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# **JOURNAL FÜR FACILITY MANAGEMENT**

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## **Preface of the publisher**

### **27<sup>th</sup> Journal für Facility Management: Science meets Practice**

In the last years the EU published the Corporate sustainability reporting directive (CSRD) which enlarged the number of companies subject to reporting obligations and the scope of reporting on sustainability aspects. In addition, the ESRS defined the way and the content of reporting standards in an extended way. In order to strengthen the EU's competitiveness and reduce bureaucratic obligations the Omnibus was published in spring this year. It is to remove at least 80% of companies from the scope and simplify reporting requirements for large companies through a revision of the European Sustainability Reporting Standards (ESRS). This reduces the effort for sustainable reporting and actions to a high extend. On the other hand, other regulations like the Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency are still in place and ask for more efficiency and optimisation. Therefore, sustainability as a topic has still high importance for the real estate sector. To provide research-based answers how we can cover the requirements and even create added value this issue of the IFM journal includes the following papers:

- How does FM contribute to the social dimension of ESG?
- Data Envelopment Analysis for Sustainable Healthcare: Ranking Hospitals based on CO<sub>2</sub> Emissions; Desirable/Undesirable Output
- New version of the Building Efficiency Directive 2024: Current developments and implications for the future management of buildings
- High-Performance Climbing Plants for Urban Climate Improvement: Maintenance Strategies for Climbing Plants in Vertical Greening Systems

The first paper investigates how Danish FM companies and professionals manage the challenge to develop social sustainability practices and measure the social dimension of ESG. It presents a literature review on social sustainability and the results of a survey among Danish FM practitioners. The paper gives suggestions to practitioners to work with social sustainability and measuring the social dimension of ESG.

The second paper presents the data envelopment analysis (DEA) as a widely used tool for performance measurement tool in healthcare due to its flexibility in handling multiple inputs and outputs, including both desirable and undesirable factors. This study applies a customized DEA model to evaluate the performance of hospitals. The results highlight the potential of DEA in addressing current challenges in healthcare performance management.

The third paper deals with the Energy Performance of Buildings Directive (version 2024), which defines the "smart readiness" of buildings and asks for a renovation passport including a renovation roadmap for buildings. This directive is in line with the European Sustainability Reporting Standards (ESRS) and points out the synergy effects in terms of data collection, evaluation and utilisation. Adapting processes can generate added value and reduce additional costs.

The fourth paper is more practically orientated. Vertical Greening Systems (VGS) in urban areas play a crucial role in urban climate adaptation, energy efficiency, and biodiversity, but their sustaining benefits depend on species-specific care and maintenance. Tailored interventions from planting through preservation maintenance are essential to optimise Plant Coverage (PC) and Wall Leaf Area Index (WLAI), enabling effective cooling and bioshading that directly impact these ecosystem services. The paper delivers practical recommendations and checklists for the sustainable management of VGS, providing a practical framework for building owners, planners, and facility managers to maximise environmental, economic, and aesthetic benefits.

At this point, I want to thank all international researchers who sent us numerous abstracts and papers for the double-blind review. The decline rate was kept high. I also want to thank the members of the editorial and the scientific board for their terrific work. They supported me in reviewing first the abstracts and then the full papers and gave a lot of input to the authors. The high decline rate, the high reputed members of the editorial and the scientific board and the supporting universities ensure that the articles are not only highly scientifically qualified, but also that practitioners can put them into practice easily. I also want to thank my team, especially Barbara Gurdet and Elisabeth Morillo-Napetschnig. Without their personal engagement the journal would not be available in this high quality.

I wish you all the best from Vienna, an enjoyable read, a lot of input for your research and/or for your daily work. I look forward to new striking research in the next IFM Journal and a refreshing exchange at the 19<sup>th</sup> IFM Congress 2026.

Your

Alexander Redlein

Head of Editorial Board

To my family Barbara, Caroline Sidonie und Alexander David

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## Table of contents

**7 Science meets Practice: ESG and its Implementation**

**8 How does FM contribute to the social dimension of ESG?**

*C. Behrens<sup>1</sup>, S. Martens<sup>2</sup>, P.A. Jensen<sup>3</sup>*

*<sup>1-2</sup> Konsulentgruppen Strandgade*

*<sup>3</sup> DTU Engineering Technology, Technical University of Denmark*

**27 Data Envelopment Analysis for Sustainable Healthcare: Ranking Hospitals based on CO<sub>2</sub> Emissions; Desirable/Undesirable Output**

*F. Masoudian, K. Lennerts*

*Institute of Technology and Management in Construction / Facility*

*Management, Karlsruhe Institute of Technology, Karlsruhe, Germany*

**44 Die Neufassung der Gebäudeeffizienz-Richtlinie 2024: aktuelle Entwicklungen und Auswirkungen auf die zukünftige Bewirtschaftung von Gebäuden**

*S. Geissler<sup>1</sup>, M. Hoffmann<sup>2</sup>*

*<sup>1</sup> SERA global – Institute for Sustainable Energy and Resources Availability, Wien, Österreich*

*<sup>2</sup> FHWien der WKW, Wien, Österreich*

**66 High-Performance Climbing Plants for Urban Climate Improvement: Maintenance Strategies for Climbing Plants in Vertical Greening Systems**

*A.K. Briefer, M. Poiss and R. Stangl*

*Institute of Soil Bioengineering and Landscape Construction, Department of Landscape, Water and Infrastructure | BOKU University, Vienna*

# **Science meets Practice: ESG and its Implementation**

# How does FM contribute to the social dimension of ESG?

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## **Abstract:**

Reporting on ESG has now become a reality for large companies in the EU. This paper investigates how Danish FM companies and professionals manage the challenge to develop social sustainability practices and measure the social dimension of ESG. It presents a literature review on social sustainability in general and particular the EU ESRS requirements related to the social dimension of ESG. The paper is empirically based on national interview surveys in 2023 and 2024 among FM practitioners in Denmark in both public and private organisations and provider companies, a desk study of how private provider companies' measure the social dimension of ESG, and case studies of social housing associations.

The results show that client organisations, provider companies and social housing associations present very different approaches to social sustainability. Client organisations do not have much focus on social sustainability and FM organisations do not play a major role in the companies' ESG reporting. Provider companies mainly focus on own workforce, which can be an inspiration to client organisations when setting targets and data requirements concerning ESRS S2 (value chain workers). Social housing associations mainly focus on their tenants, but also include concerns for own employees, workforce in the supply chain, and the surrounding community. FM organisations in other companies can benefit from experiences from social sustainability in social housing associations. The paper can help practitioners to work with social sustainability and measuring the social dimension of ESG.

## **Keywords:**

Facilities Management, ESG, social, sustainability, stakeholders

## **1. Introduction**

According to the ISO Standard 41011, the purpose of FM is to improve the quality of life of people as well as the productivity of the core business (ISO 2017). This clearly indicates that social aspects are or should be an essential and integrated part of FM. Reporting on ESG has now become a reality for large companies in the EU. The purpose of the paper is to investigate how Danish companies and FM organisations manage the challenge to develop social sustainability practices and measure the social dimension of ESG.

Social sustainability is one of the three dimensions in ESG together with environment and governance. In the building industry and in FM, the focus on sustainability has for a long time mainly been on the environment (Bröchner et al. 2019). This has changed to a certain degree in recent years in the building industry, for instance in line with building certification systems being developed from focusing solely on environmental aspects to becoming more holistic sustainability systems. In FM, this development has been slower, but there are now also holistic sustainability certification systems for buildings in use (Oberfrancová1 & Wollensak 2021). However, even though FM has major impact, for instance on health and well-being, social sustainability is an underdeveloped area within the FM industry.

The paper presents a literature review on social sustainability in general and particular the EU ESRS requirements related to the social dimension of ESG. The paper is empirically based on national interview surveys in 2023 and 2024 among FM practitioners in Denmark in both public and private organisations and provider companies, a desk study of private provider companies' social ESG policies, and case studies of social housing associations (SHAs).

## **2. Framework**

Jensen et al. (2024) presented an overview of the development of sustainability concepts and frameworks leading up to the present EU ESG. The focus on corporate ethics and accountability for social aspects can be traced back to the book "Social Responsibilities of the Businessman" by Howard Bowen from 1953. However, Corporate Social Responsibility (CSR) did not become more generally recognized before the 1990's, and the UN Global Compact was launched in 2000 *"to bring business and the United Nations together to give a human face to the global market"*.

It is the world largest CSR initiative with more than 20.000 businesses in more than 160 countries (UN Global Compact 2024).

The UN Global Compact published the report “Who Cares Wins” (UN Global Compact 2004), which coined the term “Environment, Social and Governance” (ESG) and established a crucial link between ESG actions and financial performance. According to ISO/TR 41019 (ISO 2024), CSR is a precursor to ESG: *“CSR provides a qualitative assessment of an organisation’s effects on its stakeholders and society. ESG measures an organization’s impact on the environment and society, using quantitative measurement methods with the aim of delivering long-term stakeholder value.”*

According to the UN Global Compact (2024) *“Social sustainability is about identifying and managing business impacts, both positive and negative, on people. The quality of a company’s relationships and engagement with its stakeholders is critical. Directly or indirectly, companies affect what happens to employees, workers in the value chain, customers, and local communities, and it is important to manage impacts proactively”*. This definition identifies four generic groups of stakeholders, which are applied to the contexts of FM and public housing associations in this paper.

Based on the above a specific definition for social sustainable FM was formulated by a working committee in the Danish FM Association DFM: *“Social sustainability concerns FM-organizations’ impact on working and living conditions for employees at internal and/or external customers, FM’s own employees, employees in provider companies, and the local community, which contributes to social sustainable development.”* (DFM 2025)

The EU specifications for ESG in the Corporate Sustainability Reporting Directive (CSRD) (EU 2022) includes requirements to report on the following social and human rights factors: (i) equal treatment and opportunities for all; (ii) working condition; and (iii) respect for the human rights, fundamental freedoms, democratic principles. The directive is supplemented by European Sustainability Reporting Standards (ESRS) and as for now four of these standards for social aspects have been published: ESRS S1 Own workforce, ESRS S2 Workers in the value chain, ESRS S3 Affected communities, and ESRS S4 Consumers and end-users (EFRAG, 2023). This resembles the four generic stakeholders mentioned above.

The CSRD requirements will be modified, if the EU's proposal for the so-called Omnibus directive is approved (EU 2025). The research in this paper does not take this into account.

The CSRD does not define fixed KPIs for ESG reporting but requires in the directive's associated standards that the company prepares a double materiality analysis, based on which it is assessed and documented, which KPIs are relevant for the company in question in its specific context. A mapping of all 82 disclosure requirements in the CSRD found that 21 of these requirements were FM-relevant (Jensen et al. 2024). The specific requirements for each company can vary, but these 21 requirements are a relevant starting point for most FM organisations.

### **Social housing in Denmark**

Social housing is an important part of the Danish welfare state and receives financial support as part of governmental social policy. SHAs own the buildings and have a high degree of tenant democracy. They build, manage and operate the buildings with social support as their mission and are supervised by the local municipality. The municipality has by law the right to refer social challenged families or individuals to 25 % of the homes, which the Copenhagen municipality has agreed with the SHAs can be 35 %. Public housing portfolios are divided in departments each covering an estate typically with many multi-storey or terraced houses. More information about social housing in Denmark can be found in the publication BL (2017), which is both in English and Danish.

