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Deliverable D 1.6

User Adoption and Perceptions of DC Solutions

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Executive Summary

This deliverable (D1.6) is part of the Shift2DC project and results from task T1.6, "User Adoption of DC Solutions," in work package 1 (WP1).

The purpose of this document is to provide a detailed overview of user aspects related to the adoption of DC devices and tools, which will be developed in the later packages of the project. It involves the identification of various user roles associated with DC technology, their challenges from literature reviews, and sessions with DC experts to gather their perceptions for the widespread adoption of DC solutions.

The task employed an expert elicitation method to collect user perceptions by involving experts in two independent sessions – the first with experts within the consortium and the second with experts outside the consortium. During the sessions, eleven (11) DC devices and tools were presented for experts to provide their perceptions.

Results show that all the presented DC devices and tools presented in the two EE sessions were perceived as feasible and important for the demonstrators of the project, which are ports, industry, data centres, and buildings. As for the barriers, there is still a missing link between DC's advantages to the general public, the lack of enough trained personnel, and the lack of awareness and will to change from AC to DC by end users. These are among the commonly described and rated higher barriers to DC adoption by experts in both sessions. A further challenge is the availability of alternative technologies in the market, which makes the need for this project to bring more awareness and contribute on the unique strengths and value propositions of DC devices and tools.

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Acronyms

BIM	Buildings Information Modeling
CAT	Consumer Acceptance Test
DC	Direct Current
EE	Expert Elicitation
EU	European Union
EV	Electric Vehicle
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IT	Information Technology
LVDC	Low Voltage Direct Current
MVDC	Medium Voltage Direct Current
RESs	Renewable Energy Sources
Shift2DC	Shift to Direct Current project
TAM	Technology Acceptance Model
UTAUT	Unified Theory of Acceptance and Use of Technology
WP	Work Package

1 Introduction

The Shift to Direct Current (Shift2DC) project is a European Union's Horizon Europe research and innovation funded project. It aims to design, develop, and test Direct Current (DC) solutions for low- and medium-voltage direct current use.

DC is a new technology that can impact the activity of different users interacting with its solutions. Recent concentration in the development of DC solutions is due to the growing integration of energy storage services, transition to Renewable Energy Sources (RESs), and also increasing usage of DC-powered electronic loads and equipment, such as in data centres, Light Emitting Diode (LED) lighting systems, Electric Vehicles (EVs), DC motors, and other battery-operated equipment [1], [2], [3]. Furthermore, it is anticipated that the future of smart grids will revolve around high efficiency households, renewable energy parks, and hybrid energy storage systems[1]. The DC power has been widely utilized in High Voltage (HV) applications in long distance transmission due to its capacity for low power losses compared to AC [4], [5]. Still, recent interest in the integration of RESs in the Low Voltage (LV) and Medium Voltage (MV) levels has brought DC power to the spotlight [6].

Considering the benefits mentioned above and application areas that DC in both voltage levels have and their potential towards energy transition, the Shift2DC project aims to develop and test twenty-four (24) technological DC business models, devices and tools applied in data centres, buildings, ports, and industry.

Besides developing and testing, the project also aims to gain an in-depth understanding of the perceptions of the end-users of DC devices and tools. This deliverable presents the results of task 1.6 (Users adoption and perception of DC solutions), specifically designed to address these aspects.

The remaining of this document is organized as follows: Chapter 2 provides a concise literature review on the state of the art in adopting DC technologies and the methods used to capture user perceptions. This chapter concludes by identifying the selected method and the rationale behind its choice for the task objective. Chapter 3 describes the methodology used to gather user insights, beginning with user identification based on their roles in DC, followed by details on data collection and analysis techniques. Chapter 4 presents findings from the first session of the expert elicitation with the members from the consortium, and outlines improvements made to the protocol before the second session. Chapter 5 then discusses the key findings of the second expert elicitation session, conducted with experts outside the consortium. Finally, the report concludes with a general discussion on how the results address the task objectives in Chapter 6, followed by a conclusion in Chapter 7.

1.1 Scope and Objectives

This task aims to evaluate the users' perspectives regarding the proposed DC devices and tools in the Shift2DC project. The task covers identifying expected users, their relevant roles, and needs in using DC devices and tools. Thereafter, this task identifies the DC users' perspectives regarding its widespread adoption.

1Research, Demonstration, and Commercialisation of DC Micro-grid Technologies: https://cordis.europa.eu/project/id/734796/reporting

1.2 Relationship with other deliverables

This deliverable is closely linked to several others within WP1, WP4, and WP5. Although deliverable D1.6 is complete at this stage, related deliverables in WP4 and WP5 are still ongoing and in their early phases.

Within WP1, this deliverable aligns with deliverables D1.1, D1.3, and D1.4. Deliverable D1.1 thoroughly assesses the challenges and opportunities associated with DC investment, providing critical insights for developing this task. Additionally, deliverable D1.3 elaborates on use-cases in the four application areas of the Shift2DC project, supporting the operational definitions and specifications of DC-based systems. These use-cases have been integrated into task T1.6 to calibrate participants in both expert elicitation sessions. Finally, the thorough definitions and specifications of the Shift2DC solutions presented in deliverable D1.4 provided the basis for selecting the most appropriate ones to include in the expert elicitation protocol.

In WP4, which focuses on testing the designed DC devices and tools, the findings from this deliverable will guide the evaluation of these designs from end-user perspectives across the four demonstrators.

Finally, this work also connects with WP5, which aims to develop innovative strategies for identifying and motivating potential DC users. These users have been clearly defined in this deliverable, so being aware of the DC users shall help analyze market trends and foster user engagement. These strategies are essential for the widespread adoption and sustainability of DC solutions.

2 State of the Art

This chapter presents an overview of the current state of research in DC adoption and perception through analysis of various literature. It starts by explaining user perceptions of adopting DC and its associated technologies. This is followed by descriptions of the methods applied in assessing user perceptions of technology adoption. It ends by specifying the rationale behind the selected method.

2.1 User Adoption and Perception of DC

In assessing the DC buildings, several studies have reported various factors that influence users' adoption of DC technologies. The following factors have been highlighted: good attitude towards' sustainability [7], [8], and technology and market readiness [9]. On the other hand, in DC micro-grids the following factors were found more influencing, these includes; ease of use, relative advantage, and perceived behaviour [10].

Critical barriers to DC adoption among end-users include: limited markets for DC components and devices, negative public perceptions of DC systems, and concerns about electric shock and fire hazards due to a myth that DC power is dangerous [9]. Additionally, a general lack of consumer awareness about DC power systems contributes to doubts regarding the reliability and cost-effectiveness of DC circuits and other related devices [11], diversity of safety and protection equipment for humans (for example, workers, operators, etc.), lack of enough technical expertise to work on DC micro-grids and its technologies, lack of specific agreed standards for Low-Voltage Direct Current (LVDC) and Medium-Voltage Direct Current (MVDC) voltages, high initial investment costs, and lack of enough trained personnel's [1], [9], [12].

Despite the aforementioned barriers, DC technologies offer benefits such as more affordable electricity rates, enhanced quality of life and productivity, job creation, and a reduction in energy poverty [13], [14], [15]. However, transitioning to DC directly impacts consumers. This underscores the necessity for evaluating non-technical variables or factors that influence user acceptance regarding the implementation of DC solutions. This has been identified as an area that remains underexplored in academic research, as presented by [12], [13], and [14].

2.2 User Inputs Gathering Methods

This section elaborates on various methods used to gather user inputs or assess factors that influence technology adoption.

The leading influencing factors presented in the publications listed in Section 2.1 have been gathered from the wide use of acceptance theories or models. These theories have been widely implemented in assessing end-user acceptance or adoption of technologies. Among them, there are the Technology Acceptance Model (TAM) [17], the Pleasure, Arousal, and Dominance paradigm of affect [18], Consumer Acceptance of Technology (CAT) [19], Theory of Planned Behaviour, Unified Theory of Acceptance and Use of Technology (UTAUT) [20]. All these are assessed by identifying factors that might influence user's adoption of a technology under study.

Some of the theories have resulted from merging others. For example, the Consumer Acceptance of Technology (CAT) was developed from the Technology Acceptance Model (TAM) and the Theory of Reasoned Action (TRA) [19]. A study by FakhrHosseini et al. [21] demonstrated that theories incorporate various aspects of technology adoption, taking into account attributes of the user, system, environment, tasks, and context. This raises significant concerns about the generalizability of existing theories when applied to emerging technologies, such as DC systems. Moreover, the limited real-world pilots and demonstrations of DC technology make it challenging to adopt and validate technology acceptance theories. Alternatively, there are several methods, such as expert elicitation [22] and future studies [23] that can be considered based on the audience under study.

Expert Elicitation (EE) is a method applied across various fields, including science, engineering, and decision-making, to collect and synthesize expert insights on topics where empirical data may be limited, uncertain, or sometimes unavailable [11]. This approach systematically solicits and aggregates judgments from individuals with relevant expertise, knowledge, and experience in a specific subject area – namely, experts in their fields or subject matter [11], [24], [25]. Given the current state of DC implementations, this method is particularly suited for analyzing non-technological factors like public perceptions and market growth of technologies.

Future-oriented technology analysis is essential in research and development planning, as it assesses upcoming technological advancements and their potential impacts. By engaging stakeholders in participatory, interdisciplinary processes and methodological approaches, this field aids in understanding the factors influencing technology acceptance among users [26], [27]. Key methods within this field include frameworks [27], [28], and scenarios [29], [30], each focusing on aspects like energy storage technology, digital applications, and public perceptions of energy technologies. This approach ensures that energy technologies are both efficient and aligned with societal needs and values.

As elaborated in previous paragraphs in this section, the aforementioned methods, acceptance theories or models, expert elicitation, and future-oriented technology analysis have been used in various contexts. The decision on which method to use depends on multiple factors. This includes the participants from whom information is gathered, the level of uncertainty of the technology, and the goal of the study, as shown in Table 2.1.

Table 2.1: Methods for Technology Adoption Studies

Method	Participants	Level of Uncertainty	Study goal
Acceptance theories or models	End-users or consumers	Low	Factors influencing adoption
Expert elicitation	Experts	Moderate	Focused insights on a specific, well-defined topic
Future-oriented technology analysis	Experts	High	Broader scope and for long-term strategic planning

Since the target users of the DC solutions developed in the Shift2DC project are experts in fields of data centres, buildings, industry, and ports, their involvement is essential. Although DC technology is not entirely new, it remains in an early stage, leading to a moderate level of uncertainty in the solutions. Additionally, a key goal of the project is to understand these experts' perceptions of the developed DC technologies.

The expert elicitation method was selected as the most suitable approach, compared to, acceptance theories or models, and future-oriented technology analysis. This choice was guided by three key considerations.

First, the **nature of the audience** in the Shift2DC project played a decisive role. The target group consists of domain experts specializing in the DC across four application areas: data centres, buildings, industry, and ports.

Second, the **developmental stage of DC technology** factored into the decision. DC is currently in its infancy, characterized by a moderate level of uncertainty. This contrasts with future-oriented technology analysis, which is more appropriate for contexts with higher uncertainty levels.

Finally, the **scope and focus of the Shift2DC project** influenced the selection. The project emphasizes highly focused insights on a specific and well-defined topic, whereas future-oriented technology analysis is better suited for exploring broader, less narrowly defined scopes.

3 Methodology

This chapter starts by elaborating on various user roles to identify potential participants in the EE sessions and future project tasks focusing on the DC ecosystem's main stakeholders. After that, the section elaborates on the EE procedure, which contains information on the protocol contents and decision on the number of EE sessions, expert recruitment procedure, and explanations on the platforms to host the EE sessions.

3.1 User Roles in the DC Ecosystem

In the context of this task, user roles refer to responsibilities that users carry on in accomplishing their tasks [31]. For a thorough understanding of user roles in DC, a total of six (6) user groups have been identified: DC solutions, ports, data centres, industry, buildings, and the general end-users of DC. More detailed information concerning these user groups has been included in Appendix A.

The identified user groups have been categorized into six categories, which are elaborated below.

The first category is named *administration, finance, sales, and marketing*. These refer to users who deal with the general administration of people working in DC application environments. Of our six user groups, only five have roles that fall into this category; DC solutions have sales, marketing, and support; Ports have people dealing with the general management of ports, control ports logistics and supply chain, customer service and relations, and cargo handling. Data centres have general administrators and those in logistics and inventory control. In industry, there are roles in finance and administration, supply chain and logistics, also sales and marketing. Conversely, buildings are typically associated with companies specializing in sales and marketing, commonly referred to as real estate firms. All these roles have been captured in Figure 3.1.

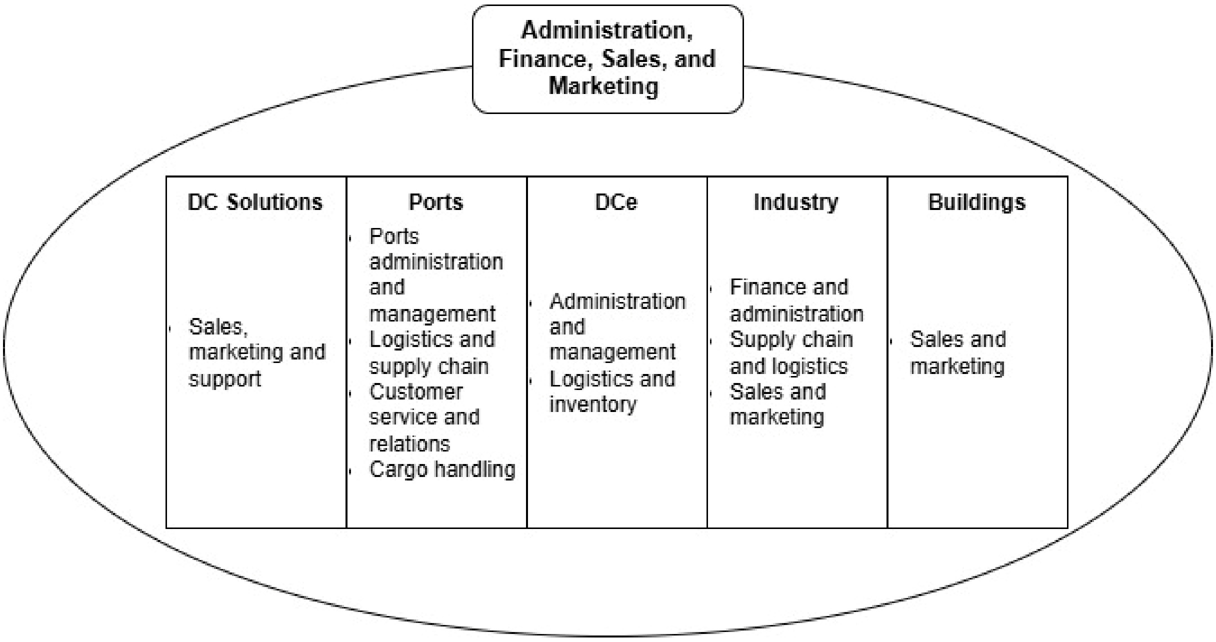

Figure 3.1: Administration, Finance, Sales, and Marketing

The second category is *IT systems management; the legal and ethical issues* are shown in Figure 3.2. Given the development and broad application of science and technology in various sectors, even the DC equipment in their various application environment has software that supports smooth running and operations. Hence, this brings a need to control user behavior in interaction, which is why the legal and ethical issues belong here.

Therefore, five groups have roles in this category; in DC solutions, there are systems designers who deal with installations, commissioning, and compliance with DC systems. In ports, there are Information Technology (IT) and Information and Communication Technology (ICT) roles and collaborators who deal with regulatory compliance and legal issues, which is the same for buildings and industry. In data centres, added roles related to this category deal with backup and emergency systems due to the need for data control and security in IT.

