Transforming a university campus into a sustainable energy district: Multi-criteria mapping of implementation options

Graz University of Technology's largest campus shall be turned into a low-carbon energy district. We explore ways of transformation by using a deliberative multi-criteria approach, in order to "open up" stakeholder perspectives. The results shed light on discrepancies among the participants: While they share doubt about carbon capture, utilization and storage, the experts differ widely in their assessments of other options. We conclude by outlining a strategy harmonizing divergent assumptions and expectations.

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GAIA 32/2 (2023): 249–256

Abstract
Low-carbon energy districts are considered to play important roles for achieving the ambitious climate targets set by the *Paris Agreement.* While such districts are expected to integrate all dimensions of sustainability, assessing their sustainability performance remains challenging. Against this background, we take multi-criteria mapping (MCM), a deliberative and stakeholder-driven multi-criteria decision-making approach, to evaluate Graz University of Technology's current efforts to turn its largest campus into a low-carbon energy district. Based on scoping interviews, a focus group, and eleven mapping sessions with key stakeholders, nine core options were identified and assessed. By analyzing quantitative assessments and the specific criteria and argumentation patterns that underlie these assessments, our study "opens up" different perspectives on potential implementation options and highlights the complex and contradictory nature of sustainable (energy) transformations at the district level. The study concludes with the suggestion of using future workshops to align diverging perspectives and expectations.

Keywords
carbon-neutral campus, Graz University of Technology, innovation district, low-carbon energy district, multi-criteria mapping, socio-technical transition, sustainable university

Universities are being more frequently expected to become positive role models in (contributing to) achieving sustainable development goals (Purcell et al. 2019, Leal Filho et al. 2020, Gratzer et al. 2019). To take on such a role model function, these universities must perform activities in multiple fields of action, including education, research, governance and operation (Schopp et al. 2020, Amaral et al. 2020). In order to address the latter field of action, which comprises efforts to transform the physically built environment, more universities are planning to retrofit their campuses and turn them into climate-neutral energy districts (Opel et al. 2017, Zheng et al. 2021, Tian et al. 2022, Getzinger and Thaler 2023, in this issue).

District-scale solutions are considered to play important roles for mitigating climate change (Sareen et al. 2022). According to UNEP (2022, p. 42), the building sector was responsible for 37% of global carbon dioxide emissions in 2021; thus, it is critical in the transition to a post-carbon society. At the same time, building-related emissions have increased in recent years despite improvements in energy efficiency and continuous efforts to reduce the sector's environmental impact (Brozovsky et al. 2021). To reverse this trend, efforts are being made to shift the focus beyond individual buildings to the district level (Becchio et al. 2018). These efforts have resulted in the development of various concepts, including "net (or nearly) zero-energy districts" (Heendeniya et al. 2020), "net zero-energy neighborhoods" (Cortés et al. 2020) and "positive energy districts" (Jepsen et al. 2022).

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https://doi.org/10.14512/gaia.32.2.8
Received November 16, 2022; revised version accepted June 21, 2023 (double-blind peer review).

Because shifting the focus away from individual buildings to a district or neighborhood level is a relatively novel approach, open questions and unknown factors still exist (Sareen et al. 2022). For instance, a key challenge is the required (smart) integration of different systems, infrastructures and technologies and the question of how to optimally operate such integrated configurations (Cortés et al. 2020, Adhikari et al. 2012). An even greater challenge is precisely how to redesign existing districts to "secure energy supply as well as a good life for all in line with social, economic and environmental sustainability" (JPI Urban Europe and SET Plan Action 3.2 2020, p. 7). To smooth the decision-making process and select the most appropriate transformation pathway for a district, scholars have developed optimization models (Chacón et al. 2022, Heendeniya et al. 2020, Jepsen et al. 2022), conducted cost-benefit analyses (Becchio et al. 2018, Saarloos and Quinn 2021) and applied the Life-Cycle Assessment (LCA) methodology (Moslehi and Reddy 2019).

