Selecting Communication Technology Components for the Smart Grid: A Technology Configurator

Vasco Seelmann, Steffen Nienke, Markus Schwank, and Manja Schölling
Institute for Industrial Management (FIR) at RWTH Aachen University, Aachen, 52074, Germany
Email: {Vasco.Seelmann; Steffen.Nienke; Markus.Schwank; Manja.Schölling}@fir.rwth-aachen.de

Abstract —The shift towards a decentralized electricity supply based on renewable energy sources requires constant communication between the entities in the electric grid. To satisfy this communication need, energy market players have to select suitable communication technologies for their use cases. Conventionally, these decisions are made on a case-by-case, non-systematic basis. This paper proposes a technology configurator, which is a systematic, solution neutral approach for energy market players to select the most suitable communication technology for their communication use case. The developed methodology consists of eight steps, in an interaction between a user and a system, leading to a prioritized list of technology recommendations for the given use case. In conclusion, the proposed approach presents energy market players with a systematic way to select the best suitable communication technology to connect their system to the smart grid.

Index Terms—smart grid; energy; communication technology; technology configurator

I. Introduction

In the course of developing a sustainable energy supply system, a digital transformation of the traditional electrical power grid into a modern smart grid is necessary to achieve the global goals for climate change mitigation while preserving energy security and economic development [1]. Information and communication technologies play a fundamental role in managing and controlling the grid. They allow it to be more decentralized and responsive which improves the reliability, security and efficiency of the energy supply [2]. The interaction of multiple interconnected entities therein requires bidirectional communication and real-time data transmission. Consequently, the energy market players have to choose the communication technology that best fulfils their demands and is smoothly implementable in their environment.

Since all available communication technologies have both advantages and disadvantages, the best choice cannot be a general solution but has to be one that depends on the variables on hand.

A. *Identified Problem*

Currently, each decision for a certain technology is made on a case-related basis, tailored to an individual user within a specific situation. Often, the energy market players make suboptimal decisions. This result was worked out in discussions with consortium partners of the research project “eSafeNet” and various energy sector companies. There is a large potential for a systematic, streamlined decision process. Previous research has already been performed to develop criteria that narrow the technological options down based on the environmental influences, but the final decision still relies on handpicking the technology. For example, the Fraunhofer institute ESK and E.ON Metering GmbH have presented a five-stage process model for selecting smart grid communication technologies where the available technologies are identified, assessed depending on their suitability for the relevant region and finally examined to what extent the future requirements of the energy provider are matched [3].

B. *Solution Approach*

Within the research project “eSafeNet”, which works on an energy-efficient and safe communication network for the internet of energy, a technology configurator was developed to address this issue. It is the first concept that functions in an entirely automated manner, consolidating the user’s input data specific to his use case and environment and presenting a final list of results consisting of suitable communication technology. All the necessary criteria have been integrated into a matching methodology that is based on a decision tree and allows an automatic allocation of the optimal technology to the energy market player. For the user, this saves time, money and resources and allows for a comprehensive consideration of information about the technologies and their characteristics. Data-driven solutions improve a decision’s quality immensely since large sets of data can improve the accuracy of predictions and avoid human biases. On the other hand, considering more data leads to more complexity of the task [4]. Therefore, automating the process permits a consideration of all components whilst still being manageable to use.

In this paper, the development process and functioning of the technology configurator will be described. The paper is structured in the following way: Section 2 introduces and describes the concept of the technology configurator and its step-by-step approach. The advantages of this approach and its future evolution will be discussed in section 3. Finally, section 4 serves as a short summary and concludes the paper.

Manuscript received April 25, 2018; revised September 21, 2018.
doi:10.12720/jcm.13.10.581-587

II. Technology Selection Methodology

As shown in Fig. 1, the technology configurator's decision process consists of seven steps that culminate in a sorted list of results. To begin with, the configurator asks the user to choose his role in the energy market. For this role, the system recognizes applicable use cases that the user could want to implement. Based on the chosen use case, the configurator subsequently determines the prerequisite information needs. For further specification and consideration of other criteria for the technological solution, the user then inserts his environmental data. Finally, the configurator sorts the results by their economics and outputs a list of all possible technologies including their prize.

