Classifying the factors affecting the adoption of the SDN-microSENSE innovations

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This paper presents the results of a survey conducted in order to identify the most critical factors that can affect the market adoption of the innovations developed in the H2020 R&I project SDN-microSENSE. A hierarchy of the main criteria and sub-criteria was created using the Fuzzy Analytical Hierarchy Process method and experts in the area expressed their preferences through a web-based survey. The results of this process provide an insight on the expert's vision regarding the importance of the factors that are crucial for the adoption of cyber-security solution in the Electrical Power and Energy Systems domain.

CCS CONCEPTS • General and reference • Document types • Surveys and overviews

Additional Keywords and Phrases: Cyber-security, smart-grid, decision making, market

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1 Introduction

The rapid increase of cyber-attacks towards Electrical Power and Energy System (EPES) intensifies the need for advanced cyber security solutions. SDN-microSENSE project is a H2020 R&I project [1] that intends to provide a set of secure, privacy-enabled and resilient to cyberattacks tools, thus ensuring the normal operation of EPES as well as the integrity and the confidentiality of communications. Before the innovations of SDN-microSENSE are introduced to the market a deeper understanding of the main aspects that experts are valuating is required. Towards this direction we conducted a survey among experts using the Analytical Hierarchy Process (AHP) trying to identify the most crucial parameters that can affect the market adoption of the SDN-microSENSE solutions. We believe that the outputs of this activity can also be used as guidelines from stakeholders developing similar solutions. The paper is organized as follows: in section 2 a brief description of the Analytical Hierarchy Process (AHP) framework is presented, section 3 presents how the framework was used to analyse the factors that can

* Place the footnote text for the author (if applicable) here.

affect the market adoption of the SDN-microSENSE innovations and section 4 presents the results. Finally, section 5 concludes the paper.

2 Multi-criteria decision framework

Analytical Hierarchy Process (AHP) is a methodology used for multi-criteria decision making. It was introduced by Thomas Saaty [2] and has been extensively used over the years in different domains such as education [3], engineering [4], industry [5] and resource allocation [6]. The last years it was also used for ranking alternative options in the field of ICT [7]-[9].

AHP is a structured technique for dealing with complex decisions, based upon a rational and comprehensive framework for decomposing an unstructured complex problem into a multi-level hierarchy of interrelated criteria, sub-criteria and decision alternatives. By incorporating judgments on qualitative and quantitative criteria, AHP manages to quantify decision-makers' preferences. The relative priorities of the criteria, sub-criteria and alternatives are finally reached by a mathematical combining of all these various judgments.

AHP is implemented in three steps: in the first step the problem under investigation is formulated and the criteria and sub-criteria that are crucial for the satisfaction of the objective are defined. The multi-level hierarchy is then constructed, consisting of three levels. In the second step questionnaires are created and distributed to experts requiring the pairwise comparison of the criteria in each of the levels. The last step is the estimation of the criteria and sub-criteria weights. More details about the method and how it can be applied in similar cases can be found in [9].

3 Criteria and sub-criteria

As a first step a wide range of factors that may have impact on the market adoption of the project results has been drafted. After discussions among the partners of the SDN-microSENSE consortium four were defined as the most important criteria that would play crucial role in the market adoption of the project's innovations: performance, technology/features, security and business aspects. More specifically performance includes aspects related to availability, usability and scalability while technology / features is associated with aspects such as islanding, reconfiguration, energy balance management and trading system. Security includes aspects related to compliance, privacy and accountability while the aspects of cost, licensing, transition and continuity are included in the business aspects criterion.

For each of the criteria a number of sub-criteria were defined, these are attributes that are associated with each of the criteria.:

For the performance criterion, four sub-criteria were identified:

- **Resilience and reliability**: the system will have high reliability and resilience
- **Usability:** the system will provide a comfortable experience to users
- **Availability:** the overall functionality supported by the SDN-microSENSE should always be available
- **Scalability:** the system should be able to expand its capabilities

Regarding the technology / features criterion the following four sub-criteria were selected:

- **Islanding:** SDN-microSENSE will use islanding schemes as counter measure against cyber-attacks or improper grid operation
- **Network reconfiguration:** the SDN controller will be able to conduct network reconfiguration
- **Energy balance management:** the system will be able to conduct constant energy balancing actions to mitigate possible issues in case of attack or failures in the grid
- **Blockchain based trading system:** SDN-microsSENSE will provide a safe peer-to-peer energy trading system among grid stakeholders

For the security criterion, four sub-criteria were selected:

- **Compliance with regulation:** SDN-microSENSE will be compliant with the latest regulations regarding security and data protection, like GDPR
- **Privacy protections (prosumers, consumers):** the system will protect prosumers and consumers against data breaches and will preserve their privacy
- **Privacy protections (energy providers):** the system will protect datasets containing personal identifiable information when exposing these to third parties
- **Accountability: a**ll cyber-attack access attempts and actions should be properly recorded

Finally, for the business criterion the following four sub-criteria were identified:

- **Cost / Sustainability:** the cost of adopting the SDN-microSENSE must be sustainable
- **Licensing:** the system will have an intellectual property modular design that will allow organizations to deploy the components that suit the licensing terms
- **Transition:** a smooth transition from current state must be made when adopting the SDN-microSENSE solution
- **Continuity:** business continuity must be satisfied

The full hierarchy with all the criteria and sub-criteria is presented in Figure 1.

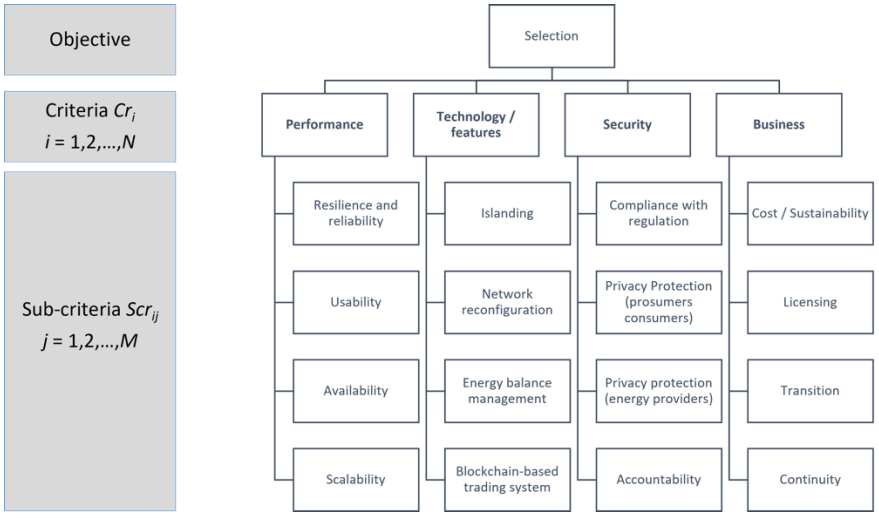

Figure 1: Multi-level hierarchy set of criteria and sub-criteria for SDN-microSENSE

3.1 Description of the survey

A web-based survey was created to collect the responses from the experts. All elements required by the fuzzy AHP were taken into account in order to implement the survey and as a result experts were asked to provide their input regarding the (sub)criterion of their preference and the upper and lower limits of the importance. The web-platform was implemented using LimeSurvey (https://www.limesurvey.org/), an open-source tool for web surveys that was deployed in the project's website. Since Limesurvey does not have modules for implementing a fuzzy logic AHP and performing the needed calculations, the responses from the survey were extracted and imported to a tool implemented in Matlab to estimate the weights that signify the importance of criteria and sub-criteria.

An introductory page provided a short description of the project along with details about the methodology that was used. The same page also contained information about the funding of the project, links to social media of the project and the data policy. The responses were strictly anonymous; no personal data were collected during the survey.

4 Results

The link of the survey was distributed to partners within the SDN-microSENSE project. From the thirty-three experts who participated in the survey, ten questionnaires were discarded as inconsistent, since their associated Consistency Ratio (CR) was >0.1. Regarding their profile of the experts all type of organizations that participate in the project are represented. Forty percent of the experts are researchers working in academia and research centers, 35% in SMEs, while 15% work on operators and 10% in industry.

4.1 Weights of criteria

The weights of criteria are shown in Table 1. According to experts' preferences the most important criterion is the Technology / Features with a weight equal to 0.33 (33%), followed by Security with a weight of 0.29 (29%). Performance ranks third with weight equal to 0.20 (20%) while the criterion with the lowest weight is Business with 0.18 (18%).