Other added role is the Buildings Information Modeling (BIM) relating to buildings application areas. It plays a crucial role in managing energy in buildings by enabling detailed energy simulations, optimizing designs for efficiency, and supporting sustainable practices throughout the building lifecycle. The BIM integrates building geometry, materials, and systems into a centralized model, allowing for energy performance analysis, such as thermal performance and lighting optimization.

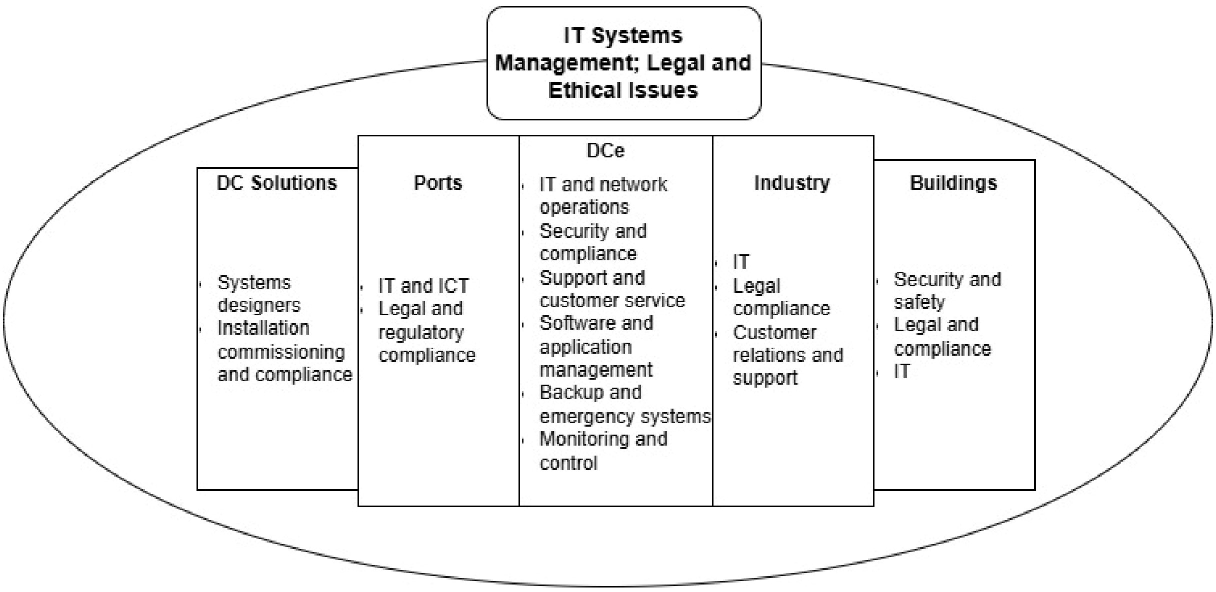

Figure 3.2: IT Systems Management; Legal and Ethical Issues

A third category, named *manufacturing, engineering, and certification*, shown in Figure 3.3, deals with industrial design, development, testing, standards development, and certification of DC technologies. The five groups have roles that are common in this category. The DC devices and tools have project management, manufacturing, testing, certification, operations, and maintenance. Then, in ports, there are people dealing with vessel operations, safety and security, energy and sustainability managers, and those in installations, maintenance, control, and monitoring. In data centres, there are energy and sustainability managers, as well as installation and maintenance. In industry, there are engineering and design roles, production and operations, maintenance and facilities, and quality assurance and control. Finally, in buildings, there are property managers who also deal with operations, maintenance and technical support, energy sustainability, and tenant and resident services.

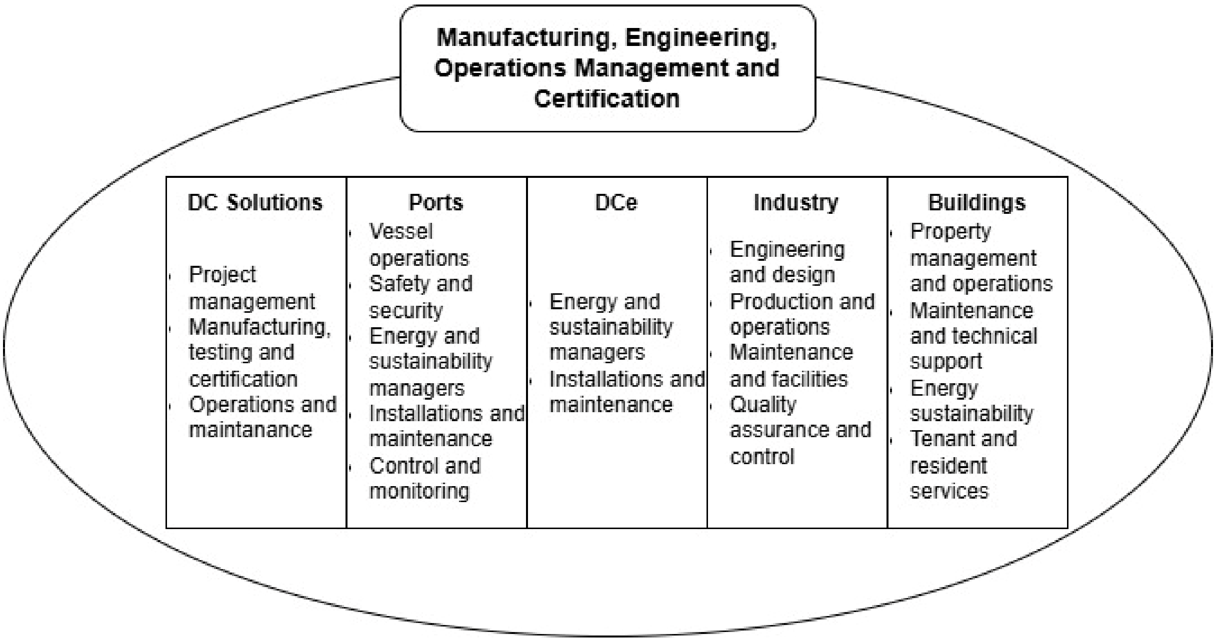

Figure 3.3: Manufacturing, Engineering, and Certification

The <u>fourth category</u> is named *research and development*, as shown in Figure 3.4. People in this category deal with DC research design, development, innovation and dissemination of results through publications and providing education that informs other sectors. The roles here are research and development in DC solutions, data centres, buildings and industry.

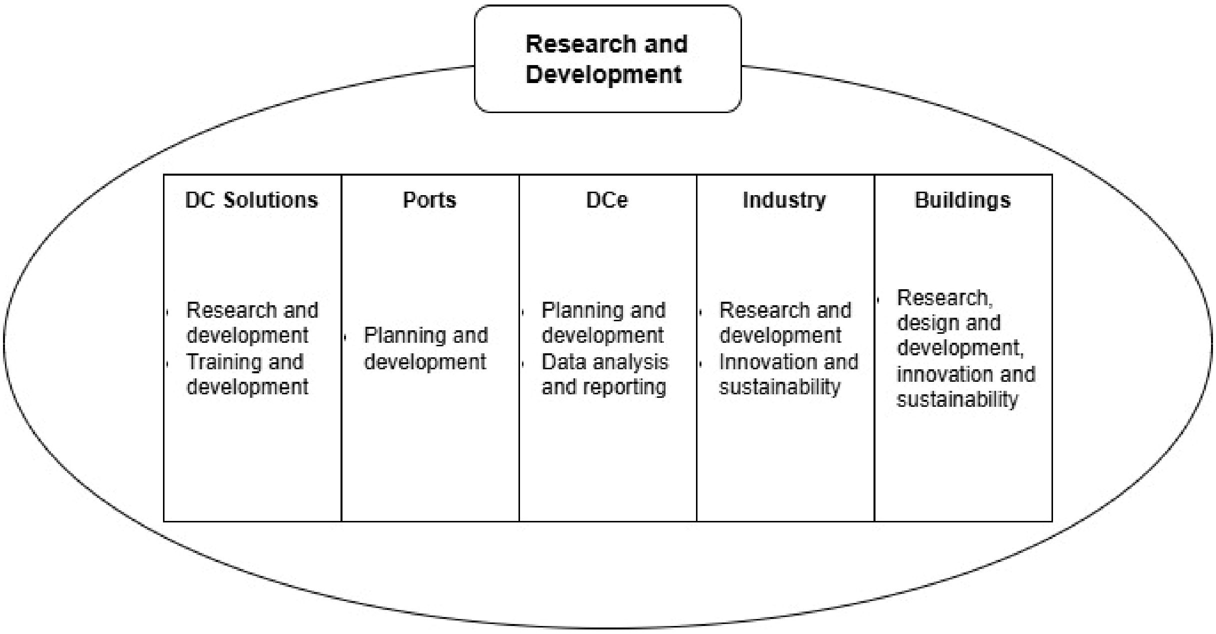

Figure 3.4: Research and Development

The <u>fifth category</u> is named *visitors to the ports, data centres, and buildings*. There are different types of visitors that visit the three aforementioned groups. In ports, visitors are ship captains and crew who deal with ship docking and operations, tourists, also passengers. In the data centres the visitors are clients and potential customers inspecting facilities, as well as the regulatory inspectors ensuring compliance with standards. In buildings, the visitors are residents and tenants who are users of the space, also, people dealing with building maintenance are in this category since they occasionally visit the buildings to make sure all equipment and systems are in place and safety of the buildings.

In all five categories, one group of roles has not been included purposely these are *end-users.* The end-users, as shown in Figure 3.5, are user groups that consumes or use DC solutions, or technologies to achieve daily tasks or other related duties. For example, agricultural users use DC equipment for irrigation.

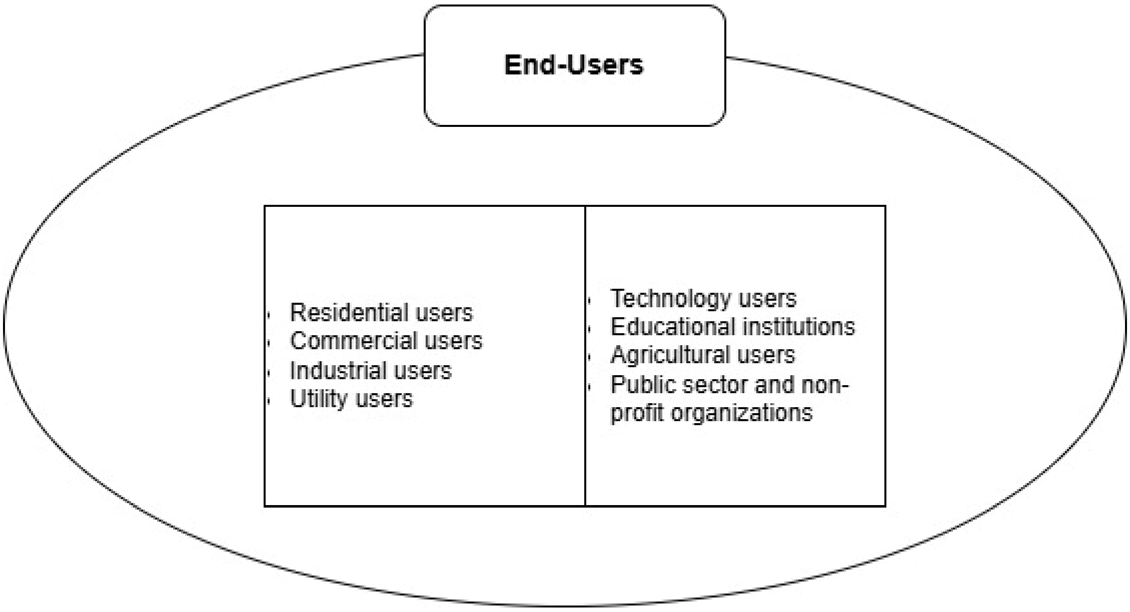

Figure 3.5: End-Users

This section on DC user role identification and detailed explanations serves two primary purposes. First, it aims to identify the relevant roles of individuals engaged in ports, industry, data centres, and buildings as part of the EE sessions. Second, it is intended for future use in assessing user engagement with DC solutions to be developed, which is anticipated to occur in Work Package 5 (WP5).

For the EE session, only four among the five categories were found to be necessary to be involved in the EE sessions as subject matter experts. This is because the category of visitors contains a repetition of experts who belong to other categories but also contains the end-users or consumers of DC. Mostly, these end-users do not have the required knowledge or subject matter expertise compared to the other categories of users like administration, finance, sales, and marketing due to their experience in DC companies or even among the demonstration areas like ports, buildings, data centres, and industry.

The literature considers experts to be people with relevant subject matter knowledge and experience in a specific relevant field to the study [11], [32], [33]. Hence, Figure 3.6 shows categories of users considered pertinent to the DC in the Shift2DC project.

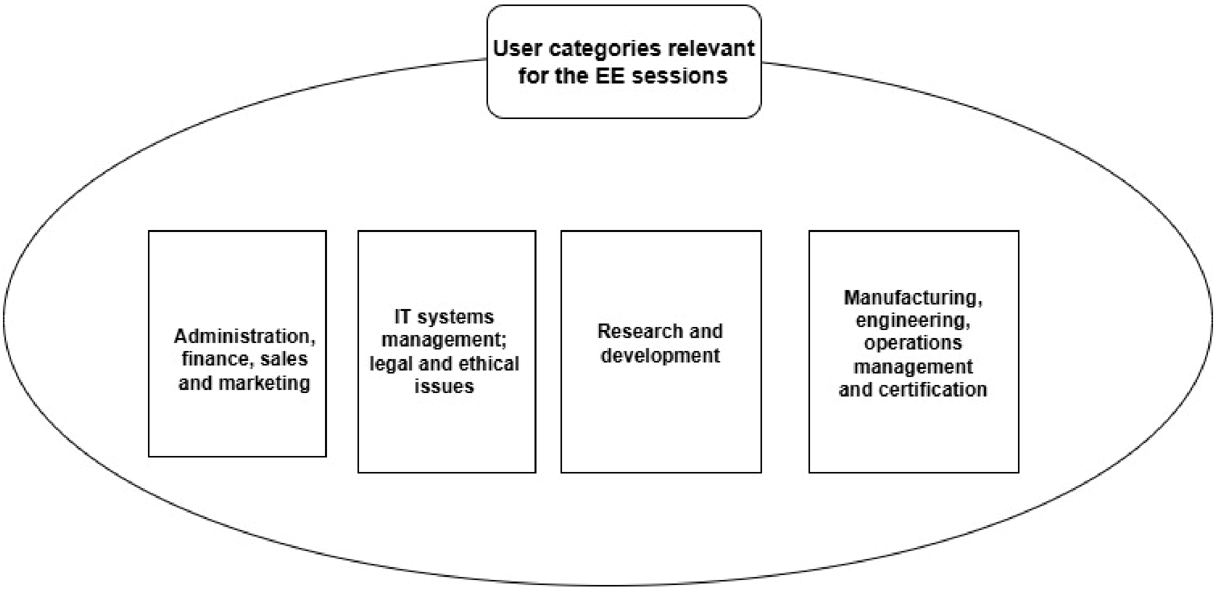

Figure 3.6: User Roles Relevant for the EE Sessions.

3.2 Expert Elicitation Procedure

This section explains three main considerations in preparation for the EE sessions: the EE protocol, expert recruitment, and the session platform.

3.2.1 Expert Elicitation Protocol Development

The EE protocol is a document used to guide the EE sessions. It contains thorough details of the goal of the session, as well as the structure of the parameters of interest to achieve the elicitation objective(s). To achieve the task goal, the elicitation team planned two EE sessions. The first session with experts within the consortium, and the second session with experts outside the consortium. Therefore, a first EE protocol was developed (found in ANNEX 1: The EE Protocol – First Session), and based on results from the first session, the second protocol was developed (see ANNEX 3: The EE Protocol – Second Session).

Table 3.1 and Table 3.2 list the questions asked in the first and second EE sessions, respectively.

Table 3.1: EE Protocol Questions - First EE Session.

