Model-Based Valuation of Smart Grid Initiatives

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Model-based valuation of smart grid initiatives: Foundations, open issues, requirements, and a research outlook

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ABSTRACT

To support the value assessment of technically feasible smart grid initiatives there exist several valuation methods. To determine whether those methods address all concerns relevant for smart grid valuation, 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, requirements, and remaining challenges. 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. Based on the findings, we suggest the application of conceptual modeling as an instrument to address the identified deficiencies. Therefore, we reflect on the role that current modeling approaches can play in smart grid valuation.

This paper is a part of a larger project whose ultimate goal is to develop a model-based method for multi-perspective valuation of smart grid initiatives. The purpose of this paper is to establish a foundation for the realization of the envisioned method. The design of the model-based valuation method itself, its application and evaluation, are subjects of future work.

1. Introduction

A smart grid can be defined as an electricity network which, supported by Information Technology (IT), can integrate the behavior and actions of all users connected to it [1]. It holds the promise to contribute to an economically efficient and sustainable power system, as well as to security and safety of power supply [2,3].

Several smart grid initiatives exist, ranging from virtual currencies to promote the trade of green energy [4], to the use of blockchain technologies to address infrastructural challenges associated with electric vehicles [5,6]. However, assessing the potential of such smart grid initiatives is a complex issue, among others, calling for an assessment of the proposed technologies [7,8], of (regional) policies and regulations [2,9], and of the associated business case [7,10,11].

This paper centers on assessing the business case of smart grid initiatives, with a particular focus on the value for the involved stakeholders. As discussed in [7,9,11–14], this is not a trivial issue. For one, the notion of value typically encompasses, among others,

readily quantifiable (e.g., lower transaction costs, a reduction in CO_2 emissions), as well as qualitative benefits (e.g., protection of the environment), of different types (economic, social, environmental), which must be assessed for single actors, as well as for a network of actors. Therefore, 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 [7,9,14]. They follow defined steps for smart grid assessment and associate each step with corresponding analysis questions and artifacts. The proposed methods, which are typically based on cost–benefit analysis (CBA), have been used for the valuation of various smart grid initiatives. Nevertheless, by confronting the analysis questions of extant valuation methods to the capabilities of the key artifacts they provide, and by a review of survey papers on smart grid valuation, we observe notable deficiencies, namely: (1) a lacking systematic consideration of stakeholders goals. Although all valuation methods consider goals and the associated stakeholders as important, in the end they mostly provide a narrow focus on monetization. Likewise, no systematic goal analysis is done, e.g., in terms of relationships between goals or goal fulfillment based upon Key Performance Indicators (KPIs); (2) a lacking systematic consideration of IT and associated investments. However, given the inherent reliance of a smart grid initiative on IT, this concern has an important influence on its valuation; and (3) 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 of valuation (e.g., instruments that enable stakeholders to explore different scenarios of who exchanges value with whom in a workshop-like setting).

Considering the above, we argue that there is a need to extend the capabilities of existing valuation methods. We also argue that such an extension requires usage of an instrument that would help dealing with complexity, increase understanding, and enable communication between involved stakeholders. A promising instrument seems to be the application of conceptual modeling, which can be roughly defined as "the activity of formally describing some aspects of the physical and social world around us for purposes of understanding and communication" [15]. We deem it promising 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, among others, the calculation of cash flows, and reasoning on goal fulfillment.

Against the backdrop of a larger research project aiming at MOdel based, multi-perspectiVe valuatIoN of smart Grid initiatives (MOVING), the objective of this particular paper is to provide the foundations for MOVING. These foundations express themselves in the following contributions: (1) based on the conducted systematic literature analysis, we identify open issues and challenges that should be addressed to support multi-perspective valuation of smart grid initiatives in their entirety, (2) we show why and how conceptual modeling and selected approaches can be applied to address the identified problems, and finally, (3) we provide a first sketch towards such a model-based valuation method, relying on the carefully-selected set of modeling languages together with supporting tools ensuring not only quantitative, but also qualitative valuation of the initiative in question. Please note however, that the exact configuration of the MOVING method as well as a demonstration of its effectiveness using a comprehensive real world scenario, is not covered here, but is the subject of a separate paper.

