?	Profitability calculations - Net Present Value, Internal Rate of Return (in line with EPRI), calculations supported by (A4.1) the smart grid computational tool	Use of NPV, NPV calculations supported by (A4.2) the e^3*value* software tool
Sensitivity analysis	(Q5.1) What changes in our CBA occur when varying: the discount rate, electricity consumption, or when shifting the peak load?	(Q5.2) Excerpt (p. 160): What are possible evolutionary scenarios for a business idea: scenarios which result in changed valuation functions, scenarios that result in changed numbers of scenario paths occurrences and probabilities, or scenarios that result in a changed value model structure?	Different typical parameters are suggested: varying discount rate (suggested as being important), growth rate of electricity consumption and electricity efficiency potential, as well as peak load transfer	Evolutionary scenarios, may lead to changes in e^3*value* models (models are relevant when performing the sensitivity analysis on parameters that reflect changes in the model, e.g., different value transfers in terms of value objects, actors, or otherwise)

*any exact steps here refer to the steps from the JRC. While those of the EPRI deviate, they do so only slightly and for the sake of argument, EPRI and JRC can be treated as similar.

quantified. Also, different constellations of actors are explored as a preparation for a cost-benefit analysis in the next step. We elaborate on the considerations examined in this step as follows.

Different types of values for benefits and costs: Both JRC/EPRI and BUSMOD broaden the scope beyond purely economic, profit-driven, cost-benefit analysis. Returning again to the analysis questions in Table 2.1, we find this reflected in the analysis question (Q3.1) of JRC/EPRI to consider different benefits types, in particular social, environmental, and economical benefits. Similarly, different values are also reflected in the analysis question Q1.6 of BUSMOD in terms of different goal types for goal analysis in Step 1, namely environmental, market, quality and efficiency.

In addition, as alluded to in Step 1, multi-attribute CBA methods [64, 78, 54], also assess the non-monetary values brought about by a smart grid initiative. This is exemplified by [64, p. 30], who, next to an analysis of economic goals, also propose to take into account (a) the contribution of an initiative to smart grid realization, whereby for example contributions to EU policies like CO_2 reduction are assessed, and (b) externality assessment, whereby, e.g., social impacts like customer satisfaction are assessed. While the particular types of value considered can be questioned, the main point remains: capitalizing on the main strengths of multi-attribute decision strategies, one moves beyond a purely economic-driven assessment of value.

Quantification of value: We find that the surveyed valuation methods assess value as far as it can be quantified. When it comes to monetary values JRC/EPRI turn to identifying the Capital Expenditures (CapEx) and Operating Expenditures (OpEx) of the initiative at hand (analysis questions Q3.2 and Q3.3). BUSMOD, meanwhile, focuses on monetary quantification, such as exemplified by the analysis question Q3.6: "For the customer: is every value object estimated in monetary units and included in profitability sheets?" [45, p. 151].

Quantification equally pertains to assessing the non-monetary value of a smart grid initiative, such as its environmental and societal impact. Here, JRC proposes the definition of Key Performance Indicators (KPI), as exemplified by the analysis question Q3.5: "what are KPIs for non-monetary benefits?". Elaborating on JRC, the multi-attribute CBA method proposed by [64, p. 32] equally relies on KPIs to assess the extent to which different alternatives satisfy criteria set out in the AHP analysis.

Scenario exploration by means of value exchange analysis: Finally, BUSMOD considers scenario exploration with a focus on different value exchanges between actors, as part of cost benefit identification. Among others this is visible in its analysis questions Q3.7 and Q3.8 wherein identification of value exchanges associated to actors is central.

For BUSMOD such scenario exploration is enabled by conceptual models. The semi-formal and visual nature of such conceptual models allow on the one hand, the discussion of alternative constellations of actors in a workshop-like setting, and on the other hand, serve as an input for cash flow calculation in the subsequent step: cost-benefit analysis.

2.4.4 Cost-benefit analysis

The costs and benefits identified in the previous step are analyzed in terms of both a profit calculation for monetary values and an assessment of non-monetary values (using different instruments), which gives rise to the following two considerations.