SHAs are not covered by the EU ESG reporting requirements. However, the Danish SHAs have decided to develop a similar sustainability reporting standard (AlmenKompas 2025). They have defined 20 measures with indicators divided in 8 for social, 6 for environment and 6 for governance. The 8 for social are listed below. It is noticeable that there are no measures for workers in the supply chain:

- Employees:
  - Composition of staff
  - Wellbeing
- Tenants:
  - Life opportunities
  - Quality of life and health

- Local area
  - Affordability of social housing
  - Rate of social housing in the area
  - Functions in the area
  - Local community

In connection with social housing in Denmark there is The National Building Fund (LBF - Landsbyggefonden). The fund supports projects for social development in public housing and large-scale renovation projects social housing. For social development projects a social master plan (SMP) and for renovation projects a physical master plan must be prepared (LBF, 2024). SMPs are initiated by SHAs and the municipality and are implemented by targeting a range of stakeholders, including tenants, neighbourhood, local institutions, police, and voluntary organisations. SMPs are often implemented without physical interventions, but in the case in this paper it is implemented alongside physical master plans with renovation projects and infrastructure improvement. There are four general goals of SMPs:

- *Education and life chances:* There must be a professional promotion of children and young people from the residential area, so that more children become school-ready and more young people take an education
- *Employment:* More of the area's adults must be linked to the labour market
- *Crime prevention:* Children and young people must be supported in a life without crime, and residential areas must be experienced as safe to live and move around in
- *Cohesion and citizenship:* More residents must be part of the community and participate actively in society

### **3. Methodology**

The paper applies a mixed-method approach with qualitative studies. The research was divided into the following three parts:

- National interview surveys in 2023 and 2024 among FM practitioners in Denmark in both public and private organisations and provider companies
- A desk study of private provider companies' social ESG policies
- Case studies of SHAs

## Surveys in 2023 and 2024

Two qualitative surveys among Danish private and public companies were conducted in 2023 and 2024 by Konsulentgruppen Strandgade. The purpose of the 2023 survey was to:

- Analyse the companies' preparedness for ESG reporting and their compliance with the new ESG requirements set out in the CSRD and ESRS.
- Define best practices for governing and managing FM operations with an ESG focus.

In 2024, the ESG legislation went into force in Denmark, so the FM organisations contribution to the ESG reports were expected to significantly increase. A follow-up survey was conducted in 2024 with the following expectations:

- FM organisations are considered more critical as input and knowledge providers and are gaining a more significant role in the strategical ESG work.
- The FM organisations have increased awareness of their need for data and data-based analysis from their service providers as well as internally.
- Working with ESG has led to a development in the IT landscape supporting FM.
- While “E” has been the dominant KPI in the ESG reports, “S” and “G” will attract more resources in the coming reports.

Based on these expectations, the follow-up survey in 2024 had the following purpose:

- Identify if there had been any development in ESG focus, given that the CSRD and ESRS regulation had now been implemented in Danish law.
- Specifically analyse how and to what extent the social dimension of ESG was implemented by Danish organisations.

The 2023 survey was conducted through interviews with FM and ESG representatives from the participating companies, typically the heads of FM and heads of sustainability. These interviews were based on a questionnaire distributed prior to the interviews. The 2024 follow-up survey was conducted as a questionnaire aimed at FM and ESG representatives without elaborating interviews. Table 1 shows an overview of the two surveys.

**Table 1: Overview of surveys**

<b>Survey</b>	<b>2023</b>	<b>2024</b>
<b>Methodology</b>	Questionnaire and interview	Questionnaire
<b>Number of respondents</b>	15	10
<b>Type of companies / Organisations participating</b>	Private global companies Private local companies Public authorities FM service providers	Private global companies Private local companies Public authorities

### **Desk study of private provider companies' sustainability reports**

A desk study was chosen because it makes it possible to gather and compare measurable social KPIs and metrics from publicly available sustainability reports. All qualitative descriptions and intentions are not part of the study. The study focuses on measurable social KPIs. In order to get a broad understanding of the KPIs and metrics relevant to FM, the desk study included 11 provider companies. To ensure a uniform search for KPIs and metrics, 10 KPIs and 15 metrics were defined based on a KPI database developed by the consultant company of the second and third author. Table 2 shows an overview of the 11 provider companies included in the desk study divided in types of providers.

**Table 2: Overview of sustainability reports included in desk study**

<b>Type of provider</b>	<b>No. of providers</b>	<b>Comments</b>
IFM providers	2	FM service providers offering a complete FM package including hard and soft services
Hard FM providers	3	FM service providers offering hard services such as building maintenance and technical maintenance
Soft FM providers	3	FM service providers offering soft services such as cleaning and catering
Single service providers	3	FM service providers offering a single FM service such as security, waste or outdoor maintenance (green & white)

## Case studies

SHAs were chosen because they can be seen as Facilities Management (FM) organisations, and they represent an extreme case for studying, how FM can support social sustainability as they have social concerns as a central part of their mission. The stakeholders in the definitions in section 2 can for housing organisation be translated to own staff, employees in the value chain, tenants and the local community. The cases were two SHAs – *fsb* and *SAB*.

*fsb* was chosen because it is the largest SHA in the Copenhagen area and has elaborate sustainability strategies. They also have experiences from many large-scale renovation projects and projects for social development. The case study included both a project for social development and large-scale renovation projects supported by LBF. The study was based on documents and interviews with three key informants shown in Table 3.

Table 3: Overview of interviews

No.	Position	Focus	Date	Duration
1	Teamleader in building department	Building renovation	06-03-2024	30 min.
2	Head of social housing	Social sustainability	18-04-2024	60 min.
3	Leader of social masterplan	Social master plans	08-05-2024	90 min.

*SAB* was chosen because they in 2024 introduced the concept of “Social operation”. The case is based on documents studies and a meeting in November 2024 with two key informants – the person employed to roll-out the concept among all *SAB*’s employees and the ESG-manager from the umbrella administrator KAB, which administers the housing estates of *SAB*’s and many other SHAs.

## 4. Findings

The findings are presented separately for each of the three empirical studies.

### Surveys

The aim of the survey in 2023 was to determine whether heads of FM collected and monitored performance on some or all the 21 requirements (Jensen et al. 2024) as a proxy to analyse the degree of compliance with ESG regulations among the

participating companies and organisations. The conclusion was that none of the participating companies were fully compliant, and overall, the degree of compliance was limited, especially among public sector companies. This conclusion may not be seen as surprising, given that the survey was conducted in 2023, before the ESG regulations had been implemented in Danish law.

The follow-up survey found that the different FM organisations have an equally divided perception of the development within their ESG work. But looking beyond the FM organisation and into the entire organisation, the majority (70 %) of the respondents' organisations has developed an ESG strategy. 86 % of the organisations with an ESG strategy have FM specific goals. One of the major barriers – reported by 54 % of the respondents – within ESG work, is finding finance to upscale the FM organisation to focus on and develop the ESG agenda as well as data accessibility, see Figure 1. Yet 40 % of the respondents inform that the ESG regulation has resulted in organizational changes in the FM department, see Figure 2.

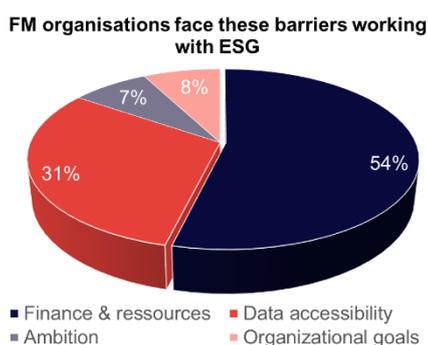


Figure 1: Main barriers working with ESG

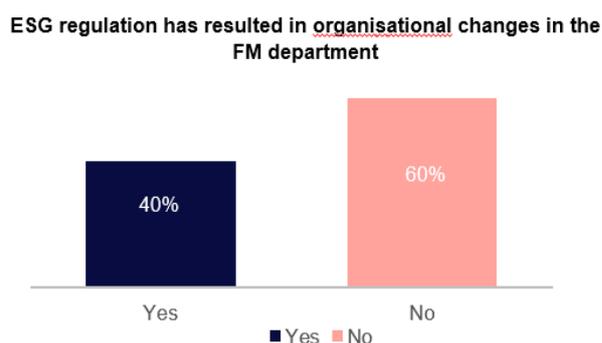


Figure 2: Changes in the FM organisations

Data accessibility is another major barrier. The awareness of need for data is present, but from 2023 to 2024 there is an increase in manual management of ESG data, see Table 4.

The development has been focused on establishing ESG departments, formalizing structures and procedures but the FM organisations still need development of data management and data analysis systems to be able to easily report on all relevant disclosure requirements as well as to support the continuous improvement of sustainability in a data driven manner.

The 2024 survey specifically investigated the respondents focus on “S” and “G”, as the ESG regulation was expected to widen the sustainability focus from mainly environmental issues. There hasn't been any shift in focus – 80 % of the KPIs relates

to “E”. Only 13 % of the respondents KPIs relates to social matters. The respondents who have social KPIs are not FM-specific, they are linked to their broader organisation and mainly focus on ESRS S1 (own workforce). Table 4 shows an overview of selected conclusions from the two surveys.

**Table 4: Overview of selected conclusions**

<b>Topic</b>	<b>2023 conclusion</b>	<b>2024 conclusion</b>
Is ESG a question of compliance or opportunity creation?	Opportunity creation: 45 % Compliance: 55 %	Opportunity creation: 50 % Compliance: 40 % Both: 10 %
Who will lead the ESG agenda: Provider or customer?	Customers: 60 % Service Providers: 7 % Both: 33 %	Customers: 78 % Service Providers: 11 % Both: 11 %
Use of an IT system (e.g. FM-IT) or other types of technology to register and maintain ESG-relevant data: How integrated is the IT system and the business core/enterprise systems? On a scale from: 1 = None/Manually 5 = Dedicated & Integrated	Manually: 42 % 25 % 25 % 8 % Dedicated/ Integrated: 0 %	Manually: 50 % 20 % 10 % 20 % Dedicated/ Integrated: 0 %

The main conclusion of the follow-up survey is that FM responds to group strategies rather than leading or strategically impacting the ESG agenda.

### **Desk study of how private provider companies measure the social dimension of ESG**

In extension of the 2024 ESG follow-up survey, a desk study was conducted to further explore and define social KPIs. The aim was to extend the KPI database to help customers determine social data requirements in FM contracts.

FM service providers are specialised in offering professional FM services to their customers. One could expect that the providers are leading the development of the FM business and at the forefront of new initiatives and legislation. Service providers are typically employee intensive companies, employing a very diverse workforce. As an FM customer, the service provider’s workforce is part of the value chain workers (ESRS S2), which the customer is required to disclose information about. The information demands must be included in the contracts and agreements between customers and

providers, but the market expects very specific data requests. For this reason, it is interesting to investigate which data the providers report in their own sustainability reports where they must report on their own workforce (ESRS S1)

The study provided the following learnings:

- The suppliers are already reporting on many “S”-relevant data
- Hard FM service providers are generally reporting on more Social KPIs than IFM, single service and soft service providers
- The number of reported “S” KPIs varies a lot
- The suppliers are using different metrics, which makes it hard to compare
- Many suppliers have mapped their ESG-KPIs with the SDG’s

The sustainability reports in the study were from 2022 and 2023 – which was before the ESG legislation went into force in Denmark, but the service providers were certainly prepared. As expected, they all had a social focus and there were a lot of intentions and policies described. Despite a great variation in the number of social KPIs they all had measurable KPIs and a baseline to show the development.

An issue with the selected sustainability reports were that the global entities didn’t report on Scandinavia or Denmark in the same way. Some of the results were global or clustered in different regions. To an FM customer, in e.g. a tender process, this means that they need to define if they are interested in the local or global social data.

The data requirements from the customers must focus on both the KPI, such as continuous education, and the specific metric, such as number of hours spent on education. The study found 17 social KPIs and 45 different metrics as shown in Table 5 and with frequencies of issues in Figure 3.

