Deliverables T2.2.1 & T2.3.1

Concept study:
Power conversion system architecture

Report on energy utilization and storage concepts

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List of abbreviations

AC	Alternating Current
BESS	Battery Energy Storage System
BIPV	Building-integrated Photovoltaics
DC	Direct Current
EV	Electric Vehicle
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
MPPT	Maximum Power Point Tracking
PV	Photovoltaics
V2G	Vehicle-to-grid

1 Introduction

1.1 Context

The purpose of this report is twofold. The first purpose is to address Deliverable 2.2, by providing a comprehensive concept study on the power conversion system architecture for the SolarEMR project. The second purpose is to address Deliverable 2.3, by demonstrating the energy utilization and storage concepts achieved for the presented use cases. Both deliverables are discussed in this document, because they are closely related to each other. Consequently, this way of presenting the results will provide a clearer overview of the achieved results. A short overview of which section answers to which deliverable is provided at the end of the introduction section.

The first use case is a noise barrier with infrastructure integrated photovoltaics along highways in the vicinity of roadside parkings with electric vehicle charging infrastructure. The second use case is office buildings with building-integrated photovoltaics in facades, combined with battery storage and lighting. The main objective of this study is to define the most cost-effective power system architecture for interconnected building-integrated PV (BIPV) and infrastructure-integrated PV (IIPV) systems.

Overall, this report provides valuable insights into the concept study of power conversion system architecture for interconnected BIPV and IIPV systems. It aims to inform decision-makers and stakeholders about the advantages, challenges, and potential of DC distribution systems for BIPV and IIPV applications.

The report is organized in five sections. The first section briefly discusses the renaissance of DC distribution systems and highlights the advantages of using DC power for various applications. The second section delves into the use case of noise barriers integrated with PV systems, providing insights into the DC distribution architecture and the generation, storage, and consumption of power in this context. The third section focuses on the use case of building nanogrids, exploring the DC distribution architecture specific to office buildings with BIPV, battery storage, and lighting.

In the fourth section, the report identifies barriers to the adoption of DC distribution systems, including limited awareness, limited know-how, limited equipment availability, and limited standardization. These barriers are crucial to address in order to facilitate the widespread implementation of DC power systems.

Finally, the last section concludes the report by summarizing the key findings and recommendations. It emphasizes the need for further research and development to overcome the identified barriers and highlights the potential benefits of transitioning to DC power distribution.

1.2 Deliverable overview

1.2.1 Deliverable 2.2:

- Why DC distribution systems?
- Use case: infrastructure integrated noise barriers along highways
  - Demand and generation
  - System Architecture
- Use case: BIPV powered DC microgrid
  - System architecture
- Barriers to adoption

1.2.2 Deliverable 2.3:

- Use case: infrastructure integrated noise barriers along highways
  - Battery storage
  - Benefits of a DC infrastructure
- Use case: BIPV powered DC microgrid
  - Benefits of a DC infrastructure
- Boundary conditions

2 Why DC distribution systems?

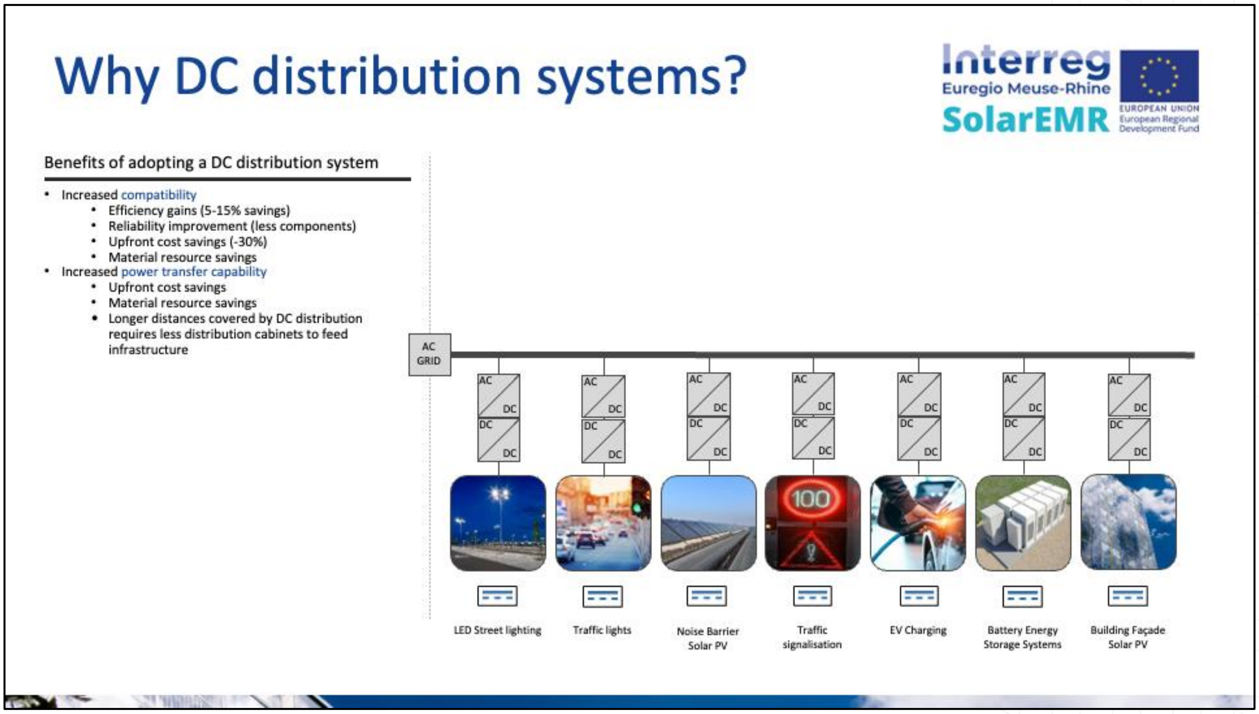
Although our conventional electrical infrastructure relies on alternating current (AC) for over a century to transmit and distribute electrical power, the majority of applications today generate, store and consume power as DC. Photovoltaic systems output DC voltage and current, batteries store power as DC and power is eventually consumed as DC in electric vehicles, LED lights and ICT equipment. Even heating, ventilation and air conditioning systems, although driven by highly efficient AC motors, have electronics that typically first convert the AC input power to an intermediate stage to drive the motors at variable speeds. The majority of equipment runs natively on DC, while the intermediate transmission and distribution infrastructure still relies on AC to get power from A to B.