Table 1: Fuzzy and Crisp Weights of criteria

Sub-criteria (SCij)	Crisp Weight	Fuzzy Weight (lower; mean; upper;)
C_1: Performance	0.20	(0.20;0.29;0.42;)
C_2: Technology / Features	0.33	(0.20;0.30;0.45;)
C_3: Security	0.29	(0.21;0.31;0.45;)
C_4: Business	0.18	(0.07;0.10;0.15;)

Technology and features of the developed solution is the most important factor among experts, they value the different features that the final product will have as the most critical ones. Security that is one of the main aspects of the SDN-microSENSE solution is ranked second, these features are important but not as the technology. These two criteria have a total weight of 0.62 highlighting that these two factors are clearly the most important ones.
Performance follows at the third place followed by business in the last place. It seems that at this early stage of the project with most of the components still in early development phase experts are more focused on criteria associated with the development. Business factor is more related to a product that is already close to commercialization.
A different way of interpretation of the results is that the decision making does not always imply a discrete choice between the alternatives, but could also refer to probabilities, possibilities or considerations concerning opportunities vs. risks. The usage of fuzzy numbers could then be taken to guarantee the minimum and maximum values. An α-cut can also be taken into account in order to define narrower lower and upper limits of the relevant weightings based on risk considerations.
In order to better understand that effect, the fuzzy weights are illustrated in Figure 2. Technology is the most important factor among the criteria although it has high uncertainty, there is a significant overlap with security that also has high uncertainty. The other two criteria present lower uncertainties but are clearly the ones ranked at the last places.

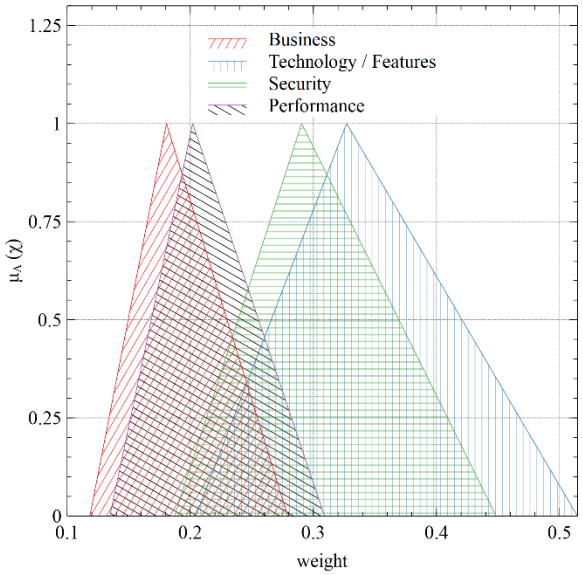

Figure 2: Fuzzy evaluation of criteria

4.2 Weights of sub-criteria

At the next step we examined the ranking among the different sub-criteria under each of the criteria. Table 2 shows the ranking of the Performance sub-criteria. Resilience and reliability sub-criterion has the highest weight of 0.40 (40%), followed by availability with a weight of 0.34. The other two sub-criteria have significant lower weights: the usability has 0.14, while scalability has 0.12.

Table 2: Fuzzy and Crisp Weights of Performance sub-criteria

Sub-criteria (SCij)	Crisp Weight	Fuzzy Weight (lower; mean; upper;)
SC_{11}: Resilience and reliability	0.40	(0.28;0.40;0.57;)
SC_{12}: Usability	0.14	(0.10;0.14;0.20;)
SC_{13}: Availability	0.34	(0.24;0.34;0.48;)
SC_{14}: Scalability	0.12	(0.08;0.12;0.17;)

Seeing the fuzzy weights that are illustrated in Figure 3, one can observe that resilience ranks first although it has a partial overlap with availability. It is interesting that the expert preference is clear that these two are the most important ones as there is no overlap with the other two sub-criteria. Experts valuate high systems that have high resilience and availability, and they prefer these two characteristics over usability and scalability. These two options come as additional features that are good to be present but the most important is to have a stable and available system.

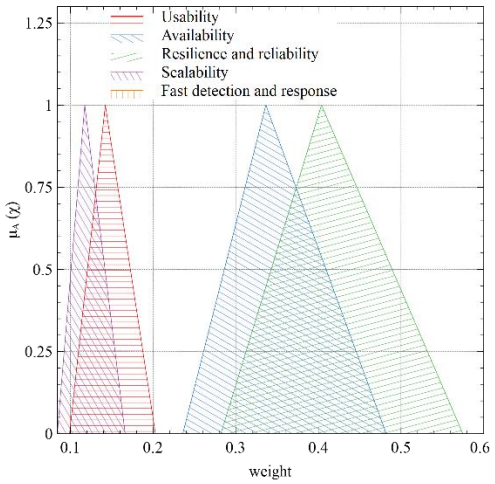

Figure 3: Fuzzy evaluation of Performance criterion

For the technology criterion, the ranking of the sub-criteria is presented in Table 3. The three out of the four sub-criteria present similar weights. Energy balance system ranks first with 0.31, followed by Network reconfiguration with 0.30 and Islanding with 0.29. The blockchain trading system has the lowest weight of 0.10.