In addition, some researchers have suggested the use of multi-criteria decision-making (MCDA) tools to identify optimal implementation pathways for energy districts (Yuan et al. 2020, Safder et al. 2019, Yang et al. 2018). Since energy districts are characterized by multidimensional objectives that are associated with numerous, potentially conflicting criteria, applying such tools can yield valuable insights. However, the tools used in the above-mentioned studies generally apply conventional MCDA principles; thus, they are used to identify single-best options and tend to neglect ambiguities inherent to sustainability assessments (Stirling 2010). Furthermore, these tools were based on predefined criteria, thereby limiting the ability of study participants to apply their own principles of assessment.

To fill this lacuna, we take an alternative, deliberative and stakeholder-driven MCDA approach, multi-criteria mapping (MCM), to evaluate Graz University of Technology's current efforts to turn its largest campus into a sustainable, low-carbon energy district. Along these lines, we conceptualize the planned district as an emerging socio-technical system that requires "profound innovations from architectural, planning and construction points of view" (Sibilla and Abanda 2022, p. 2).

Institutional context: The innovation district

In 2020, the *Roadmap – Climate Neutral TU Graz 2030* was launched. This roadmap defines more than 40 measures that can be applied to achieve climate neutrality, bundled into ten action areas (Getzinger 2021). Discussions about the best way to implement the defined measures spawned the idea of creating an urban innovation area. As a result, the Innovation District Inffeld was founded to create a fruitful innovation environment on the largest of the three university campuses (Inffeld Campus) and support research and development to achieve climate neutrality by the year 2030 (Pabst 2021). The campus is within the Graz city limits and currently contains 27 buildings with a gross floor area of 130,000 m^2, which will be expanded by about 5,000 m^2 per year. The site hosts 22 university institutes and 8 cooperative research companies ("Competence Centres"). It contains offices and lecture halls as well as energy-intensive laboratories, large-scale test rigs and extensive workshops. Most of the employees on the campus are research staff working in the fields of electrical engineering, mechanical engineering and computer science.

To support the development of the Innovation District Inffeld on the behalf of the research institutes located on campus, the research project *User-Centered Smart Control and Planning of Sustainable Microgrids* was initiated in 2021 (UserGRIDs 2021). In the project, the Innovation District Inffeld is used as a case study to develop digital methods ("digital energy services") that can be used to decrease the greenhouse gas emissions of urban districts. The application of the MCM approach presented in this study was the first step taken to involve the inter- and transdisciplinary project consortium. This consortium includes stakeholders with highly relevant technical expertise and/or decision-making authority regarding the transition process of the campus.

Multi-criteria mapping

While traditional multi-criteria analyses can be carried out to find single-best options, MCM can be used to explore "the ways in which different pictures of strategic choices change, depending on the view that is taken" (Coburn et al. 2019, p. 10), and to map the opinions and argumentation patterns that underlie (quantitative) assessments. More precisely, MCM is a heuristic multi-criteria approach that: 1. includes a diversity of relevant perspectives, 2. illuminates competing views, and 3. puts the participants "in the driving seat". (For details, see Stirling and Mayer 2001.) MCM "focuses equally on quantitative representations of performance under different perspectives" and on "documenting qualitative information concerning the reasons for performance patterns and uncertainties under each perspective" (Raven et al. 2017, p. 584). The tool is especially appropriate when no clear "either-or" decision is possible.

The web-based software tool MCM was used in our study, which had three phases: 1. preparing the MCM project, 2. one-on-one mapping sessions with stakeholders, and 3. analyzing the mapping results. The preparatory phase included defining the focal goal, formulating core options and recruiting study participants. Considering the climate-neutrality strategy of Graz University of Technology, the defined goal was to *turn the main campus of the university into a low-carbon energy district.* We then analyzed 22 scoping interviews to identify the options available to achieve this focal goal. These interviews had been conducted at the beginning of the *UserGRIDs* project with both project members and representatives of project-external institutes and competence centers who were deemed to have potentially relevant technical knowledge (figure 1). In addition, we organized a focus group with three key stakeholders, then held two written feedback rounds. Table 1 (p. 252) shows the final set of options that