The motivation to adopt an AC infrastructure in the past did make sense however. AC allowed the world to easily step up the voltage close to centralized power plants and step it down in cities close to the load. Moreover, in the early days of electrical power systems, electrical power was just to drive light bulbs, which were basically indifferent and could be supplied with both AC and DC, and AC motors, which required less maintenance than their DC counterparts. However, times have changed and since then we have witnessed a quiescent uptake of DC powered loads, such as the ones mentioned before. Look around and notice that there are very few devices not running on DC power.

As a result, as shown in Figure 1, societies have introduced power conversion equipment to convert the electrical power from the conventional AC grid into DC to drive loads. Most people are familiar with adapters to charge laptops and cellphones and chargers of electric vehicles, but power electronics are also present in LED light bulbs to rectify the AC voltage into DC and to adapt and stabilize the voltage. At the other end of the spectrum, solar photovoltaics output power as DC and inverters have been introduced to inject it into the grid. It is needless to say that this results in a suboptimal electrical power infrastructure. Power is generated as DC, run through a DC/DC converter that adapts the voltage and performs the maximum power point tracking (MPPT), subsequently converted by means of a DC/AC converter, distributed as AC and eventually converted back to DC at the load side.

Imagine a world where power would be distributed as DC. In this case, the intermediate power conversion steps can be greatly simplified, or sometimes even entirely eliminated. As such, there are less electronic hardware components in the system. Less is more. Less electronics means higher efficiency, less electronics means higher reliability and less electronics means higher return on investment. On top of these benefits, the fundamental physical characteristics of DC voltage and current, allow to transfer more power across existing or new cable infrastructure, depending on the selected voltage levels. Hence, material resource savings occur in both the electronics as well as the conductor material to transfer power between where it is generated to where it is consumed.

As societies electrify transport and heating, as well as adopt distributed generation, DC power has seen a renaissance in the last 15 years. A variety of applications, ranging from data centers, over commercial buildings, industrial facilities, street lighting, rural electrification and power distribution onboard aircraft and ships, are moving towards DC power distribution because of the benefits outlined in Figure 2.



Why DC distribution systems?

Interreg
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SolarEMR
EUROPEAN UNION
European Regional Development Fund

Benefits of adopting a DC distribution system

- Increased compatibility
    - Efficiency gains (5-15% savings)
    - Reliability improvement (less components)
    - Upfront cost savings (-30%)
    - Material resource savings
- Increased power transfer capability
    - Upfront cost savings
    - Material resource savings
    - Longer distances covered by DC distribution requires less distribution cabinets to feed infrastructure

Figure 1 Why DC distribution systems?

DC technology is hence favored in a variety of applications

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European Regional Development Fund

Datacenters

Running on 380V_{DC}

- 10% efficiency gains (ABB, Green.ch datacenter, 1 MW)
- 15% less upfront capital cost
- 33% less floor space occupied
- Increased availability

Source: https://www.quadranet.com

Commercial buildings and districts

Running on +/-380V_{DC}

- Reduce the number of converters
- Less conversion losses
- Able to operate in islanding mode
- Able to provide ancillary services to the AC grid

Source: Anta Power

Industry

Running on 600V_{DC}

- DC improves immunity and grid stability
- 40% less copper consumption
- Able to operate in islanding mode

Source: DC Industrie

Street lighting

Running on +/-350V_{DC}

- Copper conductor savings
    - Feeder length up to 4 km reduces the number of AC connection points
- LED driver becomes more reliable

Source: Direct Current BV

Electricity access - Rural electrification

Running on 48V_{DC}

- 4000 households in India
- 125W solar panel, lead-acid battery and a controller
- LED lighting, DC ceiling fan and smartphone charger

Source: A. Jhunjhunwala, "The people's grid," IEEE Spectrum, vol. 54, no. 2, pp. 44–50, Feb. 2017.

All-electric aircraft

Running on 270V_{DC}

- Hydraulic actuators are going electric (Boeing 787 - Airbus A380)
    - Weight reduction
- DC systems reduce the number of components
    - Weight and reliability improvement

Source: Airbus

Figure 2 DC technology is favored in a variety of applications

3 Use case: infrastructure integrated noise barriers along highways

3.1 Case definition

This section introduces a specific use case for the power conversion system architecture: a DC microgrid located near a highway parking facility, powered by noise barriers with infrastructure-integrated photovoltaics spanning over a 1 km distance. The loads within the microgrid consist of electric vehicle chargers, traffic signalization systems, and LED street lighting. Additionally, battery storage is installed for peak shaving purposes. The particular site studied in this use case is located in Rotselaar, close to Leuven, Belgium (Figure 3).

