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An Assessment Framework to Determine the Strategic Value of IT Architectures in Smart Grids

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Abstract

As traditional power grids are transformed with the concept of the smart grid (SG), it is imperative for companies and governments to develop standard roadmaps on their path to support SG transformations. While there are different approaches to assess SG projects, there is limited interest at assessment of SG elements beyond cost factors. We adopted a design science research method to develop an assessment framework based on three components: the Smart Grid Architecture Model (SGAM) as the reference model, the adapted Bedell's method as the assessment method and a Decision Support System to perform assessments. We evaluated our framework in a real world case study within a blockchain-inspired European project. The new assessment framework is useful to determine the strategic value of SG projects in terms of their importance and effectiveness. The framework offers a holistic valuation that may help energy companies to tackle challenges other than economic issues such as energy efficiency and CO2 emissions.

Keywords decision support system, smart grids, assessment, smart grid architecture model, design science research

1 Introduction

Smart Grids (SG) encapsulate electricity network system with digital technology to monitor and manage electricity transport for meeting changing electricity demands of end users (Bush 2014). Due to the integration of IT within the electricity network system, it is plausible to apply IT architectures to support SG projects. Since the design and implementation of SGs are evolving, the underpinning IT architectures are also changing and reflecting upon the SG requirements.

The SGs deal with several challenges relating to interoperability, regulations, social acceptance and assessments. Firstly, SGs must define standards that allow transparent *interoperability* among traditional (e.g. network operators, energy retailers) and new (e.g. technology providers) stakeholders. As traditional power grids are transformed with the concept of SG, it is imperative for companies at the corporate level and governments at the national/ international level to develop standard roadmaps on their path to improve SG operations and/or determine their capabilities for benchmarking. Second, SG projects should also be compliant with national as well as international *regulations*. For instance, although the integration of renewables that can be supported by SGs is overall promoted at the European level, it is up to the individual countries to define the implementation of such regulations (EU 2009). This autonomy leads to a plethora of regulatory frameworks that SGs have to deal with. Third, SGs are also challenged by the lack of *social acceptance* mostly due to privacy and security concerns. In this sense, while some SG projects can help to optimize electricity consumption, they rely on consumers that are willing to allow these solutions to remotely control the customers' electricity consumption (Bush 2014).

Finally, given the innovative aspect of some SG projects, e.g. demand-response programs, there is also a need to guarantee not only the economic feasibility of the projects but also to conduct overall *strategic value assessments* of those projects towards the electricity sector. In this light, current efforts such as the so-called System Value (SV) metric focuses on assessing the overall value of SG projects rather than only looking at investment issues (OECD/IEA 2015). By taking a systemic perspective, SV provides a trade-off between the positive and the negatives elements of SG projects.

This research aims to address the final challenge related to the overall value of SG projects by providing an assessment framework to determine the strategic value of IT architectures in SG projects. Unlike economic value that focuses mostly on monetary issues, strategic value aims to reflect the effectiveness and importance of IT architectures that support SG projects (Schuurman et al. 2008).

The framework (a) uses standardised SG models, and (b) allows to assess strategic importance and effectiveness of SG projects, which can then help energy companies to meet their SG related goals. The assessment method is demonstrated using a decision support system (DSS) that is underpinned by the Smart Grid Architecture Model (SGAM) (CEN-CENELEC-ETSI 2012) as the reference model. The DSS also applies an adapted version of Bedell's method (Schuurman et al. 2008) as the assessment model to determine the strategic value of SG projects modelled in SGAM.

The rest of the paper is organized in the following way. Section 2 presents related work on different approaches to assess and evaluate SG projects. Section 3 describes the design science research (DSR) method that was followed to develop our assessment framework as an artefact, whereas Section 4 details the design and development of the artefact – the assessment framework based on the adapted Bedell's method as the assessment model and the SGAM as the reference model. Section 5 illustrates the demonstration of the artefact by building a DSS. Afterwards, Section 6 presents the evaluation of the framework in a real world case study within a blockchain-inspired European project. Section 7 provides a discussion on assumptions and lessons learned. Finally, Section 8 presents conclusions and direction for future work.