Profit calculation: The reviewed methods typically employ established valuation methods to project the profit over a given period of time. For JRC/EPRI, as can be observed from the analysis questions Q4.1 and Q4.2, such methods include Benefit Cost Ratio and Net Present Value (NPV).[2] Alternative methods such as annual comparison or Internal Rate of Return (IRR, which is actually closely associated to NPV) are also discussed in [20, p. 29]. However, a full treatment of each would be beyond the scope of this paper. Similarly BUSMOD generates profitability numbers for each actor (as per the analysis questions Q4.4 and Q4.5), which are typically calculated with NPV, and potentially complemented by IRR, cf. [45, p. 163].

[2] Briefly, in NPV, one calculates the profit expected at a future point in time by subtracting the *present value* of cash outflows from the *present value* of cash inflows [48, p. 103]. Here, present value refers to the fact that a certain amount of money X presently has a different worth than that same amount of money X at a future point in time (e.g., due to inflation).

Assessment of non-monetary values: As hinted by the analysis question Q4.3, JRC assesses non-monetary value in terms of performance assessment. Briefly, such a performance assessment entails that, for a given asset (e.g., a wind turbine), one associates benefits to KPIs defined in the previous step, and on the basis of individual KPI scores one computes a global weighted score [20, p. 37].

As a complement to this, multi-attribute CBA methods typically follow the associated decision strategy to calculate non-monetary values. To exemplify this consider the application of AHP in [64, p. 32], which, as stated, is suggested to complement the assessment made in JRC.

2.4.5 Sensitivity analysis

Both JRC/EPRI and BUSMOD suggest to modify the parameters for the initiative at hand. This is so since the assumptions made, e.g., the electricity consumption or the electricity prices, heavily influence the result of a cost-benefit analysis. Such modifications should take place systematically, e.g., by modifying one parameter while keeping all others untouched. Thus, we arrive at the following consideration:

A need to vary parameters for a sensitivity analysis: As indicated by analysis question Q5.1, JRC/EPRI recommend to vary the discount rate (which, in NPV and IRR, is the variable that is used to take into account the time value of money), electricity consumption and prices, or the estimated energy efficiency potential, and analyze the subsequent impact [20, pp. 31-34]. Meanwhile, cf. analysis question Q5.2, BUSMOD considers similar changes to parameters, but equally considers (minor) changes to the structure of value models (such as changing a value exchange between actor A and B to a value exchange between actor A and C).

2.5 Open issues

Now we discuss the fourth question *"what open issues can we identify, when we confront the considerations of surveyed methods with the artifacts they provide?"*. Five open issues are identified.

Open issue 1: A lack of systematic analysis of actors and their goals. *Rationale*: As stated in the previous section, many of the surveyed valuation methods strive to make actors and their goals explicit. However, in terms of used artifacts none of the key methods systematically focuses on goal analysis. Concerning the artifacts of the main methods reviewed, artifact A1.1 in Table 2.1 shows that EPRI/JRC recommend a plain text description of goals and actors in the business case definition. Moreover, this description is optional, as also reflected in JRC's tentative formulation of elements of a business case description: "This *may* involve providing *(some of)* the following information:" [20, p. 18] (emphasis added). In BUSMOD, the artifacts for goal analysis constitute plain text tables (cf. artifact A1.2). While providing more structure, these tables offer limited reasoning when it comes to goals' fulfillment, e.g., on the basis of goal dependencies, propagating fulfillment of leaf goals to more abstract goals, or identification of goal conflicts.

The same limitations also present themselves for multi-attribute CBA methods. While goals form an inherent part of initial applications of AHP [54, 78], there exists no dedicated instrument yet for goal analysis in the tradition of goal-oriented requirements engineering [31]: reasoning on fulfillment of high-level goals by propagating satisfaction values of lower-level goals, the identification of goal conflicts, etc.

Open issue 2: A lack of systematic consideration of IT infrastructure and associated investments. *Rationale*: While both JRC/EPRI and BUSMOD consider a dedicated IT infrastructure as relevant, in terms of the used artifacts the reviewed methods fall short. This is visible by the artifacts presented under artifacts A2.1 and A2.2 in Table 2.1. On the one hand, JRC/EPRI provide a plain text description of IT assets only (cf. artifact A2.1), which is furthermore not clearly differentiated from other asset types. In BUSMOD, the use of UML deployment diagrams is suggested (cf. artifact A2.2). However, a deployment diagram is relatively light-weight in terms of the required expressiveness [42]: it has no dedicated attributes for expressing desired qualities, neither do deployment diagrams establish a relation to associated investments.