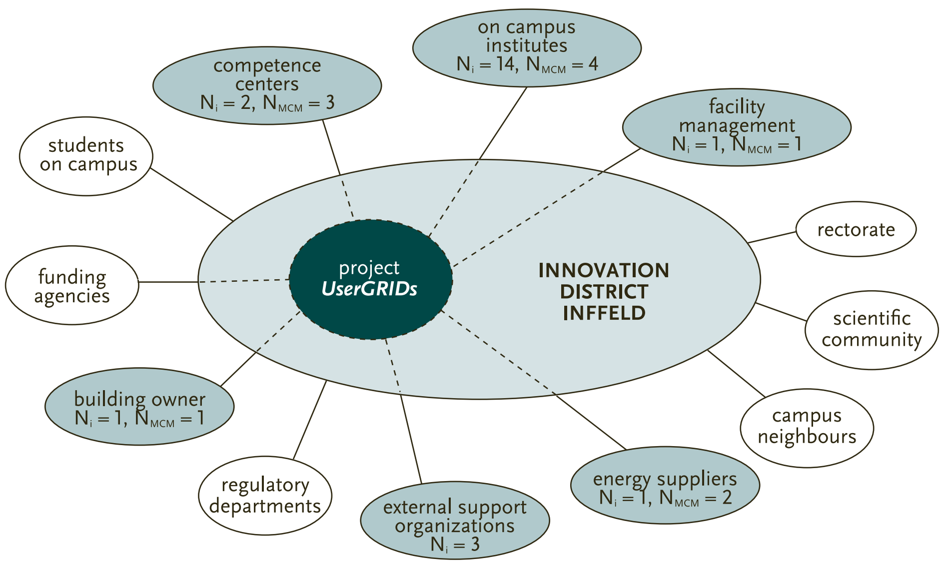


FIGURE 1: Stakeholder groups associated with efforts to establish a climate-neutral campus. Groups that were represented in scoping interviews and mapping sessions are shown in green.

N_i = number of scoping interviews
N_{MCM} = number of multi-criteria mapping sessions

were formulated. For the individual mapping sessions, eleven persons were recruited (figure 1): eight members of the *UserGRIDs* project and three institute/competence center representatives who had shown a strong degree interest during the scoping interview and were willing to participate. Two of these institutes/centers represented the largest energy consumers on campus. The *UserGRIDs* project members were recruited from across the inter- and transdisciplinary consortium. Mapping participants are coded with P1 ... P11 below.

The mapping sessions lasted two to three hours each and were recorded and transcribed. These sessions began with an explanation of the predefined options to ensure that the interviewees were familiar with them (and to give the participants the chance to define additional options). Subsequently, participants were asked to define their individual criteria (i. e., all factors they considered when choosing options or comparing their pros and cons). During this step, the influence over the participants' choices was kept as low as possible. Once the criteria had been formulated, the participants were asked to evaluate the options for each criterion on a scale from 0 (low performance) to 100 (good performance). To consider 1. uncertainties (lack of information), 2. variability (if the assessment depends on context factors), or 3. sensitivity (if several assumptions are equally plausible), optimistic and pessimistic scores had to be defined (Stirling and Mayer 2001). Care was taken to ensure that the participants justified and explained each score so that we clearly understood the underlying logics. After assessing the options, the participants were asked to weight the criteria and critically evaluate the final ranking.

Once all of the one-on-one mapping sessions were completed, the aggregate assessment scores were calculated and visualized (for the underlying calculations, see Coburn et al. 2019, annex A). The participants' considerations and key points of reason were also analyzed to interpret the quantitative patterns.