2 Related work

Traditional methods to assess SGs as well as renewable energy projects in general have mainly focused on analysing economic, i.e. cost-related issues, e.g. Levelized Cost of Electricity (LCOE), Levelized Avoided Cost of Electricity (LACE), System LCOE and System Value (EIA-US 2017; OECD/IEA 2015; Ueckerdt et al. 2013). On the one hand, LCOE and LACE take a company-centric perspective and only consider costs (capital and operational) and expected electricity generation hours which help computing the average revenue per unit of energy production (EIA-US 2017). On the other hand, System LCOE and System Value also consider integration costs that occur at the system level due to

the integration of renewables and other transformations (e.g. adding storage in the form of electric batteries) (OECD/IEA 2015; Ueckerdt et al. 2013). Moreover, System Value tries to capture positive (e.g. CO₂ reduction costs) and negative (e.g. extra balancing services) effects arising from such transformations. Cost-related assessments are useful for valuation and top management understanding.

These methods, nonetheless, overlook or simplify the overall impact of IT architectures on SG transformations. As an attempt to alleviate this issue, the Smart Grid Maturity Model (SGMM) developed by the Software Engineering Institute at Carnegie Mellon University (SEI 2010) assists companies to assess their SG transformation. SGMM is essentially a management tool that comprises six maturity levels (Level 0 Default to Level 5 Pioneering) across eight domains (logical groupings of smart grid related characteristics) that provides a set of 175 characteristics in total, offering a comprehensive list of features to assess at each stage of the smart grid journey (SEI 2010). The SGMM proposes a five phase expert-led assessment journey in which the relevant stakeholders initially complete a SGMM compass survey (a questionnaire-based assessment to yield maturity ratings) and later the survey findings are validated to identify opportunities and challenges during a workshop to reach consensus as part of their assessment. SGMM offers global trainings and partnership programs that are widely popular within the US and North American market (SEI 2010).

In Europe, the Smart Grid Architecture Model (SGAM) has been proposed by the Smart Grid Task Force as an enterprise-wide and service-oriented framework to describe SG architectures (CEN-CENELEC-ETSI 2012; Greer et al. 2014). SGAM has been used to support the design and analysis of SG architectures in different European Union (EU) projects (DISCERN 2016; Migliavacca et al. 2017). The SGAM framework covers five **domains**: bulk generation, transmission, distribution, distributed energy resources (DERs) and customer premises; six power-management **zones**: process, field, station, operation, enterprise and market; and five interoperability **layers**: business, function, information, communication and component. Such level of detail aims to provide a good understanding on all elements that are part of SG projects. Despite the standardisation effort, SGAM still lacks tools to assess the value of the overall IT architecture since the available tools are mostly focused on analysing specific but relevant issues such as costs, interoperability or security (CEN-CENELEC-ETSI 2012).

The Bedell method (Schuurman et al. 2008) has been previously proposed for the assessment of IT architectures to report their strategic importance and effectiveness. This method relies on gathering information via questionnaires about the perceived importance and effectiveness of all the elements that compose an architecture (Schuurman et al. 2008). In this research, therefore, we explore the opportunity to develop an assessment method using the Bedell's method as the assessment model to determine the strategic value of SG-IT architectures based on SGAM.

Unlike SGMM that views IT architecture as one of the domains under technology for assessment, our assessment framework puts the IT architecture at the centre stage of assessment driven by an Enterprise Architecture perspective, i.e. SGAM to provide an overall valuation scheme for the SG. There are several benefits of this approach such as transparent communication with different stakeholders (via SGAM models such as the five interoperability layers), which leads to a much better understanding of the impact of disruptive IT solutions beyond SGs, for e.g. Internet of Things (IoT) or blockchain (OECD/IEA 2015). Furthermore, we believe SGAM is a *de-facto* standard-to-be that is extensively used to guide the design of SG projects in Europe as well as other regions, e.g. China (Brunekreeft et al. 2015), USA (Greer et al. 2014) and Australia (CSIRO and ENA 2017).