S/No	Question	Options
1.	Are you ready to start?	Calibration question
2.	How FEASIBLE is the use of DC in the previous described demonstrators?	Not feasible, somewhat feasible, feasible, very feasible, not able to respond

3.	How important is this solution? (For each DC solution in each of the three categories	Not important, somewhat important, important, very important, not able to respond.
4.	Barriers to adoption {a total of eleven barriers were presented for experts to select all that they perceive applies}	Select the top 5.
5.	When will we see a widespread adoption of these solutions? (for each of the DC solution in each of the three categories)	<2030, 2030, 2040, 2050, >2050, not able to respond/ never going to happen.
6.	What is the risk of non-availability or delay in adopting these technologies? (for each of the DC solution in each of the three categories)	Insignificant, moderate, critical, very critical, not able to respond.
7.	Are there any other vital barrier(s) not listed?	Open-ended question.
8.	General discussion	Open-ended question.

Table 3.2: EE Protocol Questions - Second EE Session

S/No	Question	Options
1.	Are you ready to start?	Calibration question
2.	How FEASIBLE is the use of DC in the previous described demonstrators?	Not feasible, somewhat feasible, feasible, very feasible, not able to respond
3.	How important is this solution? (for each DC solutions)	Not important, somewhat important, important, very important, not able to respond.
4.	Barriers to adoption {a total of twelve barriers were presented for experts to select all that they perceive applies}	Select the top 5.
7.	Are there any other vital barrier(s) not listed?	Open-ended question.
8.	General discussion	Open-ended question.

3.2.2 Experts Recruitment

In this document, the term *expert* refers to *professionals specializing in power electronics, energy systems, and related fields, including manufacturers* of energy infrastructure, also *academicians and researchers* in energy and its associated systems*. This designation encompasses individuals at both the technician level and those with advanced educational qualifications.*

The recruitment exercise of experts for the EE sessions, both first and second, there were email communications and sharing of proposed sessions (for experts to choose from), and then the most selected date and time is communicated as the agreed session time. Also, in the emails is where the consent form is shared for experts to fill in before the sessions, as ethically required for studies with humans, a consent form was developed for experts to fill in before both EE sessions. A sample of the consent form can be accessed in ANNEX 2: Consent Form - Both EE Sessions, which was used in both of the EE sessions. In the email communication, the experts were informed of the requirements for the EE sessions, as each expert was supposed to have an internet-enabled second screen to use for answering questions. The participants of the first session were directly invited by the research team based on their expertise, whereas the participants in the second session were recruited from a pool of candidates created from suggestions of the project partners and a survey of relevant ongoing and closed research and innovation projects on DC systems and technologies.

3.2.3 The EE Sessions Support Tools

Finally, the session platform was decided at this stage. Here, the platforms include the software tools to support the sessions. Microsoft Teams was selected to host the sessions. Microsoft Teams serves as a comprehensive messaging platform for organizations, offering a centralized workspace that enables real-time collaboration, communication, meetings, file sharing, and application integration. This platform was decided due to its capacity to consolidate multiple functions into a single, accessible interface to enhance team connectivity and productivity. Furthermore, this tool is widely used and accepted by the session participants in their day-to-day activities.

All the questions in the EE protocols were coded in Slido, a comprehensive platform for facilitating questions and answering sessions and polling in both live and virtual meetings and events. The decision to use Slido was due to its interactivity capacity, which was deemed vital to support the interaction between the elicitation team and the experts during the EE sessions.

The recording and transcriptions were necessary to ensure all expert's perceptions were captured during the EE sessions. The Read.AI was selected as it works in a hybrid environment by enhancing meeting effectiveness and offering summaries, transcription, playback, and automation features necessary for the EE. After each session, all the data was transferred from the online platform to an offline storage system that was only accessible to the researchers working on this task. After the successful data transfer, all the data was permanently deleted from the online server.

4 Expert Elicitation – First Session

The session took place on Monday, 23rd September 2024, for two (2) hours. It intended to capture involved experts' perceptions on the feasibility of the proposed DC devices and tools, barriers to their adoption, time for widespread adoption, risks of delay in adoption, and finally, an open-ended general discussion forum.

The session started with the team welcoming note to the participants and a brief introduction of the session's objectives, setting the tone for a detailed discussion on selected DC devices and tools. The primary focus was on the Shift2DC, which aims to develop guidelines and roadmaps for MVDC and LVDC systems across various sectors.

A detailed description of each participant and their area of expertise can be found in Table B.1 in APPENDIX B: The EE Participants – First and Second Sessions, while Table 4.1 here provides a summary of the number of participants by expertise. The session included thirteen (13) participants: seven (7) in DC power electronics, two (2) in DC protection systems, two (2) in port electrification, and one each from data centre electrifications and from academia. Evidently, all participants possessed a strong background in DC systems. The specified expertise is in the category of manufacturing, engineering, and certifications, as well as the category of research and development.

Table 4.1: Number of Participants – First EE Session

S/No	Expertise	Number
1	DC power electronics	7
2	DC protection systems	2
3	Ports Electrifications	2
4	Data Centre electrifications	1
5	Academician/ researcher	1

The session protocol focused on nine (9) DC solutions, which were demo crosscutting among the twenty-four (24) to be developed in the Shift2DC project. The selected nine (9) DC solutions are categorized into three main categories, as shown in Figure 4.1. The materials category contained two solutions: smart and sustainable DC cables and DC connectors. The second category, named protections, contained three solutions, which are static-based, semi-conductor-based, and protection design tool, and the final category, called devices and tools, had four, which are DC-DC converter, LVAC-LVDC interlink converter, DC measurement device, and DC solutions design tool.

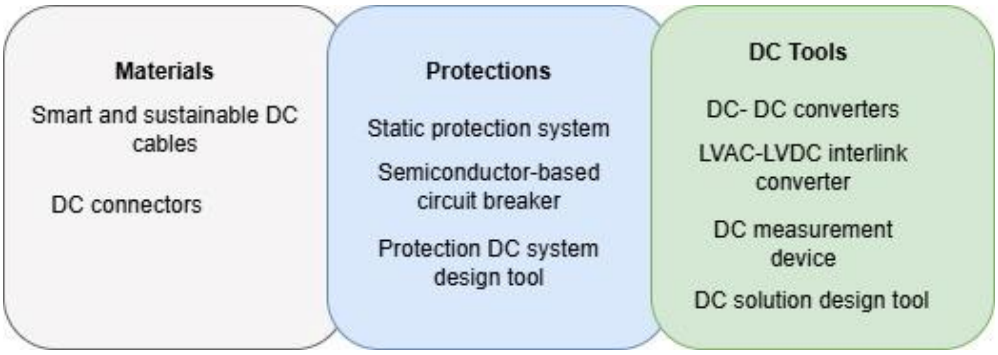

Figure 4.1: Selected DC Solutions – First EE Session

4.1 Results – First EE Session

The results of the first EE session with experts within the consortium are presented in this section.

4.1.1 Feasibility and Importance of the DC devices and tools

This parameter aims to gather expert's opinions on the feasibility of all the proposed three categories of DC devices and tools shown in Figure 4.1, this is based on the described project target and the wide application of the chosen DC devices and tools. Eleven (11) participants voted on it, as shown in Table 4.1, where all of them positively rated the feasibility of the proposed DC devices and tools by voting for them as *feasible* or *very feasible*.

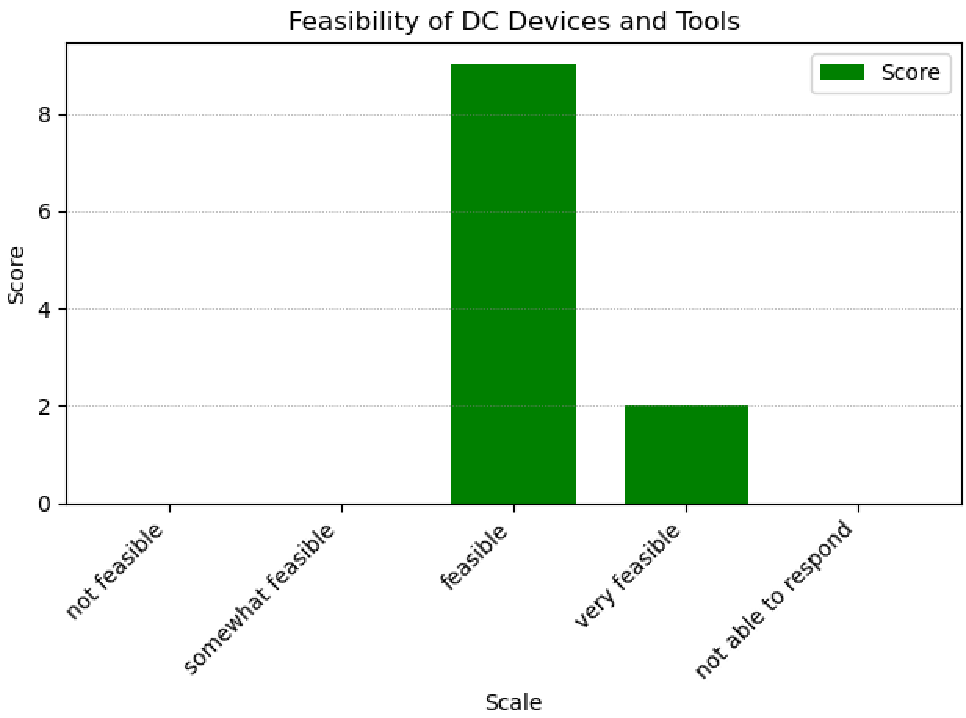

Figure 4.2: Feasibility of DC devices and tools - First Session

Thereafter, the participants were asked to rate the importance of each of the DC devices and tools. The results are shown in Figure 4.3, where the majority perceived each of the DC devices and tools as being *very important,* while one voted *somewhat important* for the smart and sustainable DC cables. The elicitation team asked for clarification on the reasoning behind that response. Following a discussion with the experts, it became clear that the panel had not fully grasped the concept of sustainability in cables. The team clarified that this was due to the anticipated design plan and the materials to be involved in its development. This explanation was provided to ensure that the experts felt comfortable with the smart and sustainable DC cables that the project is proposing.

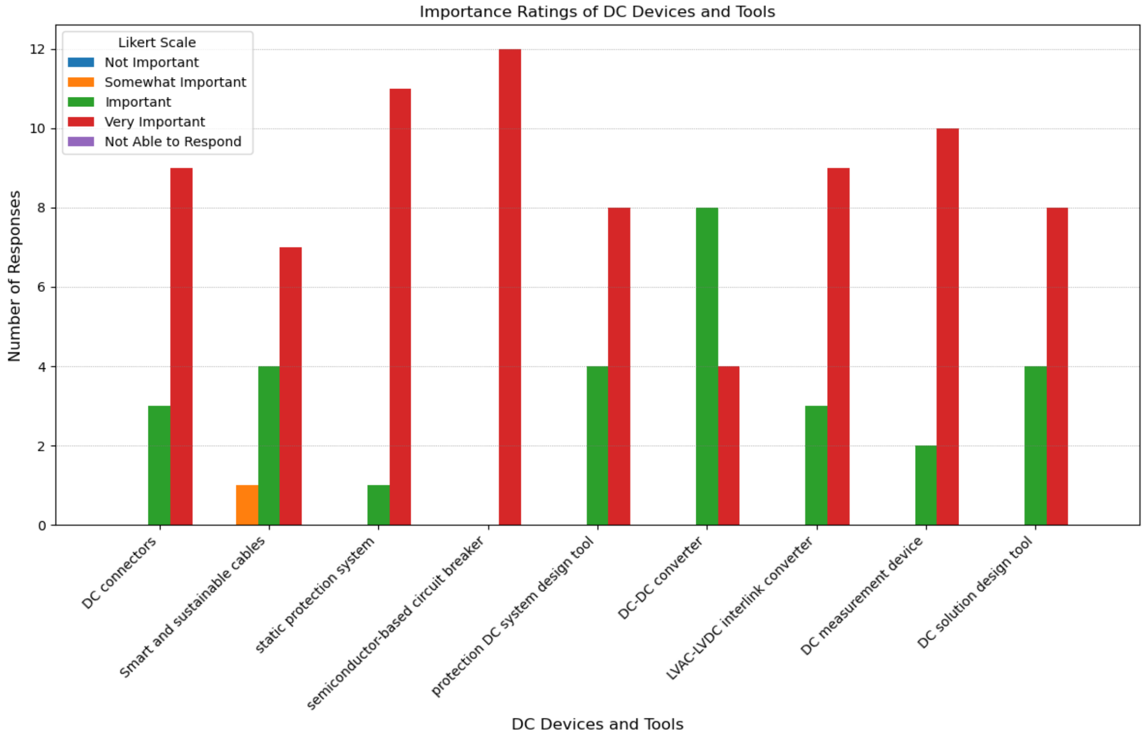

Figure 4.3: Importance of each of the DC devices and tools - First Session

4.1.2 Barriers to the adoption of the DC devices and tools

A total of eleven barriers were presented for the experts to rate them by selecting the top 5 barriers. In Figure 4.4, the findings are presented according to the frequency of experts' selections, from the most to the least chosen barrier. *'Lack of sufficient trained personnel'* and *'high costs of DC solutions'* were the highest-rated barriers, each receiving nine responses. '*Uncertain utility interaction: net metering, utility ownership, and agreed standards'* was selected eight times, as was *'misconception and lack of knowledge'*, *'uncertain regulatory roadmap'* scored six responses, and *'public perception of DC'* received five. *'Lack of pilot projects'* was chosen by four respondents, while *'power losses, quality, and safety'* each received three responses. Both *'lack of advantageous DC use-cases'* and *'incompatibility of DC system components'* obtained two votes. Finally, *'reduced reliability in DC devices'* was the least selected barrier.

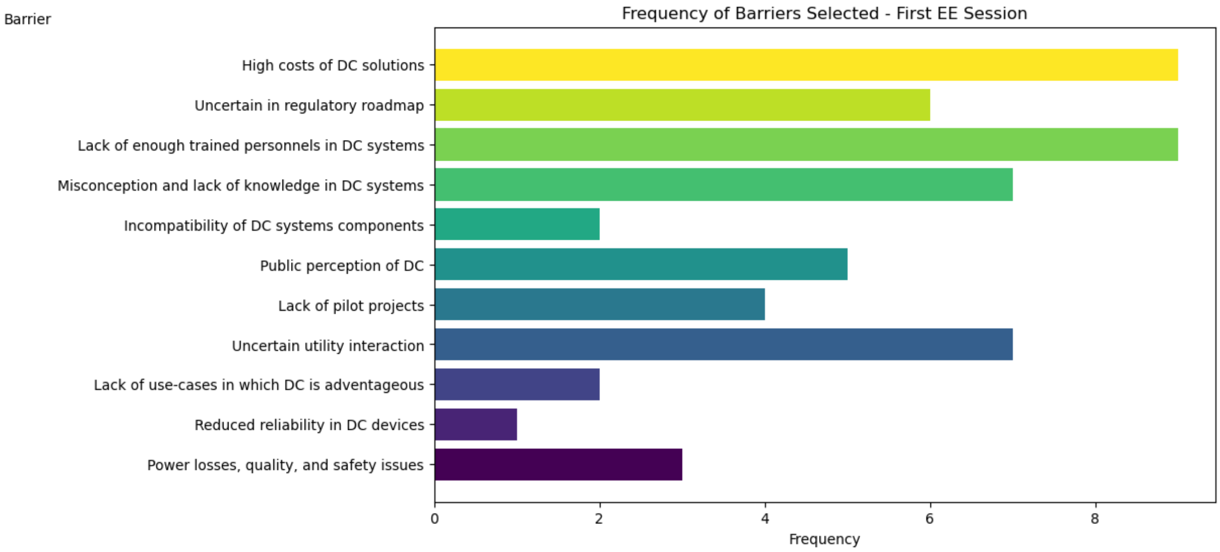

Figure 4.4: Barriers to DC Adoption - First Session

The team further requested the experts to provide any other vital barriers that they perceive to affect the adoption of the DC devices and tools in the demonstration targets of the Shift2DC project. Additional barriers mentioned by experts in the session are shown in the word cloud Figure 4.5.