The MOVING project can be categorized as design science [16,17]. Its overall research design, in terms of the stages from the well-established engineering cycle [18, p. 28], is depicted in Fig. 1, and encompasses: (1) problem investigation, (2) treatment design, (3) treatment validation, (4) treatment implementation, and (5) treatment evaluation.

We report on stages 1–3 in this paper, and provide a preliminary sketch towards accomplishing stage 4 at the end of this paper. A full-fledged realization of stage 4 and 5 will be the subject of a separate paper as already mentioned above.

More specifically, during *problem investigation*, by means of a literature study, well-established smart grid valuation methods are first identified. Subsequently, for the found smart grid valuation methods, key steps, and per step, the associated considerations, are identified, too.

We confront the identified valuation considerations to the actual artifacts provided by existing valuation methods, so as to identify gaps that should be addressed. These gaps are referred to as *open issues*. During *treatment design*, the suitability of conceptual modeling to address the identified open issues is discussed and a set of requirements towards such a model-based valuation method are formulated. Then, during *treatment validation*, the extent to which existing conceptual modeling approaches fulfill the elicitated requirements is assessed, and modeling approaches that hold the promise to provide a valuable contribution to the envisioned model-based valuation method are selected. Finally, we provide a preview of what the envisioned model-based valuation method looks like.

The rest of the paper is structured as follows. After defining valuation and presenting our literature analysis process (Section 2), we present the key identified valuation methods (Section 3), the key steps followed (Section 4), the considerations important to those steps (Section 5), and the open issues found by confronting the considerations to the artifacts provided by the existing smart grid valuation methods (Section 6). Next in Section 7, we discuss the role that conceptual modeling can play in tackling the identified open issues and identify a set of requirements. In Section 8 we analyze existing modeling techniques, primarily to identify modeling languages of interest. We discuss our findings and present an initial sketch of the envisioned model-based valuation method in Section 9. We conclude in Section 10 and propose to use the results reported in this paper as a foundation for realizing the envisioned model-based smart grid valuation method in future work.
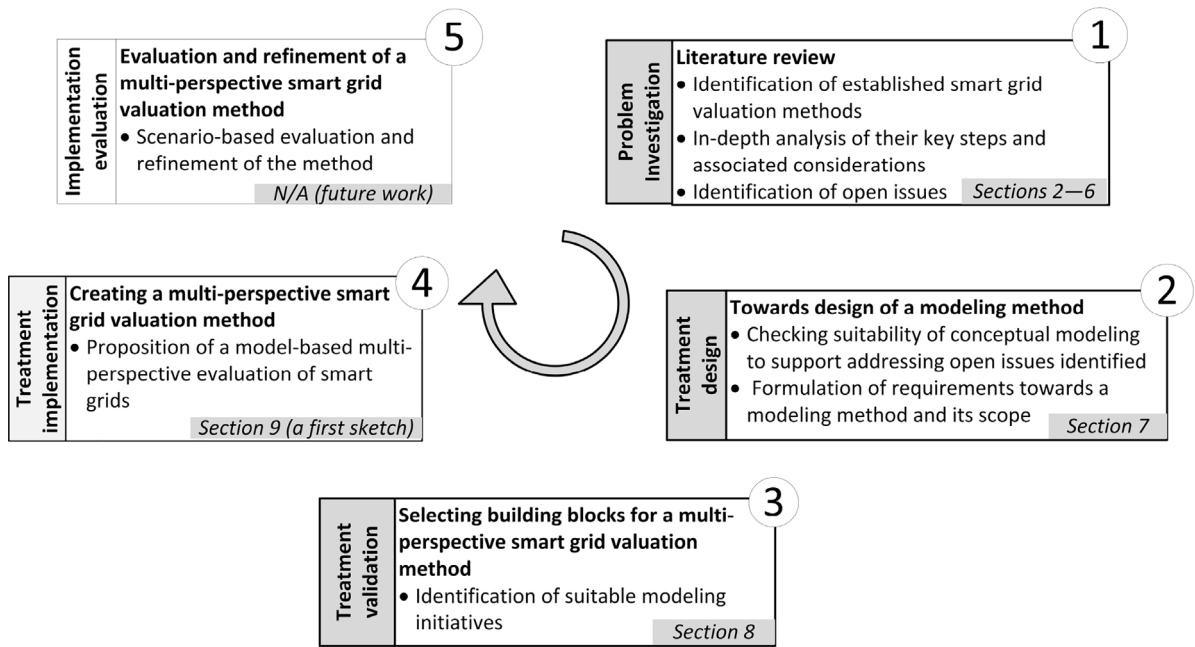
Fig. 1. Overall research design: Phases 1–3, and partly 4 are covered in this paper.

