Towards Improving Resilience of Smart Urban Electricity Networks by Interactively Assessing Potential Microgrids

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Abstract: When a city adds a renewable generation to improve its carbon footprint, this step towards a greener city can be a step towards a smarter city. Strategical positioning of new urban electricity components makes the city more resilient to electricity outages. Money and resilience are two conflicting goals in this case. In case of blackouts, renewable generation, other than distributed combustion generations, can serve critical demand to essential city nodes, such as hospitals, water purification facilities, and police stations. Not the last, the city level stakeholders might be interested in envisioning monetary saving related to introducing a renewable. To provide decision makers with resilience and monetary information, it is needed to analyze the impact of introducing the renewable into the grid. This paper introduces a novel tool suitable for this purpose and reports on the validation efforts. The outcomes indicate that predicted outcomes of two alternative points of introducing renewables into the grid can be analyzed with the help of the tool and ultimately be meaningfully compared.

1 INTRODUCTION

Integration of a renewable into the grid is an entangled task that concerns multiple domains. One might consider the renewable energy-related landscape (Barjis, 2009) and have the overall aim to reduce greenhouse gas emission (Zubelzu et al., 2015). For instance, to find a suitable location for a biogas plant, one should account for distances from the site to the biomass sources is needed (Dugan and McGranaghan, 2011). In case of solar urban planning, an important concern is the interplay between the urban form and solar energy inputs (Amado and Poggi, 2014). Importantly, planners should consider how the grid can behave in case of undesirable conditions (see e.g. (Bennett, 2007; Jung et al., 2016)).

Additionally, there is a need to account for grid resilience – the ability of the grid to withstand a failure in an efficient manner. Specifically, it concerns supplying electricity to critical infrastructures (e.g., hospitals) during blackouts, as well as the ability to quickly restore normal operation state. (Bollinger, 2015). Threat analysis related to non-adversarial and intentional threats (e.g., (Vasenev and Montoya Morales, 2016; Vasenev et al., 2016a)) can highlight which components may deserve particular attention. Distributed Generations (DGs) can also be used to compensate for the discontinuity of electricity produced by renewables. However, optimizing the cost of dispatches of DG units is needed to ensure that this task performed efficiently.

To account how the city can benefit from introducing a new generation, stakeholders might consider both monetary and resilience aspects. Such decisions might be located in the context of larger considerations on improving efficiency of fault and attack mitigation measures, threat ranking, the energy cost and resilience analysis, and the impact on different critical infrastructures.

Even though numbers of tools exist to model grids (as described in Section 2), they lack important features to enable an interactive resilience analysis, such as user interfaces and resilience calculations modules. To enable city-level stakeholders to account for resilience, an Overall Grid Modelling (OGM) was developed to account for introducing renewables into low voltage (LV) and mid voltage (MV) grid nodes. The methodology, policy and the development

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governing the OGM is available in the documentations (IRENE, 2016a; IRENE, 2016b). The decision makers are able to manipulate/control the tool and varieties of resilience coefficient metric and cost analysis across the grid are illustrated whenever a grid component modification is applied.

This paper reports initial validation efforts related to the features and functionalities of the tool in terms of its practicability and efficiency. The tool is at the center of an interactive approach where information is given to decision makers, who make their choice which is the best option in terms of grid planning, and also to evaluate how the introduction of a renewable increases grid resilience and also account for possible monetary savings.

The overall organisation structure of the paper is as follows: Section 2 reviews the state-of-the-art modelling tools to ensure that the OGM tool is aligned with standard core functionalities of the existing tools. Section 3 presents the methodology of OGM tool usages. Section 4 reports the methodology of workshop organized that validates the functionalities of the OGM tool. Finally, Sections 5 and 6 discusses and concludes.

2 STATE-OF-THE-ART MODELLING TOOLS

In this section, a state-of-the-art modelling and controlling smart grid tools are reviewed. The functionality of the smart grid tools and the OGM tool are cross-related for the functionalities in order to identify the desired functionality of the advanced smart grid modelling tools.