Open issue 3: Insufficiently accounting for additional considerations in value exchange analysis. *Rationale*: For value exchanges analysis, BUSMOD relies on a dedicated modeling method called e^3*value* (cf. artifact A3.3). Due to their semi-formal nature, the value models created as part of the e^3*value* method can be used for both scenario exploration in terms of who exchanges what of value with whom, and profitability calculations. JRC/EPRI meanwhile, for the identification of value heavily rely on predefined asset-functionality and functionality-benefit matrices (cf. artifact A3.1). Only afterwards, they assign benefits to individual actors. For example, consider the JRC method [20, p. 26]. Here beneficiaries are identified only after going through the exercise of identifying assets, linking assets to functionalities, and functionalities to benefits. This suggests that, as opposed to BUSMOD, who exchanges what of value with whom is simply not a focal concern of JRC (and in extenso also not of EPRI, upon which JRC builds).

The BUSMOD's notion of explicitly analyzing, by means of conceptual modeling, value exchanges taking place in the network of actors that jointly realize the smart grid initiative is advisable. However, building on Open issues 1 and 2, we find that BUSMOD still lacks, next to explicitly considering actor goals and IT infrastructure, a systematic relation between perspectives. In particular, the value models in BUSMOD miss a clear-cut relation to IT investments that is (ideally) identified through IT infrastructure models. Also, it lacks an assessment of quantified non-monetary values.

Open issue 4: Insufficient software tool support. *Rationale*: In terms of software artifacts the EPRI method is accompanied by the smart grid computational tool.[3] This tool provides step-by-step guidance in filling out the main artifacts of the EPRI method (the two matrices discussed under Open issue 3), to present a list of potential benefits for a given smart grid initiative. The software tool also supports NPV calculations. BUSMOD, meanwhile, offers the e^3*value* software tool[4] for creating e^3*value* models and, with a given set of parameters, to generate profitability sheets for each of the actors involved in the smart grid initiative. For the surveyed multi-attribute CBA methods, no specific software tool support is mentioned.[5]

Nevertheless, these software tools support only the considerations tackled by the existing methods. In other words, software tool support for goal analysis and for a systematic consideration of IT infrastructure, two considerations that are particularly relevant for smart grid valuation, is currently not part of any of the reviewed methods.

Open issue 5: A need to make the cost-benefit analysis more accessible to address a gap between methods and users. *Rationale*: As [59, p. 48] stress: "CBAs is based on systematic and logic reasoning, but requires expertise, insight and knowledge. Conducting CBA might appear too complicated on an area as complex as smart grid technology implementation". Therefore, there is a need for additional instruments that would facilitate understanding and support communication among all actors involved in the initiative and/or the valuation process itself. Such accessibility is already partly facilitated by BUSMOD's use of conceptual modeling for value exchange analysis in terms of value models. However, it should be extended to other considerations as well.

[3]Artifact A4.1, available under `https://www.smartgrid.gov/recovery_act/analytical_approach/computational_tool.html`. Last accessed on 28-01-2020.

[4]Artifact A4.2, available under `https://research.e3value.com/tools/`. Last accessed on 28-01-2020.

[5]Though, if desired, one can use tool support for the multi-attribute decision model in question, e.g., OS-AHP [21] for AHP.

Chapter 3

Modeling in Support of (Smart Grid) Valuation

3.1 Conceptual Modeling and How it May Contribute to Solve Open Issues

A conceptual model may be defined as a linguistic construction, an abstraction over, and a simplification of the considered phenomena [17, pp. 942–943]. Conceptual modeling, as already mentioned in the introduction, is the activity of describing (by creating models) some selected aspects of the physical and social world for purposes of understanding and communication [57]. It is often the first step to understand and describe the real or conceived world system in information system (IS) analysis and design [57, 17], and therefore, it is considered to be a core topic within the IS discipline.

A conceptual model is created by using a modeling language. A modeling language serves to create a class of conceptual models and is defined through (i) an abstract syntax, i.e., the rules for constructing syntactically correct models using the language concepts, (ii) a concrete syntax, i.e., symbols used to represent the abstract syntax, typically a graphical notation, and (iii) the semantics. Here, semantics pertains to the interpretation of modeling concepts in terms of, both, the formal semantics, such as constraints on the abstract syntax, and material semantics, in terms of a glossary, wherein the language concepts are defined for the users of the language [17]. In turn, in line with [17, p. 45], a modeling method addresses a class of problems, in our case, the valuation of smart grid initiatives, by providing a process model and one or more modeling languages for the targeted analysis.