**Table 5: Social KPIs and metrics**

<b>KPI</b>	<b>Metric</b>	<b>Metrics no.</b>
Social vulnerability ratio	Number	1
Gender representation, Top Management	% Number	2
Gender representation, total workforce	% Number	2
Wage gap between genders	% wage gap by geography Ratio (1,5 times)	2
Age	Average age Age intervals % of each interval Number of each interval	4
Ethnicity	Number of nationalities % of origin % of colour	3
Trainee or apprentice	Number	1
Continued education / training	Number of hours Number of days % of total workforce educated in a specific topic Average number of hours education pr. FTE Number of managers educated in a specific topic Number of hours pr. organisational level (Top management, management, other) Number of hours organisational level pr. Gender	7
Sick leave	% Number of hours	2
Work related accidents / incidents	Number of incidents Lost time: LTIF Lost time: LTIR Lost time: LTFIR High consequence injury rate Development over time TRIF (total recordable incident frequency)	7
Near accidents	Number	1
Fatalities	Number	1

Employee satisfaction	Engagement score On a scale (1-5) Safety index Leadership index	4
Attraction and retention	Turnover % Average employment time / seniority Number of new employments % women of new employments Number of terminations % women of terminations	6
Discrimination	Number of incidents Inclusion index	2
Initiatives from workplace assessments	-	0
Use of robots	-	0

### Some KPI's are more popular than others

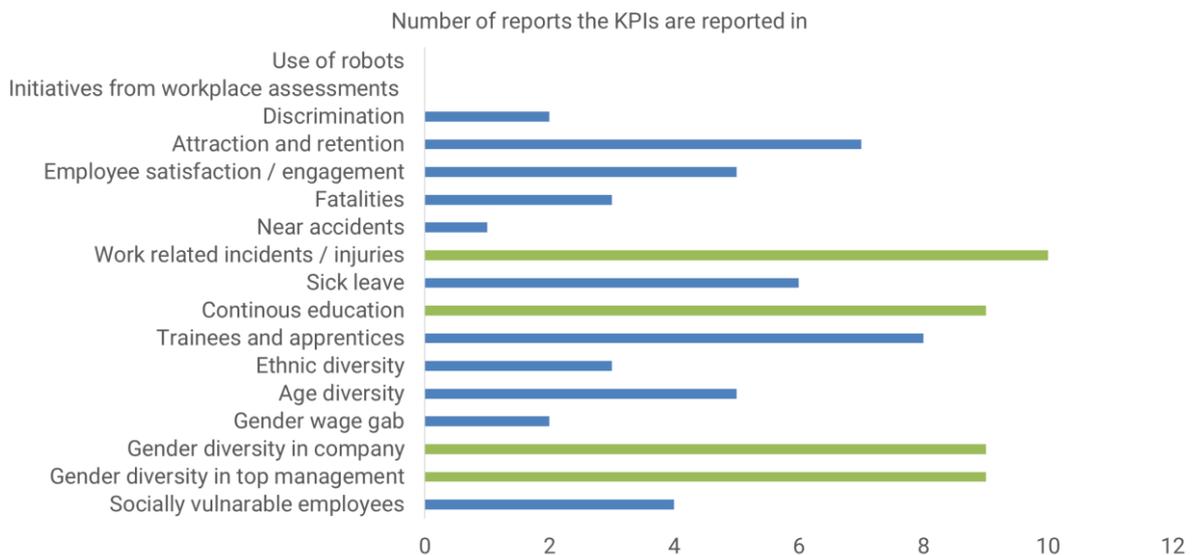


Figure 3: Frequencies of issues in provider companies' sustainability policies. (Desk study by Konsulentgruppen Strandgade, 2025)

### Case studies

#### *fsb*

*fsb* focuses on the capital region and has more than 13.000 family, youth, and elderly homes. *fsb* uses the UN SDGs as a basis for their activities and defines local goals related to SDGs. *fsb* has identified nine SDGs and describes, how they relate to their activities in five strategies – one overall about the SDGs and specific strategies for social housing, building client, environment and procurement. The case concerns a social masterplan (SMP) and building renovation in a district in Copenhagen.

The organization for the SMP included 11 employees located at an office in the area, and all are project employed, but several come from a former project in the same area. This is also the case for the leader of the SMP (Interviewee 3). The housing associations make frequently updated lists of tenants, who have not paid their rent, and these are used for outreach by the SMP and representatives for the Copenhagen municipality to counsel the residents as arrears are typical symptom of social problems. The municipality had prepared a list of contact persons, who can be involved.

The organisation offers, among other things, resident counselling and support for local networks. They work with jobs and education for young people and adults, active leisure life for children, urban development etc. They collaborate with the municipality and many other partners, including local schools, police, local and national institutions, association, and communities, and a SMP in the neighbouring area.

*fsb's* organization for building and operation is divided in a building department with 24 employees and an operation department with 21 employees at the HQ and 170 decentral employees – technical service staff taking care of the operation of the estates. All their new building projects are certified according to DGNB-DK (Danish adaptation of the German DGNB-system), and they work on also having their renovation projects certified.

The main purpose of renovation projects is to improve the housing conditions. *fsb* establishes a reference group in their renovation projects, which is closely related to the tenant democracy. They often also have good opportunities to help tenants to be rehoused temporarily during renovation projects or permanently due to a large housing stock and staff trained in tenant counselling. There is also a focus on combining physical renovation with social renovation. LBF has, together with other stakeholders, published a report on social renovation particularly focusing on reducing loneliness among elderly tenants by physical interventions. They define social renovation as a physical renovation, that takes responsibility for the coming life in the department and includes more than just technical measures, energy optimization and aesthetic upgrading (LBF, 2017).

LBF requires that at least 14 % of construction workers are apprentices on the renovation projects they support. Public housing associations also have opportunities to offer employment to tenants with limited or no employment, and this is a part of *fsb's* strategy. They have employed a person to focus particularly on the employment of

tenants, and as the renovation projects are time limited, they see employment by a contractor to be the most successful as this can lead to more permanent employment.

### **SAB**

“Social operation” differs from the project-based interventions in *fsb*. “Social operation” is an initiative, which involves the whole organisation in *SAB*. It aims at supporting and developing their employees in their encounter with residents, who are socially challenged and affected by unhappiness and mental vulnerability. The focus is to spot unhappiness earlier and address concerns towards the residents, so that it is experienced as a helping hand, and to build a bridge to municipal and regional help. *SAB* has many small homes with many single persons with low incomes. The municipality in Copenhagen uses the special agreed allocation right of 35 %, and there are many residents with mental illnesses and residents, who have been homeless and previously placed in institutions. *SAB* hired an employee in 2024 to be responsible for the implementation.

*SAB*'s board states that we in Denmark have been used to having a welfare system that steps in when there are problems. We still have that, but the network under all of us is not quite as fine-meshed as it used to be. The board is aware that many will think that it is the municipality's task to help vulnerable residents, and that it is not the residents who should pay for the task to be carried out. But they feel the consequences of the task being given a lower priority in the municipalities, and they do not believe that it is fair that it is up to one or more departments to purchase extra assistance (social caretakers). It is a common task that no department should experience being alone with. The board also believes that it is a good investment – financially and in terms of well-being – and it is a way to work purposefully to solve the problems and develop as a socially responsible housing company.

“Social operation” aims at:

- Improving social welfare among social challenged and mentally vulnerable residents in the departments
- Reducing the inconvenience some neighbours experience as a consequence of residents' unhappiness, vulnerability and negative physical and mental developments

- Freeing up resources from department boards so that they have time for other tasks instead
- Reducing the resource drain and poor working environment among operations staff who meet and communicate with residents who are affected by unhappiness and mental vulnerability
- Working to solve social challenges together across the organization, so that it is not the individual department

“Social operation” includes three tracks:

1. *Upskilling of operational staff:* Through annual theme days, operational staff must be better equipped to spot unhappiness earlier and to handle these situations.
2. *Development of strong professionalism in bridge building:* Employees are supported in developing increased awareness of whether a resident needs help, including an internal social lifeline.
3. *Support the collaboration between SAB and the municipalities:* Qualify the dialogue between SAB and the municipalities around the social challenges that the departments experience.

## 1. Discussion

The 2024 survey showed that only 13 % of the respondents had defined KPIs related to social matters, and these were not FM-specific but linked to their broader organisation and mainly focussed on own workforce (ESRS S1). The desk study of the measures defined by service providers also showed that they solely focused on own workforce.

The survey showed that FM organisations are working with ESG but at a much lower pace than expected. The majority of FM organisations are responding to group strategies and top-down goals. They are not taking part of the strategic process even though they hold a great amount of knowledge on what can be achieved and how FM with a major social and environmental impact can contribute to group ESG goals.

FM organisations are increasingly aware of the data demands, but struggle to collect, manage and use data analytically due to the continuous lack of data management systems targeting FM. The increase in manually managed data combined with a slow development of FM organisations suggests that there is a significant potential for optimisation with IT investments to support FM organisations ESG work. The social

sustainability agenda is difficult to comply with for the client organisations, so the FM provider who can support the client with measurable social goals will have a clear competitive advantage.

Table 6 shows a comparison of the different approaches to social sustainability in the case studies. It shows that they are very different in both scope and duration, but they have the main emphasis on the tenants as stakeholder. However, they also include impacts on the other groups of stakeholders. They all include concerns for neighbourhood. Building renovation has particularly impact on employees in the supply chain by social clauses and requirements for number of apprentices, even though the sustainability reporting standard for Danish SHAs does not include measures for workers in the supply chain. “Social operation” includes concerns for employees’ wellbeing.

**Table 6: Comparison of Social master plans, Building renovation and Social operation**

<b><i>Position</i></b>	<b><i>Social master plans</i></b>	<b><i>Building renovation</i></b>	<b><i>Social operation</i></b>
Scope	Local district	Housing Department	Whole housing association
Duration	4-year program	Project dependent	Permanent
Stakeholder benefits:			
Tenants	Social improvements	Housing conditions Job opportunities	Social improvements
Own staff	Social engagement	Social engagement	Social engagement Well-being
Service providers	Safer environment	Apprentices	Safer environment
Neighbourhood	Safer environment	Housing conditions	Safer environment

## **2. Conclusion**

The results show that client organisations, provider companies and SHAs present very different approaches to social sustainability. Client organisations do not have much

focus on social sustainability and FM organisations do not play a major role in the companies' ESG reporting. FM responds to group strategies rather than leading or strategically impacting the ESG agenda. However, many respondents inform that the ESG regulation has resulted in organisational changes in the FM department. Provider companies mainly focus on own workforce, which can be an inspiration to client organisations when setting targets and data requirements concerning ESRS S2 (value chain workers).

SHAs mainly focus on their tenants, but also include concerns for own employees, workforce in the supply chain, and the surrounding community. FM organisations in other companies can benefit from experiences from social sustainability in SHAs.

Despite the variability of company-specific contexts, valuable insights can be gained from facilities management practitioners and professionals operating across the broader industry landscape. The paper can help practitioners to work with social sustainability and measuring the social dimension of ESG.

The paper focus on how FM contributes to the social dimension of ESG in a Danish context. The ESG requirements are new with limited reporting experience, so it would be interesting to make follow-up studies to see how the implementation and the possible social effects develop. Similarly, it would be interesting with similar studies in other countries.

### **Contribution by the authors**

The third author initiated the paper and is the main author of section 1. Introduction and section 2. Framework. The remaining sections were written jointly by all three authors with the first and second author responsible for surveys and the desk study and the third author responsible for case studies.

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# **Data Envelopment Analysis for Sustainable Healthcare: Ranking Hospitals based on CO<sub>2</sub> Emissions; Desirable/Undesirable Output**

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## **Abstract:**

Performance management in hospitals can help optimize healthcare delivery, efficient resource allocation, and sustainability, especially in the growing operational and environmental challenges. A comprehensive review of performance measurement tools and techniques in healthcare shows that among quantitative techniques, data envelopment analysis (DEA) has emerged as a widely used tool. DEA has emerged as a prominent method in recent literature due to its flexibility in handling multiple inputs and outputs, including both desirable and undesirable factors. This study applies a customized DEA model, capable of accounting for undesirable outputs, to evaluate the performance of hospitals participating in the OPIK project in 2023. The OPIK is an open, university-led benchmarking pool for technical managers of public hospitals in German-speaking countries. The study ranks these hospitals based on efficiency scores focused on CO<sub>2</sub> emissions, an essential aspect of sustainability in healthcare facilities. The model ranks hospitals based on their efficiency and identifies benchmarks for inefficient hospitals. The results highlight the potential of DEA in addressing current challenges in healthcare performance management and contribute to the growing literature on healthcare performance evaluation.

## **Keywords:**

Data Envelopment Analysis (DEA), Undesirable Output, Performance Management, Hospital Efficiency

## 1. Introduction

Performance management plays a central role in the strategic development and sustainability of healthcare systems worldwide. According to ISO 9004, performance is a measurable result that can relate either to quantitative or qualitative findings concerning the management of activities, processes, products, services, systems, or organization (ISO 9004: 2018). This definition highlights the flexibility and scope of performance indicators, which are especially crucial in hospitals; highly complex and resource-intensive entities, that are fundamental for delivering healthcare. Hospitals consume an excessive share of healthcare expenditures and are simultaneously under pressure to improve clinical quality, reduce costs, and minimize their environmental impact, all while delivering healthcare services efficiently and meeting population needs.

Hospitals are the cornerstone of any health system, consuming a large share of resources while striving to deliver high-quality care. They account for 30–80% of total health spending (Hadian et al. 2025) and often face financial deficits even as they pursue quality objectives (Almehwari et al. 2024). Effective performance management, including operational efficiency, throughput and cost control, is therefore critical. Indeed, improving hospital efficiency and containing costs has long been an international priority (Almehwari et al. 2024). Well-managed hospitals can reallocate savings to patient care, enabling investments in new technology and staffing that further enhance quality (Hadian et al. 2025).