DNV GL, the international certification body has developed a microgrid mathematical optimization tool (DNV GL, 2016) to evaluate the full integration of distributed generations, electrical, thermal storages, new innovative technological updates, building automation and customers behavioural usages. The simulation is holistic-based and aims at maximizing the economic value and reliability of electrical system and power. The whole model simulates the day-ahead energy prices, demand forecasts, weather forecasts, dynamic performance of the buildings, storage, and distributed generation, and management of the controllable resources (CHP, storage, and Demand Response (DR)) that optimize the energy economics during the day. The optimization problem is formulated through the Mixed Integer Linear Programming (MILP) approach. The optimization tool is also capable of shifting its operational module from optimizing energy economics to maximizing the uninterruptable and critical load that can be served from available resources during the outage period.

The Massachusetts Institute of Technology (MIT) has built a laboratory-scale microgrid based on the earlier model developed from computer simulation studies (Stauffer, 2012). The project focuses on a small-scale power system that combines the energy generation and storage devices to serve local customers at low level grid. The Masdar Institute corporates with MIT by concentrating on developing an analytical-based weighted multi-objective optimization within the Microgrid (Stauffer, 2012). The analytical methods analyses the two factors (system configuration and operation planning) simultaneously that determines the costs and emissions. The method generates a set of optimal planning/designs and operating strategies that minimizes costs and emissions simultaneously.

Siemens PTI provides a consulting, software and training program to optimize system networks for generation, transmission and distribution and power plants for smart grids (Siemens PTI, 2016). The consulting services offer expertise in power system studies. This includes the system dynamics and threat analysis, energy markets and regulation, control systems, power quality, and steady-state and dynamic system evaluations.

Etap grid has developed a Microgrid Master Controller software (Etap Grid, 2015). The software controller is capable of predicting and forecasting energy generations and loads. The controller also integrates and automatically control (automated load shedding and generation) of microgrid elements, such as PVs, energy storages, back-up generations, wind, gas turbines, CHP, fuel cells, and demand management. The software automatically manages and optimizes the load during grid-connected or islanded grid operations. The software aims to lower the total cost of ownership by reducing the average cost of electricity from the national electricity price.

2.1 Summary of Smart Grid Modelling Tool Functionalities

Table 1 summarizes important features of the mentioned modelling tools. Importantly, most of them do not provide user interfaces between the software and users. This can hamper their use in an interactive manner. Besides, having user interface enables interactions with less experienced users. Also, only the DNV GL tool accounts for critical loads. As some urban-level loads in times of blackouts can be more critical than others, this functionality is particularly relevant for resilience tools. The same applies for resilience analysis.

The OGM tool, as described next, particularly focus on these aspects. Through the mathematical optimization module implemented, the important features such as the simulation of outage, islanding operation, cost and resilience analysis are performed. The users are able to manipulate/control the tool and to calculate changes in the resilience coefficient whenever a new case/scenario is applied (i.e., adding or remove a local generator). The tool does not only supports the simulation of electricity continuity planning (adding/removing alternate generation sources) from the technical perspective, but also ensures the cost concerned through the interventions for benefits of business planning (International Electrotechnical Commision (IEC), 2014).

Table 1: Summary of microgrids modelling tools in comparison with the OGM tool.

	Tool	DNV GL	MIT	Masdar Institute	Siemen PTI	Etap Grid	*OGM tool*
Functionality	Mathematical optimization	✓		✓	✓	✓	✓
	User interface ready	✓			✓		✓
	Demand forecasts	✓				✓	✓
	Generation and storage modelling	✓	✓	✓	✓	✓	✓
	Account for critical loads	✓					✓
	Support of threat ranking						✓
	Islanding operation	✓				✓	✓
	Scenario/case studies	✓	✓		✓	✓	✓
	Outage/contingency simulations	✓			✓	✓	✓
	Cost analysis	✓		✓	✓	✓	✓
	Emission analysis	✓		✓			
	Resilience analysis						✓
	Reliability analysis	✓	✓	✓	✓		
	Power flow analysis		✓		✓	✓	

3 THE OGM TOOL

The network topology tree (or the system architecture) is loaded into the GUI and as shown in Fig. 1, where the architecture included a number of city grid components. The distribution of grid components as in Fig. 1 is presented in Table 2.

The OGM tool incorporates a graphical-based user interface (GUI) (see Table 1). The GUI is to facilitate continuous interactions with the tool that is user-friendly, easily controllable and manipulated.

As the tool is aimed for decision makers (Municipal authority planner, DNO, Developers, Critical Infrastructure Operator, Business and Citizen Representative) with various technical/conceptual background, the tool aims to be easily-interpretable for fellow decision makers, without incorporating complex power-flow model and analysis. The components can be introduced/removed/moved within the grid.