Mapping results

Figure 2 (p. 253) shows the final scores aggregated across all participants and all criteria. Considering the averages for the optimistic and pessimistic mean scores (i. e., the median points between the two ends of the orange bars), the options *demand-side management* (DsM) and *renewable electricity generation* (Ren) have the highest scores, whereas *carbon capture, utilization and storage (CCUS)* has the lowest score. However, given the uncertainty ranges associated with the scores (length of orange bars), the ranking changes depending on which scenarios are considered. For instance, while the general assessment of the option *energy communities* (EnCo) is rather moderate, its most optimistic score is still higher than the DsM pessimistic score. The variability of the ranking is also influenced by the fact that the level of uncertainty differs significantly, with DsM and CCUS showing the highest levels, and Ren and *purchase of UZ 46 electricity* (UZ 46) showing the lowest levels. In addition to the predefined options, four further options were suggested: *energy efficiency in buildings, wood constructions, self-commitment of institutes* and *use of environmental heat.*

Overall, the participants defined 49 criteria, which were grouped into 15 main criteria and five categories: 1. environmental aspects, 2. political feasibility, 3. social impact, 4. economic aspects, and 5. other aspects (table 2, p. 254). Below, the assessment results are analyzed in more detail by illustrating the scores for each category (see figure 3 for the rankings aggregated by category, p. 255). The explanations are based on qualitative statements made in the mapping sessions.

Environmental aspects

Environmental aspects consist of the criteria decarbonization, conservation of resources, and campus-based contribution (i. e., the degree to which the options avoid shifting resources away >

TABLE 1: Predefined options (potential strategies to achieve climate neutrality on campus).

OPTIONS	DEFINITIONS
alternative fuels (AlFu)	Switch to alternative or, whenever possible, renewable fuels (liquid and gaseous) on campus to significantly reduce greenhouse gas emissions.
demand-side management (DsM)	Intelligent control of power and heat and demand-side timing of power-intensive tests and trials, considering their start time, trial duration and power peak.
electric car charging stations (ECar)	Installation of electric car charging stations to help decarbonise commuter and visitor traffic. This option includes the use of PV electricity and bidirectional charging stations.
energy communities (EnCo)	Expansion of local energy production networks, where Inffeld Campus serves as the main consumer, to ensure a low-carbon supply of electricity, heat and fuels.
renewable electricity generation (Ren)	Increased use of electricity from PV systems and other on-site renewable power generation facilities.
seasonal thermal storage (SeSt)	Construction and utilization of seasonal heating and cooling storage facilities to make the best possible use of waste heat, electricity surpluses and solar radiation.
electricity storage (EleSt)	Construction and utilization of electricity storage facilities with high storage capacities to store self-generated electricity or electricity from the public grid.
purchase of UZ 46 electricity (UZ46)	Purchase of green electricity certified according to the Austrian UZ 46 standard to ensure the use of low-carbon electricity from the public grid.
carbon capture, utilisation and storage (CCUS)	Construction and use of carbon capture installations to spatially and/or chemically fix carbon emissions and, ideally, recycle them to create more resources.

from somewhere else). The best-rated options[1] were *purchase of UZ 46 electricity, seasonal thermal storage,* and *demand-side management*. The former two were rated positively in terms of their decarbonization potential: only P9 argued that the use of UZ 46 electricity would not lead to real greenhouse gas savings, as these savings are also urgently needed somewhere else. However, the ratings for demand-side management were ambiguous on this point: some participants argued that demand-side management only brings about minor savings (P1, P3, P11), while P7 and P9 referred to efficiency gains as well as to synergistic effects with the other options (e.g., claiming that it had a higher decarbonization potential when combined with seasonal storage).

Renewable electricity generation also scored well but was rated poorly by some participants due to its lack of contribution to resource savings and the low expansion potential on campus. Regarding the option *electricity storage,* the assessments differed based on the participants' assumptions about alternatives. Citing UZ 46 electricity as an ideal decarbonization option, P7 and P10 only saw a limited decarbonization potential for electricity storage systems. In contrast, P11 expected the future availability of UZ 46 electricity to be limited; therefore, they viewed electricity storage as an effective option. In terms of seasonal thermal storage, P10 and P11 pointed out difficulties associated with receiving decarbonized heat from off-campus, while P7 emphasized the limited potential of storing heat emitted by and on campus.