Table 3: Fuzzy and Crisp Weights of Technology sub-criteria

Sub-criteria (SCij)	Crisp Weight	Fuzzy Weight (lower; mean; upper;)
SC_{21}: Islanding	0.29	(0.20;0.29;0.42;)
SC_{22}: Network reconfiguration	0.30	(0.20;0.30;0.45;)
SC_{23}: Energy balance management	0.31	(0.21;0.31;0.45;)
SC_{24}: Blockchain based trading system	0.10	(0.07;0.10;0.15;)

Examining the fuzzy weights that are presented in Figure 4, we see that the three sub-criteria present high overlap and similar uncertainties. It seems that all these three characteristics are required and have similar importance according to experts. The trading system based on blockchain presents clearly a characteristic with lower importance. Experts are very confident that this is a feature they prefer less in terms of technology.

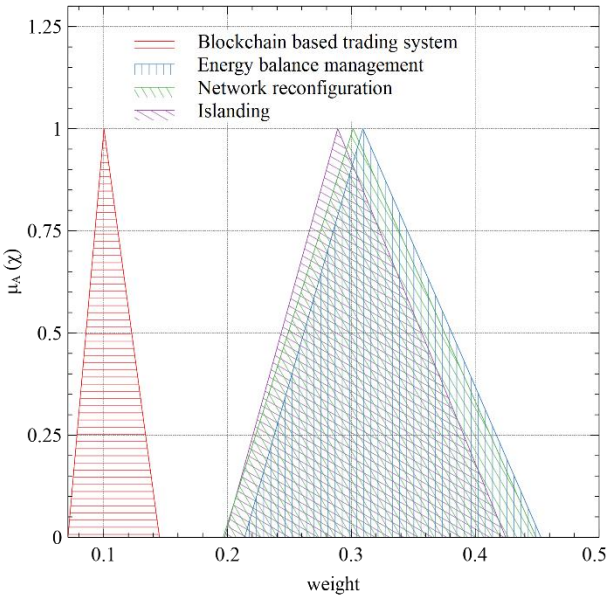

Figure 4: Fuzzy evaluation of Technology criterion

Proceeding to the security criterion we see the weights in Table 5. Compliance with regulation has the highest weight of 0.33 while the other three options present similar weights. Privacy protection for consumers ranks second with a weight of 0.25, followed by privacy protection for energy providers with a weight of 0.22. Finally, accountability ranks last with a weight equal to 0.20.

Table 4: Fuzzy and Crisp Weights of Security sub-criteria

Sub-criteria (SCij)	Crisp Weight	Fuzzy Weight (lower; mean; upper;)
SC_{31}: Compliance with regulation	0.33	(0.23;0.33;0.47;)
SC_{32}: Privacy protections (prosumers, consumers)	0.25	(0.17;0.25;0.36;)
SC_{33}: Privacy protections (energy providers)	0.22	(0.16;0.23;0.32;)
SC_{34}: Accountability	0.20	(0.14;0.20;0.29;)

Examining the fuzzy weights that are presented in Figure 5, we can see that compliance with regulation ranks first although there are overlaps with all the other options and has the highest uncertainty among all of them. The overlap is significant among the other three sub-criteria. All of these sub-criteria are characteristics that are valued almost equally by experts.

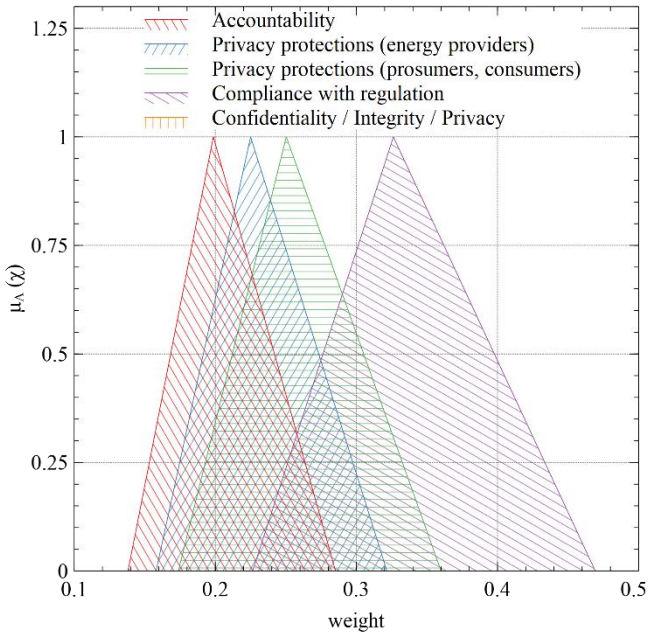

Figure 5: Fuzzy evaluation of security criterion

The weight of the sub-criteria of the business criterion are presented in Table 5. Cost has the highest weight (0.31) followed closely by continuity (0.30). Transition ranks third with a weight of 0.21 while licensing with weight of 0.17 takes the last place.