2. Smart grid valuation: Design of literature analysis

Valuation may be defined as an analytical process of determining the current (or projected) worth, i.e., the value, of something [19–23]. Various valuation methods have been proposed, e.g., [19–21], 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 [22,23]. The gains and losses should be expressed in monetary terms, irrespective to whom they accrue, cf. [22].

To identify factors important for the valuation of smart grid initiatives, we conduct a literature review following the relevant guidelines, cf. [24–26]. Our 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 to the artifacts they provide?

We focus on the following literature types: (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 apply the following query: "smart grid" AND (value OR valuation OR assessment OR "cost benefit" OR "cost–benefit") AND (method OR model OR approach OR framework), to titles and abstracts of works in selected publication databases. Among others, we have selected Google scholar (27000 documents) and Scopus (3810 documents), taking into consideration their reported characteristics [27]. Please note that, in addition to scholarly publications, Google scholar also includes relevant approaches outside of the scientific community, e.g., from governmental bodies or working groups.

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 the Electric Power Research Institute, the International Energy Agency, and various European Union (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.

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 [24]. If so, we proceeded to check for exclusion criteria. We excluded articles (1) when the proposed method applies to a specific part of the smart grid only, e.g., electricity storage, hence the method is not suitable for smart 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) studies with a notable overlap of already included work. In the case of overlaps, the paper(s) providing the most comprehensive description have been selected and used for the analysis. As the exclusion criteria require interpretation, first two authors independently conducted

the literature assessment, and then they discussed the results finding no significant disagreements. Finally, the resulting lists coming from different databases have been integrated.

In the subsequent sections, we discuss our findings answering the four formulated questions.

3. Identified valuation methods

Overall, the surveyed valuation methods aim at assessing whether benefits exceed the costs of a particular smart grid initiative [8,28,29], such as the roll-out of smart meters [30], or of smart distribution system with intelligent electric vehicle charging [31]. 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.

In line with the findings of others, cf. [8,29,32], 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 [14] provides a step-wise method for evaluating the costs and benefits of smart grid initiatives. It allows for business case assessment by identifying and evaluating respectively (a) different categories of benefits, such as economic, environmental, reliability, safety, and security; and (b) 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., [10,33–38]. Nevertheless, the EPRI method has several shortcomings. Among others, the EPRI method emphasizes the (in part) outdated electricity infrastructure of the USA [39], 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 [8, p. 32]. All in all, the JRC method, compared to EPRI, places more emphasis on non-monetary quantification considering on the one hand, e.g., environmental impacts such as CO_2 reduction, and on sensitivity analysis on the other hand [9].

The second type of smart grid valuation methods rely on multi-attribute decision strategies [8,32,40]. 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 [8, p. 32] [40, 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, [41] 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 type of valuation methods relies on conceptual modeling. We find [42,43] that actively use value modeling as part of their CBA. In particular, we found the BUSMOD method [7,44]. 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, while BUSMOD hints at the relevance of other perspectives informing valuation, such as inventorying and analyzing the required technologies [44, 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.

4. 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 and the conceptual modeling method BUSMOD, follow similar steps. This is also in line with surveys on smart grid valuation [8,28,29]. These steps are: (1) Business case description, in terms of, e.g., project goals, involved stakeholders, 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 (NPV); 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, complementing the aforementioned cost–benefit methods, tend to follow the steps of the associated decision strategy in addition. We discuss here briefly the method proposed by [40,41], 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 [40, pp. 19–20]. As such, it involves among others additionally the step of decision making formalization, in terms of alternatives to be considered and criteria to be assessed, and the step of a pairwise comparison, whereby roughly speaking alternatives are compared against criteria in a pairwise manner.

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[1] An alternative multi-criteria CBA method, SG-MCA, is reported in the survey from [32, pp. 8–10]. However, apart from [32, pp. 8–10] unfortunately no clear documentation of SG-MCA could be found.