3 Method

To design our solution, we follow a DSR approach (Peppers et al. 2008), in which we cover the following elements:

- **Problem identification and motivation.** As explained in Section 2, current methods to assess the value of SGs either neglect or oversimplify the importance of the IT architecture that supports the operation of such SGs. This issue limits companies' understanding on what IT investments are needed to improve their operations.
- **Definition of the objectives for a solution.** The main objective being pursued in this research is, therefore, to design an assessment method to understand the strategic value of IT architectures that support the operation of SG projects.

- **Design and development.** Section 4 provides a description of the components that are part of our assessment framework (the artefact) as well as on the design decisions behind each one of them.
- **Demonstration.** Section 5 demonstrates how a DSS proof-of-concept of the artefact was developed and tested locally.
- **Evaluation.** Section 6 presents the NRGcoin project that is currently being deployed by a technology provider in Belgium and the Netherlands (Mihaylov et al. 2014). We have used our framework to assess the strategic value of the IT architecture that supports NRGcoin.
- **Communication.** The initial concept has already been communicated to technical audience (Razo-Zapata et al. 2017). This paper continues with our communication effort to a wider audience in the Information Systems community.

By adopting a DSR approach to develop and evaluate our assessment framework using an actual IT architecture for a smart grid, our research goes beyond conceptual and analytical approaches often used in Green IS research, which is the type of research called for by Gholami et al. 2016.

4 Artefact Design and Development

To achieve our research objective, we propose adapting Bedell's method (Schuurman et al. 2008) to determine the strategic value of SG architectures that are designed based on SGAM (CEN-CENELEC-ETSI 2012). SGAM is proposed as the reference model that supports a holistic description of all the elements within an SG architecture. Bedell's method is proposed as the assessment model that allows to determine value of the importance and effectiveness of the SG architecture. By the same token, to collect information required by Bedell's method and determine the value of the SG architecture, we also propose the use of a DSS that can assist in data-driven decision making. The overall interaction between SGAM and Bedell's method is governed by the DSS that provides insights on the strategic importance and effectiveness of different SG elements and offer recommendations for the improvement of SG architectures based on the assessment results. The following paragraphs explain how the artefact was designed and developed using Bedell's method and SGAM.

4.1 Adaptation to the Bedell's method

Bedell's method was originally designed to analyse the contribution of information systems to an organisations' business value (Schuurman et al. 2008). The method, nonetheless, has been also adapted to analyse IT portfolios based on Enterprise Architecture models (Quartel et al. 2012). Once SGAM has been used as a reference model for an IT architecture of SG project, the main steps that need to be followed for assessment are given next (Quartel et al. 2012):

- Determine the **importance** of:
 - All organizational *business processes* to the *organisation* (IBO)
 - All *activities* executed in the *business processes* (IAB)
 - All *activities* to the *organisation* (IAO)
- Determine the **effectiveness** of the *systems* currently in place to the *activities* (ESA)
- Calculate the **effectiveness** of:
 - the single *systems* and the total of *information systems* (ESB)
 - the *information systems* to the *organisation* (EIO)
- Determine potential **importance** of:
 - The *information systems* to the *business processes* (IIB)
 - The *information systems* to the *organisation* (IIO)
- Determine whether investment is needed for: the whole IT architecture; business processes; or activities (decided by relevant decision makers based on the assessment results)

To determine the importance of elements within the SGAM, a set of questions are presented to the relevant stakeholders as a survey as highlighted in Table 1. This set of questions demonstrates progressive achievement of the elements' importance and it applies only to variables IBO, IAB and

IIB. As one can see, the answer options provide scores in the range [0-10] (Schuurman et al. 2008).

Question	Answer option (score)
Is the element NOT operationally important?	Counteracting (0)
Is the element operationally important?	Administrative/support (2)
Does the element support other strategic elements?	Capacity adding (4)
Does the element directly contribute to long-term goals?	Direct contributing (6)
Does the element accomplish strategic objectives for SG's long-term goals?	Strategic (8)
Does the element achieve an outstanding performance/goal on the SG's objectives?	Critical strategic (10)

Table 1. Set of questions to determine the importance of SGAM elements

Likewise, in order to determine the variable ESA (effectiveness), a different approach is used, as seen in Table 2. This assessment requires evaluating whether activities are properly supported (Schuurman et al. 2008). Akin to the importance scores, the scores for effectiveness are also in the range [0-10].