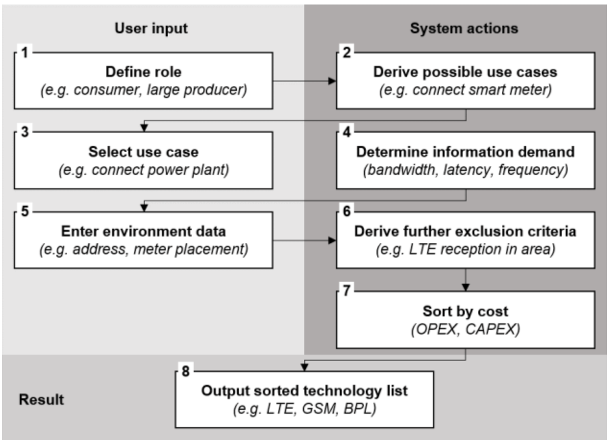

Fig. 1. Technology configurator step-by-step procedure

TABLE I: IDENTIFIED ROLES IN THE GERMAN ENERGY MARKET

Grid operators	Energy market players	Marketplaces	Authorities	Other market players
• Transmission system operators	• Electricity providers / generators	• Joint Allocation Office	• Federal Network Agency	• Associations
• Distribution system operators	• Electricity distribution companies	• Electricity exchange	• Registry operators	• Providers operators energy systems
• Meter operators	• Balancing group managers		• Various authorities	• Operators' communication network providers
• Metering service providers	• Balancing coordinators			• Platform solution providers
	• Power traders			• Providers research
	• Consumers			
	• Private producers			
	• Storage operators			
	• Operational responsible parties			

A. Determine the Role

In the first step, the technology configurator presents a list of possible roles in the energy market that the user can choose his position from.

Having a clear distinction of separate roles is important for a systematic approach. Hereby, the differentiation between roles that can be found on the marketplace and the actors that exercise those roles is essential. Whereas an actor is always a specific person or organization, a role represents a function, it describes the external intended behavior and enables a common terminology [1].

Applying a role model creates a clear basis for the design of market processes and data formats and supports the scalability and reusability of process modules. Firstly, it is necessary to determine the stakeholders, actors and representatives involved in the energy market as well as their tasks and relationships among each other. Previously, the BDEW has determined nine different roles for the energy market [2], whereas the German Federal Network Agency (Bundesnetzagentur) differentiates between 47 different roles in six overall market functions [3]. The European Network of Transmission System Operators for Electricity proposes a harmonized electricity market model with 37 roles [1].

For the role model used in the technology configurator, a stakeholder analysis was conducted with the support of the project consortium. All interest groups in the energy and/or communication market were collected and their relevance assessed. The distinguishing criteria of the first draft included the individual key position, external laws, norms and standards, external formal groups and informal groups. Afterwards, the stakeholders were interviewed based on a question catalogue. Identifying and quantifying the stakeholders resulted in a complex constellation of approximately 60 external stakeholders. For a more concise handling, all relevant functions were summarized in 23 main roles and structured into five subordinate groups, as shown in Table I.

B. Derive Possible use Cases

In the second step, the technology configurator derives possible use cases for the chosen role by looking for matches in his data bank.

In order to transfer the user's diverse requirements into a workable model, several possible use cases were developed. The use case methodology combines the stakeholders in a system with their goals and scenarios that include the different outcomes of possible approaches into a comprehensive standardized representation, as specified in the standard IEC 62559-2 [4]. By combining the requirements for a successful realization of a goal and abstracting the concrete solutions for this into a common understanding, the use case, it is easier to precisely handle the user's aspirations.

For the development of use cases for the technology configurator, the consortium partners of "eSafeNet" were asked questions about their view on the energy market actors' interests and information needs. The focus hereby lied on information and communication technology solutions that already existed as well as future requirements for them. The input was subsequently consolidated in several workshops and talks. Afterwards, the information was distilled into concrete use cases for the communication net. In doing so, it was important to take all aspects of the smart grid into account – namely the customer applications, grid applications, integration of energy generators, data collection and analysis and formulate the actions that would be sought for.

C. Select the use Case

In the third step, the configurator presents the use cases that it derived out of the chosen role in a drop-down menu. The user can select the concrete use case that he wants to have realized.

Theses use cases include e.g.:

- Integrating a new component such as a smart meter or generating plant,
- Monitoring the already implemented devices,
- Reception of various data points about the power plants, frequency, electricity balance and forecasts,
- Exchange of information about consumption or storage,
- Collection of information regarding supply and demand.