The elicitation team enquired about the meaning of the TCO comparison term, and participant **P10** explained it as *"Total Cost of Ownership (TCO) referred to as a comparison between the two solutions in a more comprehensive scenario. This includes not only installation costs but also the cost of operation and other factors to compare the two technologies over a longer period of time"*. The explanation was seconded by Participant **P3** that it's a problem when users make comparisons while they're not at the same level. Adding that advantages offered by the DC micro-grid aren't being compared accurately to the AC grid standard; they're just compared to traditional AC installations, which misses the point. Therefore, participant **P3** suggested that there is an opportunity to **propose a method to compare the real performance**.

'Lack of awareness of the general public', 'clarity in incentives', 'DC equipment's interactions' like grid resilience, and '*lack of client-oriented advantages*' were among the other barriers mentioned by the experts. Adding to this, participant **P4** explained a scenario where DC was of interest to be used in the building, yet the end-users lacked a clear advantage on why opting for DC instead of AC.

On the other hand, participant **P6** referred to the challenge of adopting new technology: *"What I had in mind here is that, as we're entering a new kind of protection technology—moving into power electronics-based solutions—this is completely new for this area. This might be an obstacle when deciding whether to rely on decades-old, proven protection technology or to step into this new technology. It could definitely be a topic that creates some headaches"*.

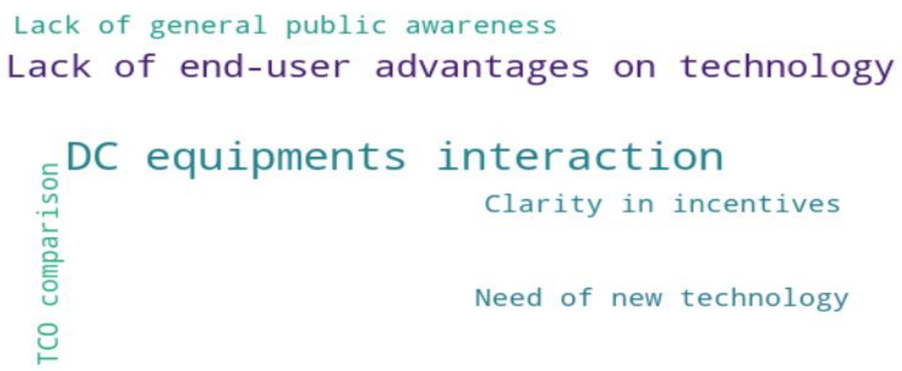

Figure 4.5: Barriers to DC Adoption Experts' View - First Session

Some barriers previously mentioned from the literature were also perceived by our panel experts, especially in what concerns user aspects, such as public perceptions of DC solutions being dangerous and lack of knowledge of DC technologies.

4.1.3 Time for Widespread Adoption of DC devices and tools

This parameter aimed to gather experts' opinions on the expected time for widespread adoption of the nine DC devices and tools presented in this session. The resulting scores are shown in Figure 4.6. A total of 13 experts provided their perceptions of each of the DC solutions.

Overall, six out of nine DC devices and tools were rated as being able to be adopted earlier before 2030. These are the DC solution design tool, the DC measurement device, the DC-DC converters, the protection DC system design tool, the DC connectors, and the LVAC-LVDC interlink converters.

The static protection system had a flat rating option being, before 2030, 2030, and 2040, by four votes on each of the options. The elicitation team enquired about an explanation from experts on this rating. Participant **P3** was quoted as follows: *“Maybe it needs to be clarified at the beginning of the presentation what exactly a static protection system is. So, I would suggest having an example at the beginning of the presentation when, in the design process, the knowledge or the product of the static protection system comes into play. Because for me, at least it was not totally clear what's the static protection system and then what it's like, then you have the static solid-state circuit breakers, of course, and then you have the tool. So maybe elaborate with an example.”*

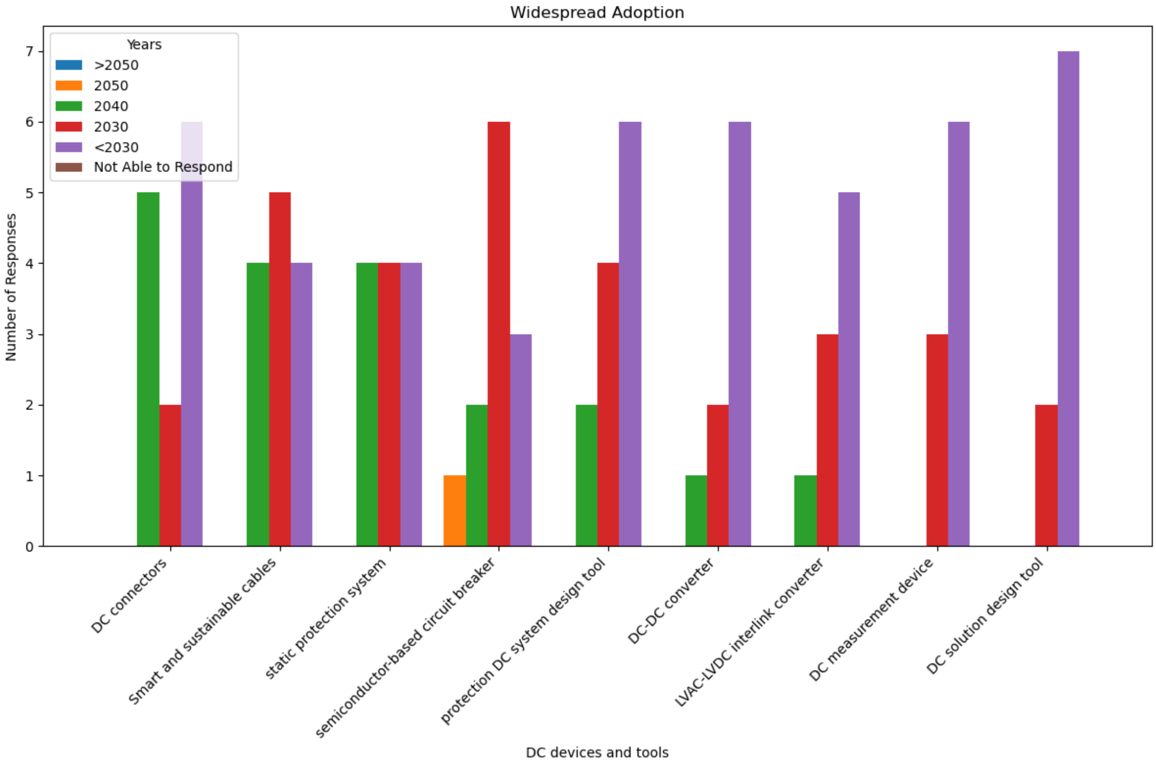

Figure 4.6: Widespread Adoption – First Session

4.1.4 Risks of Delay in Adoption

Risks of delay in the adoption of DC solutions were also captured per each of the nine DC devices and tools as depicted in Figure 4.7, the options being: insignificant, moderate, critical, very critical, and not able to respond.

The DC connectors, smart and sustainable DC cables, and the protection DC system design tool were rated by a single vote, indicating that their risks are insignificant.

While a moderate risk was perceived by seven votes for the DC measurement device and DC design tool. Seven experts rated the risk as being *critical* for DC connectors, and four experts rated the risk of delay in adoption as being critical for smart and sustainable DC cables, DC-DC converters, and LVAC-LVDC interlink converters. The reason for this rating was explained by the majority of experts as the availability of alternatives in the market already. Participant **P2** argued against others, viewing all solutions equally and rating them on the task performed, but the participant added that this is due to negligence in the innovation in the proposed technologies, like the concept of *intertripping wire* in the DC cables proposed by the Shift2DC project.

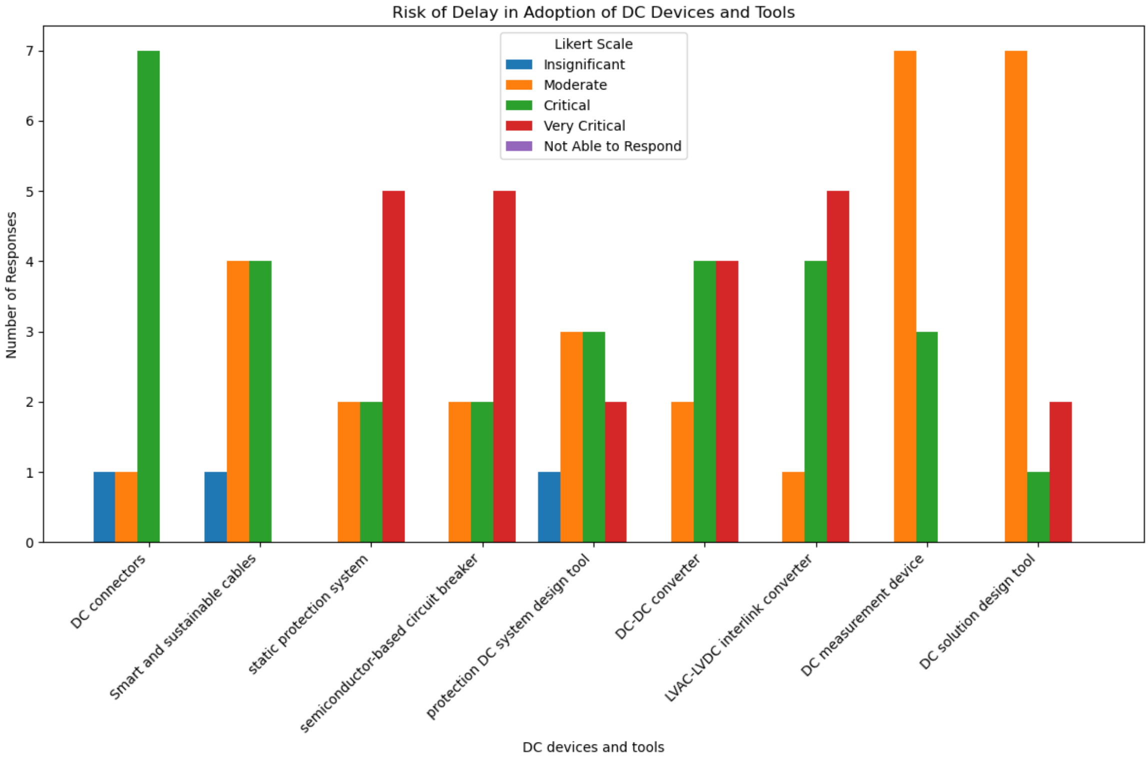

Figure 4.7: Risk of Delay in Adoption – First Session

4.1.5 General Discussion – First EE Session

This subsection includes the general discussion with experts on the open-ended questions.

The experts were asked to provide their views on any other vital DC solution that they perceive as being needed based on the project description provided. Participant **P2** claimed, *"I feel that, yes, one of the important solutions we are developing now—though I'm not sure how far we can go with it—is this Energy Management System (EMS). Energy management tailored for DC, I believe, is a critical point. You can develop a lot of different equipment, but we need something to interconnect them. This is also a solution for interoperability. If we can establish some common ground on the EMS side, then we can at least implement things".*

4.2 Results Consolidation – First Session

This section summarizes the key findings of the first EE session.

Expert knowledge and participation: all experts demonstrated a high level of knowledge of DC and its solutions, with no "*not able to respond*" votes. That indicates a high level of knowledge on the topic and specifically on the proposed DC solutions. However, there was a gradual dropout of experts during the session, with participation decreasing from 13 to 7 participants in the later part of the session. This aligns with the challenge of expert patience, as described by Morgan [34]. Hence, it was necessary to review the first session protocol and decide on what to be involved in the second expert elicitation session to avoid overloading experts with a lot of information needed from them, which would cause the elicitation session to take more time and again fall into the trap of *experts losing their patience.*

Feasibility and criticality: most participants agreed on the importance of DC systems, particularly for specific applications like data centres, buildings, and industrial sectors. There was some skepticism about the speed of large-scale deployment feasibility, given barriers related to cost, standardization, and training.

Barriers and Challenges: "*Reduced reliability in DC devices*" scored lowest among barriers, indicating significant progress in DC device reliability. Key challenges to widespread adoption include technical issues, particularly around compatibility and interoperability between different DC components. Then, there is a shortage of expertise and personnel, impacting both feasibility and adoption speed. Thereafter, high costs of critical components, especially long-distance DC cables, affect both initial and ongoing expenses.

Importance of Standards: the lack of clear, universal standards for DC systems is a major bottleneck. This affects not only costs but also interoperability between different systems and components. The industry is actively working on standards, but the timeline for comprehensive standardization remains uncertain.

4.3 Lessons Learned - First EE Session

Time was identified as the most significant challenge to address for the success of future EE sessions. Consequently, it was decided to evaluate the relevance and effectiveness of questions in achieving task objectives. The second consideration was the number of DC devices and tools to be selected for the session.

Evaluating the relevance and effectiveness of the questions: observation was that questions about widespread adoption rarely achieved consensus among experts due to the numerous variables to be considered so as to administer and provide a clear understanding with the experts in the panel. To improve the protocol's efficiency, it was decided to remove this set of questions. For example, the clarity concern on this parameter was during the session, participant **P7** was quoted, *“One thing that you also have to take into consideration is what you consider the spread, the widespread. If it's for investment, purposes are one thing. If it's for the general public, it's another.”* Another consideration was regarding questions related to the risk of non-availability, where experts provided insightful feedback, noting that these risks fluctuate over time and are challenging to manage effectively. As the question's relevance was lower than initially anticipated, it was also decided to remove it to the next session.

In reviewing the DC devices and tools: during the pilot, experts pointed out that some solutions lacked relevance compared to others and that the importance of certain solutions varied depending on the demo in question. In response, we decided to review each DC solution based on provided perceptions and consider only DC solutions which have wide application. This is because the second EE session shall also not being *demo specific* rather generalizing all application areas of the Shift2DC.

5 Expert Elicitation – Second Session

The second expert elicitation protocol was designed to be conducted in a single session as well, hence taking advantage of the expertise of all the recruited experts at the same time.

Eighteen (18) experts agreed to participate in the session. A follow-up conversation was shared, having a doodle for experts to select the suitable session and fill out the consent form. This exercise reduced the number to eleven (11) due to collisions with other experts' commitments.

For the DC solutions, after thorough discussion within the elicitation team and reviewing the results of the first session, a total of five DC devices and tools were considered, as seen in Figure 5.1: smart and sustainable DC cables, DC connectors, LVAC-LVDC interlink converter, network design tool for DC solutions, and the solid state circuit breaker. The main reason for selecting these solutions was the fact that they could be considered enablers of more advanced DC solutions, hence not being directly connected to any of the four demonstration sites of the Shift2DC project.

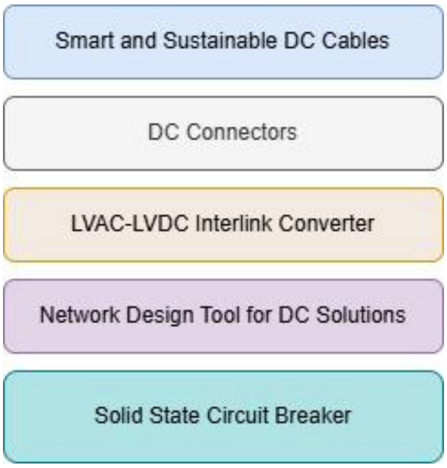

Figure 5.1: Selected DC Solutions - Second Session.

The session took place online on the 25th of October 2024. After a welcoming note, each expert introduces themselves, with their expertise depicted in Table B.2 in Appendix B. The group expertise is summarized in Table 5.1. Also, since the experts were external to the project, the elicitation team made themselves known to the experts. This was followed by a brief introduction of the Shift2DC project, its demonstration areas, and target DC solutions to be designed, developed, and tested. Experts were informed that among the DC solutions targeted by the project, only five (5) were selected for them to provide their perceptions on. The reason for the decision is due to the allowed time for the session, but these DC solutions have wide application across all the four demonstrators of the project.