Criterion	Answer option (score)
No system is currently installed, or it is so ineffective as to be worthless.	No support (0)
The system supports the activity it was designed to support, but ineffectively. Improvements are so extensive, that, in the long term, the system will have to be replaced.	Ineffective (1)
Reasonable support to the activity, but substantial improvements are necessary to improve functional appropriateness, technical quality, or cost-effectiveness; however, it does not need to be replaced	Moderately effective (5)
Functionally appropriate, technically adequate, and cost-effective. Little or no additional work required than routine maintenance.	Highly effective (10)

Table 2. Effectiveness of elements

Finally, to determine the value of ESB, IIO and EIO, we apply the following formulas as derived by Schuurman et al. (2008).

$$ESB = ESA * IAB$$

$$IIO = \sum(IBO * IIB) / \sum(IBO)$$

$$EIO = \sum(ESA * ISO) / \sum(ISO)$$

4.2 Integration of SGAM and Bedell's method

As explained before, SGAM supports modelling SG architectures by providing a three-dimensional representation that focuses on domains, zones and interoperability layers (CEN-CENELEC-ETSI 2012). *Domains* deal with the electrical conversion chain which covers bulk generation, transmission, distribution, distributed energy resources (DERs) and customer premises (CEN-CENELEC-ETSI 2012), whereas *zones* deal with six levels of power system management: process, field, station, operation, enterprise and market (CEN-CENELEC-ETSI 2012). Likewise, *interoperability layers* hierarchically represent business elements (products/services), functions, information exchange and models, communication protocols and (physical) components (CEN-CENELEC-ETSI 2012). Figure 2 shows the connection between SGAM interoperability layers and Bedell's variables that are needed to determine the importance (IIO) and effectiveness (EIO) of the SG-IT architecture. Finally, the so-called Focus Factor (FF = IBO * IIB) tries to reflect the importance of all IT elements to business processes and the organization (Schuurman et al. 2008).

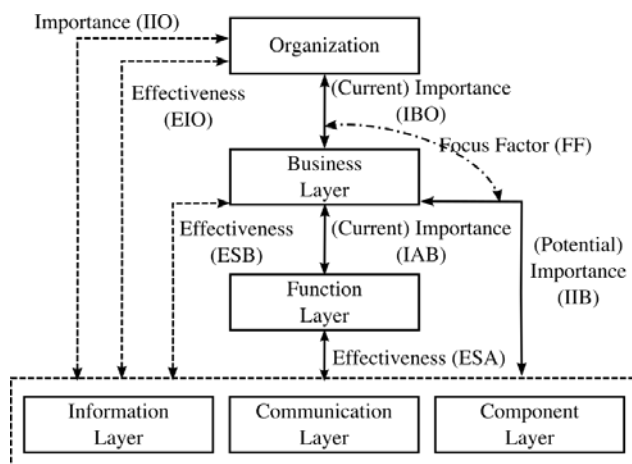


Figure 2: SGAM interoperability layers related to Bedell's variables

5 Artefact Demonstration

To collect survey data from relevant stakeholders for the elements that are part of IT architectures and analyse such data for decision making, we demonstrated our artefact using a DSS. DSS has been proven to enhance decision performance, even when perceptual factors are considered (Jarupathirun and Zahedi 2007). The primary objective for DSS assessment of survey data are twofold: to provide an effective means to reduce the assessment data overload, and to objectively measure the importance of the SGAM elements across layers in order to determine value of the SG architectures. In this way, the DSS system can execute a transparent method to influence improvements in the way SG architectures are designed and implemented. Figure 1 illustrates our DSS workflow model to compute strategic importance and effectiveness of elements within the layers of the SG architecture. Such DSS workflow has been applied in other disciplines to determine capability and improve processes, for example in IT Service Management (Shrestha et al. 2014). The model has been developed using the Business Process Model and Notation (BPMN) version 2.0.