Table 1

Comparison of the valuation methods JRC/EPRI and BUSMOD — Part 1.

Aggregate[a]	Analysis questions		Key artifacts	
	JRC/EPRI	BUSMOD	JRC/EPRI	BUSMOD
Business case description	E.g., (Q1.1) What is the overall project objective? (Q1.2) What are the relevant stakeholders? What are regional legal concerns? (p. 18)	E.g., (Q1.3) What are the main goals to be achieved? (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 is a goal of type "Environmental", "Market development", or "Quality and efficiency"? (p. 102)	(A1.1) Textual description	Textual description (core business idea); (A1.2) Goal hierarchy table, Goal conflict table
Technology identification	(Q2.1) What are the necessary assets, both electricity sector assets and IT assets? (p. 18)	E.g., (Q2.2) What technology characteristics are essential for the business case, especially for the fulfillment of goals? (Q2.3) What quality parameters need to be defined? (Q2.4) What influence do these quality parameters have on price and cost? (p. 142)	(A2.1) textual description of assets	(A2.2) UML deployment diagram (p. 115)

[a]Any exact stages here refer to the stages 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.

5. Considerations in smart grid valuation steps

To answer 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 analysis 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 Tables 1 and 2. Additional discussion on the considerations relevant to multi-attribute CBA methods is also provided.

To establish a *business case description* in the first 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 Table 1 start by determining the scope of the initiative at hand, typically 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 the business case 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 (AHP) as a complement to the JRC method, [40, 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.

In the second step, *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 IT. 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 [44, p. 140]. In particular, as shown in Table 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.

Table 2

Comparison of the valuation methods JRC/EPRI and BUSMOD — Part 2.

Aggregate[a]	Analysis questions		Key artifacts	
	JRC/EPRI	BUSMOD	JRC/EPRI	BUSMOD
Cost benefit identification	E.g., 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?	E.g., (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) Is the actor really offering the outgoing value object? (p. 132)	(A3.1) assets-functionalities matrix, functionalities-benefits matrix, (A3.2) Smart Grid Computational Tool	(A3.3) the e^3value method, (A3.4) the e^3value software tool
Cost Benefit Analysis	E.g., (Q4.1) What is the Benefit Cost Ratio for each of the involved actors? (Q4.2) What is the NPV for each of the involved actors? (Q4.3) For JRC: for a given benefit, how does an asset perform in terms of associated KPIs? (p. 28)	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 — NPV, 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^3value 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) E.g., 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? (p. 160)	Suggested parameters: discount rate, growth rate of electricity consumption and electricity efficiency potential, peak load transfer	Evolutionary scenarios, may lead to changes in e^3value models (models are relevant when performing the sensitivity analysis)

[a] Any exact stages here refer to the stages 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.

The third step concerns *cost–benefit identification*, both monetary and non-monetary, and associates them to actors, mainly on the basis of the assets from Step 2. Subsequently, the costs and benefits, to the extent it is possible, are quantified. Also, different constellations of actors are explored as a preparation for a cost–benefit analysis in the next step. We elaborate on these considerations 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, 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, values are also reflected in the analysis question Q1.6 (cf. Table 1) of BUSMOD in terms of different goal types for goal analysis in Step 1: environmental, market, quality, and efficiency.

In addition, as alluded to in Step 1, multi-attribute CBA methods [32,40,41], also assess the non-monetary values brought about by a smart grid initiative. This is exemplified by [40, p. 30], who, next to an analysis of economic goals, also proposes to analyze the contribution of an initiative to (a) smart grid realization, whereby, e.g., 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?" [44, 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 [40, 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, for cost–benefit identification 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.

In the fourth step, *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) are also discussed in [9, 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. [44, p. 163].

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 [9, 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 [40, p. 32], which, as stated, is suggested to complement the assessment made in JRC.

Finally, during the fifth step, *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, such as by modifying one parameter while keeping all others untouched. Thus, we arrive at the subsequent 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 consideration the time value of money), electricity consumption and prices, or the estimated energy efficiency potential, and analyze the subsequent impact [9, 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).