D. Determine the Information Requirements

In the fourth step, the system determines the information needs based on the chosen use case. Depending on the specific tasks that the technology is expected to realize, there are certain performance and technical requirements to be covered. Those requirements, especially regarding frequency and latency, are added up for a first filtering. The configurator internally cuts the list of possible technologies down to the ones that would be generally suited for the desired use case.

In pursuance of assigning the right technology that considers the user's information needs and the basic technological requirements to realize those, an information logistics notation was developed for "eSafeNet". The approach visualizes the information logistics within an entity or in between various entities. This overview about the information flow allows a better understanding of the interdependencies between demand and supply. The resulting concept is an information map that shows where what kind of information comes from and is directed towards and in which time interval this happens.

To create the information logistics concept, broad research on the interdependencies between information objects and the role models was conducted. Hereby, four groups were analyzed: Grid operators, actors on the energy market, marketplaces, authorities and other market players. For each group, the roles and stakeholders were listed and their information needs were noted. Particular attention was paid on the awareness of where the data comes from (source), in which form it will be processed (unity) and how the cancellation works. It was also important to state the group's tasks and use cases. Depending on the use case, the data exchange happens at different rates of frequency and with a different time interval between the accesses. Therefore, it is crucial to know what rate of actualization the actors need and how sensible the values are to change. Afterwards, the links between roles and information objects were represented in a technology combination matrix. In the end, the information logistics concept was validated by consortium and external experts.

In order to be able to match the available technologies correctly, the fundamental characteristics of each technology were rated and listed into a morphology. The focus hereby lied on the current availability and future viability as well as the profitability, reliability and data security. Since the sufficient specifications for each use case set the basis for the technology choice, the first filtering can already be made after the initial three steps. The use cases involve distinctive smart grid applications that all have various communication network requirements, depending on e.g. their available interface, physical size, power consumption, data rate and volume, device access, network reliability (tolerance to drop-outs) and connectivity coverage (worldwide or within a small region that you could deploy your own network infrastructure) [9]. At this point, the first differentiation criteria are latency and bandwidth as they define the speed and capacity of the network. Latency means the time interval between stimulation and response, it defines how long it takes for one bit to travel from the starting to the end point and therefore characterizes the delay in the network. Latency is determined by the transmission medium and limits the maximum transmission rate. It is such a stringent requirement because missing inputs could be substituted with inputs from other sensors which would then produce different actions leading to erroneous results [10]. Hereby, the technologies were divided into five categories – those with a latency higher than 1000ms; 1000-500ms; 500-200ms; 200-50ms; and lower than 50ms. Bandwidth determines the transmission speed by defining the amount of data that can be transferred during one second. The bandwidth requirements are a direct factor for choosing the transmission medium and communication technology. For the morphology, the bandwidth was divided into categories of under 1 Mbit/s, 1-10 Mbit/s, 10-100 Mbit/s, 100-1000 Mbit/s or more than 1000 Mbit/s. Depending on how frequently and critically the data transmission in the use case is, those variables need to fulfil a different threshold.

E. Input Environmental Data

In order to identify best technology for our use case, environmental factors that influence the calculation of technology configurator had to be figured out. So at first the information requirement has to be defined and environmental data have to be entered in technology configurator to estimate the best technology. User can choose all environmental data by a drop-down menu.

Place of location is one of these environmental factors because it has a significant impact on network coverage of wireless technologies varying from the location. The user has to enter the address of the use case by postal code in technology configurator. Probably it is the most important factor if a wired or wireless technology will be installed. In the next step, the local position for installation of smart meter within the building has to be identified. Place of installation depends on the use case if a smart meter will be installed for a consumer or if a generating plant will be integrated for producer. Smart meter for consumer will be installed inside of a building. Generating plants (except combined heat and power generation) will be installed outside but instrumentation and control engineering can be installed inside of a building. Therefore, information about topology of a building are very important because they have a significant impact on wireless reception [5, 19f., 6, 1482f.].

Additionally interferences play a role for wireless reception. In this step, five states of interferences are defined in technology configurator, which range from no technical influences by other systems to heavy interfering signals. It plays an important role to figure out, if a wireless or a wired communication technology will be implemented. Information about accessibility for a wired technology are necessary, too and can be divided into five classifications. User has to figure out if an access or a base for access already exists, or if an infrastructure has to be provided, or if it is just possible with higher expenditure, or if cost-benefit ratio doesn't fit and supply of a new infrastructure isn't possible. Additionally, power consumption must also be implemented in the system because it affects on data size and costs. To specify power consumption, user can choose between six stages, which will be elucidated in chapter 2.8.