The options *alternative fuels, electric car charging stations* and *energy communities* scored the worst. Regarding alternative fuels, conversion inefficiencies (P3, P7, P10) and low consumption volumes on campus (P11) were highlighted. The latter aspect was also emphasized in the context of electric car charging stations (P2, P11). The assessment of energy communities depended on how the system boundary was drawn. While P9 and P10 interpreted energy communities as being a fully integrated part of the campus, P5 saw them as external elements and rated their on-site contribution poorly. *Carbon capture, utilization and storage* was rated positively; however, the environmental performance of this option was only assessed by three participants (P1, P3, P5), and P1 pointed out an uncertainty regarding its decarbonization potential, since how the carbon-holding materials would be handled afterwards is currently unknown.

Political feasibility

The political feasibility group comprises the criteria stakeholder acceptance, internal legitimacy and active support. The option *renewable electricity* generation was ranked highest in this category. The participants generally agreed that this option is internally legitimized, actively supported and accepted by the public. *Electricity storage* was assessed similarly by the participants. *Alternative fuels, electric car charging stations* and *purchase of UZ 46 electricity* were rated rather positively as well. Still, some participants (P5, P8) rated the internal legitimacy of the latter as low with reference to competence centers, because these centers – organized as companies – must pay for the electricity costs themselves. In terms of electric car charging stations, legitimacy problems were expected as well by P1, P2, P4 and P11. These participants stated that, while those who currently commute with a fossil-fueled car would feel forced to switch to an electric car, those who proactively push for sustainable mobility would

1 If not stated otherwise, the rankings presented in the mapping results sections are based on the averages of the optimistic and pessimistic mean scores.