The tool simulates outage consequences using the input of known outage scenario (winter/summer;

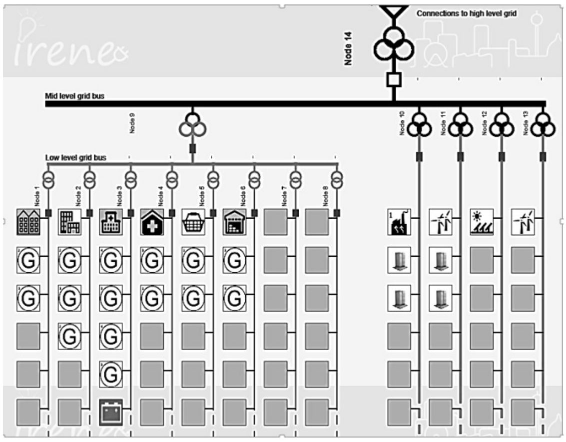

Figure 1: The baseline system architecture of the OGM tool.

Table 2: Number of distributed generators, energy storages, types of consumer profiles and their populations included.

Node no.	Number of generators: Non-renewable	Number of generators: Renewable	Number of energy storage	Profiles included	Populations
1	2	2	1	Households	15000
2	3	2	0	Offices	2
3	4	0	1	Hospitals	2
4	2	0	2	Outpatient clinics	5
5	2	1	2	Supermarkets	5
6	2	0	2	Warehouses	5
7	0	0	0	-	-
8	0	0	0	-	-
9	0	0	0	-	-
10	1	0	2	-	-
11	0	1	2	-	-
12	0	1	0	-	-
13	0	1	0	-	-
14	0	0	0	-	-

start/stop time) Critical loads are known, as well as specifics of generation profiles. Then, computations modules will process the outage scenario. Output results will demonstrate the monetary savings and resilience indicator through the component changes. The decision makers will select most suitable alternative for grid outage mitigations and repeat the simulation if needed.

This tool assumes that hardware solutions to island a microgrid (de-attach and re-attach it to the main grid) can be located at the point of coupling nodes (transformers). Thus, each node with a critical load might strive to be self-sustaining: balance the (critical) supply and demand. A node can be either connected or disconnected completely from the main grid. Thus, we have only one connection to the main grid for each single nodes in the tool. We do not account for mesh networks. The tool particularly focuses on threats that lead to outages: (1) those resulting in the disconnection of a node from the main grid; and (2) outage of a component (e.g., a DG as an electricity generation element).

Support for threat ranking is another distinctive feature of the OGM tool. Taking as input threat analysis methodologies, such as the need to envision which grid component approaches should be paid particular attention to. Such analysis can be related to non-adversarial threats (e.g., (Vasenev and Montoya Morales, 2016; Vasenev et al., 2016a)) as well as threats related to intentional disruptive actions (e.g., (Le et al., 2016; Vasenev et al., 2016b)). This provides opportunities to enter threat characteristics to calculate relative value of threat event frequencies. Analysts, equipped with this information may focus on grid components where this value is higher of a predefined threshold.

Concerning technical implementation details, the GUI of the OGM is developed using IntelliJ IDEA, the Java IDE software. For the numerical optimization algorithm, the dual-simplex algorithm is applied for such Linear Programming problem of the grid optimization. The lp_solve 5.5.2.3 (lp_solve, 2015) is applied as the library file for Java that is called to perform the optimization algorithm for the OGM tool. The configuration as defined in Fig. 1 is simulated.

The tool calculates two indicators – resilience coefficients and monetary costs (with or without savings) – to inform users how the grid would operate during a blackout. The resilience coefficient in this paper is computed based on the extents in which the amount of energy demand within consumers are met when there is an outage in the grid (Bollinger, 2015). The resilient coefficient is determined as the mean fraction of the demand served for the outage node divided by the overall demand to be served. The resilience coefficient in this case is therefore the fraction of demand served at dth consumer ($P_{d,t}$) divided by the total demand D ($P_{D,t}$) in the contingency state at time t:

$$\alpha(t) = \frac{P_{d,t}}{P_{D,t}}. \tag{1}$$

A grid is robust and resilient when the computed resilient coefficient is high, or is maintained throughout the outage period. The cost savings are determined based on the difference in between the business-as-usual operation of the traditional grid (without capability of islanding, and also without implementation of DGs, energy system storages and renewables), and the alternative operation mode, when DGs, energy storage systems and renewables are activated.