Table 5: Fuzzy and Crisp Weights of Business sub-criteria

Sub-criteria (SCij)	Crisp Weight	Fuzzy Weight (lower; mean; upper;)
SC_{41}: Cost / Sustainability	0.31	(0.22;0.31;0.45;)
SC_{42}: Licensing	0.17	(0.12;0.17;0.24;)
SC_{43}: Transition	0.21	(0.15;0.21;0.31;)
SC_{44}: Continuity	0.30	(0.21;0.30;0.44;)

Examining the fuzzy weights (Figure 6) we can see that the first two ranked factors have almost complete overlap, these are almost equal important factors according to experts. Transition ranks third although there is partial overlap with the two most high weight options.

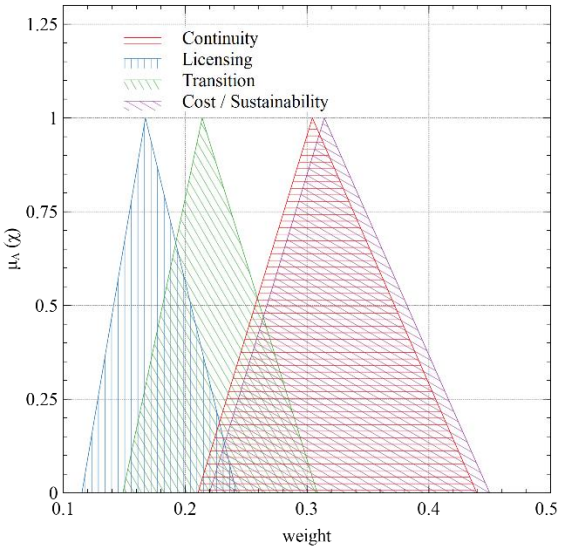

Figure 6: Fuzzy evaluation of business criterion

4.3 Global weights of sub-criteria

In order to capture a global view of the sub-criteria ranking, global weights must be calculated. The global weights are obtained by multiplying the sub-criteria weights by their parent's (criteria) weight. The global weights for all the sub-criteria must sum up to 1. Table 6 presents the global weights and the ranking for all the sub-criteria examined in the survey.

Table 6: Global Weights and ranking of Sub-criteria

Sub-criteria (SCij)	Global weight	Global rank
SC_{11}: Resilience and reliability	0.101	01
SC_{12}: Usability	0.036	14
SC_{13}: Availability	0.084	02
SC_{14}: Scalability	0.029	15
SC_{21}: Islanding	0.072	08
SC_{22}: Network reconfiguration	0.075	07
SC_{23}: Energy balance management	0.077	05
SC_{24}: Blockchain based trading system	0.025	16
SC_{31}: Compliance with regulation	0.082	03
SC_{32}: Privacy protections (prosumers, consumers)	0.063	09
SC_{33}: Privacy protections (energy providers)	0.056	10
SC_{34}: Accountability	0.050	12
SC_{41}: Cost / Sustainability	0.078	04
SC_{42}: Licensing	0.042	13
SC_{43}: Transition	0.054	11
SC_{44}: Continuity	0.076	06

Resilience and reliability sub-criterion ranks first (with a weight of 0.101), followed by availability with weight of 0.084. Compliance with regulation (0.082) is in the third place, Cost is in forth with weight of 0.078 while Energy balance system with weight of 0.077 concludes the top-5 list.
Regarding the ssub-criteria with the lowest weight, these are Accountability, Licensing, Usability, Scalability and Blockchain based trading system

5 CONCLUSIONS

In this paper, an analysis of the factors that are most important for experts for cyber-security products in the EPES domain were identified and classified. Technology and security are the most important factors according to experts while performance and business factors are considered less important. Regarding the technology sub-criteria; islanding, network reconfiguration and energy balance management are valued high and with similar importance from experts. Examining the global rankings of sub-criteria resilience and reliability, availability and compliance with regulation are the three most important ones. We expect that this analysis can be used as guidance for the stakeholders in the EPES domain in order to create their strategy.

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