Table 5.1: Number of Participants – Second EE Session

S/No	Expertise	Number
1	DC power electronics	4
2	Academician/ researcher	3
3	Ports Electrifications	1
4	Buildings electrifications	1
5	DC interoperability	1
6	AC-DC power systems	1

5.1 Results - Second EE Session

In this section, we present and discuss the results of the expert elicitation process. The findings cover key concerns on aspects such as the general feasibility of DC, the perceived importance of each of the five proposed DC solutions, barriers to technology adoption, and additional barriers identified based on expert insights. The session concluded with an open discussion, allowing experts to suggest technical innovations and potential breakthroughs for the Shift2DC project.

5.1.1 Feasibility of each DC devices and tools

The target of this parameter was to gather experts' perspectives on the feasibility of the proposed DC solutions in the Shift2DC application areas (demonstrators). The results are shown in Figure 5.2, where all experts perceived the DC solutions as being feasible. The votes ranged between feasible and very feasible, which had seven (7) and four (4) votes, respectively.

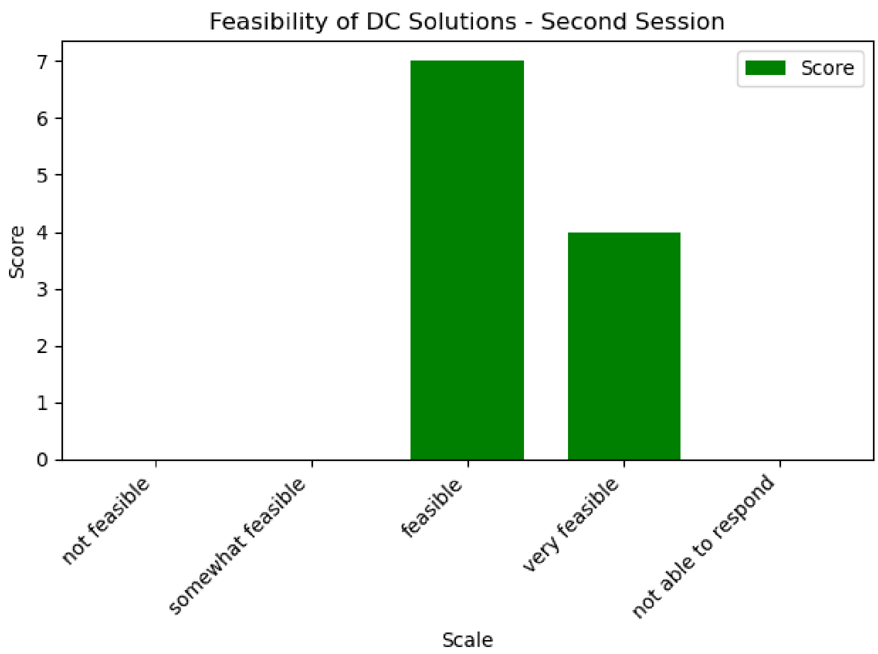

Figure 5.2: Feasibility of DC devices and tools - second EE session

5.1.2 Importance of each DC devices and tools

Thereafter, their insight on the importance of each of the DC devices and tools was presented.

For this question, the results presented in Figure 5.3, provide an analysis for all of the five DC devices and tools. An equal number of participants, five (5) each, rated smart and sustainable DC cables as "important" and "very important," while one participant marked them as "not important." The team then requested an explanation for this response, and participant **P8** clarified, as quoted, *“For me, it wasn’t about saying that it’s not important. It’s not that we don’t need the DC cables to be smart—that wasn’t my intention. My point was that it's not essential. We need cables, of course, but there are already cables, and we’ve found that you typically shouldn’t need extra insulation with them. So, in some cases, you could actually use AC cables if you wanted to.”* In conclusion, making DC cables smart and sustainable, and as similar as possible to their AC counterparts would significantly enhance the appeal of DC installations.

For DC connectors, over half of the participants (six) rated them as *very important*, while one voted for *not important*. Concerns raised included the notion that connectors have already been thoroughly researched, suggesting that existing options might be sufficient, especially since not all components in grids are designed for plug-and-play. Additionally, participant **P2** noted that in DC installations originating from the distribution cabinet, components are typically not designed for direct plugging. The experts agreed that this depends on where you are in the grid.

Concerning the solid-state circuit breaker, nine participants voted it as very important, with only one vote for it not being important. While there was no explanation for this rating, other experts consolidated the relevance of this solution. For example, participant **P6** said, *“Actually, if we are thinking about interrupting currents in DC, it's a big deal. So, these devices must be important. We have to put some thinking when building them because they will be much harder to build than the other ones in AC”.* The comment was further supported by the elicitation team, which is actually in the SHIFT2DC, that is what is needed and focused on its development.

For the LVAC-LVDC interlink converter, a total of nine votes were on the very important option, while no one rated it as not important. These results were very close to the network design tool, which had eight votes on very important, while none on not important.

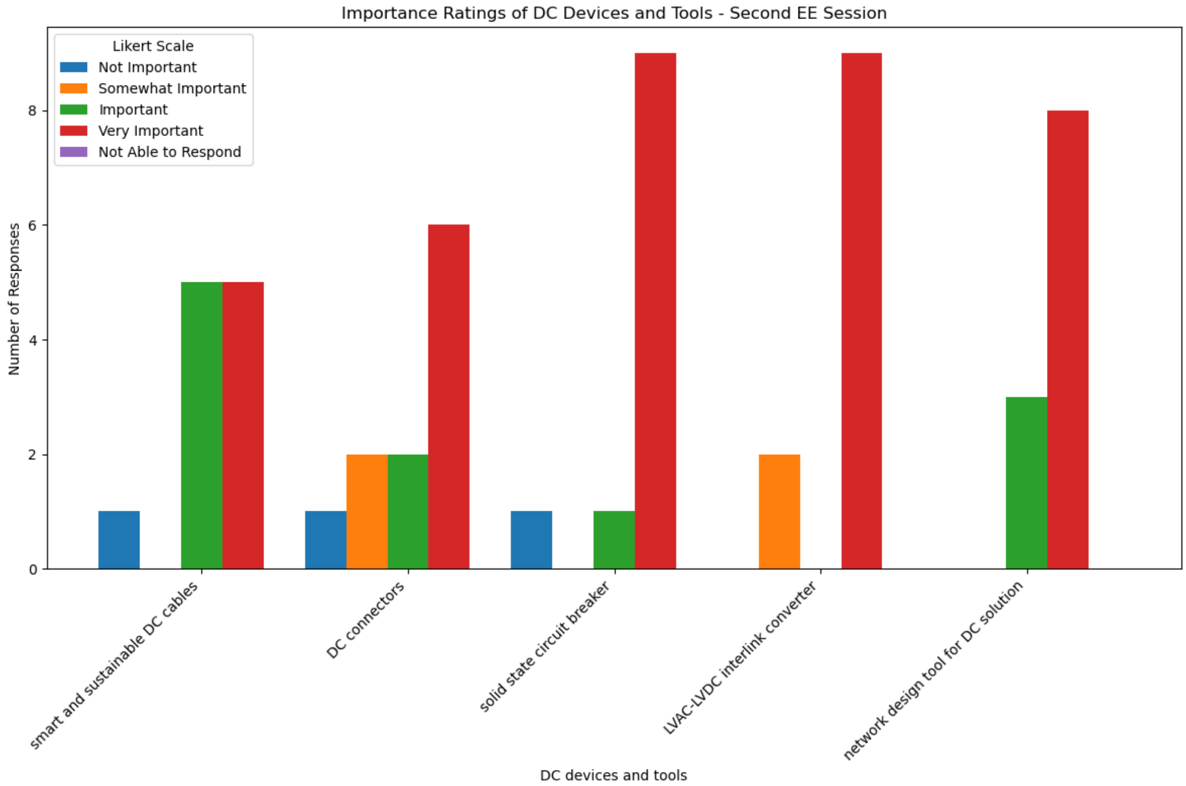

Figure 5.3: Importance of each DC solution - Second EE Session

5.1.3 Barriers to Adoption of DC Solutions

Here, a total of twelve (12) barriers were presented for participants to vote, and the results are shown in horizontal bar chart, in Figure 5.4.

The barriers are ranked from the most to the least selected based on expert responses. '*Lack of sufficient trained personnel in DC systems*' and '*uncertainty in the regulatory roadmap*' each received eight responses. These were followed by 'lack of use-cases in which DC is advantageous', '*public perception of DC*', and '*readiness to champion installations from DC projects*', along with '*misconception and lack of knowledge leading to lengthy or expensive design and permit processes*', each of which received six responses. Three other barriers — 'lack of pilot projects', '*high costs of DC solutions'*, and *'safety issues'*—each scored four responses. The barriers related to *'reduced reliability of DC devices'* and *'uncertain utility interaction: including net metering, utility ownership*', and *'agreed standards'* received three responses each. The least selected barriers were *'incompatibility of DC system components'*, followed by *'power losses and quality'*.

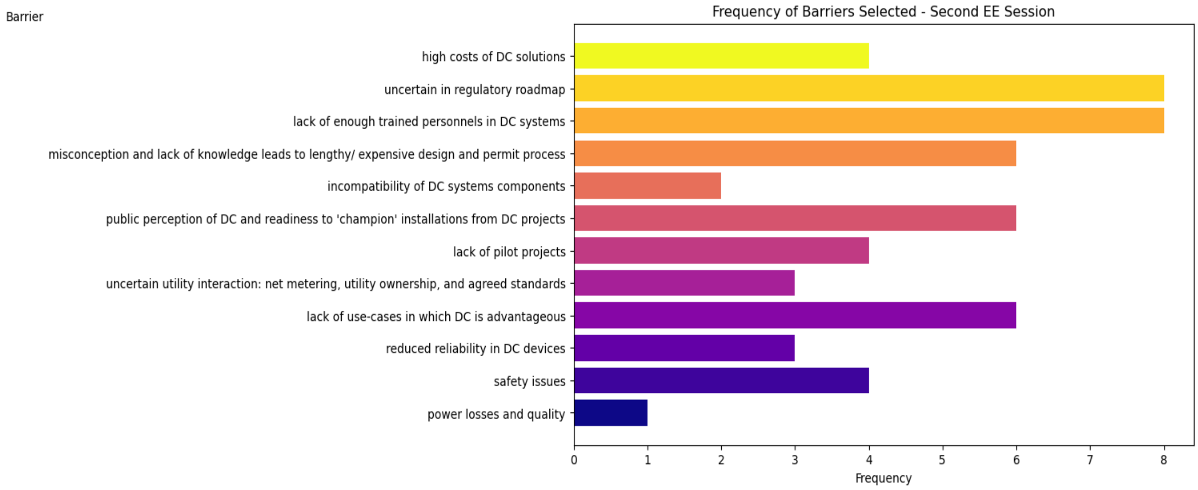

Figure 5.4: Barriers to DC adoption - Second EE Session

The discussion of barriers was further fuelled by prompting participants to provide any other barriers that were deemed vital and were not listed in the earlier question. The results are as in the word cloud shown in Figure 5.5. The most mentioned are the *'DC grid code', 'high CAPEX', 'test facilities for DC systems', 'regulations', 'no availability to change', 'the inertia to change mind-sets', 'public authorities' understanding of benefits', 'robustness issues and aging of power converters', 'DC protection faults (mentioned in two different ways: DC fault protection, fault protection and mitigation)',* and *'investor preference and interests'.*

Participant **P4** elaborated further on these barriers, emphasizing the importance of public understanding and support for changes to the grid code. Others contributed that without a clear rationale for these changes, public support would be difficult to achieve, which in turn would hinder the likelihood of any significant alterations to the grid code.

Furthermore, they expressed scepticism regarding the willingness of utility companies to advance, noting that these companies have historically focused on AC technologies. The discussion concluded by highlighting the necessity of public authority support and mentioned ongoing efforts at the European Commission related to the strategic plan for DC technology.

Figure 5.5: Barrier as presented by experts - second EE session

5.1.4 General Discussion – Second EE Session

Other topics raised in this session were the need to train personnel specifically for DC and at the technician level, not engineers, as added by Participant **P2.** The speaker further lamented the challenges associated with transitioning from AC to DC technologies, highlighting the significant obstacles that arise from their fundamentally different physical principles. Despite the extensive knowledge and expertise that professionals possess regarding the complexities of AC systems, they must essentially start from scratch when working with DC technology, as the methodologies and frameworks used in AC cannot be directly applied to DC. This indicates that a complete paradigm shift is necessary for successful implementation. The need for such a paradigm shift raised another very interesting discussion around the need to develop a series of education programs that go beyond advanced degrees like MSs and PhDs. In fact, it was suggested that it is necessary to create foundational courses and degrees on DC systems, systems whose foundations are considerably different from those of AC systems. Furthermore, the experts underscored the necessity for both AC and DC systems to co-exist in the future, acknowledging the complexity of this integration.

Experts were asked to further discuss if there are any more technologies that could be suggested. Participant **P7** emphasized that *"Nothing. All the technologies are already in place with us. We have to only bring the awareness on the DC systems and then the general public will be ready for change".*

The discussion further continued. Participant **P5** informed, *"We are at the beginning of this journey, and much remains to be established. Interacting with existing utilities and navigating grid code compliance are significant challenges. Connecting energy between systems and securing the required certifications to integrate new equipment into the infrastructure involves extensive bureaucracy. To address these hurdles, implementing more pilot projects across Europe and enhancing data exchange will be highly beneficial, particularly as we progress toward high-voltage installations"*.

5.2 Results Consolidation – Second EE Session

This section summarizes key findings from the second EE session.

Expert knowledge and participation: All experts demonstrated adequate knowledge and clear understanding of the project and its presented application areas. This conclusion is reached due to two reasons: first these experts were all from outside the consortium so being able to answer all presented questions, without option of "not able to respond" that demonstrate understanding. Second is being able to participate to the session from start to finish, this indicates high engagement but as well commitment and motivation to contribute to the session.

Awareness and Clarification of Practical Advantages: The session underscored a pressing need for awareness of DC and its advantages to the general public so, as to build familiarity and confidence in DC technology. Most experts perceived that, without an informed and supportive public, any regulatory or infrastructural changes would face significant resistance. Experts further informed the elicitation team that, in their point of view, this will support the smooth running and implementation of pilot projects across the EU.

Two different worlds that will have to co-exist: Additionally, several experts pointed out that while DC technologies and components are mostly ready, successful implementation hinges on bridging the gap in public and industry understanding. As one expert noted, AC and DC are based on distinct physical principles, making it essential for AC and DC systems to coexist rather than replace one another.

More and Better Education: On the other hand, is the need to consider to properly structure the curriculum for DC trainees at technician level and not considering on short term training of existing technicians. They further recommended, educational initiatives by concentrating more on building DC technicians from scratch and not considering shifting from AC to DC as a transition. Considering the rating of barriers to adoption, those related to end-users' awareness and misconceptions received high scores. This highlights the need for initiatives to educate the public on the advantages of DC systems and dispel the misconception that DC is dangerous for use in buildings.

Positive Evolution of the Technology: Further analysis of the barriers reveals a low rating for those related to DC equipment/solutions, specifically '*incompatibility of DC system components*' and '*power losses and quality'*. This suggests that industrial research and development efforts have been effective in improving DC solutions overall.

Importance of regulation: Moreover, high score for *'uncertain regulatory roadmap'* emphasizes the need to revisit regulations and policies related to energy for the public good.

6 Discussion

This work thoroughly identified the main categories of DC users deemed valuable for DC in general, as well as in ports, buildings, data centres, and industry. It further discusses and categorized the relevant user groups to be involved in the EE sessions as experts. Other remained categories of DC users would be useful in WP4 and WP5 where they will be involved in testing the DC solutions as well as in engagement for adoption strategies development respectively.