Fig. 2 shows the example of resilience coefficient and monetary costs calculated for the grid described in Fig. 1, where the top panel presents the plot of monetary savings in relation to the business-as-usual and the optimised grid planning, and the bottom panel that illustrates the distribution of resilience coefficient. Negative monetary savings indicate additional costs, whereas positive savings indicate the cost

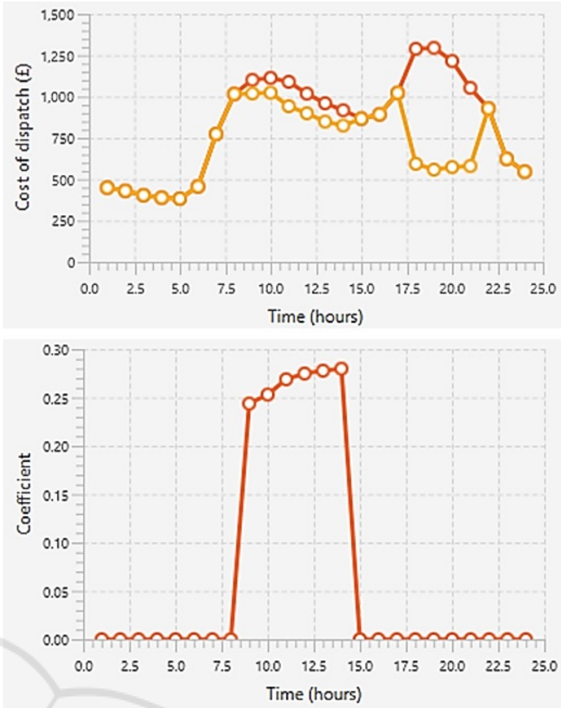

Figure 2: Resilience coefficient and monetary costs calculated for the grid: top panel – plot of monetary savings in relation to the business-as-usual and the optimised solution; bottom panel – the distribution of resilience coefficient.

saved through the grid planning improvement. The resilience coefficient would be between 0 – 1 (the resilience coefficient is computed as zero at a particular time interval when no outage occurs) because of the fraction of demand served over the overall demand during an outage event.

4 VALIDATING THE TOOL

4.1 Methodology

The gaming workshop with students was conducted to validate the applicability of the OGM tool as a support tool for improving the resilience of the urban electrical grids. In the beginning of the workshop, mini-lectures on smart grids were delivered to introduce students to major ideas of smart grids, as well as the current issues and challenges. The OGM tool was demonstrated to students to clarify the idea how modelling tools can be used to improve the resilience of the overall grid.

During the gaming session, exercise handouts were given to six PhD students. Students formed two groups (Group A & B). Within each group students represented stakeholders (City planner, DNO, and Citizen & Business Representative). These stakeholder roles correspond to professionals who might benefit from using the OGM tool. These professionals need to collaborative decide how to introduce new components or modifying the existing components to improve resilience of the grid. The system architecture as illustrated in Fig. 1 and Table 2 was used as the baseline configuration, where the amount of renewable sources are low. In addition to the description of the grid architecture, students were briefed on the changes that the grid context might undertake. It was suggested that the city grows, hence the populations within the city are increased, and towards the decarbonization plan. Specifically, amount of city components would be as follows: Households = 25000; Offices = 3; Hospitals = 3; Outpatient clinics = 5; Supermarkets = 5; Warehouses = 6.

After providing the information, students were asked to discuss what grid updates might be introduced to ensure that a city can withstand a blackout with less negative impact. The aim of this exercise is to investigate how the manipulation of the OGM tool can guide the fellow professionals to improve the resilience of a complex urban grid, in the context of collaborative decision making in the situation of uncertainty.

Two different outage scenarios (4 and 8 hours) were chosen to examine the resilience of the city in sustaining both the shorter or longer outages. The outage in every single node is also examined, because it is intended to examine the outage effects on the changes of the supply towards the demand profile across individual consumer and the overall demand, as well as the changes in the monetary savings and resilient coefficient in the grid level city as shown in Table 3. The 'economic-islanding' capability during the normal grid operation is enabled that employs DGs, renewable sources and energy storage systems to provide power at times of high electricity price, rather than drawing the electricity from the main grid (IRENE, 2016b).

Questionnaires were disseminated to fellow students at the end of the workshop.