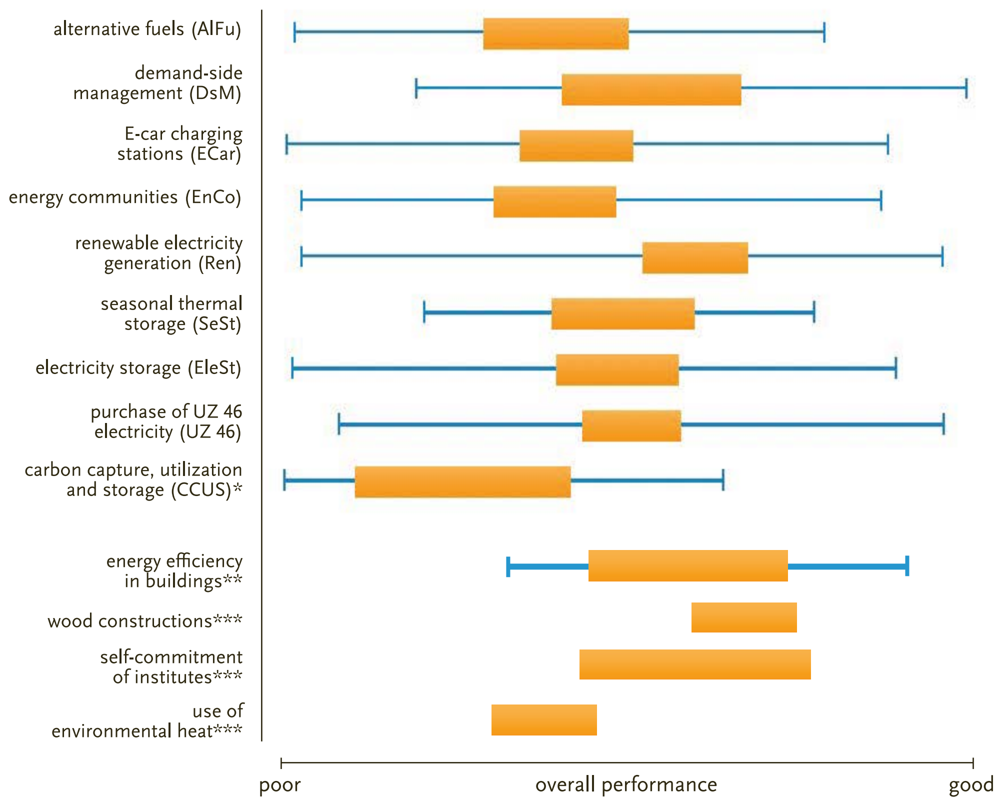


FIGURE 2: Final weighted scores for the predefined and added decarbonization options, aggregated across all participants. The x-axis is a relative scale indicating low (0) to high (100) performance. The orange bars indicate the range between (average) pessimistic and optimistic scores, illustrating the degree of uncertainty regarding future performance. The end points of the blue lines indicate extreme scores. For the individual scores (and criteria), see the online supplement: *https://doi.org/10.14512/gaia.32.2.8.suppl*. UZ 46 electricity: green electricity certified according to the Austrian UZ 46 standard.

*Excluded from assessment by six participants (P6 – P11).
**Added and assessed by three participants (P1, P9, P11).
***Added and assessed by one participant each (P2, P4, P7).

demand active mobility, rather than scaling up the number of electric cars.

Demand-side management was rated rather negatively, because the participants assumed that the measures associated with it would restrict everyday research operations (P2, P4). Referring to potential positive effects for digital energy service (DES) managers, however, P6 indicated a wide range of uncertainty in this regard. P5, in turn, argued that a large proportion of the stakeholders would not be affected by the measures and would thus tend to have an indifferent attitude. The option that performs worst is CCUS, but, at the same time, the ratings for this option show the highest ambiguity: P2 categorically rejected CCUS, while P1 and P4 emphasized the emotional nature of the topic and did not rule out growing support in the future, both from the public and at the university.

Social impact

This group is made up of the criteria user comfort, safety, and change in awareness. The option *demand-side management* is among the best-ranked options, but its ratings are also subject to the greatest individual uncertainties. This is mainly due to the fact that negative impacts were expected for research staff working in energy-intensive facilities. The participants also experienced difficulties in assessing the associated loss of comfort, such as the potential need to conduct experiments at night. P10, however, expected that this form of management would significantly simplify the daily work routine of those responsible for energy management, leading to clear improvements in user comfort. The options *electric car charging stations* and *seasonal thermal storage* were also rated comparatively positively (except by P6 and P10, who did not see a significant impact on user comfort). P7, for instance, argued that seasonal thermal storage could improve cooling performance in summer and increase thermal comfort.

Economic aspects

The economic aspects category consists of the criteria abatement costs, investment and operational costs, and life-cycle costs. The options *renewable electricity generation* and *demand-side management* were ranked highest. With regard to renewable electricity generation, participants argued uniformly that renewables are already profitable and that economic feasibility would only improve as energy costs rise. Thus, investment, operational and abatement costs were assessed consistently positively. Due to the high flexibility as a software solution and the manageable development costs, demand-side management was seen as a highly viable option as well. Although all participants underlined the low investment and operating costs, P6 pointed out that unexpected additional costs could arise for competence centers due to potential operational restrictions. Different evaluations were also linked with *seasonal thermal storage*. While P1 and P11 rated the economic performance as very poor due to the high investment costs, P4 and P6 rated this more positively, as they expected low abatement costs once the technology matured. The greatest uncertainty regarding costs was related to *alternative fuels,* a >

TABLE 2: Assessment criteria defined by the participants. The numbers in brackets show how many participants mentioned the criterion. The aggregate weighting of the categories decreases from left to right (i. e., environmental aspects were weighted as most important).

ENVIRONMENTAL ASPECTS	POLITICAL FEASIBILITY	SOCIAL IMPACT	ECONOMIC ASPECTS	OTHER ASPECTS
■ decarbonization (6) ■ conservation of resources (4) ■ campus-based contribution (3)	■ stakeholder acceptance (4) ■ internal legitimacy (4) ■ active support (2)	■ user comfort (4) ■ safety (1) ■ change in awareness (1)	■ abatement costs (4) ■ investment and operational costs (3) ■ life-cycle costs (1)	■ strategic management and planning (5) ■ technological readiness (4) ■ geospatial feasibility (3)

result which can be attributed to the range of applications and pathways associated with the option. The worst-performing option was again CCUS; participants who rated this option considered it to be economically unfeasible.