Conceptual models serve different purposes. Among others, they foster communication and common understanding between different stakeholders [50, 53, 69], and support analysis of the considered phenomena, both 'as-is' as well as evaluating alternatives or determining the impact of some changes [40, 50].

In addressing the open issues defined in the previous chapter, we advocate a method that relies on conceptual modeling. By relying on conceptual models, we can firstly capitalize on their already mentioned capability to foster communication, thus making a cost-benefit analysis more accessible to end users (cf. Open issue 5). Such communication capabilities are fostered not only by the main feature of models to help handling complexity through abstraction, but also by, both, the visual nature of conceptual models (a graphical representation), as well as their capability to offer domain-specific concepts, which are close to the professional language of end users [17, p. 942] [53, pp. 870–871]. Those features of conceptual models shall not only foster communication during the valuation process, but also (ideally) leverage a shared understanding of the valuation process among various stakeholders involved in the analysis.

Secondly, the semi-formal nature of conceptual modeling ensures computational fitness [53, pp. 870–871] [24, p. 1187], hence making software tool support for conducting various analyses possible (cf. Open issue 4). Such a software tool support not only allows for creating models that are in line with the language specification, but importantly it also allows for reasoning capabilities, such as profitability calculations, or propagating satisfaction of lower-level goals, on the basis of, e.g., KPIs, to higher-level goals.

Thirdly, different modeling languages, focusing on different perspectives such as value exchange, goals or IT infrastructure, applied together, offer a multi-perspective view of a smart grid initiative we are interested in (cf. Open issues 1–3). As we have shown already in our previous research [43], the application of a modeling language with a dedicated modeling method forces one to be concrete, which is especially beneficial with a fuzzy term such as valuation, and extends the analyses possibilities at hand.

Taking the above claims into account, we argue that the application of conceptual modeling in the valuation process is able to provide the required support for systematic analysis of the domains of interest, and contribute to addressing the identified open issues of currently existing valuation approaches.

3.2 Existing Modeling Languages and Their Suitability to Support Valuation Process

Looking at the results of the analysis reported on in Chapter 2, to support valuation of smart grid initiatives a set of modeling languages/methods are required that would enable modeling and analysis of at least the following aspects: (1) goals and involved actors, (2) value and value exchange process, (3) IT infrastructure; and allow for their integration. For the needs of goal modeling, we need a language that provides substantial analysis capabilities to elicit the fulfillment of high-level actor goals on the basis of the extent to which low-level goals are fulfilled, as judged on the basis of their associated Key Performance Indicators (KPIs). Furthermore, for the needs of value exchange modeling, we require a modeling language that has a systematic relation to a valuation method. In this way, cash flow computations can be made on the basis of annotated elements in the associated value exchange models (e.g., the amount of customer needs for a given time frame, or the amount of money associated with a value exchange). Finally, when it comes to modeling of IT infrastructure, a language should be able to distinguish between different kinds of assets and their interrelations, e.g., to distinguish between a 'smart contract' and the hardware that it runs on. Furthermore, it is pertinent that the language allows for differentiating between different types of costs, and that it can associate these cost types systematically to different types of IT infrastructure assets.

In the following, we provide a short overview on existing modeling languages and approaches to model those three aspects, and we discuss their suitability to address the identified open issues.

3.2.1 Dedicated smart grid modeling approaches

The Smart Grid Architecture Model (SGAM) is an architecture model that provides a set of concepts, viewpoints, and a method for standardized decomposition of smart grid systems with a focus on interoperability [73]. SGAM allows to classify smart grid elements according to smart grid specific dimensions, such as the transmission grid, distribution grid, or end customers, and to analyze them according to a set of interrelated viewpoints, such as information, communication (e.g., communication protocols) or business [73, 28]. Nevertheless, the SGAM model provides only a high-level representation of smart grid systems. Therefore, confronting SGAM to the open issues, it lacks (1) a dedicated consideration of IT infrastructure assets (Open issue 2), let alone an identification of relevant IT investments; (2) a dedicated focus on value exchange analysis (Open issue 3); and (3) a dedicated support for actors and goal analysis (Open issue 1), due to its provision of a broad "business" and "function" layer only [73, p. 30]. Although modeling approaches building upon SGAM have been proposed, cf. [71, 27], importantly, in line with SGAM they remain on a high level of abstraction. Hence these modeling approaches fall short in a similar manner when it comes to addressing the identified open issues.