6. Open issues

Considering 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 may be 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, Label A1.1 in Table 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:" [9, p. 18] (emphasis added). In BUSMOD, the artifacts for goal analysis constitute plain text tables (cf. label 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 [32,41], there exists no dedicated instrument yet for goal analysis in the tradition of goal-oriented requirements engineering [45], e.g., reasoning on fulfillment of high-level goals by propagating satisfaction values of lower-level goals.

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 Labels A2.1 and A2.2 in Table 1. On the one hand, JRC/EPRI provide a plain text description

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[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 [20, 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).

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 [46]: 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 *e³value* (cf. artifact A3.3). Due to their semi-formal nature, the value models created as part of the *e³value* 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 [9, 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).

In the method we will sketch, we build upon 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. Nevertheless, while the value exchange analysis forms a nice point of departure for our method, building on Open issues 1 and 2 we find that BUSMOD lacks, next to explicitly considering actor goals and IT infrastructure, a systematic relation between perspectives. In particular, the value models in BUSMOD lack a clear-cut relation to IT investments as (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 *e³value* software tool for creating *e³value* models and, with a given set of parameters, to generate profitability sheets for each of the actors involved in the smart grid initiative.[4] For the surveyed multi-attribute CBA methods, no specific software tool support is mentioned.[5]

Nevertheless, existing tools support only the current considerations of existing methods. This also means that software tool support for goal analysis, or for a systematic consideration of IT infrastructure, two considerations that are particularly relevant for us, is currently not part of any of the reviewed methods.

Open issue 5: Gap between the valuation methods and their users, which needs to be addressed by making the cost–benefit analysis more accessible to users. *Rationale*: As [8, 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 supported by BUSMOD's use of value models for value exchange analysis, but it should be extended to other considerations as well.

7. Conceptual modeling, its role, and resulting requirements

A conceptual model may be defined as a linguistic construction, an abstraction over, and a simplification of the considered phenomena [48, 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 the purposes of understanding and communication [15]. It is often the first step to understand and describe the real or conceived world system in information system (IS) analysis and design, e.g., [15,48], and therefore, it is considered to be a core topic within the IS discipline. In our context, conceptual modeling has already demonstrated its potential in supporting valuation in the BUSMOD method, wherein conceptual models are exploited to make value exchange scenarios and CBA analysis more accessible to users. In the following, we argue for the application of conceptual modeling to support valuation of smart grid initiatives in the form of a set of requirements that a model-based valuation method should satisfy. In particular, we derive the mentioned requirements as a response to the identified Open issues, so that they "address solutions to problems hitherto not addressed" [49, p. 55]. Moreover, during the definition of the requirements, we always keep an eye out for the expected feasibility of a solution [49].

Requirement 1. *The method shall use domain-specific modeling languages with domain specific graphical visualizations to facilitate understanding and support communication among all actors involved in the initiative and/or the valuation process itself*

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 [48, p. 942] [50, 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.

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[3] Artifact A4.1, available under https://www.smartgrid.gov/recovery_act/analytical_approach/computational_tool.html. Last accessed on 06-08-2021.

[4] Artifact A4.2, available under https://research.e3value.com/tools/. Last accessed on 06-08-2021.

[5] Though, if desired, one can use tool support for the multi-attribute decision model in question, e.g., OS-AHP [47] for AHP.

Requirement 2. *There should be a modeling tool available to guide the application of the selected modeling approaches, as well as for semi-automated analysis purposes*

The semi-formal nature of conceptual modeling ensures computational fitness [50, pp. 870–871] [7, p. 1187], hence opening the door to software tool support for conducting various analyses (cf. Open issue 4). Such a software tool support not only allows for creating models that are in line with the domain rules encoded into a modeling language specification, but importantly it also support required analysis and calculations, in line with later requirements.

Requirement 3. *The model-based valuation method should allow to account for multiple perspectives in tandem*

Different modeling languages, which each focus on a different perspective – value exchange, goals, and IT infrastructure (as per the Open Issues 1–3) – applied together, offer a multi-perspective view of a smart grid initiative we are interested in. As we have shown already in our previous research, cf. e.g., [13], 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.

Considering the results of the analysis reported on in previous sections, 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 perspectives: (1) goals and involved actors, (2) value and value exchange process, (3) IT infrastructure; and allow for their integration. Next, we discuss detailed requirements related to these three perspectives.