4.2 Results

In order to access the effectiveness of the collaborative decisions as made by Groups A & B, normal and failure of grid operations are simulated for each node, and also the entire microgrid level. Failures occur when there is a line-disconnection between the microgrid and main grid level, and also the line disconnection within the microgrid nodes. When there is a line-disconnection due to a failure event, the islanding capability is activated to ensure uninterrupted operation during a utility system outage with *N*-1 compliance (IRENE, 2016b). Decisions placed and the performance of the implemented decisions by each groups are compared with the baseline case in terms of resilience coefficients and monetary savings.

Table 3: Type of grid operations and the indicators applied.

Grid operation	Economic islanding capability	Indicators	
		Resilient coefficient	Cost saving
Normal	✓		✓
Outage 4 hours for single node		✓	✓
Outage 8 hours for single node		✓	✓
Outage 4 hours for complete grid outage		✓	✓
Outage 8 hours for complete grid outage		✓	✓

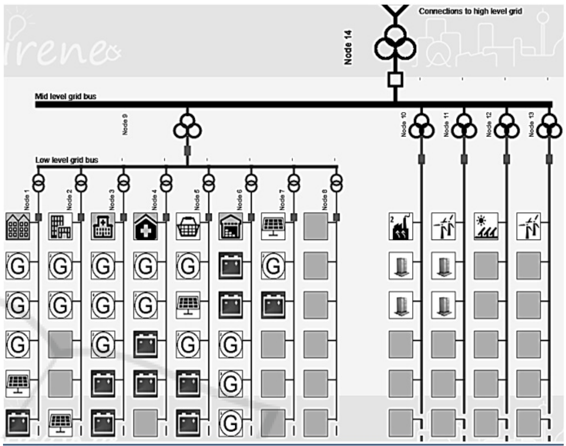

Figure 3: The modification of the grid architecture as proposed by Group A.

The decisions are simulated using the OGM tool and the timeline for the simulation is allowed for 24 hours. The grid with various operating conditions are simulated for the baseline case, Groups A & B.

Group A after some discussions proposed to update the base scenario (Fig. 1) as shown in Fig. 3. The updates were:

i. Move solar PV from Node 2 to Node 7;
ii. Remove one non-renewable generation in Node 2;
iii. Remove one non-renewable generation and add one energy storage in Node 3;
iv. Add one non-renewable generation in Node 6;
v. Remove solar PV and add one non-renewable generation in Node 1;
vi. Add one non-renewable generator and one energy storage in Node 7.

The collaborative decisions as proposed by Group B, using the base configuration of Fig. 1 were

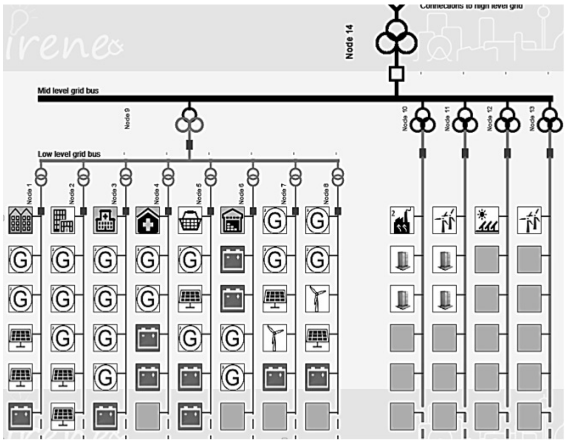

Figure 4: The modification of the grid architecture as proposed by Group B.

presented in Fig. 4, which were:

i. Add two non-renewable generations in Nodes 7 & 8;
ii. Add one solar PV in Nodes 7 & 8;
iii. Add one small-scale wind turbine in Nodes 7 & 8;
iv. Add one energy storage in Nodes 7 & 8.

4.2.1 Case 1 – Normal operation

In this case, assuming no failure occurs, the normal mode of operation is applied. The cost savings and resilience coefficient achieved for baseline, Groups A & B are shown in Table 4.

Table 4: Cost savings and resilience coefficient for normal operations.

	Baseline	Group A	Group B
Cost savings (£)	1865.39	2112.27	**2136.36**
Resilience coefficient	0	0	0

Based on Table 4, the collaborative decisions proposed by Group B achieve higher amount of cost savings than Group A, and also higher than the Baseline scenario. Hence the decision by Group B achieves higher amount of cost savings, particularly for 'economic-islanding' normal mode of grid operations. The resilience coefficients are all zeros. This is because the grid resilience is not considered during the normal mode of operation (without any outage events). The simulation excludes the addition of installation and maintenance costs of individual generators.