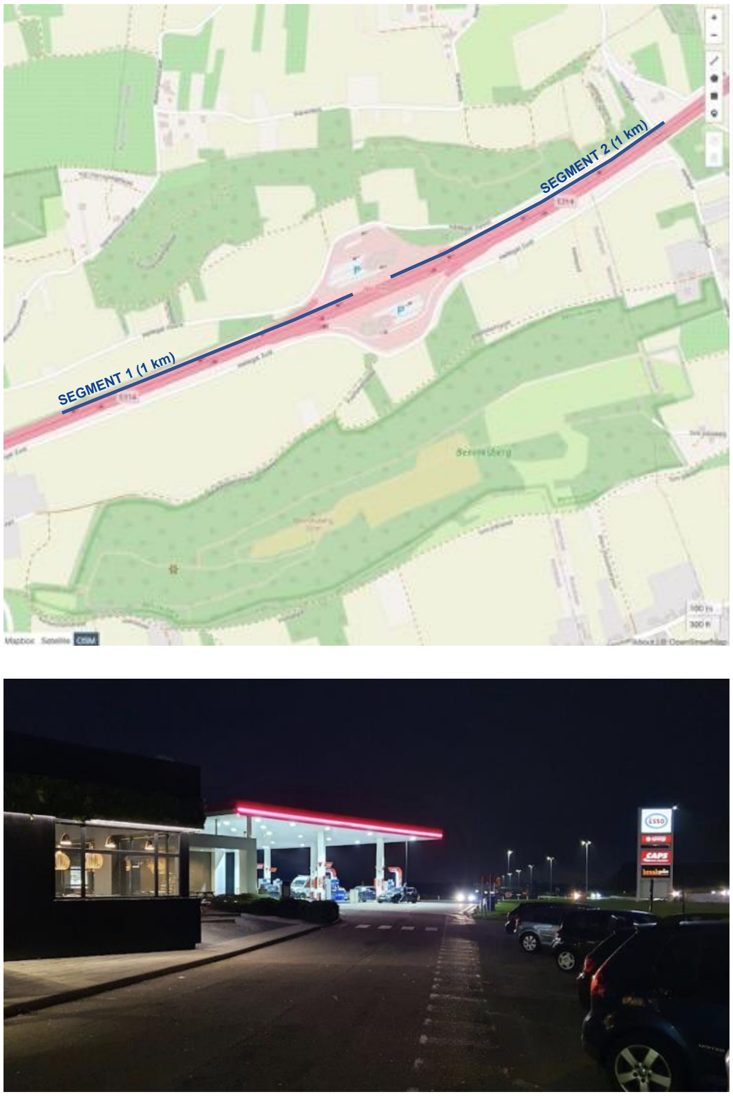
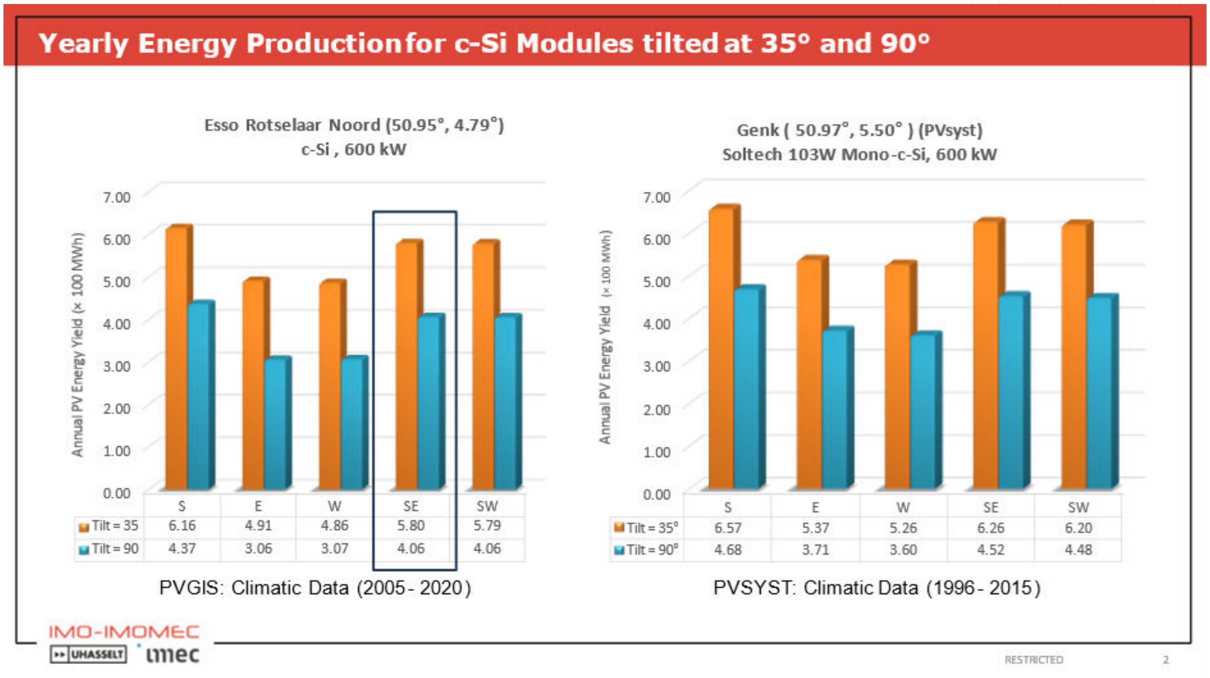


Figure 3 Electric vehicle charging near highway parkings

3.2 Demand and generation

Based upon simulations in PVGIS and PVSYST, performed by UHasselt, the IIPV modules in the noise barriers are estimated to yield 676 kWh/kW (Figure 4). Due to vertical orientation and the south-east orientation, the specific energy yield is lower than conventional solar modules which are optimally oriented. Nevertheless, over 1 km distance, 600 kW of solar modules can be integrated, 2000 modules of 300 W each, yielding 406 MWh on an annual basis. These modules are not bifacial.



Yearly Energy Production for c-Si Modules tilted at 35° and 90°

Esso Rotselaar Noord (50.95°, 4.79°)
c-Si , 600 kW

	S	E	W	SE	SW
🟧 Tilt = 35	6.16	4.91	4.86	5.80	5.79
🟦 Tilt = 90	4.37	3.06	3.07	4.06	4.06

PVGIS: Climatic Data (2005 - 2020)

Genk (50.97°, 5.50°) (PVsyst)
Soltech 103W Mono-c-Si, 600 kW

	S	E	W	SE	SW
🟧 Tilt = 35°	6.57	5.37	5.26	6.26	6.20
🟦 Tilt = 90°	4.68	3.71	3.60	4.52	4.48

PVSYST: Climatic Data (1996 - 2015)

RESTRICTED 2

Figure 4 PV generation energy-yield simulation results

The generated solar power is primarily utilised for fast charging electric vehicles at 150 kW. At peak power capacity, the PV installation can generate power for 4x 150 kW EV chargers (600 kW in total). The study assumes that each charger delivers 2 charge sessions every hour between 06:00-22:00 and 1x 6 hour charge session during 22:00-04:00 to charge electric trucks at nighttime. In total, this yields an annual consumption of 3650 MWh. Hence 11% of the demand is covered by onsite generation.

In addition, 12 MWh is required to power 1 km of streetlights for 3800 hours every night, requiring 3.2 kW of total power (40 poles consuming 80 W each). And 18 MWh for keeping the traffic signalisation (2x 1 kW) continuously on throughout the year.