Requirement 4. *The model-based valuation method should allow for goal modeling and analysis, particularly: (a) allow to model goals and their interdependencies, as well as involved actors; and (b) provide substantial reasoning capabilities for goal driven analysis.*

When it comes to goal modeling, apart from allowing to model goals their interdependencies, as well as involved actors, a goal modeling language should provide 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).

Requirement 5. *The model-based valuation method should allow for value modeling, particularly: (a) ensure understanding of the network of actors in terms of what of value is exchanged and with whom; and (b) support conducting profitability calculations based on created models.*

In turn, 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 calculations 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).

Requirement 6. *The model-based valuation method should allow for IT infrastructure modeling to enable a systematic consideration of IT infrastructure and associated investments, more specifically: (a) allow to model elements of IT infrastructure and their characteristics allowing to express the desired qualities relevant for the needs of valuation process; (b) support differentiation among various asset types and their interrelations; and (c) allow differentiating between different types of costs, and associating these cost types systematically to different types of IT infrastructure assets.*

When it comes to IT infrastructure modeling, we need a modeling language that can distinguish different kinds of assets and their interrelations. For example, to distinguish between a "smart contract" and the hardware that it runs on. Furthermore, it is also pertinent for the modeling language to allow for differentiating between different types of costs, and associating these cost types systematically to different types of IT infrastructure assets.

In the following section we check the suitability of currently existing modeling approaches to meet the defined requirements.

8. Existing modeling languages and their suitability to support valuation process

8.1. Dedicated smart grid modeling approaches

The most well-known smart grid modeling approach is the Smart Grid Architecture Model (SGAM). It provides a set of concepts, viewpoints, and a method for standardized decomposition of smart grid systems with a focus on interoperability [51]. 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 [51,52]. Nevertheless, the SGAM model provides only a high-level representation of smart grid systems. Therefore, confronting SGAM to the requirements, it lacks (1) a dedicated consideration of IT infrastructure assets (Req. 6), let alone an identification of relevant IT investments, (2) a dedicated focus on value exchange analysis (Req. 5), and (3) a dedicated support for actors and goal analysis (Req. 4), due to its provision of a broad "business" and "function" layer only [51, p. 30]. Although modeling approaches building upon SGAM have been proposed, cf. [53,54]. 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 and subsequently derived requirements.

8.2. 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 [48,55]. Therefore, it seems beneficial to check whether they do not already offer a set of integrated perspectives we are interested in. There exist different enterprise (architecture) modeling approaches, prominently ArchiMate [56], Architecture of Integrated Information Systems (ARIS) [57], 4EM [55], and Multi-Perspective Enterprise Modeling (MEMO) [48]. 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 (1) ArchiMate [56], due to its popularity; and (2) Multi-Perspective Enterprise Modeling (MEMO) [48], 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 [56]. Of interest to addressing the open issues is that, as part of its language specification, ArchiMate offers concepts related to IT infrastructure, to value, and (as part of the motivation and migration extension) to expressing goals. Nevertheless, by design ArchiMate offers a set of generic concepts only [58, pp. 76–77]. As a result, for our purposes ArchiMate exhibits the same central weakness as SGAM: it lacks modeling facilities, i.e., by design ArchiMate does not offer expressiveness or analysis capabilities for dedicated considerations (Reqs. 3–6). Although ArchiMate has been complemented with other languages, e.g., with business models [59], with value models [60,61], and with an IT portfolio evaluation method [58,62], 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 [48]. It offers a set of integrated Domain Specific Modeling Languages (DSMLs), such as for modeling business processes and organizational structures (OrgML [48]), goal modeling (GoalML [63]), and IT infrastructure modeling (ITML [64,65]). Thus, as part of its design philosophy, MEMO provides expressiveness and corresponding analysis capabilities that fit well with the model-based valuation method MOVING that we aim to develop. Also, it provides expressiveness for IT infrastructure, and organizational goals, which are two considerations of relevance (cf. Req. 4 and Req. 6). Yet MEMO lacks the capability to conduct value exchange analysis (cf. Req. 5), and it is limited in its reasoning capabilities and software tool support for goal analysis. Therefore, for the purposes of MOVING, we cannot use MEMO as is, but instead we focus on the ITML only.