3.2.2 Enterprise (Architecture) Modeling (EM) approaches

EM approaches cover *multiple* perspectives on an organization (e.g., by considering in tandem organizational goals, business processes, or IT infrastructure), and relate these perspectives to each other [17, 70]. Therefore, it seems beneficial to check whether they already offer a set of integrated perspectives we are interested in.

There exist different enterprise (architecture) modeling approaches, prominently ArchiMate [76], Architecture of Integrated Information Systems (ARIS) [74], 4EM [70], and Multi-Perspective Enterprise Modeling (MEMO) [17]. These methods are based on different modeling foundations and assumptions, and define different sets of modeling concepts for describing selected perspectives on an organization, in most cases encompassing also modeling of goals, or IT infrastructure. In the following, we elaborate on two of such EM approaches: (1) ArchiMate [76], due to its popularity; and (2) Multi-Perspective Enterprise Modeling (MEMO) [17], due to its comprehensiveness and expressiveness.

ArchiMate is an open enterprise architecture modeling language, which can be used to express different perspectives on an organization's enterprise architecture [76]. Of interest to addressing the open issues is that, as part of its language specification, ArchiMate offers concepts related to IT infrastructure, value, and (as part of the motivation and migration extension) to expressing goals. Nevertheless, by design ArchiMate offers a set of generic concepts only [50, pp. 76-77]. As a result, for our purposes ArchiMate exhibits the same central weakness as SGAM, i.e., by design ArchiMate does not offer expressiveness or analysis capabilities, for dedicated considerations (Open issues 1–3). Although ArchiMate has been complemented with other languages, e.g., with business models [35], with value models [8, 12], and with an IT portfolio evaluation method [65, 50]; none of the proposed combinations cover fully the considerations relevant for a smart grid valuation method.

MEMO aims at integrating different aspects that should be considered while designing, implementing and using business information systems [17]. It offers a set of integrated Domain Specific Modeling Languages (DSMLs), such as languages for modeling business processes and organizational structures (OrgML, [17]), for goal modeling (GoalML, [61]), and for IT infrastructure modeling (ITML, [29, 13]). Moreover, as part of its design philosophy, MEMO provides expressiveness and corresponding analysis capabilities in these DSMLs. In particular, the provided expressiveness for IT infrastructure and organizational goals are relevant for tackling Open issues 1–2. Yet MEMO lacks the capability to conduct value exchange analysis, and its reasoning capabilities and software tool support for goal analysis are limited. Therefore, we cannot use MEMO as is, but instead we focus on ITML only.

ITML allows to enumerate the required software and hardware, their connection, and their technical characteristics. Furthermore, in an elaboration of ITML, [29, pp. 227-252] provides a conceptualization of different cost types, (e.g., fixed versus variable) and an association of said cost types to different IT infrastructure elements. This allows us to express, in a differentiated manner, the costs of purchasing, installing, operating, and maintaining different IT infrastructure assets. Subsequently, these costs may inform the value being exchanged. Thus, while alternatives exist for IT infrastructure modeling, such as UML deployment diagrams (for an overview of IT modeling languages, cf. [42]), as none of the other existing approaches allows for a differentiated treatment of IT infrastructure elements, and most importantly, nor do they provide a systematic relation to various types of costs, ITML becomes our recommended modeling language for expressing the IT infrastructure perspective.

3.2.3 Stand-alone approaches

Stand-alone modeling languages have been proposed focusing on modeling selected perspectives only, e.g., goals or value. Regarding the latter, especially two languages are of interest that aim to enable *value modeling*, i.e., e^3*value* [26] and Resource-Event-Agent (REA, [19]). e^3*value* focuses on value exchange modeling, i.e., who exchanges what of value with whom [26]. It has originally been developed for analyzing the value exchanges needed for realizing an e-business idea, but later on has also been used for other types of analyses e.g., profitability analysis under uncertainty [41], service bundling [67], and as per BUSMOD, it has been used for value exchange analysis in the electricity industry [24]. In turn, REA is a business ontology that was originally aimed at designing accounting systems by allowing to specify the economic rationale behind business interactions [19]. A notion important to REA is its duality principle: an event causing an increment in the value of a resource must have at least one corresponding event that decrements the value of another resource [33, p. 16]. Especially, this duality principle can be used for economic consistency checks.