The work was able to bring attention to the needs of other user categories based on the provided expert's perspectives. These needs include the necessity for having well-structured educational curriculums for training DC technicians and not expecting a light training shift of AC to make them competent in DC. Ultimately, this may be among the reasons why, in most literature, like in [9], [11] the challenge of trained personnel is still a mystery. Also, in the selection of barriers *'lack of trained personnels'* was highly ranked in both EE sessions.

Furthermore, public awareness and acceptance of the value of DC technology as an effort towards a clean energy transition are needed. This has been consolidated in recent literature [9], [35] which were also further perceived highly by experts in both two sessions in this report as shown in Figure 4.4 and Figure 5.4 respectively.

An impressive low ranking of barriers concerning DC equipment/solutions like in *'incompatibility of DC systems', 'power losses, quality', and 'reduced reliability in DC devices'* in both sessions. This implies the positive progress in DC in general.

Familiarising experts on the topic is vital so as to eliminate bias in their perceptions [36]. Despite that being thoroughly done in both EE sessions, there were results that indicated that there was an understanding challenge between experts. For example, in Figure 4.6**,** which provides results about the widespread adoption of DC in the static-based protection system, there was a flat rating of four votes scattered before 2030, 2030, and 2040. This range is considerably large, and the concern of the elicitation team was confirmed by a participant who declared that the technology discussed was not clear.

A promising trend was observed regarding the barrier named '*reduced reliability in DC devices*'. It scored 1.82% and 5.45% in the first and second EE sessions respectively. This low rating indicates there is an improvement in the reliability of DC devices. This shall also be consolidated by the novel approaches that the Shift2DC project targets to its proposed DC solutions.

7 Conclusion

In order to obtain DC users' perspective in the Shift2DC project, this task employed an expert elicitation method. The decision is due to the nature of the project's audience.

Two EE sessions were conducted, the first session acting as a pilot and using the lessons learned in it to build the second session. It assesses other issues like the protocol contents package, clarity in questions to the audience, session time estimation, and how the presented DC solutions were understood. All challenges observed in this session were mitigated and reflected in the second EE session.

Both sessions provided a clear direction toward the perceived relevance of the proposed DC solutions, the challenges that society faces due to not having enough trained personnel in DC, and proper regulations to handle the existence of both AC and DC in power systems as energy generation from renewables increases.

7.1 Main Challenges

"*There are always many things to ask than what time and experts' patience will allow*," Morgan [34]. In addition to Morgan's quote, another major challenge was recruiting experts for the sessions. The challenge of time management encountered in the first sessions made each parameter have a different number of participants, and hence, this poses a limitation to the results.

The experts' recruitment challenges resulted in not being able to conduct sessions for each of the demonstrators, which would have increased the coverage of the DC solutions that would have been presented. Other DC solutions are demo-specific; therefore, they wouldn't have been presented or included in the general EE session if specific sessions had been conducted. However, it is important to stress that such pilot-specific studies will be developed within the scope of the activities in WP4.

7.2 Next Deliverables

The work in this task T1.6, as clarified in Section 1.2, will contribute directly to WP4 and WP5. The user roles identified here will specifically guide the selection of target groups for testing developed designs. Additionally, these roles will support user-centered approaches to drive innovative strategies and strengthen user engagement within the proposed DC solutions project.

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APPENDIX A: User Roles in DC

DC Solutions

Project Management (and Administration)

Oversees the entire DC project lifecycle, coordinating between different teams, managing budgets, schedules, and ensuring the project meets its objectives. There can be several project managers, e.g., product manager and operation manager. On top of the project manager we can also consider the Administration, with a role that is more on the financial side of the project.

System Designers

Includes a whole range of engineers (e.g., electrical, power systems, mechanical), and industrial designers that are responsible to designing the entire system. This goes from the design of electrical circuits and systems, physical components and enclosures, and user interfaces.

Manufacturing, Testing and Certification

Includes a whole range of engineers (e.g., production), and technicians (e.g., assembly line workers, and quality control inspectors) that that responsible for the manufacturing of DC components and solutions.

This category also includes test engineers that develop and perform tests to validate the functionality, safety, and reliability of DC devices. Finally, the is also the certification staff that are responsible for ensuring that the products meet the industry standards and regulatory requirements.

Sales, Marketing and Support (Customer and Technical)

Includes a wide range of specialists in DC systems. From the sales this includes sales engineers and marketing specialists that are aware of the DC systems and their benefits. Marketing specialists on the other hand may not be fully aware of DC, but are able to develop marketing strategies and campaigns to promote DC products.

Once the product is sold, customer support representatives provide post-sales support, addressing customer inquiries and issues related to the installed DC system. This entity creates a bridge with the technical support engineers that provides technical assistance in troubleshooting the DC system. Finally, if necessary, field service engineers will provide on-site support and repays for the DC systems.

Installation, Commissioning and Compliance

Includes installation technicians (which can also take the role of field service engineers, but not necessarily). These technicians install the DC system components according to the design/engineering specifications and safety standards.

Once installed, commissioning engineers have the responsibility of testing and verifying that the installed systems operated as intended, ensuring that all components are functioning correctly and safely. Finally, compliance officers will ensure that the system complies with all relevant laws, standards, and regulations, including environmental and industry-specific requirements.

Operation and Maintenance

Once installed the system needs to be maintained by maintenance technicians – performing regular maintenance, and operations engineers – manage the day-to-day operation of the DC system. In this case, this is more use case related, since these professionals are more specialized in the actual setting that that are working.

Research and Development

This includes research teams. It can be R&D engineers, focusing on aspects such as innovation and efficiency, academics (professors, PhD students, etc.), focusing more on long-term research aspects. This category also includes test engineers that are specifically trained for exploring new components and systems. Note that these test engineers are not the same that were presented in the manufacturing, testing and certification category.

Training and Development

This category includes staff that is specialized in training. This can be at the very practical level, e.g., training of staff already working on or entering the field; or at a more academic level, in university programs including undergraduate and graduate programs. The key aspects is to enhance the skills and knowledge of others, ensuring that they are up-to-date with not just the basics but also with the latest technologies and practices in DC systems.

Ports

Port Administration and Management

Includes the port manager/director that oversees all port operations, including strategic planning, budget management, and overall coordination of port activities. It also includes the operations manager, who manages the day-to-day operations, ensuring smooth cargo handling, vessel scheduling, and resource allocation. It also includes other managerial positions like finances, human resources, and environmental compliance officer who is responsible for ensuring that the port operations meet environmental regulations and standards.

Logistics and Supply Chain

The Logistics Coordinators are tasked with managing the procurement, storage, and distribution of specific components, including both DC and AC parts for hybrid systems, as well as essential electrical equipment for port operations. The Supply Chain Manager oversees the entire supply chain, ensuring optimization in logistics, inventory, and distribution processes. Warehouse Managers focus on the efficient handling and storage of goods within the port's warehouses, maintaining proper inventory control. Customs Brokers facilitate the clearance process for imports and exports, ensuring compliance with regulations. Finally, Inventory Managers maintain and oversee the inventory for both AC and DC components, ensuring that necessary parts and supplies are readily available when needed.

Customer Service and Relations

Customer Service Representatives handle inquiries, provide support, and address issues, including those related to DC and hybrid systems, as well as liaising with shipping companies and other stakeholders. Client Relationship Managers focus on maintaining and strengthening relationships with key clients to ensure customer satisfaction. Technical Support Engineers offer specialized support for DC and hybrid systems, troubleshooting power sources, inverters, and electrical equipment used in port operations.

Cargo Handling

Stevedores/Longshoremen are responsible for loading and unloading cargo from ships, ensuring it is handled and stored correctly. Crane Operators manage the movement of cargo containers and other goods using cranes and heavy machinery. Forklift Operators handle the movement of cargo within the port using forklifts and other material handling equipment.

Vessel Operations

These roles focus on ensuring safe and efficient vessel movement within the port. The Harbour Master oversees the arrival, departure, and navigation of vessels, ensuring smooth operations. Pilots guide ships in and out of the port, navigating through challenging or congested waters. Tugboat Captains operate tugboats to assist larger vessels with manoeuvring during docking and departure.

Safety and Security

These roles focus on maintaining safety and security within the port. Port Security Officers monitor access points, conduct patrols, and respond to incidents to ensure the port's security. Health and Safety Officers ensure compliance with health and safety regulations, conducting inspections and providing training to port workers.

IT and ICT

These roles focus on managing and securing the port's IT infrastructure. The IT Manager oversees networks, systems, and software. Systems Analysts work to improve port operations through technology, focusing on efficient data management and system integration. Cybersecurity Specialists protect the port's digital assets from cyber threats, ensuring data security and compliance.

Legal and Regulatory Compliance

These roles focus on legal and regulatory oversight in port operations. Legal Counsel provides advice on contracts, disputes, and compliance issues. Regulatory Compliance Officers ensure the port adheres to all relevant local, national, and international regulations and standards.

Planning and Development

These roles focus on planning and executing port development projects. Port Planners create long-term plans for port expansion, infrastructure development, and operational improvements. Project Managers oversee construction and development projects, ensuring they are completed on time and within budget.

Energy and Sustainability Managers

This category covers roles in electrical and energy engineering: Electrical Engineers design port electrical systems and integrate AC and DC components. Power Systems Engineers handle DC power generation, storage, and high-voltage systems, and manage AC/DC integration. Renewable Energy Engineers focus on DC systems from solar and wind sources and their integration with AC infrastructure. Sustainability Coordinators enhance energy efficiency, reduce environmental impact, and promote green technologies.

Installation and Maintenance

This category includes roles related to installing and maintaining the port systems, mainly covering aspects related to energy. Installation Technicians are trained to install DC systems and hybrid setups, including handling DC-specific components and safety protocols. They also install port electrical equipment like lighting and power panels. Maintenance Technicians maintain and repair both AC and DC systems, including managing power sources and hybrid converters, and perform routine upkeep to ensure system reliability. Electrical Inspectors review installations to ensure they meet safety standards and regulations.

Control and Monitoring

This category includes roles related to the different monitoring and control needs in port operations. Control Room Operators monitor the port's power systems in real-time using SCADA systems, managing both AC and DC power flows and responding to alarms. SCADA Specialists develop, maintain, and program these systems to ensure effective integration and operation of AC and DC components in hybrid setups.

Port visitors

The main visitors of ports include ship captains and crew, who use port facilities for docking and operations; port authorities and officials, who manage and oversee port activities; cargo handlers and stevedores, who handle loading and unloading; customs and immigration officials, who process goods and personnel; freight forwarders and logistics managers, who coordinate shipments; shipping agents, who manage vessel operations; maintenance and repair technicians, who service port infrastructure; suppliers and service providers, who offer necessary resources to ships and operations; and, in some cases, locals, tourists and visitors, who explore port areas or participate in tours.

Industry

Finance and Administration

In the manufacturing of electronic components, the Finance and Administration roles are crucial for maintaining the financial stability and operational efficiency of the facility. The Financial Controller manages all financial aspects, including budgeting, forecasting, and financial reporting, ensuring the facility operates within its financial parameters. The Human Resources Manager oversees the recruitment, training, and management of employees, ensuring a skilled workforce and compliance with labour laws. Meanwhile, the Administrative Manager handles office management, recordkeeping, and provides essential support to executive staff, ensuring smooth administrative operations within the organization.

Engineering and Design

Engineering and Design roles are vital for developing and optimizing both products and manufacturing processes. The Mechanical Engineer designs and develops the machinery, tools, and equipment essential for production. The Industrial Engineer focuses on improving production efficiency by optimizing processes, reducing waste, and enhancing overall productivity. The Manufacturing Engineer ensures that manufacturing systems and processes are designed to be efficient, cost-effective, and scalable. Electrical Engineers are responsible for developing and maintaining the electrical systems and controls within manufacturing equipment and facilities. The Process Engineer continuously works to optimize the manufacturing process, aiming to improve efficiency, quality, and production consistency. Finally, the Product Design Engineer is involved in the design and development of new products, ensuring they can be manufactured, meet quality standards, and can be produced at scale.

Production and Operations

Production and Operations roles are crucial for ensuring that production meets targets and quality standards. The Production Manager oversees the entire production process, managing schedules, resources, and staff to achieve production goals. The Operations Manager ensures day-to-day operations run smoothly and efficiently across the facility. The Plant Manager is responsible for the overall management of the manufacturing plant, covering everything from production and maintenance to safety and staff management. Shift Supervisors manage production staff during specific shifts, ensuring production targets are met and addressing any issues that arise. Machine Operators are responsible for operating and maintaining manufacturing machines, ensuring they run correctly and efficiently. Assembly Line Workers perform repetitive tasks on the assembly line, contributing to the production process. Finally, Quality Control Inspectors play a critical role in inspecting products and processes to ensure they meet the required quality standards and specifications.

Maintenance and Facilities

Maintenance and Facilities roles are essential for ensuring the continuous and safe operation of the manufacturing plant. The Maintenance Technician performs routine maintenance and repairs on manufacturing equipment, helping to prevent breakdowns and ensure smooth operation. The Facilities Manager oversees the physical infrastructure of the plant, managing maintenance activities, ensuring safety, and ensuring compliance with regulations. The Electrical Technician specializes in maintaining and repairing the electrical systems and components within the facility, ensuring that all electrical systems function reliably and efficiently.

Quality Assurance and Control

Quality Assurance and Control roles are critical for maintaining high standards of product quality. The Quality Assurance Manager develops and implements quality assurance policies and procedures to ensure that products consistently meet the required standards. The Quality Control Engineer designs and implements systems and tests to monitor and maintain product quality throughout the manufacturing process. The Continuous Improvement Manager is dedicated to enhancing overall product quality by focusing on process improvements, defect reduction, and efficiency gains through methodologies like Lean, Six Sigma, and Kaizen.

Supply Chain and Logistics

Supply Chain and Logistics roles are vital for ensuring that materials and products flow smoothly through the production process and to the market. The Supply Chain Manager oversees the entire supply chain, including procurement, production scheduling, inventory management, and distribution, ensuring efficiency and cost-effectiveness. The Procurement Manager is responsible for purchasing raw materials, components, and equipment necessary for manufacturing, securing the best quality and prices. The Logistics Manager handles the transportation and distribution of finished products, ensuring they are delivered on time and within budget. Lastly, the Inventory Manager manages inventory levels, ensuring that all materials and products are adequately stocked to meet production demands without overstocking.

Research and Development (R&D)

Research and Development (R&D) roles are crucial for driving innovation and maintaining a competitive edge. The R&D Engineer is responsible for conducting research and developing new products, materials, and manufacturing processes that push the boundaries of technology and efficiency. The Product Development Manager oversees the entire lifecycle of new product development, from initial concept through to production, working closely with other departments to ensure successful product launches. The Materials Scientist focuses on studying and developing new materials that enhance product performance and improve manufacturing efficiency, playing a key role in advancing the capabilities and quality of electronic components.

Information Technology (IT)

Information Technology (IT) roles are essential for supporting and enhancing operational efficiency through technology. The IT Manager oversees the facility's IT infrastructure, ensuring that systems are secure, reliable, and meet operational needs. The Automation Engineer focuses on developing and maintaining automation systems, including robotics and programmable logic controllers (PLCs), to improve manufacturing efficiency and precision. The Systems Analyst examines and optimizes IT systems and software used in manufacturing processes, ensuring they align with business objectives and enhance overall productivity.

Sales and Marketing

Sales and Marketing roles are critical for driving revenue and maintaining strong customer relationships. The Sales Manager leads the sales team, devising strategies to sell manufactured products and meet sales targets, while managing relationships with clients and identifying new business opportunities. The Marketing Manager develops and implements marketing strategies to promote the company's products, enhance market presence, and build brand awareness. The Customer Service Representative manages customer inquiries, processes orders, and addresses complaints, ensuring a high level of customer satisfaction and support.