The ITML allows to enumerate the required software and hardware, their connection, and their technical characteristics. Furthermore, in an elaboration of ITML, [64, 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. [46]), 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, the ITML becomes our modeling language of choice for expressing the IT infrastructure perspective.

8.3. Stand-alone approaches

Modeling languages exist which can be characterized as stand-alone, in the sense that they concentrate on modeling selected perspectives only, e.g., goal modeling or value exchange modeling only. Regarding value exchanges, especially two languages are of interest in that they concentrate on *value modeling* (cf. Req. 5), i.e., e^3value [66] and Resource–Event–Agent (REA, [67]). e^3value focuses on value exchange modeling, i.e., who exchanges what of value with whom [66]. 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 [68], service bundling [69], and as per BUSMOD, value exchange analysis in the electricity industry [7]. 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 [67]. REA's 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 [70, p. 16], can be used for economic consistency checks.

While REA and e^3value offer concepts interesting to valuation, they focus on *one valuation aspect among many*: 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. Req. 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^3value [71] 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^3value also enables cask flow analysis, prominently (discounted) Net Present Value calculations (cf. Req. 5). e^3value 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 [7,72]. In contrast, while REA also focuses on value exchanges, it lacks a capability for cash flow calculation. Therefore, e^3value becomes the instrument of choice for value exchange modeling, to be integrated with other languages/perspectives.

When it comes to goal modeling (cf. Req. 4), there exist a variety of Goal-Oriented Requirements Analysis (GORE) modeling techniques, such as i-star [73], the Goal-oriented Requirements Language (GRL) [74] or TROPOS [75]. For a recent overview, we refer to [76]. With their focus on modeling (short, medium or long-term) goals, these techniques form a useful point of departure for
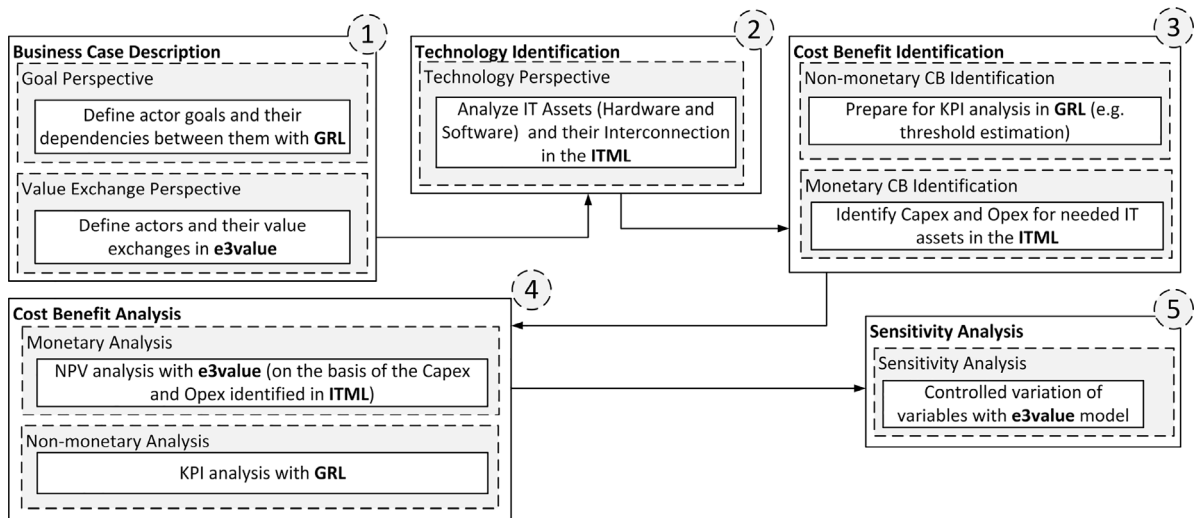
Fig. 2. Conceptual modeling in support of smart grid valuation: a first sketch.

goal analysis and have also been used to that extent, cf. [66]. Taking into account the reasoning and analysis capabilities, especially the Goal Requirements Language (GRL) [77] is of interest. The GRL focuses on stakeholders objectives and on reasoning about their achievement. The prominent concept in the 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. The 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 the GRL is accompanied by a mature software tool called jUCMNav.[6] Especially the mature software tool support sets the GRL apart from competing goal modeling languages (cf. Req. 2 and Req. 4b), such as i-star or Tropos [45], which provide concepts and reasoning capabilities similar to those of GRL. Therefore, the GRL is the modeling language of choice for expressing stakeholder goals and reasoning about them.