Other aspects

This category subsumes the criteria strategic management and planning, technological readiness, and geo-spatial feasibility. The best-rated options were *renewable electricity generation* and *demand-side management*. While the former was considered as mature and easy to apply on campus, the latter was evaluated differently among the participants due to emphases on different measures. The options *electricity storage* and *seasonal thermal storage* were considered as highly important from a strategic management perspective (contributing to the stability of the overall energy system). At the same time, P3 and P6 pointed out geospatial difficulties associated with the local implementation of seasonal storage systems. Assessments of the strategic importance of *alternative fuels* varied strongly. While some participants highlighted public grid support and attributed less importance to this option (P10, P11), others stressed the strategic relevance of working on hydrogen solutions by highlighting the prospective role of hydrogen in the future energy system (P3, P8). Lastly, P3 linked energy communities with the possibility to implement a more flexible energy management system on campus. Participants gave contradictory answers to the question of whether this option would lessen the burden on the public electricity grid (P10, P11).

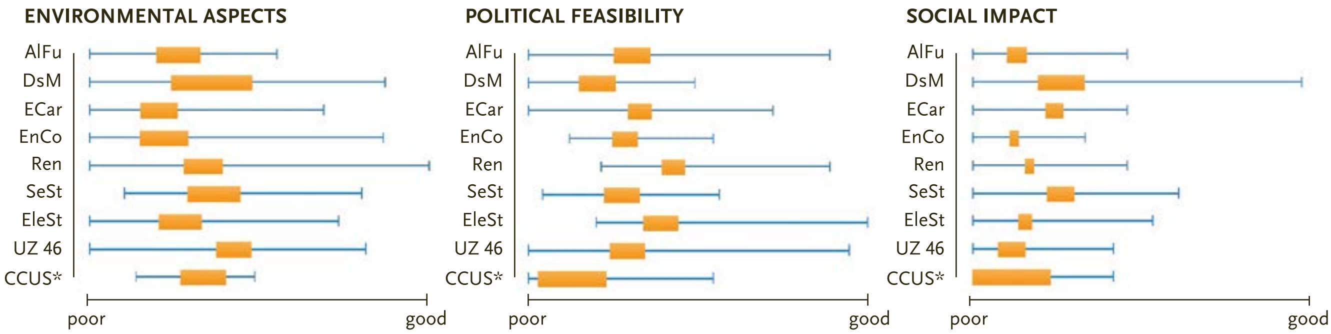
Lessons learned and outlook

In this study, decarbonization options for the Graz University of Technology Inffeld Campus were identified and subsequently assessed by 11 key stakeholders. While the aggregate scores allow us to distinguish between better- and worse-performing options, the rankings of the individual participants show notable differences. This is particularly remarkable given the fact that all participants are qualified in energy technologies and are very familiar with the campus. Many of these differences can be explained by the specific sets of criteria selected by the individual participants. In some cases, however, the participants' assessments diverged substantially even when they referred to the same criteria.

These less obvious cases occurred for multiple reasons. First, assessments diverged because of the different but equally plausible estimations of future developments. This happened, for instance, when the decarbonization potential of electricity storage systems was rated differently based on the expected future availability of UZ 46 electricity. Second, the mapping exercises left room for individual assumptions regarding precise delimitations of the infrastructural and technological scope. For example, the assessments about the decarbonization potential of demand-side management varied depending on whether synergies with other options had been considered or not. Third, divergent evaluations can be explained by the fact that the participants viewed the questions from their personal and professional perspectives (see figure 1). Finally, participants sometimes simply lacked relevant knowledge, such as when one participant did not consider the continuous investments in expanding renewable energy production that are associated with the UZ 46 electricity scheme.