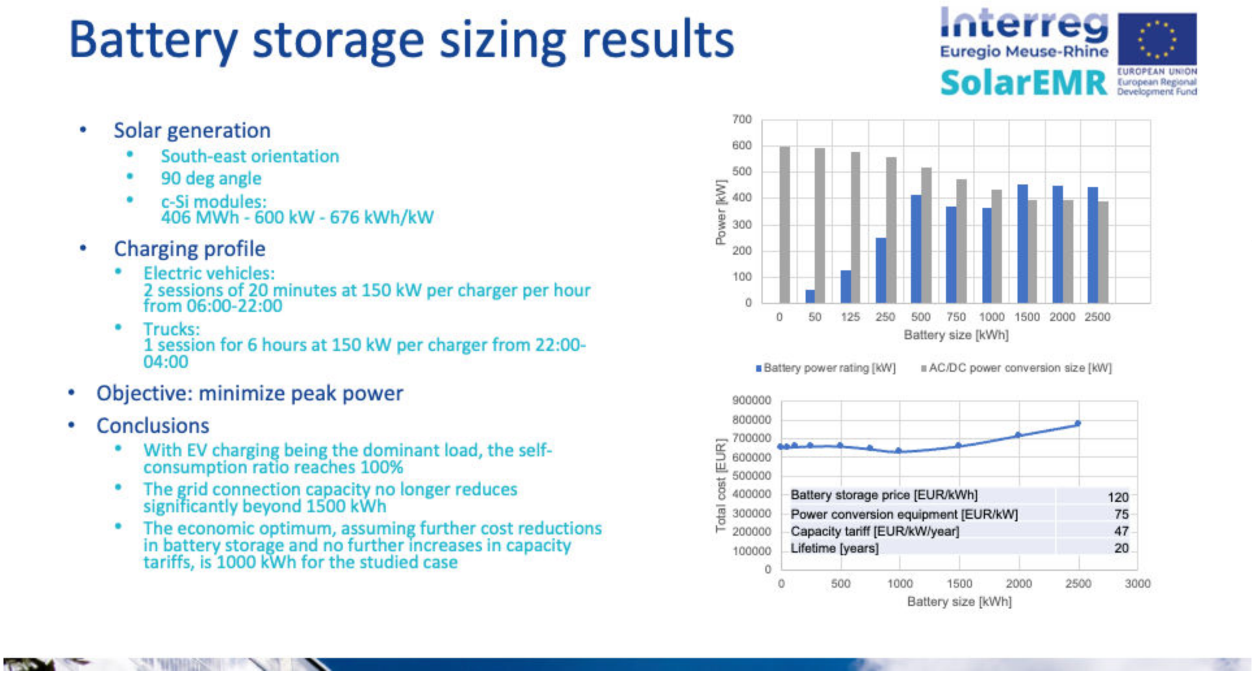
3.3 Battery storage

The PV generation, street lighting, traffic signalisation and electric vehicle charging infrastructure is complemented with a battery energy storage system (BESS). The battery energy storage system serves as a backup power supply in the first place, to continue powering the street lights in case of an outage or power quality disturbance.

Furthermore, the entire microgrid is interfaced with the public utility grid at medium voltage to meet the remaining demand of the electric vehicle chargers. The BESS hence serves a second purpose of minimising the peak power drawn from the utility and hence reducing demand charges.

Because of the EV charging infrastructure, the self-consumption of the microgrid - i.e. the ratio of energy directly consumed locally relative to the total generation - reaches 100%.

Figure 5 shows the results based upon the simulation model taking into account the generation and load profiles for the microgrid for an entire year. The results demonstrate that, by adding a 1500 kWh battery energy storage system to the microgrid, the peak power drawn from the utility can be reduced below 400 kW, which is a reduction of 33% compared to the 600 kW connection capacity required otherwise. Adding more battery storage does not appreciably reduce the connection capacity further. There is a plateau in the simulation results, because the energy needs of the microgrid remain to be fulfilled.


Battery storage sizing results

- Solar generation
  - South-east orientation
  - 90 deg angle
  - c-Si modules:
    406 MWh - 600 kW - 676 kWh/kW
- Charging profile
  - Electric vehicles:
    2 sessions of 20 minutes at 150 kW per charger per hour from 06:00-22:00
  - Trucks:
    1 session for 6 hours at 150 kW per charger from 22:00-04:00
- Objective: minimize peak power
- Conclusions
  - With EV charging being the dominant load, the self-consumption ratio reaches 100%
  - The grid connection capacity no longer reduces significantly beyond 1500 kWh
  - The economic optimum, assuming further cost reductions in battery storage and no further increases in capacity tariffs, is 1000 kWh for the studied case

Battery storage price [EUR/kWh]	120
Power conversion equipment [EUR/kW]	75
Capacity tariff [EUR/kW/year]	47
Lifetime [years]	20

Figure 5 Simulation results of the battery storage sizing

When assuming a 120 EUR/kWh price for the battery energy storage system, a connection capacity tariff of 47 EUR/kW/year, a specific cost for power conversion equipment of

75 EUR/kW and a lifetime for the system of 20 years, the total cost of the system including battery storage is minimised around 1000 kWh. At this point, the additional investment costs into battery energy storage offset the additional charges incurred from a higher grid connection capacity. Adding more battery storage beyond this point is not recommended as it adds to the capex without further reducing the opex.

In addition, a 1000 kWh battery energy storage system is sufficient to power the street lights and traffic signalisation for over 192 hours when fully charged. In conclusion, enough battery back-up capacity is available for the critical loads.

3.4 System architecture

All generation, loads and storage assets are interfaced at the DC level. In order to align with international standardized voltages below 1500 V (defined as the low voltage limit in the EU low-voltage directive), but to reduce the cabling infrastructure, a voltage level of 1400 V DC is selected to collect all generated IIPV power. The electric vehicle chargers and battery energy storage systems are connected to the same DC bus (Figure 6).

Because LED street lighting is a low power consumer and the availability of LED drivers beyond 350 V DC is limited, a bipolar 350 V DC cable is proposed for the street lights, as well as for the traffic signalisation. Hence the cable is sized for 700 V DC, with a center midpoint to connect individual LED drivers and traffic signalisation to, typically operating at 24 V DC.