9. Discussion

In the previous sections, we laid the foundations for designing a model-based multi-perspective valuation method for smart grid initiatives. 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 that said valuation methods actually provide, and identified open issues that are yet to be tackled by smart grid valuation methods. Following this, we discussed the extent to which current modeling approaches can address the identified open issues, and finally nominated 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, promising individual modeling languages exist, namely, the ITML for IT infrastructure modeling, *e³value* for value exchange modeling and analysis, and the GRL for goal modeling and reasoning on goals. Applying them in tandem shall support the multi-perspective valuation we are interested in (cf. Open issues 1–3), and allow us to exploit the modeling and analysis tools associated with them (cf. Open issues 4–5).

Building on this foundation, Fig. 2 provides a first sketch of how these conceptual modeling languages, when used in tandem, can support smart grid valuation. Note that a full-fledged development of the envisioned model-based valuation method, its application using a real world scenario, and its evaluation are subjects of our future work, to be reported in a separate paper. In particular, during the *business case description* step, modeling support is constituted by a combination of the "early-phase" requirement analysis techniques the GRL and *e³value*. Specifically, the GRL can be used for eliciting a goal perspective (see Fig. 2), in the sense of identifying goals of actors participating in the smart grid initiative, and relating these goals to each other. Thereby, potential conflicts and complementarities between actor goals can also be observed. Through employing *e³value*, meanwhile, one elicits a value exchange perspective in terms of value exchanges taking place between specific actors.

During the *technology identification* step, the ITML can be used for eliciting and analyzing the technology perspective, in particular, by means of analyzing the required hardware, software, and relations between these.

We envision that the technology identified with the ITML also forms a systematic input to the next step: *cost–benefit identification*. In particular, regarding the identification of monetary costs and benefits, we capitalize here on the capability of the ITML to capture

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different cost types (as observed in Section 8) to populate the value exchange model created during the business case description step, with information regarding the capital expenses (Capex) and operating expenses (Opex) of the technology assets at hand. For the identification of non-monetary costs and benefits, meanwhile, we aim at specifying threshold values and KPI values for the GRL model (as mentioned in Section 8).

During the *cost benefit analysis* step, we can subsequently perform a monetary valuation analysis by using e^3value, in particular by relying upon the Net Present Value calculations natively supported by e^3value and its accompanying software tool (as discussed in Section 8). Similarly, for performing non-monetary valuation we aim to rely on the GRL and its tooling support for analyzing the extent of goal fulfillment through a combination of the KPI values and thresholds found during cost benefit identification, and the goals and their interrelation found during the step of business case description.

Finally, during the *sensitivity analysis* step, one can in a controlled manner vary parameters of the valuation carried out. Initially, we especially foresee using e^3value and its tool support to this end, to do a typical sensitivity analysis of the monetary valuation carried out. However, varying KPI parameters in the GRL, to experiment with non-monetary sensitivity analysis, is possible as well.

10. Conclusions

In this paper, we have provided a foundation for a model-based method for the valuation of smart grid initiatives. From a synthesis of well-established and often used smart grid valuation methods, we derived steps typical to smart grid valuation, and considerations important to these steps. We then identified five open issues, by confronting the stated considerations with the artifacts provided by the smart grid valuation methods. Finally, we introduced conceptual modeling and selected three modeling languages, which when used in tandem have the potential to address all the identified open issues. We demonstrate by a first sketch how conceptual modeling can support different steps important to smart grid valuation.

Using the research reported in this paper as a foundation, as future work we aim to construct a model-based method for smart grid valuation. We are especially interested in benefiting from method engineering approaches [78,79], because of their underlying philosophy of method construction by the purposeful and systematic reuse of existing method fragments or chunks.

Finally, while we firmly believe that the open issues and requirements identified in this paper provide a solid foundation for designing a model-based valuation method, for a next iteration of our method it would be interesting to identify more perspectives wherein conceptual modeling can play a useful role. One such perspective could be the modeling of legal considerations, which often inhibit or foster the regional roll out of a smart grid initiative.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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