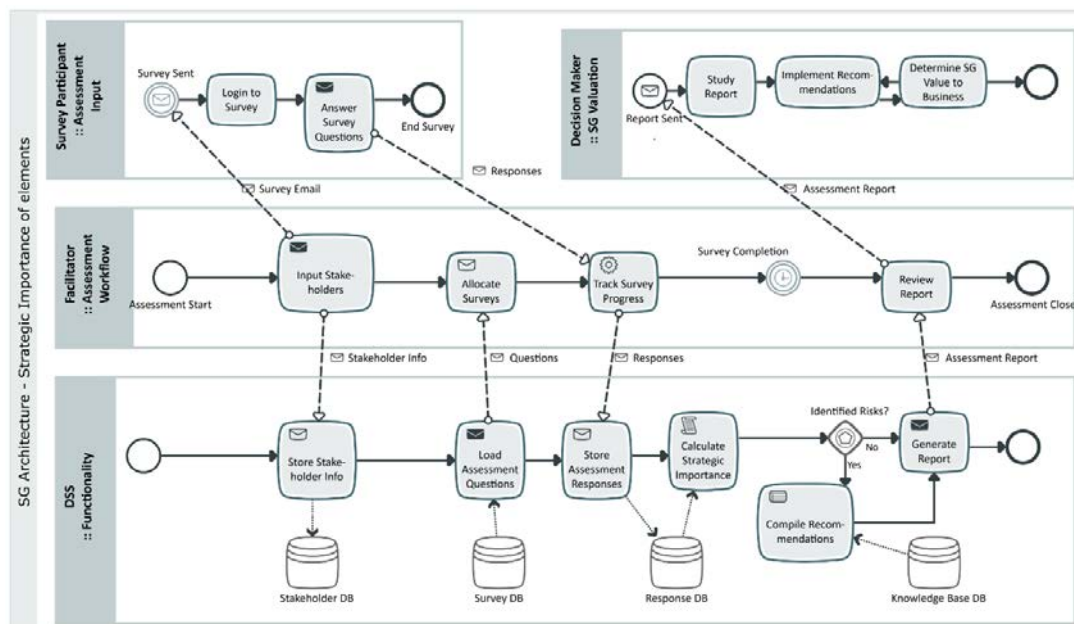


Figure 1: Determination of Strategic Importance and Effectiveness of SG Architectures using SGAM and Bedell's method facilitated by a DSS

As depicted in Figure 1, the DSS supports the overall assessment framework in terms of assessment data collection (survey), measurement (determination of survey response scores) and recommendations (insights based on the analysis of survey results). There are three key actors involved during the assessment: assessment facilitator, survey participants (relevant stakeholders)

and decision maker. The assessment facilitator initiates the process by capturing details of the stakeholders and their roles in the survey. The survey questionnaire is then allocated to the relevant stakeholders using the DSS. As the participants respond to the survey questions, the assessment facilitator can track the survey status. Finally, a report generated by the DSS is produced to the decision makers (say senior management at SG providers) that provides the effectiveness and importance scores as well as how the scores can be used to determine the overall value of the SG architecture. The DSS stores a collection of recommendations in a knowledge base and relevant recommendations can be produced in a report based on risks, for example, assessment scores below 5.0 in terms of effectiveness. The report can help the decision makers understand the overall value of SG to the business and enable the implementation of the recommendations offered by the DSS.

The next section reports the evaluation of our assessment framework using the DSS during an SG project that is currently underway in Belgium and the Netherlands.

6 Artefact Evaluation

6.1 NRGcoin

NRGcoin is a blockchain-inspired project that offers two services (business processes) within the so-called low-voltage grid, i.e., NRGcoin billing and NRGcoin exchange (Mihaylov et al. 2014). On the one hand, NRGcoin billing rewards prosumers (i.e. consumers of electricity that can also generate electricity for their own consumption) with NRGcoin(s) for the energy they inject to the grid that matches consumption while charges consumers (also using NRGcoins) for the green energy they consume from the grid. Moreover, the NRGcoin protocol rewards electricity utilities with NRGcoins because they facilitate the exchange by providing the infrastructure. On the other hand, NRGcoin exchange is a cloud-based currency market that allows consumers and prosumers to respectively buy and sell NRGcoins.

The NRGcoin project can be deployed either on top of the current architecture or completely from scratch. To support such decision-making tasks, we have applied our assessment framework to determine the elements that need to be improved if the project is developed on top of the current architecture.

6.1.1 NRGcoin’s goals and strategic objectives

The main goal of NRGcoin is to incentivise local production and consumption of green energy based on NRGcoin billing and NRGcoin exchange.