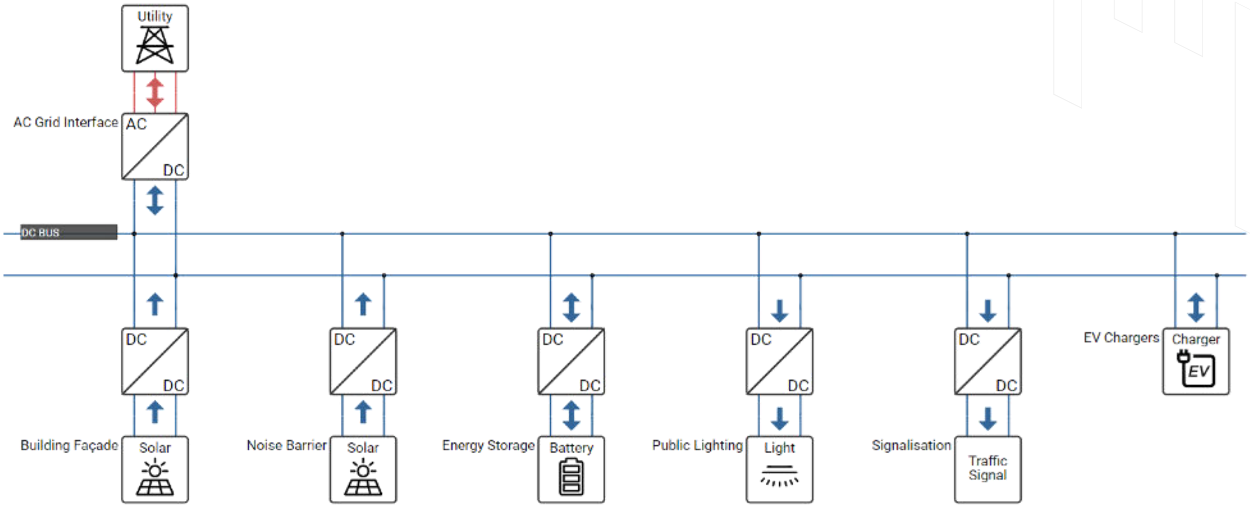
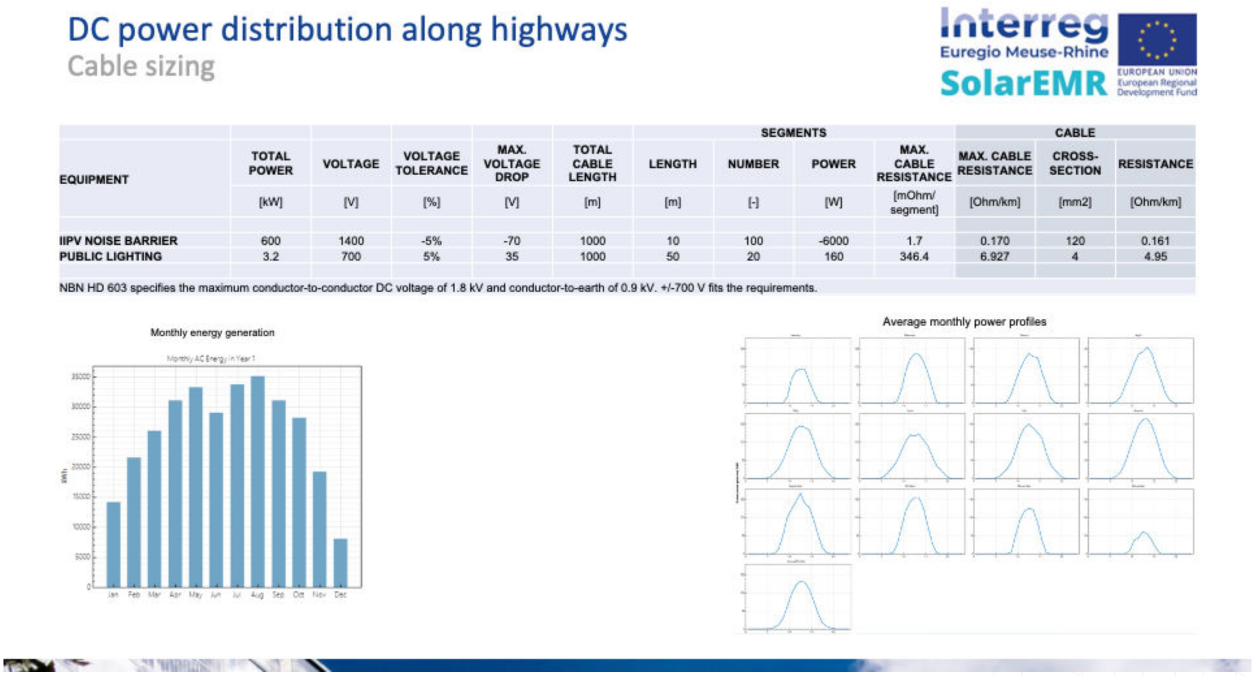


Figure 6 DC distribution system architecture

In the system architecture, storage is centralized in a single location. The option exists to distribute the battery storage system across multiple locations and further save on cabling and maximizing reliability. As such, small nanogrids are built that can operate stand-alone in case the main system would experience a disturbance.



DC power distribution along highways

Cable sizing

						SEGMENTS				CABLE		
EQUIPMENT	TOTAL POWER	VOLTAGE	VOLTAGE TOLERANCE	MAX. VOLTAGE DROP	TOTAL CABLE LENGTH	LENGTH	NUMBER	POWER	MAX. CABLE RESISTANCE	MAX. CABLE RESISTANCE	CROSS-SECTION	RESISTANCE
	[kW]	[V]	[%]	[V]	[m]	[m]	[-]	[W]	[mOhm/ segment]	[Ohm/km]	[mm2]	[Ohm/km]
IIPV NOISE BARRIER	600	1400	-5%	-70	1000	10	100	-6000	1.7	0.170	120	0.161
PUBLIC LIGHTING	3.2	700	5%	35	1000	50	20	160	346.4	6.927	4	4.95

NBN HD 603 specifies the maximum conductor-to-conductor DC voltage of 1.8 kV and conductor-to-earth of 0.9 kV. +/-700 V fits the requirements.

Figure 7 Cable sizing

3.5 Benefits of a DC infrastructure

3.5.1 Minimize power conversion equipment and losses

A DC microgrid with solar generation, battery storage, electric vehicle chargers, street lighting, and traffic signalization minimizes power conversion equipment. In a conventional AC infrastructure, power generated by the solar panels needs to be converted from DC to AC for distribution and then converted back to DC for consumption by various loads. Each conversion step incurs power conversion losses, reducing overall efficiency. However, in a DC microgrid, power generated by the solar panels can be directly utilized via the MPPT single-stage converter by DC loads or stored in batteries without the need for multiple conversions. This streamlined power conversion stages significantly reduce power conversion losses, resulting in higher overall system efficiency.

3.5.2 Higher utilisation of PV generation

As a result, more of the onsite generated PV power can be put to effective use. To add numbers to the debate: assuming that the power conversion efficiency of the solar maximum power point tracking converters increases from 96% to 98% and the power conversion efficiency of the electric vehicle chargers increases from 97% to 99%, the power conversion losses decrease from 7% of total generation to 3%. At peak power, the power conversion losses would add up to 42 kW in the AC case, as compared to 18 kW in the DC case. Hence 140 PV modules are just there to supply the power conversion losses in the AC case, which can be reduced to 60 PV modules by adopting a DC infrastructure.

3.5.3 Reduction of the number of medium-voltage distribution cabins

Furthermore, the number of connections to the medium voltage grid can be reduced by adopting a DC microgrid. Because the cable length is just limited by the voltage drop over the cables, longer distances can be covered. As shown in Figure 7, the power generated by the 1 km IIPV generation system can be collected on a 120 mm^2 feeder to limit the voltage drop below 5% at 1400 V. In an AC distribution infrastructure, the cable length would be limited by the minimum short-circuit current required to trip the protection devices. As such, multiple distribution cabins would be required along the distance of the PV generation plant, each taking up space and adding to the overall cost of the system.

3.5.4 Dim the lights without dedicated communication

A DC microgrid provides freedom to control and adjust the DC voltage locally. Consequently, the DC voltage can be used as a signal to manage power in the system. Built into LED drivers, solutions exist to dim the lights based on the supplied DC voltage. Hence, by slightly reducing the DC voltage in the system, the LED lights can be dimmed collectively without the need for additional communication wiring and interfaces. This proves to be a cost-effective solution to dim lights.