Hospitals are also unusually complex and resource intensive which are open 24 hours and 7 days a week (Lennerts et al. 2009). As the most complex facilities in a healthcare system, hospitals have high occupancy, treat critical and varied cases, and involve complex building systems and equipment (Dolcini et al. 2025). They consume vast amounts of energy (second-highest per unit area of any industry) (Dolcini et al. 2025), and they must coordinate thousands of staff and processes. This cost intensity and complexity mean that performance management must balance many factors including financial, clinical and operational, without sacrificing quality. Moreover, hospitals increasingly must meet sustainability goals. The healthcare sector contributes about 5.2 % of global greenhouse gases (Dolcini et al. 2025), and in OECD countries hospitals alone are the largest source of that footprint (roughly 28–36 % of healthcare emissions) (Dolcini et al. 2025). Thus, performance metrics are expanding beyond

traditional efficiency to include environmental impact, especially as health systems commit to Net Zero targets (Dolcini et al. 2025; Mirow et al. 2024).

Carbon emissions and environmental impact are now key performance dimensions. Healthcare's own climate footprint can undermine public health, creating a strong rationale for including sustainability in hospital metrics (Dolcini et al. 2025; Mirow et al. 2024). For example, highly developed health systems (which serve rising patient needs) paradoxically contribute significantly to climate change (Mirow et al. 2024). Hospitals emit greenhouse gases directly (from on-site energy use) and indirectly through procurement and supply chains (Mirow et al. 2024). In practice, CO<sub>2</sub> emissions are emerging as an "undesirable output" that performance evaluations must account for. Global initiatives (e.g. WHO's Healthy Hospitals Healthy People campaign and Net Zero pledge) emphasize reducing hospital carbon as essential to broader climate goals. Consequently, assessing hospital performance increasingly means measuring both healthcare outputs (like treated patients and outcomes) and environmental outputs (like CO<sub>2</sub> emissions).

DEA is a powerful tool for such multidimensional performance evaluation. DEA is a non-parametric benchmarking method that compares "Decision-Making Units (DMUs)" (here, hospitals) based on multiple inputs and outputs (Hadian et al. 2025; Jung et al. 2023). It identifies the efficient frontier of best practice units and measures others' relative efficiency. Crucially, DEA can incorporate undesirable outputs (like emissions or waste) by treating them appropriately (for instance, as inputs or by directional distance functions). This flexibility makes DEA attractive for sustainable performance analysis. In healthcare, DEA has become a leading efficiency technique (Jung et al. 2023), widely applied to hospital benchmarking (Hadian et al. 2025; Jung et al. 2023). Unlike simpler ratios, DEA handles many resources (beds, staff, costs) and outcomes (admissions, survival rates) simultaneously. In our study, a special DEA was used to include CO<sub>2</sub> emissions as an undesirable output.

Finally, evaluating hospitals today means linking to ESG (Environmental, social, and governance) and sustainability targets. Hospitals are aiming for decarbonization (in line with national Net Zero policies) by investing in renewable energy, retrofitting buildings, and optimizing operations. In short, hospital performance is now viewed through an ESG lens, economic efficiency must go hand in hand with environmental stewardship and social responsibility. As Dolcini et al. argue, embedding

environmental sustainability into health performance systems helps operationalize and prioritize green goals (Dolcini et al. 2025). By integrating DEA-based efficiency analysis to CO<sub>2</sub> benchmarks and green building metrics, our work links traditional hospital performance evaluation with the broader sustainability agenda, in this study the focus is on environmental performance.

## **2. Literature Review**

DEA was introduced in the late 1970s as a non-parametric frontier technique for measuring the relative efficiency of DMUs by Charnes et al., 1978 and has since become foundational in operations research and management (Mitakos & Mpogiatzidis 2024; Cook & Seiford 2009). Cook and Seiford's survey of 30 years of DEA research highlights its major developments (CCR, BCC models, multiplier restrictions, etc.) and broad applicability (Cook & Seiford 2009). Its flexibility, handling many inputs/outputs without pre-specified weights, has made DEA a standard tool across sectors.

### *DEA in Healthcare and Hospital Performance*

DEA has been widely applied to evaluate hospitals' technical and scale efficiency. Early studies (and many classical papers) used input or output-oriented CCR/BCC models to score hospitals, often highlighting large variation and inefficiency in public health systems (Cook & Seiford 2009; Otay et al. 2017). Over time, scholars expanded DEA's scope in healthcare. For instance, Jahantigh and Ostovare (2020) evaluated 40 Tehran teaching hospitals by first using PROMETHEE II to rank performance factors, then applying an output-oriented DEA model (4 inputs, 8 outputs) to compute efficiency (Jahantigh & Ostovare 2020). Similarly, Peixoto et al. (2018) applied Principal Component Analysis (PCA) and cluster analysis within a DEA framework to assess 20 Brazilian university hospitals, grouping them by performance characteristics and highlighting diverse efficiency profiles across regions (efficiency of hospitals with major specialty services vs smaller units). These multivariate-DEA hybrids illustrate how DEA can be embedded in larger analyses (PCA for dimensionality reduction; clustering for taxonomy) to manage many variables and classify units for benchmarking (Peixoto et al. 2018).

### *Chronological Developments in Hospital DEA*

The hospital DEA literature has evolved chronologically. Early 2000s–2010s: foundational reviews (e.g. O'Neill et al. 2008; Otay et al. 2017) established DEA as the

go-to tool for hospital efficiency analysis. Researchers applied CCR/BCC models to national hospital datasets (USA, Europe, etc.), often identifying very high average technical efficiency but also many inefficiencies due to excess inputs (beds, staff) or underutilization.

Recent years (2017–2023): focus has shifted to more complex models and contexts. Ghahremanloo et al. (2020) introduced a novel DEA-EEP model that simultaneously measures Efficiency, Effectiveness, and Productivity of hospitals (Ghahremanloo et al. 2020).

Other recent studies have compared DEA with parametric methods. For example, Moses et al. (2021) applied Stochastic Frontier Analysis (SFA) to estimate technical efficiency of Kenya's 47 county health systems, finding a median efficiency of ~84% and identifying declining efficiency trends in many counties (Moses et al. 2021).

A major theme is accommodating real-world complexities. Slack-based and non-radial DEA models, introduced by Tone (2001) and others, allow non-proportional changes and directly incorporate slacks (excess inputs or shortfall in outputs). Fang et al. (2024) applied a directional slacks-based measure (SBM) in a three-stage DEA to Chinese provincial health data (2012–2021) (Fang & Li 2024). A directional SBM, unlike radial DEA, can expand desirable outputs and contract undesirable ones without assuming radial changes. Similarly, many studies use additive or range-adjusted measures for hospitals to fully rank units. The Sustainability (2024) study on medical waste recycling explicitly notes that SBM is “particularly suitable for handling undesirable outputs” (Song et al. 2024), highlighting that slack-based, non-oriented DEA is well suited when some outputs (e.g. pollution or waste) should decrease rather than increase.

#### *DEA and Undesirable Outputs (Sustainability)*

The literature increasingly recognizes undesirable outputs in healthcare; such as waste generation, emissions, or negative patient outcomes, and incorporates them in DEA. During the COVID-19 pandemic, scoping reviews found a clear shift toward including undesirable factors (e.g. mortality rates) in DEA models (Mitakos & Mpogiatzidis 2024). Mitakos & Mpogiatzidis (2024) report that researchers explicitly added hospital mortality (an undesirable output) and other quality-of-care metrics into efficiency models to obtain a more holistic performance view (Mitakos & Mpogiatzidis 2024).

For example, Yu et al. (2020) analyzed Chinese hospital productivity using a meta-frontier DEA and Malmquist–Luenberger index, including atmospheric pollution from incinerating medical waste as an undesirable output (Yu et al. 2020). Monzeli et al. (2025) similarly incorporated both desirable and undesirable outputs in a DEA of 30 Tehran emergency wards, emphasizing that explicitly modeling waste/cost factors leads to more accurate efficiency comparisons (Monzeli et al. 2025). They note that including undesirable inputs/outputs “significantly influences the identification of the efficiency frontier”, providing a “more accurate reflection of real-world constraints (Monzeli et al. 2025).

### 3. Methodology

In DEA, an efficient DMU produces maximal desirable outputs for given inputs or, equivalently, uses minimal inputs for given outputs. The Slack-Based Measure (SBM) model introduced by Tone (2001) (Ma et al. 2018), is adopted because it is *non-radial* and handles input/output slacks directly. Unlike classical radial DEA models (CCR/BCC) that assume proportional changes in all inputs/outputs, the SBM model explicitly accounts for excess inputs and shortfalls in outputs (Yu et al. 2020, Ma et al. 2018). This feature is crucial here, as *excess capacity* (e.g. unused beds, surplus electricity usage) or *insufficient* outputs (patients served) may be present in hospitals, and these slacks need to be quantified.

Importantly, both desirable outputs (inpatients and outpatients) and an undesirable output (CO<sub>2</sub> emissions) are included. The SBM framework accommodates undesirable outputs without data transformation. It treats them like outputs that should be *minimized* rather than maximized (Yu et al. 2020, Żyłowski et al. 2023). In other words, efficiency improves when a hospital reduces CO<sub>2</sub> emissions (an undesirable “output”) while maintaining or increasing patient services. Tone (2004) showed that SBM can handle non-separable desirable and undesirable outputs simultaneously (Ma et al. 2018), and recent studies in healthcare advocate this approach for environmental impacts (Yu et al. 2020; Żyłowski et al. 2023).

We consider 12 DMUs, denoted by the index  $j$ , where  $j$  ranges from 1 to  $n$ . For each hospital (DMU) denoted by subscript 0, let the input vector be  $x_{i0}$  ( $i = 1, \dots, m$ ) where  $m = 2$  (number of beds, electricity consumption), the desirable (good) outputs  $y_{g0}$  ( $g = 1, \dots, s$ ) where  $s = 2$  (inpatients, outpatients), and the undesirable (bad) output

$b_{b0}$  ( $b = 1, \dots, t$ ) where  $t = 1$  (CO<sub>2</sub> emissions). We introduce slack variables  $s_i^- \geq 0$  for input excesses,  $s_g^+ \geq 0$  for desirable output shortfalls, and  $s_b^- \geq 0$  for excess undesirable outputs [20].

Under the assumption of constant returns to scale (CCR technology), the SBM efficiency score  $\rho$  for DMU<sub>0</sub> is obtained by:

- 1) Objective:  $\min \rho$
- 2) Constraints:

$$2.1. \quad x_{i0} = \sum_{j=1}^n x_{ij} \lambda_j + s_i^-, \forall i \in I$$

$$2.2. \quad y_{g0} = \sum_{j=1}^n y_{gj} \lambda_j - s_g^+, \forall g \in G$$

$$2.3. \quad b_{b0} = \sum_{j=1}^n b_{bj} \lambda_j + s_b^-, \forall b \in B$$

$$2.4. \quad \rho \cdot \left( 1 + \frac{1}{s} \sum_g \frac{s_g^+}{y_{g0}} + \frac{1}{t} \sum_b \frac{s_b^-}{b_{b0}} \right) = 1 - \frac{1}{m} \sum_i \frac{s_i^-}{x_{i0}}$$

Here  $n = 12$  is the number of hospitals (DMUs) in our sample,  $\lambda_j \geq 0$  are intensity variables combining peer hospitals to form a reference, and  $s_i^-$ ,  $s_g^+$ ,  $s_b^-$  are the respective slacks. These constraints ensure that each hospital's inputs and outputs are compared to a convex combination of other hospitals; input slacks  $s_i^-$  represent excess input over the reference mix, output slacks  $s_g^+$  represent shortfall in good outputs, and  $s_b^-$  represents excess undesirable output. All slacks are equal or greater than 0 and  $\lambda_j \geq 0$ . This formulation naturally minimizes inputs (through  $s_i^-$ ) and maximizes desirable outputs (through  $s_g^+$ ), while minimizing the undesirable output slack  $s_b^-$ .