By revealing stakeholder perspectives in a systematic way, our study complements the approaches previously used in the context of innovation districts (e. g., optimization models, cost-benefit analysis, standard multi-criteria analysis). It provides crucial insights about the campus and its transformation efforts. Contrary to ex ante expectations, the mapping exercise revealed major discrepancies regarding the assumptions and perceptions of the participating stakeholders (who play critical roles in the decision-making process). Our findings thus indicate the importance of initiating a consensus-building process in the context of developing low-carbon energy districts, especially at the university campus level where many stakeholder groups are involved. Moreover, our study demonstrates the value of the MCM in providing a starting point for facilitating such a process by identifying specific uncertainties, ambiguities, and potential lines of conflict.

There are several limitations in this study that should be addressed in future research. First, our analysis addressed only one of several fields of action that universities need to consider to become role models for sustainability transitions. Assessing and comparing options from other fields of action, such as education or governance, or across multiple fields would nicely continue the research presented in this paper. Second, while our analysis included social aspects through the criteria applied in the mapping sessions, social sustainability such as inclusiveness and user comfort should be emphasized more explicitly in future research



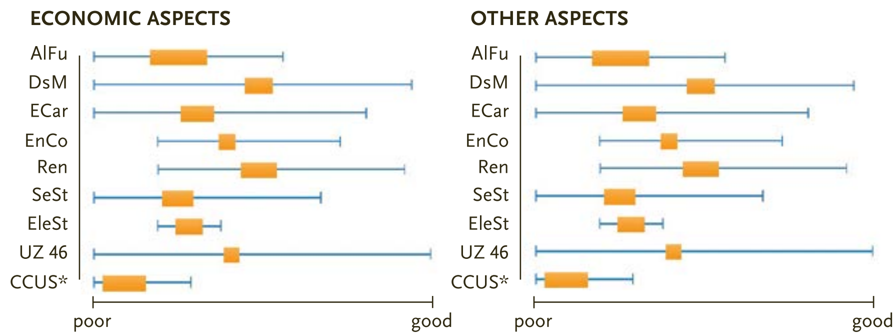


FIGURE 3: Aggregated scores of the predefined decarbonization options (full names, see figure 2) for each category of criteria. Note that the aggregated weightings of the underlying criteria in each diagram are considered as well.

* Excluded from assessment by six participants (P6–P11).

in the operation field of action. Third, important stakeholder groups such as students and neighbors were excluded from our analysis. While we focused on stakeholders with relevant technical expertise and decision-making authority, it would be an interesting avenue for future researchers to analyze the perspectives of these missing groups in terms of both identifying and assessing implementation options.

Finally, our study "opens up" stakeholder perspectives and associated discrepancies but does not indicate how these perspectives can be aligned. In the case of the Inffeld Campus, a series of future workshops are planned to facilitate this alignment and provide a decision-making basis for the rectorate, which will make the final decisions. These workshops will comprise the following three phases (Jungk and Müllert 1987): 1. a critique phase, in which the findings of the mapping sessions are presented and discussed (information), 2. a visionary phase, in which the participants try to envision potential concepts and transformation pathways (creation), and 3. a study phase after each workshop, in which the envisioned concepts are evaluated in terms of their contribution to achieving the target and their potential for realization (validation). While this alignment strategy will be applied and evaluated in the years 2023 to 2025, more research is needed to develop and assess approaches that allow for "closing down" and facilitate decision-making in situations of uncertainty and ambiguity.

Acknowledgement: We thank three anonymous reviewers for their helpful comments.
Funding: The research presented has received funding from the *Austrian Climate and Energy Fund*, under grant no. 880792 *(UserGRIDs)*, in cooperation with Green Energy Lab.

Competing interests: *GG, TM,* and *SP* are engaged in the development of the innovation district under investigation and have professional relationships with several interview partners. However, none of them were involved in the data collection and investigation process and they had only access to the anonymized interview/mapping results.
Author contribution: *MK:* conceptualization, methodology, data curation, writing, visualization, revision; *NK:* investigation, data curation, writing, revision; *GG:* supervision, writing, revision; *SP:* conceptualization, funding acquisition; *TM:* supervision, funding acquisition, writing, visualization.

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