4.2.2 Case 2 – Four Hours of Outage Duration

In this case, it is assumed that an outage within the microgrid or the entire grid occurs at 0900 for the duration of four hours. The 'economic-islanding' capability is disabled in the case of outage events. Table 5 shows the result of the simulation using the baseline scenario, Group A & B. Negative sign indicates that additional costs are introduced (no monetary savings are achieved). Overall Group A's collaborative decision promotes highest amount of cost savings than Group B, and also the baseline case. In all cases critical loads were served during the outage events. The computed resilience coefficients are identical.

Table 5: Case 2 – cost savings and resilience coefficient for outage operations.

Outage Node	Cost savings (£)			Resilient coefficient		
	Baseline	Group A	Group B	Baseline	Group A	Group B
Node 1	208.47	138.98	208.47	0.21	0.21	0.21
Node 2	-94.79	-29.06	-94.79	0.218	0.218	0.218
Node 3	198.33	368.82	198.33	0.242	0.242	0.242
Node 4	211.16	259.30	211.16	0.131	0.131	0.131
Node 5	206.19	125.25	206.19	0.109	0.109	0.109
Node 6	321.80	205.25	321.80	0.007	0.007	0.007
Grid outage	1286.65	1559.54	1558.27	1	1	1
Total savings (£)	2337.81	**2628.08**	2609.43	–	–	–

4.2.3 Case 3 – Eight Hours of Outage Duration

In the final case, it is assumed that an outage within the microgrid or the entire grid occur at 0900 with prolonged outage duration of eight hours compared to Case – 2. The 'economic-islanding' capability is also disabled. Each outage node disconnections is evaluated. Table 6 shows the result of the simulation using the baseline scenario, Group A & B. Similarly as in the previous case, Negative sign indicates additional costs are introduced (no cost savings are achieved). 'Invalid' indicates that monetary savings are not calculated as the proportions of the demand at the particular node during the outage is not met. Overall Group B's collaborative decision promotes highest amount of cost savings. The installation of a new energy storage system and also the removal of one of the non-renewable generation in Node 3 proposed by Group A results in insufficiency of energy supply to match the fraction of demand to be served for hospital loads during the outage in Node 3. The low resilient coefficient as computed in Node 3 suggests the failed portion of demand $(0.252 - 0.15 = 0.105)$ served in Node 3 during the outage.

Table 6: Case 3 – cost savings and resilience coefficient for outage operations.

Outage Node	Cost savings (£)			Resilient coefficient		
	Baseline	Group A	Group B	Baseline	Group A	Group B
Node 1	310.83	136.55	310.83	0.219	0.219	0.219
Node 2	-189.66	-159.42	-189.66	0.208	0.208	0.208
Node 3	272.31	**Invalid**	272.31	0.252	**0.12**	0.252
Node 4	225.49	116.06	225.49	0.132	0.132	0.132
Node 5	234.59	-12.35	234.59	0.106	0.106	0.106
Node 6	546.84	267.97	546.84	0.064	0.064	0.064
Grid outage	1817.43	1850.51	2118.89	1	1	1
Total savings (£)	3217.83	–	**3519.29**	–	–	–

5 DISCUSSION

Overall, the gaming exercise was successfully conducted with pros and cons of the grid component alterations within the collaborative decisions made by two groups, in comparison with the baseline case. Additionally, the gaming workshop also noted the extensive collaboration within students in successfully increasing the resilience of the electricity network that is prone to outage events.

The feedback questionnaire is shown in Table 7. Based on Table 7, the outcomes of the gaming session showed that the tasks related to grid update (including the introduction of renewables and changes in the consumption) could be effectively performed in an understandable manner. Results can be compared and a better alternative (with respect to some criteria) can be selected.

Participants indicated that the tool can be used even without having advanced domain-specific knowledge. Five participants also agreed that the OGM tool is practicable for evaluation of urban electricity network. Positive scores were obtained about the practicability of the demand management, controlled generations, islanded operations, critical loads, disconnected and uninterruptible loads in the OGM tool.