The use has to accomplish an examination if there is an already used infrastructure by energy supply company. In case of an already existing infrastructure, maybe that one can be used or developed to prevent installing a completely new infrastructure in best case. In use case, a generating plant will be integrated, the electrical power rating of production must be specified in the system. The user can distinguish between two scenarios: electrical power rating under 7,000 kWh/a and power rating of 7,000 – 15,000 kWh/a. After entering all environmental data in technology configurator, the system can exclude different technologies based on these environmental factors.

F. Derive Further Criteria for Exclusion

Besides the mentioned environmental factors above, some further criteria could be identified, which impede or influence smart meter installation. Therefore, you have to make allowance for three main criterions: communication network coverage, constructional conditions and legal framework.

Communication technologies, especially wireless technologies, differ in intensity of building penetration. Therefore, some information about form of housing schemes, building density, building fabric and topology of building are required to detect fitting technologies [7, p. 235]. Additionally, there might be individual differences in local requirements. Metal of a meter cabinet or the installation in cellar rooms can compromise wireless reception. So additional costs for antenna may incur. However, wired communication technologies do not assure a complete network coverage, too. For example, power line communication (PLC) cannot transmit data to unlimited distances. On these grounds, there are also measures or hubs necessary to amplify data transmission. Hence, in order to optimize choice of technology, it's important to know all local circumstances correctly [7, p. 224, 8, p. 198, 9, p. 12, 10, p. 140].(Fig. 2)

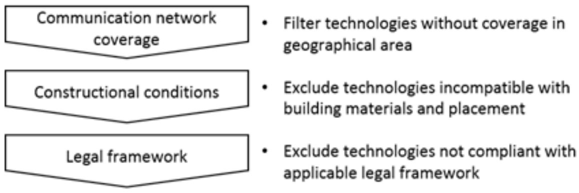

Fig. 2. System-side criteria for technology exclusion

Legal framework effect negative influence and can obstruct or complicate smart meter installations. At this point, regulations for fire protection and property permission have to be mentioned. Compliance with fire protection regulations may implicate extensive costs if firewalls have to be opened and closed professionally after inserting a cable. Placing of cables outside the meter cabinet requires a statement of agreement of proprietary. In case of a community of owners, installation can delay or even not succeed [8, p. 201].

German Parliament has determined six stages of power consumption in draft law and set a maximal annual premium for each class, which will be explained in section 2.8 [11, 2045f.]. It might be a problem for very complicated and complex use case to adhere these financial requirements because costs for installation or data transmission could exceed legal price cap in very extraordinary use cases. This problem could occur in rural areas with a less developed communication infrastructure in combination with very old buildings and a bad technical and constructional status quo. Hence, incurred costs exceed average costs and can even exceed legal price caps. In this case, there might collide two laws because German Federal Government has passed a law about digitalization of energy transition. This law defines obligatory installation of smart meters [11]. In conclusion, there might be legal need for action.

G. Sort by Economics

The algorithm of technology configurator estimates all costs for the different technologies and sorts them by economics. By considering economics of the different technologies, you have to decide between capital expenditures (capex) and operational expenditures (opex). After calculating the different technological possibilities, the system outputs a list of possible technologies sorted by economics.

Capex include investment costs for smart meters and gateways. These costs are depending if it will be a small or a large consumer. Costs for procedures for increasing reception (e.g. additional antenna) are also contained in capex. Investments for integration, installation and implementing are considered, too. Investments for smart meter increase with rising power consumption/ production and are independent of data transmission technology. Opex are composed of data transmission costs for annual premium depending on small or large consumer. Amount of costs depends on technology because some technologies are independent of data size (e.g. PLC) and some are dependent (e.g. GPRS). But usually, a fixed amount is offered for data transmission. Additionally, opex include an average amount of costs for maintenance, repair and operating failure.