3.5.5 Offgrid operation

Finally, the entire DC microgrid can operate stand-alone. In case of issues on the higher-level AC distribution network, the proposed system architecture can operate stand-alone. In case of an outage, it is possible to maintain the lighting and signaling, and to continue charging electric vehicles if sufficient onsite generation is available. This is technically not feasible in an AC system without a full-power uninterruptible power supply installation which adds significantly to the cost. In a DC microgrid, this functionality comes essentially for free. Hence the system becomes more resilient against outages and temporary power quality disturbances that affect the uptime of the entire system.

4 Use case: BIPV powered DC microgrid

4.1 Case definition

Integrating a DC infrastructure into buildings can provide similar benefits. DC microgrid technology can also play a crucial role in commercial buildings and districts by connecting EV charging infrastructure and battery energy storage systems.

It remains often unrecognized that the electrical system in commercial business parks, and more particular in self-sufficient energy buildings, will be dominated by power electronic converters. Converters that interconnect solar photovoltaics with the grid, converters that supply heat pumps-chillers, converters that supply LED lighting, converters that charge electric vehicles and battery storage and converters that convert power originating from fuel cells.

By adopting a DC microgrid architecture instead of an AC architecture, the number of power conversion steps is halved. In addition to that, by replacing the sockets, plugs and sensors typically found in a smart building's AC-installation by a safe-to-touch DC nanogrid installation, the installation costs, expandability, flexibility and energy consumption costs substantially improve.

4.2 System architecture

Figure 8 showcases the system architecture for a Building Integrated Photovoltaic (BIPV) powered DC microgrid. This advanced architecture encompasses a range of essential components, including electric vehicle charging infrastructure, battery energy storage, street lighting, heating, ventilation, air conditioning (HVAC), LED office lighting, and ICT equipment (such as USB-C powered sockets and networking equipment).

One of the notable features of this system is its ability to introduce interlinks, allowing for the seamless transfer of excess power between neighboring buildings within the district. This interconnectivity adds a significant level of flexibility and efficiency to the microgrid, ensuring that no energy goes to waste.

The central DC backbone within the building plays a crucial role in enhancing the overall functionality and expandability of the system. By having a centralized DC infrastructure, the microgrid can easily accommodate future additions or modifications, making it a versatile and future-proof solution.

Battery energy storage is another key component of this system, providing backup power supply, self-consumption and peak shaving capabilities. The batteries store excess energy generated by the PV and BIPV modules allow for uninterrupted power supply during outages or disturbances. Moreover, the microgrid is interfaced with the public utility grid, enabling the batteries to minimize peak power drawn from the utility and to maximize the utilization of onsite generation. This not only reduces demand charges but also enhances the overall efficiency of the system.

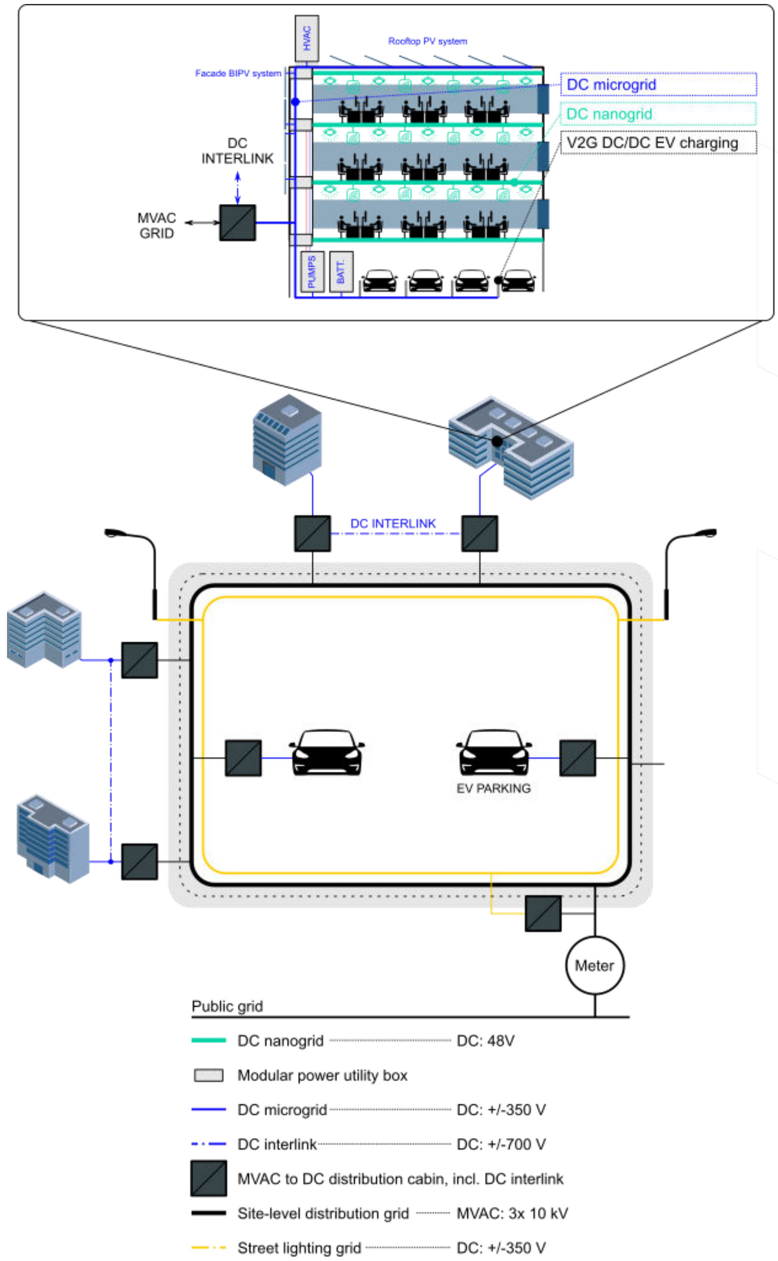


Figure 8 Use case: DC microgrid for BIPV in office buildings and commercial districts

4.3 Benefits of a DC infrastructure

The benefits of adopting a DC infrastructure in buildings strongly align with the benefits described in the previous use case:

- Minimize power conversion equipment and losses
- Higher utilisation of PV generation
- Offgrid operation

In addition, building-level DC microgrids provide benefits in terms of the permitted system architectures. Instead of a star-based system architecture, a bus-based parallel system architecture can be adopted when supported by the selected protection strategy. As such, the complexity and number of cables in the building significantly reduces.