By construction, SBM does not require any ad-hoc transformation of undesirable variables (e.g. taking reciprocals or treating them as inputs) (Żyłowski et al. 2023). Instead, it directly incorporates CO<sub>2</sub> emissions as an output slack to be reduced. This preserves the physical interpretation of each variable. Tone (2004) and others argue that SBM yields a unique efficiency score that reflects both kinds of slacks, and is thus well-suited when both input excess and undesirable outputs exist [19]. Empirical studies in healthcare efficiency under environmental constraints likewise employ non-radial SBM models with undesirable outputs (Yu et al. 2020, Ma et al. 2018). Cooper et al. (2011) note that advanced DEA models (such as SBM) have been developed to

address multiple inputs/outputs and relaxation of proportionality assumptions, which is important in contexts like hospitals. In summary, the SBM model allows us to rank hospitals by a single efficiency index that rewards lower inputs, higher patient outputs, and lower CO<sub>2</sub> emissions simultaneously.

We also adhere to common DEA practice regarding sample size. A frequently cited rule-of-thumb is  $n \geq \max \{m \times s, 3(m + s)\}$  (Wong 2021). For our case  $m = 2$ ,  $s + u = 3$  (treating the one undesirable output as an “output” in the formula), this rule gives  $n \geq \max \{2 \times 3, 3(2 + 3)\} = 15$ . Our dataset has  $n = 12$  hospitals, which falls slightly below this threshold. While many DEA applications proceed with  $n < \max \{m \times s, 3(m + s)\}$ , we note this as a limitation; a smaller  $n$  relative to  $m + s$  may reduce discrimination among units (Wong 2021). Nonetheless, the SBM approach remains valid; we interpret efficiency scores with this caution in mind. To assess the impact of sample size in this study, sensitivity tests were conducted using subsets of three DMUs. The SBM model continued to yield varying efficiency scores rather than classifying all units as efficient, suggesting that the homogeneity and similarity of hospitals in this dataset reduce the risk of trivial efficiency classification.

It should be noted, however, that if a larger number of hospitals were available, some units currently labeled efficient might no longer achieve efficient status in a more discriminatory setting. Accordingly, the results are interpreted cautiously and viewed as exploratory rather than definitive.

By explicitly incorporating CO<sub>2</sub> as an undesirable output, this model operationalizes the environmental pillar of ESG performance. The resulting efficiency scores thus capture not only operational effectiveness but also the environmental sustainability of each hospital.

#### **4. Data and variables**

The input–output data come from the KIT OPIK project (Open Benchmarking Round for hospitals). OPIK is a German-speaking hospital benchmarking network coordinated by the Karlsruhe Institute of Technology. Participants report facility metrics via a shared database. For 2023, twelve hospitals provided complete data and were included in our analysis. Our inputs are Beds (number of hospital beds in operation) and Electricity consumption (kWh), representing key resource usages. The desirable outputs are Inpatients (number of overnight-stay patients treated) and Outpatients (number of

outpatient cases). The single undesirable output is CO<sub>2</sub> Emissions associated with the hospital's energy use (in metric tons). We assume that more inpatients/outpatients is better, while more CO<sub>2</sub> is worse. (All hospitals operated in a similar regulatory environment, so we use a constant returns to scale (CRS) model. These variables reflect standard practice in environmental healthcare DEA. For example, inpatients/outpatients capture service output, and energy-related CO<sub>2</sub> is a measurable byproduct of hospital operations (Yu et al. 2020; Żyłowski et al. 2023).

The data for the model are presented in Table 1. To ensure the anonymity of the hospitals, the values have been normalized by dividing them by their respective minimum, thereby obscuring direct identification while preserving relative relationships.

**Table 1- Input values to solve the model**

<i>DMUs</i>	<i>Inputs</i>		<i>Desirable outputs</i>		<i>Undesirable outputs</i>
	<i># of Beds</i>	<i>Electricity Consumption</i>	<i>Outpatients</i>	<i>Inpatients</i>	<i>CO<sub>2</sub> Emission</i>
H1	2.9936	3.6804	3.9919	2.9404	3.3600
H2	1.0000	2.5365	4.7067	1.3920	2.3202
H3	1.5227	3.0670	1.3175	1.3706	3.1225
H4	1.8745	4.1114	2.1315	1.8968	4.3841
H5	1.3818	4.0655	1.4143	1.1801	4.3058
H6	1.5227	1.0000	1.0715	1.1985	1.1661
H7	1.4509	1.5039	1.0000	1.1539	1.5302
H8	1.0000	3.5776	1.7104	1.0000	3.9433
H9	1.2273	5.0042	1.2490	1.3462	4.0601
H10	1.3191	2.7888	1.5001	1.2096	8.1725
H11	1.3755	4.1138	2.6727	1.0765	3.9688
H12	1.4855	1.2268	1.2980	1.0572	1.0000

## 5. DEA structure

For clarity, one can imagine plotting each hospital in a multi-dimensional input-output space and then drawing an *efficiency frontier* through the best-performing points. Hospitals on the frontier (efficiency=1) have no slacks and represent best practice.

They produce the most health services with least resource waste and emissions. Hospitals below the frontier have gaps. The SBM framework constructs this frontier via linear programming and computes for each hospital how much its inputs or outputs could be improved (i.e. how much slack would need to be eliminated) (Ma et al. 2018; Żyłowski et al. 2023). In the analysis, an efficiency score for each hospital is obtained, and the peer hospitals or reference sets have also been identified. Indeed associated input/output targets required to reach the frontier, including output augmentations and input/emission reductions derived from the slacks.

## 6. Results and Discussion

Table 2 presents the efficiency scores ( $\rho$ ) for each of the 12 hospitals along with their reference sets under the constant returns to scale (CRS) slack-based DEA model. The efficiency score is a relative measure between 0 and 1, where 1 (or 100%) represents a hospital on the efficient frontier (best practice) and values below 1 indicate the proportion of performance relative to that frontier.

Table 2- Efficiency scores and reference sets

<i>Hospital</i>	<i>Efficiency (<math>\rho</math>)</i>	<i>Reference set (peer DMUs)</i>
H1	<b>1.00</b>	<b>H1</b>
H2	<b>1.00</b>	<b>H2</b>
H3	<b>0.29</b>	<b>H2</b>
H4	<b>0.34</b>	<b>H2</b>
H5	<b>0.23</b>	<b>H2</b>
H6	<b>1.00</b>	<b>H6</b>
H7	<b>0.53</b>	<b>H2, H6</b>
H8	<b>0.30</b>	<b>H2</b>
H9	<b>0.23</b>	<b>H2</b>
H10	<b>0.28</b>	<b>H2</b>
H11	<b>0.30</b>	<b>H2</b>
H12	<b>1.00</b>	<b>H12</b>

Each inefficient hospital's reference set in Table 1 identifies the efficient peer(s) that form the benchmark for that hospital. The reference set is essentially the peer group or combination of best-practice hospitals that the DEA model uses to project the inefficient hospital onto the efficiency frontier. For instance, Hospital H7 ( $\rho = 0.53$ ) has a reference set of {H2, H6}, meaning that a composite of efficient hospitals H2 and H6 (with some weighting  $\lambda$ ) defines the performance target for H7. In practical terms, H7 should strive to emulate the practices of H2 and H6 (H2 in certain aspects and H6 in others) to improve its efficiency. The presence of multiple units in a reference set implies that no single peer had the same input-output profile to dominate; instead, a convex combination of peers is needed. This is common in DEA, an inefficient DMU is often benchmarked against a mix of efficient DMUs, each contributing to the target. If only one peer is listed (as with H3 referencing H2), it indicates that a single efficient hospital (H2) was sufficient to serve as the benchmark for that DMU's improvement. The concept of the reference set is valuable for managers because those peer units can highlight the weak aspects of the inefficient hospital's performance and provide concrete targets.

#### *Slack Values and Performance Gaps*

While the efficiency score  $\rho$  tells us *how far* a hospital is from the frontier, the slack values in Table 3 reveal *where* and *how* a hospital is inefficient. Table 3 lists the slack for each input and output for all hospitals. Slack represents excess inputs or shortfalls in outputs that remain even after a hospital is radially projected onto the frontier. In the context of an SBM model, any non-zero slack indicates an inefficiency in that specific dimension. An efficient hospital will have no slacks in any input or output. It means it is impossible to improve any input or output without worsening another. Whereas an inefficient hospital typically has one or more slacks, indicating waste or underperformance in those categories.

Positive input slack indicates an excess amount of that input (unused resource that could be reduced), while a positive good-output slack indicates a *shortfall* (output that could be increased). A positive undesirable output slack (CO<sub>2</sub>) indicates an excess of emissions that should be cut down. All values are in the original units of each measure.

**Table 3- Input and output slack values**

<i>Hospital</i>	<i>Beds</i>	<i>Electricity</i>	<i>Outpatients</i>	<i>Inpatients</i>	<i>CO2</i>
H1*	0	0	0	0	0
H2*	0	0	0	0	0
H3	591.82	9.28	654619.41	5.5	10053.46
H4	563.03	1.06	845068.49	0	14669.06
H5	587.42	3.12	508328.87	0	28065.29
H6*	0	0	0	0	0
H7	316.03	0	275124.79	0	328.75
H8	309.73	2.86	329720.36	0	27316.68
H9	286.15	4.15	651778.35	0	21794.47
H10	495.07	9.52	511069.49	0	73873.62
H11	662.31	3.50	190861.76	0	26093.26
H12	0	0	0	0	0

*Interpretation of Efficiency and Reference Sets*

A score less than 1 implies relative inefficiency. The hospital could improve by either reducing inputs, increasing outputs, or both. The reference set tells us *who* the hospital should emulate. For H7, the reference set {H2, H6} means that some weighted blend of Hospital 2 and Hospital 6’s performance was used as the benchmark. If a hospital’s reference set contains multiple peers, it often implies that no single peer was a perfect role model on its own; the hospital may need to adopt different best practices from multiple sources. This is a common scenario; one peer might excel in operational efficiency (input usage) and another in service output, and the combination sets a holistic target. Identifying these peer units is extremely useful for benchmarking. They effectively form a peer benchmark group for the inefficient hospital. Hospital managers

can look at the practices of each peer to understand which changes could yield the improvements indicated by the slacks.

### *Benchmarking and Managerial Insights*

The findings from this DEA-SBM analysis can help craft targeted benchmarking strategies. Each inefficient hospital has a custom roadmap. Its efficiency score tells how much improvement is needed overall; its reference peers show who to learn from; and its slacks detail what to improve and by how much. Managers can set specific improvement targets such as “reduce electricity use by X kWh per year” or “increase inpatient admissions by Y%” based on the slack values. Because DEA provides *quantitative targets*, it moves beyond vague suggestions for inputs and outputs.

By comparing to peer hospitals, there is also a learning aspect, sometimes called *benchmarking to best practice*. If one hospital’s peers all achieve significantly higher outpatient visits per physician than it does, that points to exploring what those peers are doing differently (perhaps they have better scheduling systems or use telehealth, etc.). In this regard, the DEA results promote knowledge transfer, inefficient units have concrete examples of better-performing models. This peer benchmarking is one of DEA’s strengths, as it not only labels units as inefficient but also tells each one *how to become efficient* by emulating others.

Finally, it is worth noting the role of returns to scale in improvement strategy. Under the CRS assumption, some hospitals may be inefficient partly due to scale mismatches. In the context of this study, if any smaller regional hospital was inefficient, the solution might be to increase its catchment area or services to utilize resources fully. These strategic decisions are supported by DEA analysis, we can identify whether inefficiency is mostly due to poor internal performance (slacks) or an inappropriate scale of operation. In sum, the DEA-SBM with undesirable outputs, provides a comprehensive performance evaluation. It identifies not just *how efficient or not* each hospital is, but pinpoints *why* and *in what ways* they are inefficient and offers insight into *how* to improve along both operational and environmental dimensions.

## **7. Conclusion**

This study evaluated the performance of 12 hospitals using a CRS slacks-based DEA model that accounted for both desirable (outpatient and inpatient) and undesirable

outputs (CO<sub>2</sub> emissions). The *Results and Discussion* above highlighted that 4 of 12 hospitals were fully efficient, while the remaining hospitals exhibited varying degrees of inefficiency. By examining efficiency scores, peer reference sets, and slack values, we gained understanding of each hospital's performance shortcomings. In summary, the DEA results indicate that many hospitals are operating below their potential, it means using more resources than necessary and/or not producing as much health service as they could, and there is significant room for improvement in both operational and environmental dimensions.