6.1.2 NRGcoin’s SGAM Models

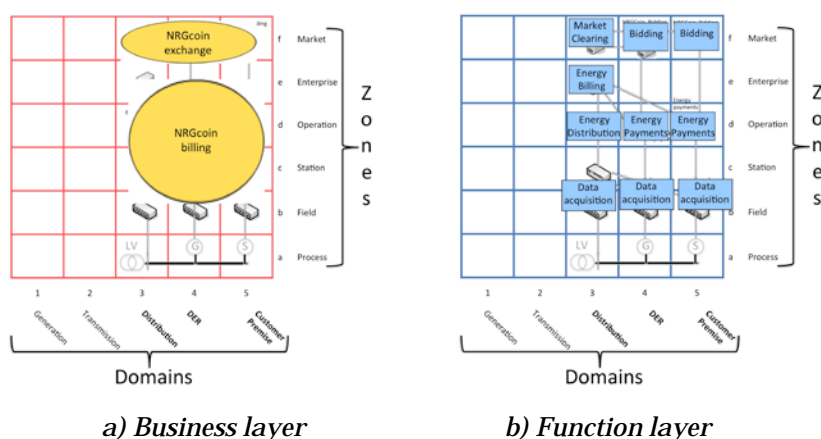


Figure 3: NRGcoin’s SGAM business and function layers

Business layer: Figure 3(a) defines the domains and zones that are covered by the NRGcoin exchange and the NRGcoin billing services. As one can see, they both cover the same three domains (distribution, DER and customer premises) but differ in the zones they cover. NRGcoin billing service only deals with the field, station, operation, and enterprise zones, whereas NRGcoin exchange deals with the market domain.

Function layer: Figure 3(b) presents the functions that must be performed to realise the two services. For instance, the NRGcoin billing service depends on data acquisition, energy distribution,

energy payments and energy billing. The NRGcoin exchange service depends on market clearing and bidding.

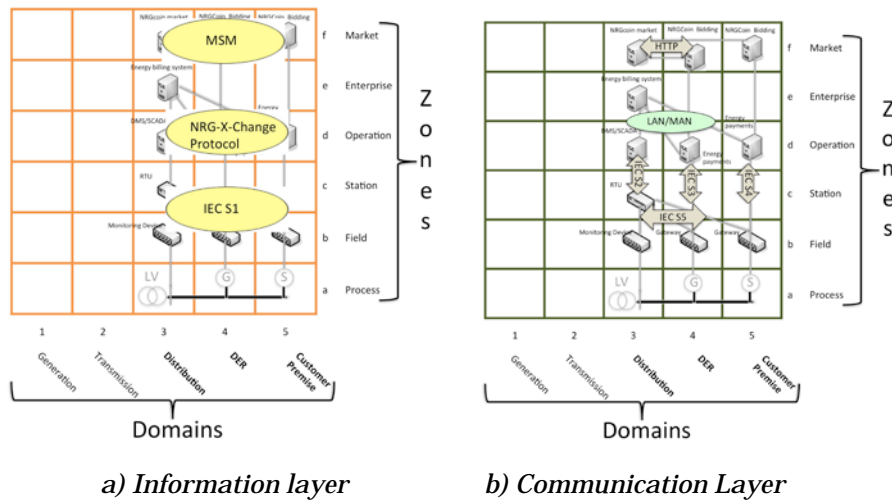


Figure 4: NRGcoin's SGAM information and communication layers

Information layer: Figure 4(a) specifies the data models that rule the exchange of information among elements. For instance, elements at the field and station zones, should ideally use an IEC standard (IEC S1) data model as described in the IEC 61850 standard (CEN-CENELEC-ETSI 2012).

Communication layer: Figure 4(b) defines the protocols that can be used to allow communications among elements across zones and domains. For example, elements at the market zone, could use HTTP-based protocols since the currency market would be placed in the cloud.