Additionally, a DC microgrid architecture allows to design compact vehicle-to-grid (V2G) DC/DC converters which enables the EV to both charge and discharge electricity back to the grid. By aggregating together multiple EVs a ‘virtual battery’ is created to be used by the grid operator to balance the energy supply and demand.

Furthermore, adopting a central DC bus has a profound impact on the complexity of the power electronic DC/DC converters that perform distributed maximum power point tracking on the BIPV modules. As the complexity of these power electronic converters reduces, their lifetime will increase alongside their increased conversion efficiency and reduced costs.

5 Converter development

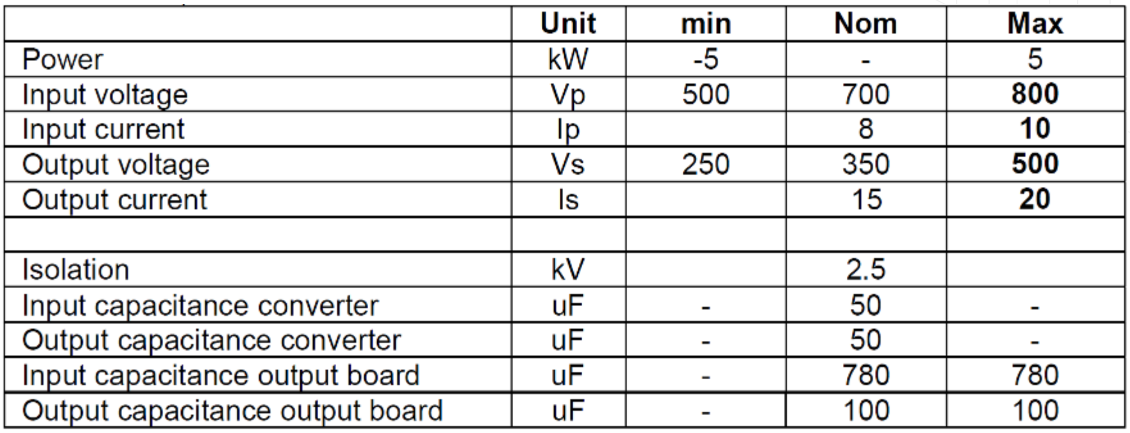
5.1 Boundary conditions

Connecting devices to the proposed architectures comes with some boundary conditions. On the one hand, the devices must be compatible with the voltages available. On the other hand, devices must be able to connect and disconnect safely. Within this project, AME designed a converter compliant with the boundary conditions applicable to the presented use cases.

5.2 Operation limits

The presented converter is a bidirectional DC/DC converter and is available in different modules of 5 kW. Using them in a modular and stacked way allows to operate the converters most efficiently, by turning converters on and off according to the power requirements of the loads or source. This section presents the operation limits of the presented converter.

Table 1: Converter hardware parameters



	Unit	**min**	**Nom**	**Max**
Power	kW	-5	-	5
Input voltage	Vp	500	700	**800**
Input current	Ip		8	**10**
Output voltage	Vs	250	350	**500**
Output current	Is		15	**20**
Isolation	kV		2.5	
Input capacitance converter	uF	-	50	-
Output capacitance converter	uF	-	50	-
Input capacitance output board	uF	-	780	780
Output capacitance output board	uF	-	100	100

Table 1 shows the hardware parameters and the limits the converter is subject to. As shown, the converter has wide voltage ranges, wider than most grid codes impose on devices connected to the grid.

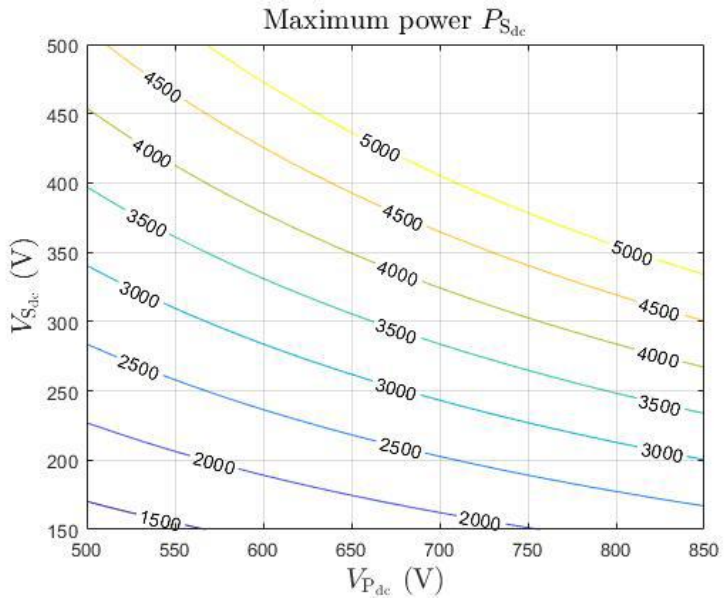


Figure 9: 5 kW DAB operational power limit with respect to primary VpDC and secondary VsDC

Figure 9 indicates the power limits of the converter, given the applied input and output voltages of the converter. For primary voltages below 500 V, the converter is always limited in power, otherwise the currents would be too high.

5.3 Connectivity requirements

Connecting a device to the grid requires several precautions to protect both the converter itself and other converters connected to the grid. First, it is important to limit the inrush currents, not to damage the capacitors present in the system. For this converter, an inrush circuit is designed, using four wire wound 7 W power resistors with a resistive value of 1 kΩ. Second, overvoltage diodes are put in place to protect the semiconductors from getting damaged. Four series 180 V 1500 W SMCJ180CA, bidirectional transorbs are used. Finally, for safe disconnection, it is required to discharge the capacitors. Four 100 kΩ 2512 resistors are used two times 27 in parallel, resulting in an equivalent discharge resistance for the 780 µF capacitors of 28 200 kΩ, with a rated power of16 W total.

6 Barriers to adoption

6.1 Limited awareness and know-how

It is crucial to address the limited awareness among design offices, electrical installers, and EV charge point operators about the benefits and potential of DC microgrids. These stakeholders play a significant role in the design, installation, and operation of electrical systems, including EV charging infrastructure. However, their lack of knowledge about DC microgrids can hinder the widespread adoption of this innovative technology.

By organizing study days and courses, sector organizations can provide a platform for education and knowledge-sharing. These initiatives should aim to provide comprehensive information about the advantages of DC microgrids, as well as the specific considerations that need to be taken into account during the design and implementation phases. Topics such as system architecture, power conversion equipment, equipment selection and sizing, and standardization should be covered in detail.