Legal and Compliance

Compliance and Legal roles are crucial for maintaining regulatory adherence and managing legal issues. The Compliance Officer ensures that the manufacturing facility adheres to all relevant laws, regulations, and industry standards, mitigating risks and ensuring lawful operations. The Legal Counsel provides expert legal advice on contracts, regulatory matters, and disputes, helping to navigate legal complexities and protect the company's interests.

Customer Relations and Support

Customer Relations and Support roles are essential for maintaining strong client relationships and addressing post-sale issues. The Account Manager is responsible for managing relationships with key clients, ensuring their needs are met, and facilitating effective communication between clients and the manufacturing team. The Technical Support Engineer offers technical assistance and troubleshooting for products after they have been manufactured and delivered, helping to resolve issues and ensure customer satisfaction.

Innovation and Sustainability

Innovation and Sustainability roles are key to advancing technology and minimizing environmental impact. The Innovation Manager spearheads efforts to develop new technologies and processes that enhance manufacturing capabilities and maintain competitiveness. The Sustainability Coordinator implements and manages programs aimed at reducing the environmental impact of manufacturing operations. The Energy Manager oversees energy consumption, focusing on reducing usage, improving efficiency, and exploring renewable energy options while managing energy procurement. The Sustainability/Energy Efficiency Specialist identifies and implements energy-saving initiatives, optimizing processes and incorporating renewable energy sources. The Power Plant Operator manages on-site power generation facilities, ensuring they meet energy demands efficiently and safely. The Renewable Energy Engineer designs and implements renewable energy solutions, such as solar panels or wind turbines, to reduce reliance on traditional power sources. The Sustainability Manager develops and oversees programs to promote renewable energy use and reduce environmental impact. The HSE Manager ensures compliance with health, safety, and environmental regulations, promoting a safe working environment, while the Safety Officer conducts safety audits and training to prevent workplace accidents. Lastly, the Environmental Engineer manages environmental compliance and sustainability initiatives, ensuring the facility operates in an environmentally responsible manner. These roles collectively drive innovation, enhance energy efficiency, and promote sustainability in manufacturing operations.

Data Centres

Administration and Management

In a data centre, various roles are crucial for its efficient operation. The Data Centre Manager oversees the overall operations, including staffing, budgeting, and strategic planning. The Operations Manager is responsible for the smooth functioning of daily activities and system processes. The Facilities Manager maintains the physical infrastructure, such as HVAC systems, security, and general building upkeep. The Finance Manager handles budgeting, financial planning, and reporting. Lastly, the Human Resources Manager takes care of recruitment, training, employee relations, and compliance with labour regulations.

IT and Network Operations

In data centres, IT and network operations involve key roles: The IT Manager oversees the overall IT infrastructure, including servers, storage systems, and network equipment. The Network Engineer is responsible for designing, implementing, and managing the network infrastructure to ensure high availability and performance. The Systems Administrator manages and maintains server hardware and software, ensuring consistent uptime and performance. The Database Administrator focuses on managing databases, ensuring data integrity, performance, and security. The Cloud Engineer is tasked with managing cloud infrastructure and services, ensuring proper integration and performance. Lastly, the DevOps Engineer streamlines the development, deployment, and operation of applications, emphasizing automation and efficiency.

Security and Compliance

In data centres, security and compliance are critical roles. The Security Manager oversees both physical and cybersecurity measures to protect against threats. The Cybersecurity Specialist focuses on implementing and managing protocols to secure digital assets. The Compliance Officer ensures adherence to regulations, standards, and best practices.

Support and Customer Service

In data centres, support and customer service roles are vital. Technical Support Engineers offer assistance and troubleshooting for IT systems, infrastructure, and electrical equipment. Customer Support Representatives handle client inquiries and support requests, focusing on customer satisfaction. Account Managers manage key client relationships, addressing their needs and ensuring high service quality.

Planning and Development

In data centres, planning and development roles are crucial. The Data Centre Planner creates long-term strategies for expansion, upgrades, and new builds. The Project Manager oversees specific projects, ensuring they are completed on time and within budget. The Construction Manager supervises construction activities for new builds or expansions.

Energy and Sustainability Managers

In data centres, energy and sustainability roles focus on environmental responsibility and efficient power management. The Environmental Manager ensures compliance with environmental regulations and promotes sustainability. The Sustainability Coordinator implements initiatives to reduce the data centre's environmental impact, emphasizing energy efficiency and waste reduction. Electrical Engineers design the electrical infrastructure, including power distribution, UPS systems, and backup generators. Power Systems Engineers optimize power systems for efficiency, reliability, and scalability.

Logistics and Inventory

In data centres, logistics and inventory roles are essential for smooth operations. The Logistics Coordinator handles the procurement, storage, and distribution of IT, facility, and electrical equipment. The Inventory Manager ensures that hardware and electrical components are always in stock, maintaining the availability of critical parts and supplies.

Data Analysis and Reporting

In data centres, data analysis and reporting are key functions. The Data Analyst examines performance data to identify trends and opportunities for improvement, while the Reporting Specialist compiles and presents reports on operations, offering insights and recommendations to management.

Software and Application Management

In data centres, software and application management roles are crucial for ensuring the smooth operation of essential systems. The Software Engineer develops and maintains applications tailored to the data centre's needs. The Application Support Engineer provides ongoing support, addressing performance issues and ensuring reliability. Additionally, Data Centre Infrastructure Managers integrate electrical systems with IT equipment, focusing on power distribution and cooling. Network Engineers collaborate with electrical engineers to ensure that power systems reliably support the networking infrastructure.

Backup and Emergency Systems

In data centres, backup and emergency systems are critical for maintaining power during outages. The UPS Specialist manages the installation, maintenance, and operation of uninterruptible power supply systems. The Generator Technician ensures that backup generators are always functional and ready for emergencies. The Battery Maintenance Technician monitors and maintains battery systems used for backup power, keeping them in optimal condition.

Installation and Maintenance

In data centres, installation and maintenance roles are essential for the reliable operation of electrical systems. Installation Technicians handle the physical setup of electrical systems, including wiring, panels, UPS systems, and generators. Maintenance Technicians perform routine inspections, repairs, and upgrades to keep these systems running smoothly. Electrical Inspectors ensure that all installations meet safety standards and regulatory requirements.

Monitoring and Control

In data centres, monitoring and control roles are vital for ensuring seamless operations. Control Room Operators monitor systems in real-time using management software, responding to alarms and ensuring everything functions correctly. DCIM Specialists manage Data Centre Infrastructure Management software to oversee power usage, cooling, and IT equipment. SCADA Specialists focus on managing Supervisory Control and Data Acquisition systems to monitor and control the electrical infrastructure.

Data Centre Visitors

Visitors to a data centre can include clients and potential customers inspecting facilities, regulatory inspectors ensuring compliance, vendors and contractors installing or maintaining equipment, auditors reviewing operations, and investors assessing assets. Other visitors might include engineers, media representatives, researchers, and employees or new hires touring the facility. Each visitor type has specific purposes, often requiring strict security and access controls.

Buildings

Property Management and Operations

Property Management and Operations roles include the Property Manager, who oversees daily operations, tenant relations, and financial management; the Building Manager or Superintendent, who handles maintenance and system functionality; the Leasing Manager, who manages leasing processes; the Concierge or Front Desk Staff, who provide customer service and manage access; and Security Personnel, who maintain safety and respond to emergencies.

Maintenance and Technical Support

The Maintenance Technician handles routine upkeep and repairs of systems like plumbing, electrical, and HVAC. The Custodian or Janitor ensures cleanliness of the building's interior and exterior. The HVAC Technician focuses on heating, ventilation, and air conditioning systems, while the Plumber deals with water supply and drainage systems. The Electrician manages electrical systems and components, and the Elevator Technician maintains elevators and escalators. The Facility Manager oversees the operation and maintenance of the building's facilities, including energy systems, and collaborates with the Energy Manager on efficiency projects.

Security and Safety

In Security and Safety for residential and commercial buildings, the Fire Safety Officer ensures compliance with fire safety regulations, conducts fire drills, and maintains fire prevention equipment. The Health and Safety Officer oversees adherence to health and safety regulations, performs inspections, and ensures that safety protocols are consistently followed.

Energy and Sustainability

In Energy and Sustainability for residential and commercial buildings, the Energy Manager oversees energy consumption, implementing strategies to enhance efficiency and lower costs. The Sustainability Coordinator develops initiatives to reduce environmental impact through energy efficiency, waste reduction, and sustainable practices. The Renewable Energy Specialist integrates renewable energy solutions, such as solar panels or geothermal systems, into the building's infrastructure.

Tenant and Resident Services

In Tenant and Resident Services for residential and commercial buildings, the Tenant/Resident Relations Manager handles communication and relationships, addressing concerns and ensuring tenant satisfaction. The Leasing Agent shows available spaces to potential tenants, explains leasing terms, and finalizes rental agreements.

Legal and Compliance

In Legal and Compliance for residential and commercial buildings, the Legal Advisor provides counsel on property-related issues, including lease agreements, tenant disputes, and regulatory compliance. The Compliance Officer ensures the building adheres to all relevant laws, regulations, and standards, focusing on safety, accessibility, and environmental impact. The Compliance Officer (Energy) specifically monitors and ensures compliance with energy regulations, updating policies and practices to reflect changes in energy standards.

Information Technology (IT)

Mainly available in commercial buildings, the IT Manager/Technician oversees the building's IT infrastructure, including internet services, security systems, and smart technologies. The Building Automation Specialist manages and maintains automation systems that control lighting, HVAC, security, and other integrated systems.

Sales and Marketing

In Sales and Marketing for residential and commercial buildings, the Sales Manager leads the strategy to attract tenants or buyers for commercial spaces or residential units. The Marketing Coordinator creates and executes marketing campaigns to promote the building, draw in potential tenants, and enhance the property's brand.

Residential Specific Roles

In residential buildings, specific roles include the Resident Association Manager, who manages the activities, meetings, and budgets of homeowner or tenant associations. The Housekeeping Staff is responsible for cleaning and maintaining individual units and common areas, particularly in luxury residences. The Doorman/Porter oversees the entryway, assists with luggage, and provides a welcoming presence for residents and guests in upscale buildings.

Visitors

In residential and commercial buildings, the main visitors include residents and tenants, who are the primary users of the space, and maintenance and service providers, who perform essential upkeep and repairs. Building management and administrative staff oversee operations and tenant relations, while contractors and vendors handle construction, renovation, and upgrades. Inspectors ensure compliance with safety, health, and building codes, and real estate agents and brokers facilitate property transactions and lease management. Emergency responders address any urgent situations, and visitors and guests come for various reasons such as meetings, events, or personal visits.

End-users or consumers play a significant role in the context of DC (Direct Current) systems, particularly from the perspective of how these systems are utilized, maintained, and interacted with. Here are the key roles for end-users or consumers.

Residential Users

Homeowners: Utilize DC systems in the form of solar power systems, battery storage, and DC-powered appliances and lighting. They are responsible for the proper use and basic maintenance of these systems.

Electric Vehicle Owners: Use DC fast chargers for their electric vehicles (EVs) and ensure proper charging practices to maintain battery health.

Commercial Users: Business Owners: Deploy DC systems for energy efficiency in commercial buildings, such as in lighting, HVAC systems, and backup power solutions. They oversee the integration and maintenance of these systems within their premises.

Facility Managers: Manage and maintain the DC systems within commercial properties, ensuring optimal performance and addressing any issues that arise.

Industrial Users: Plant Managers: Oversee the implementation and operation of DC systems within industrial settings, ensuring they meet the high power and reliability demands of industrial machinery and processes.

Maintenance Personnel: Conduct routine maintenance and troubleshooting of DC systems to prevent downtime and ensure safety in industrial environments.

Utility Consumers: Grid-Connected Users: Utilize DC systems that are connected to the power grid, such as solar power installations with grid-tied inverters. They manage their energy consumption and production, sometimes feeding excess power back into the grid.

Off-Grid Users: Rely entirely on DC systems for their power needs, managing their own energy generation, storage, and consumption independently from the main power grid.

Technology Users: IT Professionals: Manage DC power supplies for data centres and telecommunication systems, ensuring reliable and efficient operation of critical infrastructure.

Electronics Enthusiasts: Use DC systems in DIY projects, hobbyist electronics, and personal computing setups, often engaging in small-scale design and maintenance.

Educational Institutions: Schools and Universities: Implement DC systems for educational purposes, teaching students about renewable energy, DC power applications, and sustainable practices.

Students and Researchers: Engage with DC systems in labs and research projects, experimenting with new technologies and applications.

Agricultural Users

Farmers: Use DC systems for irrigation, lighting, and powering agricultural equipment, often in conjunction with renewable energy sources like solar panels.

Rural Communities: Utilize DC micro-grids to provide reliable power in remote areas, improving access to electricity and supporting local development.

Public Sector and Non-Profit Organizations

Government Entities: Deploy DC systems in public infrastructure projects, such as street lighting and public transportation, aiming for energy efficiency and sustainability.
Non-Governmental Organizations (NGOs): Use DC systems in humanitarian projects, such as providing power to remote or underserved communities, enhancing quality of life and promoting development.

APPENDIX B: The EE Participants – First and Second Sessions

Expertise per each Expert for First Session

Table B.1: Expertise of each Expert - First EE Session

S/No	Code	Expertise
1	P1	DC power electronics
2	P2	DC power electronics
3	P3	DC power electronics
4	P4	DC power electronics
5	P5	Ports Electrification
6	P6	DC protections
7	P7	Ports Electrification
8	P8	DC power electronics
9	P9	DC power electronics
10	P10	Ports Electrification
11	P11	DC power electronics
12	P12	DC protections
13	P13	Academician

Expertise per each Expert for the EE Second Session

Table B.2: Expertise of each Expert - Second EE Session

S/No	Code	Expertise
1	P1	DC power electronics
2	P2	DC interoperability
3	P3	DC power electronics
4	P4	Buildings electrifications director
5	P5	Academician
6	P6	Academician
7	P7	DC power electronics
8	P8	DC power electronics
9	P9	Academician
10	P10	Ports electrification
11	P11	AC/DC power systems

ANNEX 1: The EE Protocol – First Session

Expert Elicitation Protocol on Direct Current Tools and Technologies in (demo name)
Elicitation Protocol

Expert:..

Lucas Pereira	Catherine Ngirwa	Diogo Paulino
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1. **Introduction - Duration: 10 minutes**
   a. **State of the Art of the study:**
   The widespread concern about using renewable energies for power generation brought attention to the dominance in deploying and using DC solutions. Despite the vital role these solutions play in supporting the race to decarbonize the energy sector, there is a deficiency in studies on user (expert) perceptions of them. These users as per this project are the experts in the DC, hence this survey.
   b. **Notes on Expert Elicitation:**
   Attached, you will find a series of questions intended to elicit your expert judgments on various topics regarding DC solutions. The topics to be addressed come largely from the existing literature, where they are mainly mentioned briefly but not discussed in detail, given the infancy state of DC in general.
   Participants are asked to draw upon their expertise and provide insightful perspectives when answering the questions as individual experts. In other words, we are not asking you to represent the organization you are affiliated with. Each participant will be assigned a number that will be used in place of names when we report results for each expert in this project.
   c. **Description of the Target for the Proposed DC Solutions**
   The DC solutions identified in this section are designed to facilitate the establishment of different activities related to DC in data centres, buildings, industry, and ports. The activities include: establishment of DC energy hubs, and grids. As well as to assist in the coordination, control, durability, autonomous recovery, and protection of DC grids. Additionally, they aid in enhancing the adaptability, modular design, and expandability of these DC solutions in data centres, buildings, industry, and ports.