While REA and e^3*value* offer concepts interesting to valuation, they focus on *one valuation aspect among many*, namely, the modeling of value exchanges and the consistency thereof. They do not consider different organizational perspectives, let alone a relation to these different perspectives (cf. Open issue 3). Therefore, those approaches would need to be applied in tandem with other modeling methods to address the open issues fully.

The value modeling language e^3*value* [25] focuses on designing and analyzing value networks. It is commonly used to provide answers to questions like: what are the actors involved in the constellation? what do they provide of value and ask in return? Moreover, e^3*value* also enables cask flow analysis, prominently (discounted) Net Present Value calculations (cf. Open issue 5). e^3*value* has been used successfully to, among others, understand value networks in distributed generation of electricity and in a distributed service for balancing electricity supply and demand [24, 63]. In contrast, while REA also focuses on value exchanges, it lacks a capability for cash flow calculation. Therefore, e^3*value* becomes the instrument we recommend for value exchange modeling, to be integrated with other languages/perspectives.

When it comes to goal modeling, there exist a variety of Goal-Oriented Requirements Analysis (GORE) modeling techniques, such as i-star [80], the Goal-oriented Requirements Language (GRL) [2], and TROPOS [7]. For a recent overview, we refer to [30]. With their focus on modeling (short/medium/long)-term goals, these techniques form a useful point of departure for goal analysis and have also been used to that extent, cf. [26]. Taking into account the reasoning and analysis capabilities, especially the Goal Requirements Language (GRL) [38] is of interest. GRL focuses on stakeholders objectives and on reasoning about their achievement. The prominent concept in GRL is "goal". Goals are owned by stakeholders. High-level abstract goals are refined into low-level concrete goals (in terms of decomposition or contribution links). Achievement of low-level goals can either be measured quantitatively in terms of "KPIs" (Key Performance Indicators), supported by external analysis results, or qualitatively reasoned from rationales or argumentation captured by the concept of "belief". Low-level goals contribute to the achievement of high-level goals. GRL is equipped with (semi-)automated goal analysis techniques, to propagate achievement of low-level goals to the achievement of high-level goals by following the refinement relations among goals. Also GRL is accompanied by a mature software tool called jUCMNav.[1] Especially the mature software tool support sets GRL apart from competing goal modeling languages (cf. Open issue 4), such as i-star or Tropos [31], which provide concepts and reasoning capabilities similar to those of GRL. Therefore, GRL is the modeling language we recommend for expressing stakeholder goals and reasoning about them for a multi-perspective valuation method.

[1] `http://jucmnav.softwareengineering.ca/ucm/bin/view/ProjetSEG/WebHome`. Date last accessed: 04-03-2020.

Chapter 4

Conclusions and Next Steps

In this technical report, we laid the foundations for building a model-driven multi-perspective valuation method for smart grid initiatives. More specifically, we did so in the following steps. Firstly, we conducted a systematic literature analysis of existing well-established valuation methods. Secondly, we elicited considerations that the analyzed literature deems as relevant for smart grid valuation. Thirdly, we confronted these considerations with the artifacts said valuation methods actually provide, and identified open issues that are yet to be tackled by smart grid valuation methods. Following this, we also discussed the extent to which current modeling approaches can address the identified open issues. Finally, we identified a set of modeling languages that together can form a solid basis for model-driven multi-perspective valuation.

Indeed, although no single integrated approach suitable to our aims could be identified, suitable individual modeling languages exist: ITML for IT infrastructure modeling, e^3*value* for value exchange modeling and analysis, GRL for goal modeling and reasoning on goals. Applying them in tandem shall support the multi-perspective valuation we are interested in (cf. Open issue 1–3) and allow us to exploit the modeling and analysis tools associated with them (cf. Open issues 4-5). In our future work, we plan to design a multi-perspective valuation method for smart grid initiatives to address the open issues identified in this paper, by capitalizing on the recommended conceptual modeling languages and analysis tools.

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