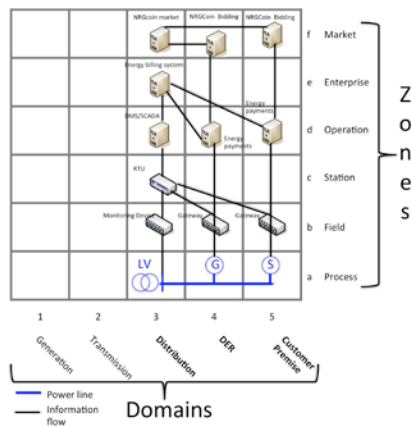


Figure 5: NRGcoin's SGAM component layer

Component layer: Figure 5 shows how power (blue lines) and information (black lines) flows across all components. E.g. at the process level, where power flows occur, we have low voltage (LV) distribution components (i.e. an electrical substation), DER components (i.e. G = electricity generator) such as solar panels, and electricity consumption components (S).

6.2 Applying our Assessment Framework

The DSS was applied within the NRGcoin project to evaluate our assessment framework. This section highlights the initial impact statement from all of the steps executed based on our assessment framework. The researcher worked in the capacity of assessment facilitator. There were two stakeholders who came to a consensus in order to respond to the questionnaire with a united voice. An expert who is also a key decision maker for the improvement of SG architectures then validated the assessment results. Table 3 presents the scores for the NRGcoin business processes and activities as well as the resulting effectiveness of IS to the organisation (EIO).

Processes	Activities	IAB	ESA	ESB	Σ ESB	Σ IAB	EIB	Σ ESO	Σ IAO
NRGcoin billing	Data acquisition (DA) at consumer side	8	10	40					
	DA at prosumer side	8	10	40					
	DA at substation side	8	10	40					
	Energy payment (EP) at consumer side	8	5	8					
	EP at prosumer side	8	5	8					
	Energy distribution (ED)	10	10	100					
	Energy billing (EB)	8	1	8	428	58	7.40	3424	464
NRGcoin exchange	Bidding at consumer side	6	1	6					
	Bidding at prosumer side	6	1	6					
	Market clearing (MC)	8	1	8	20	20	1	160	160
								3584	624
EIO - Effectiveness of IS to the organisation (3584/624)								5.74	

Table 3. Bedell's variables used to compute EIO.

In a similar vein, Table 4 shows the Bedell's variables that are needed to calculate the importance of IS to the organisation (IIO).

Processes	IBO	IIB	FF
NRGcoin billing	8	6.92	55.33
NRGcoin exchange	8	6.88	55.111
	16		110.44
IIO - Importance of IS to the organisation (110.44/16)			6.90

Table 4. Bedell's variables used to compute IIO.

Based on the results from Table 3 and Table 4, the DSS generates a report containing information on whether the importance and the effectiveness of the NRGcoin concept are balanced. As seen in Figure 6(a), while the importance of overall IT architecture to the company is relatively high (6.90), i.e. of strategic nature; the IT architecture needs to be improved because of lower effectiveness score (5.74). Effectiveness of IT architecture must be enhanced in relation to the relative importance of the underlying architecture by improving business processes and the activities associated to them.

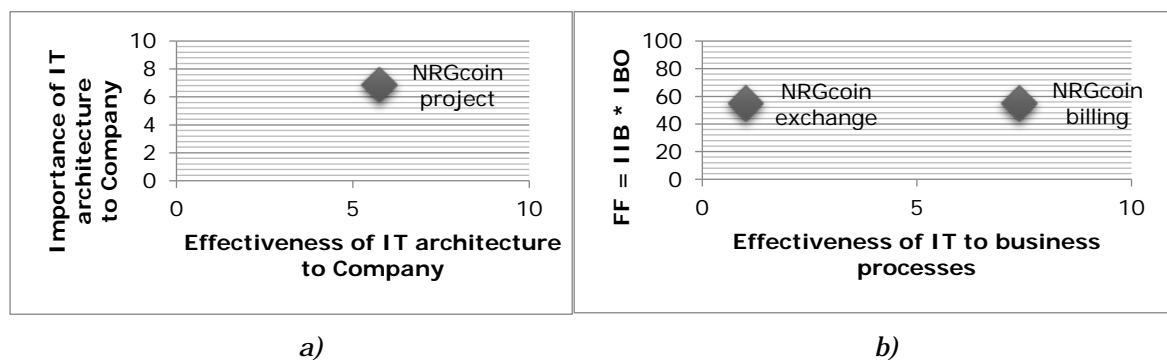


Figure 6. a) Effectiveness of IT vs Importance of IT to the Company. b) Effectiveness of IT to business process vs Focus Factor (FF).