Key findings is that several hospitals have *excess inputs* indicating that resources are not being utilized to their fullest extent. At the same time, many have *output shortfalls*, especially in outpatient visits, suggesting that these hospitals could serve more patients with the resources at hand. The incorporation of CO<sub>2</sub> as an undesirable output proved insightful that a number of hospitals that were technically efficient in service delivery were found to be environmentally inefficient, emitting more CO<sub>2</sub> than the best-practice level. This indicates hidden inefficiency. Traditional models ignoring bad outputs would miss and underscores the importance of including environmental performance in the evaluation of healthcare efficiency.

The analysis provides concrete guidance for hospitals striving to improve. First, reducing operational inefficiencies is vital as hospitals with excess capacity (e.g. unused beds or staff downtime) should seek to either scale down those inputs or increase patient volume to utilize them. This might involve budget reallocations, process improvements, or even structural changes like consolidating departments. This dual focus on operational and environmental efficiency reflects a modern view of hospital performance that values sustainability alongside productivity.

One of the strengths of this DEA evaluation is its capacity to facilitate peer learning. Each inefficient hospital has been associated with one or more best-practice peers. For hospital administrators and clinicians, this provides a very tangible starting point, they can initiate knowledge exchange with the identified peer institutions to understand how those hospitals achieve superior performance. If a hospital's peers are, say, particularly good at managing outpatient workflows (resulting in no outpatient slack), a visit or case study review could reveal specific innovations (like advanced scheduling systems, better integration with primary care, etc.) that could be adopted.

Our use of the CRS model means the efficiency scores reflect overall technical efficiency without isolating scale effects. The results suggest that some hospitals might be operating on a suboptimal scale. Policymakers can use these insights to ensure that the hospital network is well-balanced, meaning that neither overly concentrating services in a few large centers nor spreading resources too thin across many small units. In practice, combining this study's results with a variable-returns DEA or other scale analysis could pinpoint which hospitals have scale issues. For now, a prudent recommendation is that each hospital's leadership reflects on whether their institution's size is appropriate given its performance.

In closing, the DEA CRS SBM model with undesirable outputs has proven to be a powerful tool for evaluating and discussing hospital performance. It provides a comprehensive perspective that encompasses both efficiency in healthcare delivery and environmental stewardship. The results and discussion offered a detailed look at where hospitals can improve; from cutting excess resource use to boosting patient care delivery to reducing carbon emissions.

In the current context, ESG performance has become increasingly important for healthcare institutions. This study demonstrates that environmental performance can be quantitatively incorporated into efficiency assessments through innovative DEA-based approaches. By explicitly modeling CO<sub>2</sub> emissions as an undesirable output, the analysis provides a transparent and data-driven way to evaluate hospitals' environmental responsibility. This contributes to a more systematic and comparable understanding of sustainability performance across hospitals.

By following the data-driven insights (peer benchmarks and slack targets), hospitals can devise focused improvement programs. Over time, such efforts should lead to more efficient and sustainable healthcare operations, ultimately benefiting not just the hospitals in terms of cost and performance metrics, but also the patients and communities they serve through better care and a healthier environment.

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# Die Neufassung der Gebäudeeffizienz-Richtlinie 2024: aktuelle Entwicklungen und Auswirkungen auf die zukünftige Bewirtschaftung von Gebäuden

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## Abstract:

Mit dem Green Deal wurde 2019 eine konzertierte Aktion zur Transformation der europäischen Wirtschaft mit dem Ziel der Dekarbonisierung initiiert, was die Überarbeitung von rechtlichen Rahmenbedingungen erforderlich machte. In diesem Zusammenhang kam es auch zur Neufassung der Gebäudeeffizienz-Richtlinie im Jahr 2024, in der die bisher enthaltenen Elemente konkretisiert und Anforderungen verschärft werden. Das betrifft unter anderem die „Smart Readiness“ von Gebäuden und den Renovierungspass inklusive Sanierungsfahrplan für Gebäude. Die Analyse im Zusammenhang mit der EU-Taxonomie-Verordnung sowie den relevanten Europäischen Sustainability Reporting Standards (ESRS) gemäß Corporate Sustainability Reporting Directive zeigt, dass Synergieeffekte in Bezug auf Datenerfassung, Auswertung und Nutzung bestehen. Die Bedeutung von Datenbanklösungen und Gebäude-Logbüchern steigt. Mit einer Adaptierung von Prozessen kann ein Mehrwert generiert und der Zusatzaufwand vermindert werden. Damit bestehen auch Auswirkungen auf das Facility Management, die in diesem Beitrag skizziert werden.

*With the Green Deal, a concerted action was initiated in 2019 to transform the European economy with the aim of decarbonisation, which made it necessary to revise the legal framework. In this context, the Energy Performance of Buildings Directive was also revised in 2024, in which the elements previously contained were specified and requirements were tightened. Among other things, this concerns the "smart readiness" of buildings and the renovation passport including a renovation roadmap for buildings. The analysis in connection with the EU Taxonomy Regulation and the relevant European Sustainability Reporting Standards (ESRS) in accordance with the Corporate Sustainability Reporting Directive (CSRD) shows that there are synergy*

*effects in terms of data collection, evaluation and utilisation. The importance of database solutions and building logbooks is increasing. Adapting processes can generate added value and reduce additional costs. This also has implications for facility management, which are outlined in this article.*

**Keywords:**

Gebäudeeffizienz-Richtlinie, Gebäuderenovierung, Gebäudebewirtschaftung

## 1. Einleitung

Der Green Deal löste 2019 die Entwicklung und Überarbeitung von rechtlichen Rahmenbedingungen aus, um die auf Dekarbonisierung beruhenden Transformationsziele zu erreichen. (Europäische Kommission 2019). Tabelle 1 zeigt den Zusammenhang zwischen den übergeordneten Strategien und ausgewählten Politikinstrumenten für den Gebäudebereich. In diesem Beitrag wird vor allem auf die Neufassung der Gebäudeeffizienz-Richtlinie (EU) 2024/1275 eingegangen, in der die bisher enthaltenen Elemente konkretisiert und Anforderungen verschärft werden. Das betrifft z.B. die „Smart Readiness“ (Intelligenzfähigkeit) von Gebäuden und den Renovierungspass inklusive Sanierungsfahrplan für Gebäude. Weiters werden die Zusammenhänge mit der EU-Taxonomie-Verordnung 2020/852 und der Richtlinie (EU) 2022/2464 (CSRD – Corporate Sustainability Reporting Directive) beleuchtet und in Bezug auf Synergieeffekte bei der Datenerfassung, Auswertung und Nutzung analysiert. Die neuen Vorgaben haben auch Auswirkungen auf das Facility Management, die in diesem Beitrag skizziert werden. Der Beitrag ist wie folgt aufgebaut: Nach der Einleitung in Abschnitt 1 gibt Abschnitt 2 einen Überblick über die betroffenen Materien, um den unterschiedlichen Fachleuten den Einstieg in die interdisziplinäre Diskussion zu erleichtern. Abschnitt 3 präsentiert detaillierte Inhalte relevanter Bestimmungen, Abschnitt 4 präsentiert eine Analyse in Bezug auf mögliche Entwicklungen im Bereich des Facility Management und Abschnitt 5 fasst die Schlussfolgerungen zusammen. Die hier präsentierten Inhalte wurden im Rahmen der EU-Projekte TIMEPAC (Programm Horizon 2020) und easySRI (Programm LIFE), sowie im Rahmen der Forschungstätigkeit der FH Wien der WKW erarbeitet.

Table 1: Übergeordnete Strategien, Regelwerke und Politikinstrumente

<b>Strategie</b>	<b>Regelwerk</b>	<b>Instrument</b>
Green Deal	Gebäudeeffizienz-Richtlinie	Energieausweis Intelligenzfähigkeitsfaktor Inspektion der technischen Gebäudesysteme Renovierungspass
Clean energy for all Europeans package	Erneuerbare Energien Richtlinie	Erneuerbare Energiegemeinschaften Zielvorgabe Erneuerbare Energie Anteil

NDC gemäß Paris Agreement	Energieeffizienz-Richtlinie	Energieaudit Vorbildwirkung von öffentlichen Gebäuden Renovierungsrate von öffentlichen Gebäuden
	EU-Governance- Verordnung	Nationaler Energie- und Klimaplan (NEKP)
	EU-Taxonomie- Verordnung	Nachweis der Erfüllung von Anforderungen
	CSRD	ESG Berichterstattung gemäß ESRS
	Level(s)	Nachweis der Erfüllung von Anforderungen

Legende: CSRD – Corporate Sustainability Reporting Directive; ESRS – European Sustainability Reporting Standard; ESG – Environmental, Social, Governance; NDC – Nationally Determined Contribution

## 2. Grundlagen

Es werden Grundlagen im Bereich Facility Management, energie- und gebäuderelevante Rahmenbedingungen sowie Unternehmens- und aktivitätenbezogene Rahmenbedingungen kurz präsentiert. Damit werden die Grundlagen für die nachfolgenden Analysen und Schlussfolgerungen dargestellt.

### 2.1 Facility Management

Unter dem Begriff Facility Management (FM) wird „eine organisatorische Funktion verstanden, die Personen, Orte und Prozesse innerhalb einer bebauten Umwelt zu dem Zweck integriert, um die Qualität des Lebens von Personen und die Produktivität des Kerngeschäfts zu verbessern“. (ÖNORM EN ISO 41011: 2019; ÖNORM EN ISO 41011: 2023) Die Hauptaufgabe des Facility Managements besteht darin, eine Organisation bei der Erfüllung ihrer Kernprozesse vorausschauend zu unterstützen. Zunächst werden Unterstützungsprozesse in der Organisation definiert und daran anschließend entsprechende Facility Produkte ausgewählt. Beispiele für standardisierte Facility Produkte sind nach der ÖNORM EN 15221-4: 2012 im Bereich der Fläche und Infrastruktur: Fläche, Außenanlage, Reinigung, Arbeitsplatz; und im Bereich Mensch und Organisation: Gesundheit, Arbeitsschutz Sicherheit, Hospitality, Information und Kommunikation, Logistik, Geschäftsunterstützung. Facility Management kann darüber hinaus erheblich zur Ressourceneffizienz beitragen und dafür sorgen, dass mit einem guten Risikomanagement Gebäude resilienter gegenüber den Auswirkungen des Klimawandels werden. Es kann spezifische

Strategien inklusive Monitoring zur Reduzierung der Emissionen entwickeln und so das Erreichen von Emissionssenkungszielen unterstützen. (ÖNORM EN 15221-8, 2023) Erst wenn der Bedarf geklärt ist soll die Verankerung des Facility Managements in der Organisation erfolgen, wofür in der Regel vier Möglichkeiten bestehen:

- a) Die oberste Leitung führt diese Aufgabe selbst aus
- b) Die oberste Leitung nutzt externe Unterstützung
- c) Die oberste Leitung wird von der internen FM-Organisation unterstützt
- d) Die FM-Organisation ist in der obersten Leitung der Organisation vertreten und für diese Aufgabe verantwortlich. (ÖNORM EN 15221-8, 2023)

Die Aufgabenfelder und Funktionen eines Facility Managers sind in den Unternehmen somit unterschiedlich, die Schlüsselkompetenzen, wie Sozialkompetenz, Fachkompetenz, Methodenkompetenz und Individualkompetenz sind aber immer dieselben. (ÖNORM A 7002, 2015) In der Berufsbildbeschreibung werden die Anforderungen an die Fachkompetenzen folgendermaßen festgehalten:

- „» **strategische Fähigkeiten**, wie z.B. ganzheitliches Denken und Kostenorientierung [...] von Unternehmensstrategien im Facility Management,
- » **Spezialwissen**, z.B. in den Bereichen Planen, Bauen, Bewirtschaften, Betreiben, Verwalten, Umnutzen von Gebäuden und anderen infrastrukturellen Einrichtungen, Organisation von Facility Services, Projektmanagement oder auch Sicherheitsmanagement sowie [...] Informationsbereitstellung und -verarbeitung,
- » **Verknüpfungswissen**, z.B. im Hinblick auf Prozessbeziehungen, Schnittstellen oder Wechselwirkungen zur bestmöglichen Unterstützung der Kernprozesse des Unternehmens/der Organisation.“ (Facility Manager 2013, S.20-21)

## 2.2 Energie- und gebäuderelevante Rahmenbedingungen

Die Neufassung der Gebäudeeffizienz-Richtlinie (EU) 2024/1275 macht genauere Vorgaben zu Elementen, die mit der Änderungsrichtlinie (EU) 2018/844 eingeführt wurden, nämlich zum Renovierungspass und zum Intelligenzfähigkeitsfaktor. Weiters ist die Energieausweisdaten-bank verpflichtend zu führen und eine Berichterstattung zu definierten Indikatoren an die Beobachtungsstelle für den EU-Gebäudebestand ist

erforderlich. Der Interoperabilität auf der Grundlage harmonisierter Datenformate und standardisierter Datensätze wird große Bedeutung beigemessen, allerdings werden dazu derzeit keine weiteren Vorgaben gemacht. Es erfolgt lediglich der Hinweis auf das digitale Gebäudelogbuch als zentrale Datendrehscheibe und Datenspeicherplatz. Gemäß Artikel 16 Datenaustausch erlässt die Kommission bis 31.12.2025 Durchführungsrechtsakte, in denen Interoperabilitätsanforderungen und nichtdiskriminierende und transparente Verfahren für den Zugang zu den Daten festgelegt werden.