The study days and courses should be designed to cater to the specific needs and interests of design offices, electrical installers, and EV charge point operators. Practical examples, case studies, and interactive sessions can help participants grasp the concepts and apply them to real-world scenarios. Additionally, inviting experts and industry leaders to share their experiences and insights can further enhance the learning experience and inspire participants to embrace DC microgrids.

To ensure the effectiveness of these educational initiatives, it is crucial to prioritize the most recent information and industry best practices. The field of DC microgrids is constantly evolving, with new technologies, regulations, and standards emerging. By staying up-to-date with the latest developments, sector organizations can provide the most relevant and accurate information to the participants.

Furthermore, it is important to create a supportive network and community for design offices, electrical installers, and EV charge point operators interested in DC microgrids. This can be achieved through online platforms, forums, and networking events where participants can connect, share their experiences, and seek guidance from experts. Building a strong community will not only foster knowledge exchange but also promote collaboration and innovation in the field of DC microgrids. We have made considerable efforts to disseminate this knowledge and advertise in the workshops of SolarEMR, notably to the SMEs we were able to involve, as well as public authorities as potential users of the technology.

6.2 Limited standardization and equipment availability

The standardization of low-voltage DC microgrids is an ongoing process that continues to evolve. Recognizing the importance of this technology, the International Electrotechnical Commission (IEC) has established a Systems Committee dedicated to the subject. Through the collaboration of various working groups, the IEC aims to develop and set standards for voltage levels, protection strategies, operational protocols, and rules within the DC microgrid domain.

In addition to the IEC's efforts, the CurrentOS Foundation, founded by industry leaders Schneider Electric, ABB, and Eaton, is actively driving alignment within the DC microgrid industry. By bringing together key stakeholders, this foundation aims to foster collaboration and promote the development of interoperable equipment for DC microgrids.

The need for alignment and standardization in the DC microgrid industry is crucial for equipment manufacturers. Interoperability is a key factor in ensuring that different components of a DC microgrid, such as EV chargers and solar DC/DC converters, can seamlessly operate together. However, the current lack of clarity regarding equipment interoperability poses a challenge to the commercial availability of DC microgrid systems.

While there is existing equipment available for building DC microgrids, it is difficult to assess whether this equipment is truly interoperable. This uncertainty hampers the widespread adoption of DC microgrids, as potential users may be hesitant to invest in systems where compatibility issues may arise.

By establishing clear standards and guidelines, the ongoing standardization efforts by organizations like the IEC and the CurrentOS Foundation aim to address these challenges. Through their work, they strive to create an environment where equipment manufacturers can confidently develop interoperable solutions, enabling the commercial availability and widespread adoption of DC microgrid systems.

7 Conclusions

Since the energy utilization is key for the target definition of the concept study for system architectures, and storage concepts form an integral part of the design, we decided to address both Deliverables jointly in this document, rather than generating separate ones with complicated interlinks. The concept study on power conversion system architecture for the SolarEMR project has provided valuable insights into the benefits and potential of adopting a DC infrastructure in various applications. By minimizing power conversion equipment and losses, a DC microgrid offers significant advantages in terms of power conversion efficiency, overall system efficiency, and reliability. The study has focused on two specific use cases: infrastructure-integrated noise barriers along highways and building-integrated photovoltaic (BIPV) powered DC microgrids. In these two Deliverables combined, we laid out the design process from the energy yield prediction to the development of an electrical system that connects the PV generators with different types of consumers, and including storage and V2G charge points, addressing Project Specific Objective 1.

In the use case of infrastructure-integrated noise barriers along highways, the study demonstrates how a DC microgrid located near a highway parking facility can effectively generate and distribute power towards the EV charging station. The noise barriers, equipped with infrastructure-integrated photovoltaics, generate solar power that is primarily utilized for fast charging electric vehicles and powering street lighting and traffic signalization systems. The integration of battery energy storage further enhances the system's resilience by providing backup power supply and peak shaving capabilities. The study conducted simulations to optimize the system architecture and determine the optimal size of the battery energy storage system. The results show that the addition of battery storage significantly reduces the peak power drawn from the utility grid, thereby reducing demand charges and improving system efficiency.

In the use case of building-integrated photovoltaic (BIPV) powered DC microgrids, the study highlights the advantages of adopting a DC infrastructure within buildings. The system architecture includes components such as electric vehicle charging infrastructure, battery energy storage, street lighting, HVAC systems, LED office lighting, and ICT equipment. The centralized DC backbone within the building allows for future expansions or modifications, making it a versatile and future-proof solution. The integration of electric vehicle charging infrastructure directly from the DC power source eliminates the need for additional conversion steps, reducing energy losses and promoting the use of clean energy for transportation. Battery energy storage provides backup power supply, self-consumption, and peak shaving capabilities, further enhancing the overall efficiency and stability of the microgrid. The study shows the possibility of interlinks within the microgrid, enabling the seamless transfer of excess power between neighboring buildings within a district, thereby maximizing energy utilization in commercial districts. In bringing together the performance modeling for integrated PV in these cases with the model-based planning of a DC system to best utilize the generated energy, we have addressed Project Specific Objective 2, to demonstrate theoretically the optimization procedure in the design, and in so doing also the advantages that such a novel system enables. The design rules laid out here also address Main Output 2 of WP T2.

Despite the evident benefits of DC microgrids, there are barriers to their widespread adoption. Limited awareness and know-how among stakeholders, including design offices, electrical installers, and EV charge point operators, pose a significant challenge. To address this, the study suggests organizing study days and courses to educate and raise awareness about the advantages and specific considerations of DC microgrids. Practical examples, case studies, and interactive sessions can help stakeholders grasp the concepts and apply them in real-world scenarios. Additionally, creating a supportive network and community can facilitate knowledge exchange, collaboration, and innovation in the field of DC microgrids.

Another barrier to adoption is the limited standardization and availability of equipment for low-voltage DC microgrids. Establishing clear standards and guidelines is crucial to ensure equipment interoperability and compatibility. Organizations like the International Electrotechnical Commission (IEC) and the CurrentOS Foundation are actively working towards standardization and alignment within the DC microgrid industry. Their efforts aim to create a context where equipment manufacturers can confidently develop interoperable solutions, thereby enabling the commercial availability and widespread adoption of DC microgrid systems. By supporting these initiatives, the partners, in particular KU Leuven and DCinergy, are addressing Project Specific Objective 3, to clarify legislation and standardization that SMEs and investors have to follow in order to adopt this novel technology.

In conclusion, the concept study highlights the potential of DC microgrids in improving power conversion efficiency by reducing power conversion losses, and enhancing the reliability and resilience of electrical systems. By embracing this innovative technology and overcoming the barriers to adoption through education, standardization, and collaboration, society can move towards a more sustainable, efficient, and resilient power infrastructure.