There are six stages of power consumption defined in draft law based on saving potential for electricity costs. For every class a maximal annual premium is defined which is increasing with rising power consumption. Rising power consumption means increasing saving potential. Power consumption is classified into under 2,000 kWh/a, 2,000 – 3,000 kWh/a, 3,000 – 4,000 kWh/a, 4,000 – 6,000 kWh/a, 6,000 – 10,000 kWh/a and 10,000 – 20,000 kWh/a [11, 2045f., 12, p. 159]. Smart meters have internal power consumption but these costs won't be forwarded to consumer and will be declared as network losses that will be assumed by network operators [12, p. 152, 13, p. 33].

H. Output List of Technologies

In the final step, the technology configurator presents a list containing the best technologies for the chosen use cases to the user and summarizes capex, opex, available latency and available data transmission rate. The output list presents a recommendation for action for the user to install most economical and fitting communication technology for the use case.

III. Discussion

This section will discuss the novelty of the proposed approach, the role of existing and future standards in the energy and communications sectors, as well as the need for continuous updates for the technology configurator.

A. Novelty and Advantages of the Approach

Conventionally, communication technology solutions for the electricity grid are selected on a case-to-case basis and the knowledge gained from past applications is not systematically used for new cases. The technology configurator helps retaining and, if it is constantly updated, expanding the knowledge after each equipped use case. The systematic approach of the technology configurator ensures that important know-how is not lost. Furthermore, current technology selection decisions are heavily influenced by technology suppliers' sales teams. The technology configurator is a solution-neutral alternative to the conventional approach, helping energy market players making a fact-based decision. Multiple new technology solutions, such as 5G, are getting to the market today, increasing the number of available options for communication in the electricity grid. The technology configurator might help quickly selecting the most suitable use cases for these technologies.

B. Standards

Developing a communication strategy, it is important to take standards into account, both governmental principles and technological guidelines. In the beginning process, 17 relevant laws, regulations and guidelines were identified. Standards allow interoperability in order to secure a safe and accurate data transmission and integration of different components, protocols and infrastructure. In some areas, there are already governmental protocols in place, e.g. the German government published a law about the metering point operation [11]. Especially the communication unit of an intelligent metering system is highly standardized. The use cases that involve smart meters need to respect those guidelines. In other areas, there are commonly used solutions that establish themselves based on international norms, e.g. the standard IEC 61850 (Scada). Globally, there are several authorized organizations working on smart grid standardization [14]. Highly interoperable communication between all components is the major goal of smart grid communications which means that the communication should be based on a common semantic (data model), syntax (protocol) and network concept [15].

C. Ongoing Updates

The technology configurator needs to continuously be updated so that the current requirements and backgrounds can be taken into account. New guidelines can be published any day and the technological abilities change quickly as well. Especially for the security aspect, the latest improvements need to be considered. New methodologies continuously evoke forward-looking opportunities like Big Data solutions to improve data management in the smart grid that require high volume of data storage and high velocity in processing.

IV. CONCLUSION

In conclusion, this work presents an approach that solves the problem of selecting the most suitable communication technology for each energy use case. Through the transition from a centralistic energy system based on fossil fuels to a decentralized system based on renewable energy sources, a new communication network is necessary to coordinate the system. However, no single communication technology solution is suitable for all existing use cases. Today, the decision on which technology to use is made on a case to case, non-systematic basis. This paper presents the approach of a technology configurator, which is a systematic way of collecting use case requirements and matches them with the technological capabilities. The presented concept will be further validated and tested in three separate field tests in the course of the research project eSafeNet. The field tests encompass the connection of a wind turbine to a cloud server, broadband powerline test in a distribution network with heterogeneous consumers and a black-out recovery scenario. Based on the project results, the approach will be further perfected.

ACKNOWLEDGMENT

This article arose during the work of the authors, within the context of the research project “eSafeNet” funded by the Federal Ministry for Economic Affairs and Energy in Germany. The authors wish to thank the project sponsors for the generous funding and research opportunity and the project partners for their valuable insights and steady support.

REFERENCES

[1] European Network of Transmission System Operators for Electricity. The Harmonises Electricity Market Role Model. (2015). [Online] Available: https://www.entsoe.eu/Documents/EDI/Library/HAR/2015-September-Harmonised-role-model-2015-01.pdf

[2] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., “Rollenmodell für die Marktkommunikation im deutschen Energiemarkt: Strom und Gas,” 2016.