Die Erneuerbare-Energien-Richtlinie (EU) 2018/2001, geändert durch Richtlinie (EU) 2023/2413, thematisiert sowohl die verstärkte Nutzung von Gebäuden zur Bereitstellung von erneuerbarer Energie als auch den erhöhten Eigenverbrauch von erneuerbarer Energie in den Gebäuden. In diesem Zusammenhang wird auch die wichtige Rolle von Flexibilitätsdienstleistungen und damit die Bedeutung von Gebäudeautomatisierungssystemen und Dateninteroperabilität hervorgehoben. (Artikel 15a Einbeziehung von Energie aus erneuerbaren Quellen in Gebäuden)

### **2.3 Unternehmens- und aktivitätenbezogene Rahmenbedingungen**

Die Richtlinie über die Nachhaltigkeitsberichterstattung von Unternehmen (Corporate Sustainability Reporting Directive (EU) 2022/2464 – CSRD) deckt den Bereich der nichtfinanziellen Berichtspflichten ab, die bestimmte Arten von Unternehmen zusätzlich zu den seit langem etablierten finanziellen Berichtspflichten erfüllen müssen.

Die bereits fällige nationale Umsetzung dieser Richtlinie wird allerdings derzeit in Österreich erst im Justizministerium vorbereitet. Da es ein rechtsstaatlicher Grundsatz ist, dass eine Person, die eine gesetzliche Pflicht zu erfüllen hat, im Zeitpunkt der Pflichterfüllung auch die Vorschriften kennen muss, müsste es bis 01.01.2025 deutliche Hinweise geben, dass das Gesetz noch rechtzeitig bis zur Aufstellungsfrist in Kraft treten wird, andernfalls ist eine verpflichtende Umsetzung im privaten Bereich fraglich. Um Planungssicherheit zu erhalten, wird den betroffenen Unternehmen aber geraten, freiwillig eine nicht finanzielle Erklärung nach den Bestimmungen der ESRS in den Lagebericht aufzunehmen. (Dokalik, 2024)

Dazu sollten bestehende ESG-Berichte bereits analysiert und eventuelle Wissenslücken identifiziert werden. Die verwendeten ESG-Kriterien sollen die

langfristige Nachhaltigkeit und die ethischen Auswirkungen eines Unternehmens auf die Umwelt (E), Soziales (S) und Unternehmensführung (G) bewerten. Der Umweltaspekt konzentriert sich auf die Auswirkungen eines Unternehmens auf die Umwelt, einschließlich seiner Bemühungen um die Reduzierung von Kohlenstoffemissionen, die Erhaltung natürlicher Ressourcen, das Abfallmanagement und die Förderung der Nachhaltigkeit. Die soziale Dimension der ESG bewertet den Ansatz eines Unternehmens zur sozialen Verantwortung. Dabei werden Faktoren wie Arbeitspraktiken, Wohlbefinden der Mitarbeiter, Vielfalt und Integration, Engagement in der Gemeinschaft und Ethik in der Lieferkette berücksichtigt. Bei der Governance werden die Führung, die Ethik und die allgemeine Unternehmensstruktur eines Unternehmens bewertet. Dazu gehört die Bewertung der Vielfalt im Vorstand, der Vergütung der Führungskräfte, der Transparenz und der Maßnahmen zur Korruptionsbekämpfung. Jedenfalls wird die Nachhaltigkeitsberichtserstattung durch die europäischen Nachhaltigkeitsberichtsstandards European Sustainability Reporting Standards (ESRS) inhaltlich konkretisiert und harmonisiert.

Ein weiteres Instrument ist die EU-Taxonomie-Verordnung 2020/852, die ein standardisiertes Klassifizierungssystem für nachhaltige Wirtschaftstätigkeiten schafft. Sie definiert Kriterien, anhand derer festgestellt werden kann, ob eine Wirtschaftstätigkeit ökologisch nachhaltig ist, wobei der Schwerpunkt auf ihrem Beitrag zum Klimaschutz und zur Anpassung an den Klimawandel, zur nachhaltigen Ressourcennutzung und zum Schutz der Ökosysteme liegt. Sie ist eine Schlüsselkomponente der umfassenderen Nachhaltigkeitsagenda der EU, die darauf abzielt, Kapital in grüne und nachhaltige Projekte zu lenken und damit letztlich das Ziel der EU zu unterstützen, bis 2050 kohlenstoffneutral zu werden. Laut EU-Taxonomie-Verordnung gilt eine Wirtschaftsaktivität dann als taxonomiekonform, wenn sie einen wesentlichen Beitrag zu mindestens einem von insgesamt sechs Umweltzielen leistet, ohne die anderen Ziele zu verletzen (DNSH-Prinzip, „Do No Significant Harm“). Weiters sind bestimmte Mindestanforderungen, z. B. in Bezug auf Soziales und Menschenrechte, zu erfüllen. Die sechs Umweltziele sind: (1) Klimaschutz, (2) Anpassung an den Klimawandel, (3) „Nachhaltige Nutzung und Schutz von Wasser- und Meeresressourcen“, (4) „Übergang zu einer Kreislaufwirtschaft“, (5) „Vermeidung und Verminderung der Umweltverschmutzung“ und (6) „Schutz und Wiederherstellung der Biodiversität und der Ökosysteme“.

### **3. Ausgewählte neue Regelungen der Neufassung der Gebäudeeffizienz-Richtlinie**

In den folgenden Kapiteln wird auf zwei wichtige Bereiche eingegangen, die für das Facility Management relevant sind:

- die Gebäudeautomatisierung im Hinblick auf Steigerung von Energieeffizienz, Gesundheit und Wohlbefinden sowie Bereitstellung von Flexibilitätsdienstleistungen, gemessen in Form des Intelligenzfähigkeitsfaktors;
- den Renovierungspass für die schrittweise energetische Verbesserung von Gebäuden.

#### **3.1 Intelligenzfähigkeitsfaktor (Smart Readiness Indicator - SRI)**

Der SRI misst die Bereitschaft eines Gebäudes, fortschrittliche Technologien zur Verbesserung der Energieeffizienz, des Komforts und der Bequemlichkeit sowie der Netzflexibilität zu integrieren und effektiv zu nutzen. Die Grundlage dafür sind Gebäudeautomations- und -steuerungssysteme (Building Automation and Control Systems - BACS), die bei Heizung, Lüftung und Klimaanlage, Beleuchtung, Sicherheits- und Zugangskontrollsystemen, Brandmelde- und Alarmanlagen, Energiemanagementsystemen, etc. zur Anwendung kommen können. BACS ermöglichen die zentrale Steuerung und Automatisierung dieser Gebäudesysteme, mit dem Ziel, die betriebliche Energieeffizienz zu verbessern, den Komfort und die Bequemlichkeit in der Nutzung zu erhöhen und zur Stabilität des Stromnetzes beizutragen. Derzeit beruht die Ermittlung des SRI auf einer qualitativen Erhebung der Gebäudeausstattung mittels Checkliste und der Zuordnung von Punkten zu den verschiedenen Ausprägungen von Eigenschaften. Die Aggregation zum dimensionslosen SRI in Form einer Prozentzahl erfolgt mittels Gewichtungsfaktoren die auf Grundlage bestimmter Parameter festgelegt werden. Das Wertversprechen der Gebäudeautomatisierung geht also über Energieeinsparungen im Bereich der technischen Gebäudesysteme hinaus und zielt auf die Gewährleistung einer stabilen Steuerung des Stromnetzes und gesunder Innenraumbedingungen ab. (van Tichelen et al. 2023) Die Ausstattung eines Gebäudes mit einem höheren Grad an Gebäudeautomation korreliert jedoch nicht immer mit einer Steigerung der Energieeffizienz. Daher empfiehlt es sich, ein fortschrittliches BACS mit einem gut abgestimmten Facility Management zu

verknüpfen, um thermischen Komfort, IEQ (Indoor Environmental Quality) und die Integration erneuerbarer Energien zu gewährleisten. Schließlich hängt der Nutzen der Ausstattung von Gebäuden mit einem höheren Maß an BACS-Funktionalität auch vom Nutzungsprofil ab.

### **3.2 Renovierungspass**

Mit der neuen Gebäudeeffizienz-Richtlinie (EU) 2024/1275 wird in Artikel 12 die Rolle des Renovierungspasses für die schrittweise Renovierung neu festgelegt. Die Mitgliedstaaten müssen nun bis zum 29. Mai 2026 ein System von Renovierungspässen einführen, das den Anforderungen des Anhangs VIII dieser Richtlinie gerecht wird. Grundsätzlich soll das System des Renovierungspasses freiwillig genutzt werden, außer ein Mitgliedstaat legt eine verpflichtende Nutzung fest. Im Renovierungspass sind jene Renovierungsmaßnahmen anzugeben, die dazu geeignet sind, Niedrigstenergiestandard und bis 2050 Null-Emissionsstandard zu erreichen, sowie tatsächliche Energiekosteneinsparungen, die sich in der Energierechnung niederschlagen. Darüber hinaus sollen die Mitgliedstaaten für die Erstellung und mögliche Aktualisierung des Renovierungspasses ein eigens dafür vorgesehenes digitales Instrument bereitstellen. Dazu kann auch ein ergänzendes Instrument entwickelt werden, das es den Gebäudeverwaltungen ermöglicht, einen Entwurf eines vereinfachten Renovierungspasses zu simulieren und im Anschluss an eine Renovierung bzw. einen Austausch einer Gebäudekomponente eine Aktualisierung durchzuführen. Die Mitgliedstaaten haben sicherzustellen, dass der Renovierungspass in die nationale Energieausweisdatenbank hochgeladen werden kann und sorgen dafür, dass er im digitalen Gebäudeloggbuch, sofern verfügbar, gespeichert wird oder über dieses zugänglich ist. Diese Adaptierungen würden den bisher statischen Energieausweis zu einem dynamischen Tool umgestalten, und daher eine weitere Überarbeitung der OIB-Richtlinie 6 Energieeinsparung und Wärmeschutz (OIB 2023) erfordern. In weiterer Folge muss das Energieausweisvorlagegesetzes (EAVG 2012) angepasst werden. Dazu muss abgeklärt werden, in welchem Ausmaß eine Haftung für die Richtigkeit eines dynamischen Energieausweises bestehen kann (§ 6 EAVG 2012). Des Weiteren muss der dynamische Energieausweis entsprechend im Mietrechtsgesetz (MRG) und im Wohnungseigentumsgesetz 2002 (WEG 2002) verankert werden. So könnte im MRG unter §3 Abs. 2 der Umgang mit dem Renovierungspass festgelegt werden und im WEG 2002 § 28 Abs 1 die Erstellung und

Vorrätighaltung eines Renovierungspasses für das gesamte Gebäude als Angelegenheit der ordentlichen Verwaltung gelistet werden (Geissler & Hoffmann 2023).

#### **4. Analyse in Bezug auf mögliche Entwicklungen im Bereich Facility Management**

Ausgangspunkt der Überlegungen sind die gebäudebezogenen Anforderungen bzw. Nachweispflichten für nachhaltige Gebäude. In den folgenden Abschnitten werden Kriterien, Indikatoren, Nachweise und zugrunde liegende Gebäudedaten systematisch aufgelistet. In der Spalte „Gebäudedaten“ werden solche zugrunde liegenden Daten aufgelistet, die bereits vorliegen, oder im Zusammenhang mit der Neufassung des Gebäudeeffizienz-Richtlinie verfügbar sein werden. Diese Informationen dienen als Grundlage für die Ableitung von Schlussfolgerungen in Bezug auf mögliche Entwicklungen im Bereich Facility Management.