However, one of the participant outlined the difficulty in understanding the given scenario and demanded more relevant data in order to provide better decisions, rather than the overall grid outlook. Several participants also pointed out the need for additional amount of data given (particularly to advanced knowledge of decision makers) in order to provide a clearer indication of grid component modifications. Still, some additional explanations are needed before using the tool through the lectures. For instance, the participant indicated that the resilience coefficient applied is not completely understandable, as well as some advanced functionalities of the OGM tool were not clear.

Table 7: Questionnaire results.

Question	**Rating scale** (1 – Very negative, 7 – Very positive)						
	1	**2**	**3**	**4**	**5**	**6**	**7**
	Number of respondents						
Q1. Knowledge on Smart Grids	0	0	1	4	1	0	0
Q2a. Practicability of demand management capability	0	0	0	2	2	1	1
Q2b. Practicability of controlled generations	0	0	0	1	2	3	0
Q2c. Practicability of islanded operation during outage	0	0	0	0	2	1	2
Q2d. Practicability of disconnected load during outage	0	0	0	1	2	3	0
Q2e. Practicability of critical loads	0	0	0	0	1	2	3
Q2f. Practicability of uninterruptible loads	0	0	0	2	1	2	1
Q3a. Effectiveness of OGM tool in addressing outage	0	0	0	1	2	1	2
Q3b. Effectiveness of threat ranking support	0	0	2	0	3	1	0
Q4a. Speed of OGM tool to run/re-run a simulation	0	0	0	1	2	0	3
Q4b. Speed of OGM tool to construct/re-construct grid components	0	0	0	1	1	1	3
Q5a. Level of knowledge required in using the tool	1	0	2	1	0	1	1
Q5b. Level of easiness in using the tool	1	0	0	1	1	0	3
Q6. Reason for rating as 5 or above in Q5.	–There are many components and the users must have knowledge in understanding them. –The GUI of the toolset is easy to use. –The scenario is complex, and more data is preferred to make decision, instead of just having an overview. There are many components in the tool which will require background knowledge. It would be more useful to indicate electricity flow direction. It is very convenient to add/delete a component in the tool. –Functionality of the component is not quite clear. –Types of power supplies are not illustrated accurately. –The tool is useful for designing the city development. –Key parameter can be provided graphically. –Panel to support add/drag icons. –More data to make decisions. –More description of components. –Specify the different kind of threat and the type of hazardous disconnection. –Distance or distribution of grid planning is not fully presented. –Capacity of generators should be provided. –Costs and distance analysis should be considered in the tool.						
Q7a. Understandable of resilient coefficient metric	0	0	2	2	2	0	0
Q7b. Understandable of threat ranking	0	1	1	2	1	1	0
Q8a. Practicability of resilient coefficient metric	0	0	0	2	3	1	0
Q8b. Practicability of threat ranking	0	0	0	2	2	2	0
Q8c. Practicability of grid evaluation	0	0	1	1	1	1	2
Q9. Speed in providing analysis	0	0	0	0	1	2	3
Q10. Usefulness in addressing outage	0	0	0	1	0	4	1
Q11a. Usefulness of the tool as a collaborative decision support system	0	0	0	1	2	2	0
Q11b. Usefulness of the tool in establishing collaborative frameworks among stakeholders	0	0	0	1	2	3	0

6 CONCLUSION

This paper presents an approach to improve resilience of smart urban electricity networks by using a decision support tool to assess the potential microgrids. The OGM tool is developed that allow fellow decision makers to manipulate/control the tool in examining the resilience coefficient metric and the potential monetary savings across the grid are illustrated whenever a grid component modification is applied.

Overall, the obtained perspectives of the OGM tool from decision makers (simulated by students) through the workshop are indeed useful not only to improve the usability of the OGM tool, but also to improve the overall understanding of decision makers. Different cases and solutions were presented that showed the trade-off in between the resilient coefficient and monetary savings (e.g. one may wish to increase the resilience of electricity network but may result in extra investments). The tool would be needed to make the point that all those complex aspects should be considered by minimizing such trade-offs.

In summary, the idea and logic of using the tool for grid planning are well-received. Based on the feedback obtained, the tool can be further improved by providing more descriptions of the grid scenario, data information such as the capacity of generations and demands, better navigation of adding/removing components, and a clearer description of the OGM tool.

The tree representation of the grid architecture is a first step in the OGM tool. As the grid architecture does not account for mesh networks, moving to the meshed grid is the future work.