[3] Bundesnetzagentur. MaStR-Nummernkonzept. (Sept. 2016.) [Online] Available: https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/DatenaustauschUndMonitoring/MaStR/MaStR%20-%20Nummernkonzept_160907.pdf?__blob=publicationFile&v=2

[4] M. Gottschalk, M. Uslar, and C. Delfs, *The Use Case and Smart Grid Architecture Model Approach: The IEC 62559-2 Use Case Template and the SGAM Applied in Various Domains*, Cham, Switzerland.: Springer International Publishing, 2017.

[5] N. Anglani, E. Bassi, F. Benzi, L. Frosini, and T. Traino, “Energy smart meters integration in favor of the end user,” in *Proc. IEEE International Conference on Smart Measurements of Future Grids (SMFG): Proceedings*, 2011, pp. 16–21.

[6] D. Al Abri, A. S. Malik, M. Albadi, Y. Charabi, and N. Hosseinzadeh, “Smart Grid,” in *Handbook of Climate Change Mitigation and Adaptation*, W.-Y. Chen, T. Suzuki, and M. Lackner, Eds., 2nd ed., Cham, Switzerland: Springer International Publishing, 2017, pp. 1465–1501.

[7] O. D. Doleski and M. Liebezeit, “Rolloutlogistik: Vom Einkauf bis zum angebundenen Zähler,” in *Smart Meter Rollout: Praxisleitfaden zur Ausbringung intelligenter Zähler*, C. Aichele and O. D. Doleski, Eds., Wiesbaden, Germany: Springer, 2013, pp. 209–268.

[8] S. Dieper, “Rollout-Prozesse-Planung, ausführung, integration,” in *Smart Meter Rollout: Praxisleitfaden zur Ausbringung intelligenter Zähler*, C. Aichele and O. D. Doleski, Eds., Wiesbaden, Germany: Springer, 2013, pp. 183–208.

[9] I. Schönberg and T. Wolski, “Kommunikationstechnik für intelligente stromnetze mittels breitband-powerline: zählerfernauslesung, energie-effizienz und rechtliche rahmenbedingungen,” *Netzpraxis Sonderdruck*, vol. 48, no. 1, pp. 12–14, 2009.

[10] S. H. Horowitz and A. G. Phadke, *Power System Relaying*, 4th ed. Chichester, West Sussex: John Wiley and Sons, 2014.

[11] Deutsche Bundesregierung. Gesetz zur Digitalisierung der Energiewende. 43, (Sept. 2016). [Online] Available: https://www.bmwi.de/Redaktion/DE/Downloads/Gesetz/gesetz-zur-digitalisierung-der-energiewende.pdf?__blob=publicationFile&v=4

[12] Ernst & Young, “Kosten-Nutzen-Analyse für einen flächendeckenden Einsatz intelligenter Zähler: Endbericht zur Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie,” 2013.

[13] PwC Österreich, “Studie zur Analyse der Kosten-Nutzen einer österreichweiten Einführung von Smart Metering,” 2010.

[14] D. Baimel, N. Baimel, and S. Tapuchi, “Smart grid communication technologies- overview, research challenges and opportunities,” in *Proc. International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, Piscataway, 2016, pp. 116-120.

[15] F. Gasparin. (2013). Smart Grid Systems: Smart Cities Stakeholder Platform. [Online] Available: https://eu-smartcities.eu/sites/all/files/Smart%20Grid%20Systems%20-%20Smart%20Cities%20Stakeholder%20Platform.pdf

Vasco Seelmann was born in Erlangen, Germany, in 1990. He received the B.S. degree and the M.S. degree from RWTH Aachen University, both in mechanical engineering and business administration. He is currently pursuing the Ph.D. degree with the Department of Mechanical Engineering at RWTH Aachen University. His research interests include information management, technology management and industrial communication technology.

Steffen Nienke was born in Aachen, Germany in 1985. After his Diploma in Electrical Engineering and Bachelor in Business

Administration at the RWTH Aachen University, he is currently working as a research assistant and Ph.D. candidate at the Institute for industrial management (FIR) at the RWTH Aachen University. His studies focus on the industrial energy management and information logistics.

Markus Schwank was born in Cologne, Germany, in 1993. After his Bachelor in Environmental Engineering, he is currently pursuing the M.Sc. degree in Sustainable Energy Supply at RWTH Aachen University.

Manja Schölling was born in Münster, Germany, in 1995. She is currently pursuing the B.S. degree in electrical engineering and business administration at RWTH Aachen University.