List of the Proposed DC Solutions and their Descriptions - show one slide per category

S/No	DC Solutions	Description
1.	Smart and sustainable DC cables	Optimizing resilience and reliability of networks; reduced costs of installation; embedded data transmission
2.	DC measurement device	Current measurements up to 1000 A DC Voltage measurement up to 1500 V DC
3.	DC-connectors	Connector concepts and contact systems adapted to DC grid characteristics
4.	Static protection system	Static protection architecture considering power conversion, earthing choices
5.	Semiconductor-based circuit-breaker	Interrupt DC fault current
6.	Protection DC system design tool	Enable the design of protection system for DC grids
7.	DC-DC converter power distribution unit	Power-flow-control between DC appliances
8.	LVAC-LVDC energy router	Active-front-end with droop-control capabilities on the DC side
9.	DC solutions design tool	Evaluate different DC architectures and compare with convention AC radial networks. Includes sizing and economics

2. Given the goal of achieving the target in 1(c).
   a. How feasible is the use of *DC in* the described target?
   b. How important is the use of DC in the described target?
   c. How feasible are each of these DC solutions?

#	DC Solutions	Not feasible	Somewhat feasible	Feasible	Very feasible	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	DC measurement device					
4.	Static protection system					
5.	Semiconductor-based circuit-breaker					
6.	Protection DC system design tool					
7.	DC-DC converter power distribution unit					
8.	LVAC-LVDC energy router					
9.	DC solutions design tool					

3. Barriers to adoption: includes all factors which have been highlighted to hinder widespread adoption of DC solutions highlighted in 1(c).
   Which of the following do you think are **possible barriers to adoption** of DC solutions?, *select top 5*.

A)	Barrier	Select
	Power losses, quality, and safety issues	
	Reduced reliability in DC devices	
	Lack of use-cases in which DC is advantageous	
	Uncertain utility interaction: net metering, utility ownership, and agreed standards	
	Lack of pilot projects	
	Public perception of DC and readiness to 'champion' installations from DC projects	
	Incompatibility of DC systems components	
	Misconception and lack of knowledge leads to lengthy/expensive design and permit process	
	Lack of enough trained personnels in DC systems	
	Uncertain in regulatory roadmap	
	High costs of DC solutions	

B) Any other vital barrier(s) not listed:

i) ……………………………………………………………………

ii) ……………………………………………………………………

iii) ……………………………………………………………………

4. Costs and Efficiencies of the DC solutions.
   a. How critical is the cost of each of the listed DC solutions?

#	DC Solutions	Low	Moderate	Critical	Very critical	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	DC measurement device					
4.	Static protection system					
5.	Semiconductor-based circuit-breaker					
6.	Protection DC system design tool					
7.	DC-DC converter power distribution unit					
8.	LVAC-LVDC energy router					
9.	DC solutions design tool					

   b. What do you think could be the probable barriers to cost reduction of the DC solutions listed at 1(c)? Provide up to three. *Open-ended question*
   c. Which conditions could support positively cost improvements of the DC solutions listed at 1(c)? Provide up to three. *Open-ended question*

5. Expected time for widespread adoption of each of the DC solutions.

#	DC Solutions	<2030	2030	2040	2050	> 2050	Not able to respond/ never gonna happen
1.	Smart and sustainable DC cables						
2.	DC-connectors						
3.	DC measurement device						
4.	Static protection system						
5.	Semiconductor-based circuit-breaker						
6.	Protection DC system design tool						
7.	DC-DC converter power distribution unit						
8.	LVAC-LVDC energy router						
9.	DC solutions design tool						

6. Perceptions of risk of non-availability or delay in adoption.

#	DC Solutions	Insignificant	Moderate	Critical	Very critical	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	DC measurement device					
4.	Static protection system					
5.	Semiconductor-based circuit-breaker					
6.	Protection DC system design tool					
7.	DC-DC converter power distribution unit					
8.	LVAC-LVDC energy router					
9.	DC solutions design tool					

7. Discussion questions: Here open-ended questions have been included to capture more insights from experts.
   a. Which technical breakthroughs will be needed for the DC solutions listed in 1(c) to become commercial contenders in data centres, buildings, industry, and ports? *minimum of three.*
   b. Based on your expertise in DC, provide any other relevant DC solutions suitable for the data centres, buildings, industry, and ports not included in 1(c). *Minimum of three*
   c. Why is the DC important in data centres, buildings, industry, and ports?
   d. Kindly provide whatever you want to share with the elicitation team concerning DC solutions in data centres, buildings, industry, and ports.

8. Expertise level: experts self-ranking of their expertise for each of the DC solutions in 1(c).

How do you rank your **expertise** in each of the following DC solutions?

#	DC Solutions	Low	Moderate	High	Very High	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	DC measurement device					
4.	Static protection system					
5.	Semiconductor-based circuit-breaker					
6.	Protection DC system design tool					
7.	DC-DC converter power distribution unit					
8.	LVAC-LVDC energy router					
9.	DC solutions design tool					

References

Glasgo, B., Azevedo, I. L., & Hendrickson, C. (2018). Expert assessments on the future of direct current in buildings. *Environmental research letters*, *13*(7), 074004.

Knol, A. B., Slottje, P., van der Sluijs, J. P., & Lebret, E. (2010). The use of expert elicitation in environmental health impact assessment: a seven step procedure. *Environmental Health*, *9*, 1-16.

O'Hagan, A., Buck, C. E., Daneshkhah, A., Eiser, J. R., Garthwaite, P. H., Jenkinson, D. J., ... & Rakow, T. (2006). Uncertain judgements: eliciting experts' probabilities.

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Shayegh, S., Bosetti, V., & Tavoni, M. (2021). Future prospects of direct air capture technologies: insights from an expert elicitation survey. *Frontiers in Climate*, *3*, 630893.

Vossos, V., Gerber, D. L., Gaillet-Tournier, M., Nordman, B., Brown, R., Bernal Heredia, W., ... & Frank, S. M. (2022). Adoption pathways for DC power distribution in buildings. *Energies*, *15*(3), 786.

ANNEX 2: Consent Form - Both EE Sessions

Expert Elicitation Consent Form

28 Oct 2024

You are invited to the expert elicitation session for Task 1.6 of the SHIFT2DC project

Online Consent Form.

* Required

Study Title:
Users Adoption and Perception of the DC Tools, and Technologies.

Principal Investigator:
Lucas Pereira, Researcher; ITI/LARSyS, Técnico Lisboa; Av. António José de Almeida, n.º 12, 1000-043 Lisboa; lucas.pereira@tecnico.ulisboa.pt

Other Investigator(s)
Catherine Ngirwa, PhD Student; Diogo Paulino, Masters Student.

Purpose of this Study
The study aims to investigate how experts see the future of direct current tools and technologies (which will be referred to as DC solutions). The study is carried out within the research project SHIFT2DC (Shift to Direct Current), funded by the European Union's Horizon Europe research and innovation programme under grant agreement no. 101136131.

Risks
There are no foreseeable risks or discomforts to you when filling out the questionnaire or completing the tasks. The only known risk to you of your involvement in this study is the inconvenience of giving up roughly 90 minutes of your time. All safeguards will be taken to maintain the confidentiality of your data, as described in the 'Confidentiality' section below.

Benefits
No direct benefits will come to you for participating in this survey. However, there are indirect benefits arising from the potential of the survey to provide valuable information about the future of these DC solutions. Therefore, your participation in this survey will be of scientific value as it will contribute to our understanding of your perception towards adopting DC solutions in data centres, buildings, industry, and ports.

Confidentiality
Data will be collected using an online tool (Slido) and stored with code numbers to ensure confidentiality. They will be kept on secure servers and password-protected computers. The data will be stored after the termination of the current research for a period no shorter than 5 years, and at no time will any identifying information about the participants be stored along with the data. Finally, no personal information will be provided when processing the data and reporting results, e.g., names or companies that experts work for.

Participant Requirements
You are eligible for participation if you are an expert in DC solutions in applied in either data centers, buildings, industry, or ports; present no non-motor related conditions that may interfere with understanding, communication, and task execution; and are motivated to participate.

Voluntary Participation & Rights to Ask Questions
Participation in this study is voluntary and non-coercive, with no negative consequences for refusing to participate. You may choose to leave the study at any point if you experience discomfort or find that there are any parts of this study that you do not wish to complete.

Session Requirements
The session will be conducted online in Microsoft Teams, read.AI will be used for recording, and Slido will support displaying and answering questions. Due to that, you must have a second screen or an external device, such as a tablet or a smartphone, with an active Internet connection.

Statement
I have read the study description provided, and I volunteer to take part in this research. If I have questions about the research, I can ask the researcher(s) listed above. I understand that I may refuse to participate or withdraw from participation at any time.
*

○ I agree to participate

○ I do not wish to participate

Personal Information

Below we will collect your basic demographic information as an expert. This information will be used to frame our findings and highlight the experience of our experts.

2

Fullname *

3

Gender *

- ◯ Woman
- ◯ Man
- ◯ Prefer not to say

4

Nationality *

5

Email address *

Highest level of education *

- ◯ High school or equivalent
- ◯ Vocational training or non degree
- ◯ Bachelor's degree
- ◯ Masters degree
- ◯ PhD degree

7

What is the specialization of the educational level specified in previous question *

8

In which field of expertise is your current position? *

- ◯ Project Management (and administration)
- ◯ System Designers
- ◯ Manufacturing, testing and certification
- ◯ Installations, commissioning and compliance
- ◯ Operations and maintenance
- ◯ Research and development
- ◯ Training and development
- ◯ Other

Number of years you have been working in current or other relevant industry *

- Less than a year
- One to five years
- Five to ten years
- Ten to twenty years
- More than twenty years

10

The name of the organization your working (this information won't be used when reporting the results) *

ANNEX 3: The EE Protocol – Second Session

Expert Elicitation Protocol on Direct Current Tools and Technologies in (demo name)

Elicitation Protocol

Expert: ....

Lucas Pereira	Catherine Ngirwa	Diogo Paulino
Professor	PhD Student	Masters Student
University of Lisbon	University of Madeira	University of Madeira
lucas.pereira@tecnico.ulisboa.pt	2077823@student.uma.pt	2080420@student.uma.pt

1. **Introduction - Duration: 10 minutes**
   a. **State of the Art of the study:**
   The widespread concern about using renewable energies for power generation brought attention to the dominance in deploying and using DC solutions. Despite the vital role these solutions play in supporting the race to decarbonize the energy sector, there is a deficiency in studies on user perceptions of them. These users as per this project are the experts in the DC, hence this survey.
   b. **Notes on Expert Elicitation:**
   Attached, you will find a series of questions intended to elicit your expert judgments on various topics regarding DC solutions. The topics to be addressed come largely from the existing literature, where they are mainly mentioned briefly but not discussed in detail, given the infancy state of DC in general.
   Participants are asked to draw upon their expertise and provide insightful perspectives when answering the questions as individual experts. In other words, we are not asking you to represent the organization you are affiliated with. Each participant will be assigned a number that will be used in place of names when we report results for each expert in this project.
   c. **Description of the Target for the Proposed DC Solutions**
   The DC solutions identified in this section are designed to facilitate the establishment of different activities related to DC in ports, industry, data centres and buildings. The activities include the establishment of DC energy hubs and grids. As well as assisting in the coordination, control, durability, autonomous recovery and protection of DC grids. Additionally, they aid in enhancing the adaptability, modular design, and expandability of these DC solutions in ports and industry.

List of the Proposed DC Solutions and their Descriptions - show one slide per category

S/No	DC Solutions	Description
1.	Smart and sustainable DC cables	Optimizing resilience and reliability of networks; reduced costs of installation; embedded data transmission
2.	DC-connectors	Connector concepts and contact systems adapted to DC grid characteristics
3.	Protection tools (Static protection system, Semiconductor-based circuit-breaker)	Static protection architecture considering power conversion, earthing choices. For the semiconductor-based circuit breaker interrupt DC fault current.
4.	LVAC-LVDC energy router	Active-front end with droop-control capabilities on the DC side
5.	High density bidirectional DC charging station	High density V2X DC stations: Bidirectional DC charging station; direct integration into DC grids; new DC/DC converter with higher efficiency.

2. Given the goal of achieving the target in 1(c).
   a. How feasible is the use of *DC in* the described target?
   b. How important is the use of DC in the described target?
   c. How feasible is each of these DC solutions?

#	DC Solutions	Not feasible	Somewhat feasible	Feasible	Very feasible	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	Protection tools (Static protection system, Semiconductor-based circuit-breaker)					
4.	LVAC-LVDC energy router					
5.	High density bidirectional DC charging station					

3. Barriers to adoption includes all factors which have been highlighted to hinder widespread adoption of DC solutions highlighted in 1(c).

Which of the following do you think are **possible barriers to adoption** of DC solutions? *select top 5.*

A)	Barrier	Select
	Power losses, and quality	
	Safety issues	
	Reduced reliability in DC devices	
	Lack of use-cases in which DC is advantageous	
	Uncertain utility interaction: net metering, utility ownership, and agreed standards	
	Lack of pilot projects	
	Public perception of DC and readiness to 'champion' installations from DC projects	
	Incompatibility of DC systems components	
	Misconception and lack of knowledge leads to lengthy/expensive design and permit process	
	Lack of enough trained personnels in DC systems	
	Uncertain in regulatory roadmap	
	High costs of DC solutions	

B) Any other vital barrier(s) not listed (Word Cloud):

i) ……………………………………………………………………

ii) ……………………………………………………………………

iii) ……………………………………………………………………

4. Costs and Efficiencies of the DC solutions.

   a. What impact on budget is the **cost** of each of the listed DC solutions?

#	DC Solutions	No impact	Minimal	Significant	Major impact	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	Protection tools (Static protection system, Semiconductor-based circuit-breaker)					
4.	LVAC-LVDC energy router					
5.	High density bidirectional DC charging station					

   b. How satisfied with the **cost** of each of the listed DC solutions?

#	DC Solutions	Very dissatisfied	Dissatisfied	Satisfied	Very satisfied	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	Protection tools (Static protection system, Semiconductor-based circuit-breaker)					
4.	LVAC-LVDC energy router					
5.	High density bidirectional DC charging station					

   c. What do you think could be the probable barriers to cost reduction of the DC solutions listed at 1(c)? Provide up to three. *Open-ended question*
   d. Which conditions could support positively cost improvements of the DC solutions listed at 1(c)? Provide up to three. *Open-ended question*

5. Discussion questions: Here open-ended questions have been included to capture more insights from experts.

   a. Which technical breakthroughs will be needed for the DC solutions listed in 1(c) to become commercial contenders in ports, industry, data centres and buildings? *minimum of three.*
   b. Based on your expertise in DC, provide any other relevant DC solutions suitable for the ports, industry, data centres and buildings not included in 1(c). *Minimum of three*
   c. Why is DC important in ports, industry, data centres and buildings?
   d. Kindly provide whatever you want to share with the elicitation team concerning DC solutions in ports, industry, data centres and buildings.

6. Expertise level: experts self-ranking of their expertise for each of the DC solutions in 1(c).

   How do you rank your **expertise** in each of the following DC solutions?

#	DC Solutions	Low	Moderate	High	Very High	Not able to respond
1.	Smart and sustainable DC cables					
2.	DC-connectors					
3.	Protection tools (Static protection system, Semiconductor-based circuit-breaker)					
4.	LVAC-LVDC energy router					
5.	High density bidirectional DC charging station					

References

Glasgo, B., Azevedo, I. L., & Hendrickson, C. (2018). Expert assessments on the future of direct current in buildings. *Environmental research letters*, *13*(7), 074004.

Knol, A. B., Slottje, P., van der Sluijs, J. P., & Lebret, E. (2010). The use of expert elicitation in environmental health impact assessment: a seven step procedure. *Environmental Health*, *9*, 1-16.

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Schmidt, O., Gambhir, A., Staffell, I., Hawkes, A., Nelson, J., & Few, S. (2017). Future cost and performance of water electrolysis: An expert elicitation study. *International journal of hydrogen energy*, *42*(52), 30470-30492.

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