Similarly, Figure 6(b) shows the importance and the effectiveness of IT to the business processes across two services. As one can see, the NRGcoin exchange shows lower effectiveness, which means that the processes involved in the exchange service requires more improvement initiatives than NRGcoin billing service given the importance of both NRGcoin exchange and NRGcoin billing are higher and almost equivalent.

Likewise, Figure 7 shows the importance and the effectiveness of the activities, i.e. the function layer of the two services. Again, as one can see, most of the activities that need to be improved (Market clearing (MC) and Bidding) are all supporting the operation of the NRGcoin exchange service. Energy payment (EP) activities need to be improved as well to deploy the NRGcoin project, however Figure 7 shows that the Energy Distribution (ED) activity, which supports the NRGcoin billing process excels at both importance and effectiveness.

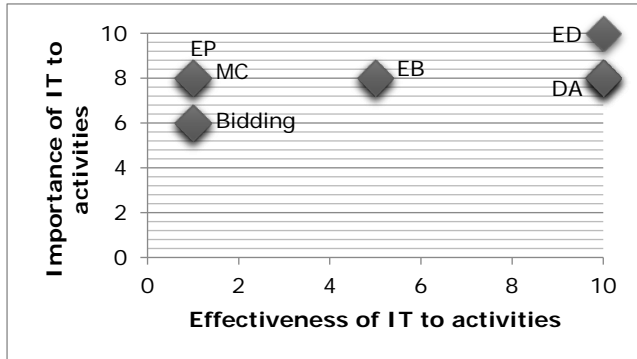


Figure 7. Effectiveness of IT vs Importance to Activities (see also list of activities in Table 3)

To sum up, based on the report generated by the DSS, the organisation's decision makers can make informed decisions to improve the operation of specific activities and business processes as well as the overall IT architecture that supports SG projects.

7 Discussion

We do not call for ignoring the existing assessment methods for SG projects, for example, LCOE, LACE, System LCOE, System Value or SGMM but rather aim to complement the valuation of SG architectures by providing a novel framework that assesses the strategic importance and effectiveness of IT architectures of SG projects. Using our assessment framework, the main stakeholders (e.g. energy utilities, retailers) can have a more holistic view on how IT architecture impact SG projects. For instance, they can analyse how business processes impact the strategic value of SG projects (e.g. Figure 6) as well as how activities impact business processes (e.g. Figure 7).

7.1 Lessons learned

The NRGcoin project's assessment results (value scores of strategic importance and effectiveness) are relatively pessimistic as most of its IT architecture elements are still under development. The results, nonetheless, may help to improve this situation. For instance, using our assessment framework, IT architects can focus on improving the most important elements (activities, processes, etc.) highlighted from this assessment or even consider redesigning the overall IT architecture based on the assessment undertaken.

7.2 Assumptions and Limitations

This paper does not aim to provide a detailed explanation on SGAM modelling but it only makes use of such modelling framework, which has been tailored for the electricity sector by SG experts (CEN-CENELEC-ETSI 2012). Another important consideration is the novel idea of reusing Bedell's method to assess IT architectures in a new domain (i.e. the electricity sector). To thoroughly validate the effectiveness of our assessment framework, more case studies should be conducted.

8 Conclusions

We have presented a framework to assess the importance and effectiveness of SG projects. This form of assessment is important for companies since they need informed recommendations on what IT elements (activities, processes or the overall architecture) must be improved to achieve their business goals.

Furthermore, although companies tend to improve operations for pure economic reasons (e.g. reducing costs or increasing revenue), our assessment framework offers a holistic valuation that may help energy companies to tackle other challenges such as energy efficiency or reducing CO₂ emissions (OECD/IEA 2016), which would benefit not only the concerned companies but also the overall energy sector and society in general. For instance, the assessment could be focused on the strategic value of

SG-IT architectures to achieve societal goals rather than company-centric goals. Future research should consider more assessment rounds on our proposed framework to improve its utility.

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