REFERENCES

Amado, M. and Poggi, F. (2014). Solar urban planning: a parametric approach. *Energy Procedia*, 48:1539–1548.

Barjis, J. (2009). Collaborative, participative and interactive enterprise modeling. In *Enterprise Information Systems, Proceedings of the 11th International Conference ICEIS 2009, Milan, Italy, May 6 – 10 2009*, pages 651–662. Springer Berlin Heidelberg.

Bennett, B. (2007). *Understanding, assessing, and responding to terrorism: Protecting critical infrastructure and personnel*, volume 4 of *10*. John Wiley & Sons.

Bollinger, L. A. (2015). Fostering climate resilient electricity infrastructure. [Online]. Available: http://repository.tudelft.nl/islandora/object/uuid:d45aea59-a449-46ad-ace1-3254529c05f4/datastream/OBJ/download. [accessed 06.12.16].

DNV GL (2016). Microgrid optimizer - a holistic operational simulation tool to maximize economic value or electrical power reliability. [Online]. Available: http://production.presstogo.com/fileroot7/gallery/DNVGL/files/original/3a1dd794f6ff46b9a279175c15af0f11.pdf. [accessed 05.12.16].

Dugan, R. and McGranaghan, M. (2011). Sim city. *IEEE Power and Magazine*, 9(5):74–81.

Etap Grid (2015). Power technologies international. [Online]. Available: http://etap.com/Documents/Download [accessed 19.01.17].

International Electrotechnical Commision (IEC) (2014). White paper - microgrids for disaster preparedness and recovery with electricity continuity and systems. Technical report, IEC WP Microgrids, Switzerland.

IRENE (2016a). D2.2 – root causes identification and societal impact analysis. Technical report.

IRENE (2016b). D3.1 – system architecture design, supply demand model and simulation. Technical report.

Jung, O., Bessler, S., Ceccarelli, A., Zoppi, T., Vasenev, A., Montoya, L., Clarke, T., and Chappell, K. (2016). Towards a collaborative framework to improve urban grid resilience. In *Proceedings of 2016 IEEE International Energy Conference (ENERGYCON), 4 – 8 April*, pages 1–6. IEEE.

Le, A., Chen, Y., Chai, K. K., Vasenev, A., and Montoya Morales, A. L. (2016). Assessing loss event frequencies of smart grid cyber threats: Encoding flexibility into fair using bayesian network approach. In *Proceedings of the 1st EAI International Conference on Smart Grid Inspired Future, 19 – 20 May 2016, Liverpool, United Kingdom*, pages 43–51. Springer Verlag.

lp_solve (2015). Introduction to lp_solve 5.5.2.5. [Online]. Available: http://lpsolve.sourceforge.net/5.5/. [accessed 19.10.16].

Siemens PTI (2016). Power technologies international. [Online]. Available: http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/planning-data-management-software/PTI/Pages/Power-Technologies-International-(PTI).aspx. [accessed 19.01.17].

Stauffer, N. (2012). The microgrid - a small-scale flexible, reliable source of energy. [Online]. Available: http://energy.mit.edu/news/the-microgrid/. [accessed 19.01.17].

Vasenev, A. and Montoya Morales, A. L. (2016). Analysing non-malicious threats to urban smart grids by interrelating threats and threat taxonomies. In *Proceedings of 2016 IEEE International Smart Cities Conference (ISC2), 12 – 15 September 2016, Trento, Italy*, pages 1–4. IEEE.

Vasenev, A., Montoya Morales, A. L., and Ceccarelli, A. (2016a). A hazus-based method for assessing robustness of electricity supply to critical smart grid consumers during flood events. In *Proceedings of the 11th International Conference on Availability, Reliability and Security, ARES 2016, 31 August – 02 September 2016, Salzburg, Austria.*, pages 223–228. IEEE.

Vasenev, A., Montoya Morales, A. L., Ceccarelli, A., Le, A., and Ionita, D. (2016b). Threat navigator: grouping and ranking malicious external threats to current and future urban smart grids. In *Proceedings of the 1st EAI International Conference on Smart Grid Inspired Future, 19 – 20 May 2016, Liverpool, United Kingdom*, pages 184–192. Springer Verlag.

Zubelzu, S., Alvarez, R., and Hernandez, A. (2015). Methodology to calculate the carbon footprint of household land use in the urban planning stage. *Land Use Policy*, 48:223–235.