##### **4.1 EU Taxonomie Verordnung und Instrumente der Gebäudeeffizienz-Richtlinie**

Die folgenden Tabellen beziehen sich auf die EU-Taxonomie-Verordnung und zeigen den „Wesentlichen Beitrag zum Klimaschutz“ für Kapitel 7. Baugewerbe und Immobilien des Anhangs I der delegierten Verordnung (EU) 2021/2139 zur Ergänzung der EU-Taxonomie Verordnung 2020/852. Aus Platzgründen kann nicht auf die „Vermeidung erheblicher Beeinträchtigungen“ in den Kategorien „Anpassung an den Klimawandel“, „Nachhaltige Nutzung und Schutz von Wasser- und Meeresressourcen“, „Übergang zu einer Kreislaufwirtschaft“, „Vermeidung und Verminderung der Umweltverschmutzung“, „Schutz und Wiederherstellung der Biodiversität und der Ökosysteme“ eingegangen werden.

Table 2: Anhang I - 7.1. Neubau

<b>Kriterium</b>	<b>Indikator</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
Gesamtenergieeffizienz des errichteten Gebäudes	Primärenergiebedarf	Energieausweis	Geometrie, Standort, Materialdaten, technische Gebäudesysteme
Qualitätssicherung während des Bauvorgangs (bei Gebäuden > 5000 m <sup>2</sup> )	Luftdichtheit und thermische Integrität	Luftdichtheitsmessung oder alternative Art der Qualitätssicherung	Inspektionen, Abnahmeprotokolle, Messdaten
Lebenszyklus-Treibhauspotenzial des errichteten Gebäudes (bei Gebäuden > 5000 m <sup>2</sup> )	Lebenszyklus-Treibhauspotenzial (GWP) für jede Phase im Lebenszyklus	Berechnung gemäß Level(s)	Materialdaten, idealerweise spezifische EPDs

Level(s) ist ein Open Source Gebäudebewertungssystem der europäischen Kommission. Es verwendet Indikatoren, um Treibhausgase, Materialien, Wasser, Gesundheit, Komfort und Klimawandel während des gesamten Lebenszyklus eines Gebäudes zu bewerten. Für jeden Indikator gibt es eine Anleitung für die Ausarbeitung<sup>1</sup>. Environmental Product Declarations (EPDs) oder Umwelt-Produktdeklarationen gemäß ISO 14025 und EN 15804 sind standardisierte, geprüfte Dokumente, die quantifizierte Daten über die Auswirkungen eines Produkts auf die Umwelt transparent darstellen.<sup>2</sup> Die sogenannten Typ III Umweltdeklarationen stellen quantifizierte umweltbezogene Informationen aus dem Lebensweg eines Produkts zur Verfügung, um damit Vergleiche zwischen Produkten gleicher Funktion zu ermöglichen. (ISO 14025)

<sup>1</sup> <https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/412/documents>

<sup>2</sup> <https://www.bau-epd.at/epd/deklarationstypen>

**Table 3: Anhang I - 7.2. Renovierung bestehender Gebäude**

<b>Kriterium</b>	<b>Indikator</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
Gesamtenergieeffizienz des renovierten Gebäudes	Die Gebäuderenovierung entspricht den geltenden Anforderungen an größere Renovierungen	Energieausweis	Geometrie, Standort, Materialdaten, technische Gebäudesysteme: vor und nach Renovierung
	Alternativ: Verringerung des Primärenergiebedarfs um mindestens 30 %	Energieaudit, validiert mittels Energieausweis	Angaben zur Ausstattung, Angaben zu Verbesserungsmaßnahmen

Gemäß der Delegierten Verordnung (EU) 2021/2139 gelten Gebäuderenovierungen als nachhaltige Tätigkeit, wenn sie den Primärenergiebedarf um mindestens 30 % verringern oder den Anforderungen einer größeren Renovierung entsprechen. Als Nachweis könnte auch ein entsprechend geregelter Renovierungspass gelten, da angegeben ist, dass die Einsparung durch eine Reihe von Maßnahmen innerhalb von drei Jahren erreicht werden kann. Details zum Renovierungspass sind in diesem Artikel in Abschnitt 3.2 zu finden.

**Table 4: Anhang I - 7.3. Installation, Wartung und Reparatur von energieeffizienten Geräten**

<b>Eine der folgenden Einzelmaßnahmen:</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
(a) Dämmung vorhandener Hüllenkomponenten, inkl. Maßnahmen für Luftdichtheit [...]	Erfüllung der energetischen Mindestanforderungen laut OIB RL 6 (bzw. Bauordnung); die zwei höchsten Energieeffizienzklassen für Produkte gemäß Verordnung (EU) 2017/1369	Eingabewerte für den Energieausweis nach Sanierung;
(b-c) Austausch vorhandener Fenster und Außentüren durch neue energieeffiziente Fenster und Türen		Eingabewerte für Maßnahmen im Renovierungspass;
(d) Installation/Austausch energieeffizienter Lichtquellen		Produktdaten laut EU-Energielabel
(e) Installation, Austausch, Wartung, Reparatur von Heiz-, Lüftungs- und Klimaanlage (HLK) [...]		
(f) Installation wasser- und energiesparender Küchen- und Sanitärarmaturen [...]	Gemäß technische Spezifikationen [...]	

Bei Installation, Wartung und Reparatur von energieeffizienten Geräten und Gebäudeteilen müssen Einzelmaßnahmen im Zusammenhang mit der Gesamtenergieeffizienz von Gebäuden durchgeführt werden. EU-Energielabel werden auf Basis der EU-Rahmenverordnung (EU) 2017/1369 und den darauf beruhenden produktspezifischen Verordnungen erstellt. Alle Produktmodelle mit Energielabel, die nach dem 1. August 2017 in Verkehr gebracht wurden, müssen seit 1.1.2019 von den Lieferanten in der EU-Produktdatenbank EPREL<sup>3</sup> registriert werden.

**Table 5: Anhang I - 7.4. Installation, Wartung und Reparatur von Ladestationen für Elektrofahrzeuge in Gebäuden (und auf zu Gebäuden gehörenden Parkplätzen)**

<b>Maßnahmen:</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
Installation, Wartung oder Reparatur von Ladestationen für Elektrofahrzeuge	Nicht spezifiziert	Gebäude-dokumentation

**Table 6: Anhang I - 7.5. Installation, Wartung, Reparatur von Geräten für die Messung, Regelung und Steuerung der Gesamtenergieeffizienz von Gebäuden**

<b>Die Tätigkeit umfasst eine der folgenden Einzelmaßnahmen:</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
(a) Installation, Wartung und Reparatur zonierter Thermostate, intelligenter Thermostatsysteme und Sensoren, [...]	Kein Nachweis spezifiziert.	Ausstattungsmerkmale: Hardware und Software;
(b) Installation, Wartung und Reparatur von Systemen zur Gebäudeautomatisierung und -steuerung [...]	Mögliche Nachweise:	Qualitative Erhebung im Rahmen einer SRI Zertifizierung;
(c) Installation, Wartung und Reparatur intelligenter Zähler für Gas, Wärme, Kälte und Strom	SRI Zertifikat;	Daten von Zählern und Subzählern
(d) Installation, Wartung und Reparatur von Fassaden- und Dachelementen mit Sonnenschutz [...]	Monitoring des Energieverbrauchs	

Details zum SRI (Smart Readiness Indicator – Intelligenzfähigkeitsfaktor) sind in diesem Artikel in Abschnitt 3.1 zu finden.

<sup>3</sup> [https://www.wko.at/energie/energielabel#heading\\_Produktdatenbank\\_EPREL](https://www.wko.at/energie/energielabel#heading_Produktdatenbank_EPREL)

Table 7: Anhang I - 7.6. Installation/Wartung/Reparatur - Technologien für erneuerbare Energien

<b>Kriterium</b>	<b>Indikator</b>	<b>Nachweis</b>	<b>Gebäudedaten</b>
Installation, Wartung, Reparatur von Fotovoltaik-systemen, solarbetriebenen Warmwasserpaneelen, Windturbinen, , [...]	Installation vor Ort als gebäude-technisches System	Kein Nachweis spezifiziert. Mögliche Nachweise: Energieausweis, Monitoring der Energiebereitstellung, BACS	Installierte Leistung, jährlich produzierte Energie, Anteil Eigenverbrauch, Lebensdauer, Investitionskosten

Table 8: Anhang I - 7.7. Erwerb von/Eigentum an Gebäuden (Gebäudedaten siehe Tab.2-Tab.7)

<b>Kriterium</b>	<b>Indikator</b>	<b>Nachweis</b>
Gesamtenergieeffizienz des Gebäudes	Primärenergiebedarf im Betrieb: Gebäude mit Baujahr vor 31.12.2020: mindestens Energieausweis Klasse A.	Nachweise, in denen mindestens die Energieeffizienz der Immobilie und die Energieeffizienz des vor dem 31.12.2020 gebauten nationalen oder regionalen Gebäudebestands verglichen werden; Differenzierung mindestens zwischen Wohn- und Nichtwohngebäuden.
	Primärenergiebedarf im Betrieb: Alternativ: Gebäude in oberen 15 % des Gebäudebestands (national/regional).	
Gesamtenergieeffizienz des Gebäudes	Gebäude mit Baujahr nach 31.12.2020, erfüllen die Kriterien in Abschnitt 7.1.	Energieausweis, Qualitätssicherung, Berechnung gemäß Level(s)
Effizienter Betrieb für Nicht-wohngebäude mit Nennleistung HKL Anlagen > 290 kW	Überwachung und Bewertung der Energieeffizienz	Bestehen eines Energieleistungsvertrags oder eines Systems für die Gebäudeautomatisierung [...]

## 4.2 ESRS gemäß CSRD und Instrumente der Gebäudeeffizienz-Richtlinie

Die folgenden Tabellen beziehen sich auf die relevanten Europäischen Sustainability Reporting Standards (ESRS) gemäß CSRD im Zusammenhang mit den Instrumenten der Gebäudeeffizienz-Richtlinie (Europäische Kommission, 2023):

- ESRS E1 Klimaschutz (ab Seite 72)
- ESRS E5 Ressourcennutzung und Kreislaufwirtschaft (ab Seite 152)
- ESRS S4 Verbraucher und Endnutzer (ab Seite 232)

Es werden in den Tabellen 9-11 nur jene Angabepflichten gelistet, für welche die zuvor beschriebenen Instrumente als Informationsquellen verwendet werden können. Die Anwendung der Standards erfolgt bezogen auf den Gebäudebestand eines Unternehmens, wobei das Gebäude als zusammengesetztes Produkt betrachtet wird.

**Table 9: ESRS E1 Klimaschutz**

<b>Angabepflichten</b>	<b>Informationsquellen</b>
Angabepflicht E1-1 – Übergangsplan für den Klimaschutz	Renovierungspass
Angabepflicht E1-2 – Strategien	
Angabepflicht E1-4 – Ziele	Renovierungspass; Level(s)
Angabepflicht E1-5 – Energieverbrauch und Energiemix	Energieausweis
Angabepflicht E1-6 – THG-Brutto-emissionen für Scope 1, 2 und 3 sowie THG-Gesamtemissionen	Level(s)
Angabepflicht E1-7 – Abbau von Treibhausgasen und Projekte zur Verringerung von Treibhausgasen, finanziert über CO2-Gutschriften	EPDs und weitere Informationsquellen

**Table 10: ESRS E5 Ressourcennutzung und Kreislaufwirtschaft**

<b>Angabepflichten</b>	<b>Informationsquellen</b>
Angabepflicht E5-2 – Maßnahmen und Mittel	Ökobilanzen
Angabepflicht E5-4 – Ressourcenzuflüsse	Ökobilanzen
Angabepflicht E5-5 – Ressourcenabflüsse	Gebäudebewertung

Table 11: ESRS S4 Verbraucher und Endnutzer

<i>Angabepflichten</i>	<i>Informationsquellen</i>
Angabepflicht S4-3 – Verfahren zur Behebung negativer Auswirkungen und Kanäle, über die Verbraucher und Endnutzer Bedenken äußern können	Gebäude-automatisierung  (gemäß SRI)
Angabepflicht S4-4 – Ergreifung von Maßnahmen in Bezug auf wesentliche Auswirkungen auf Verbraucher [...]	
Angabepflicht S4-5 – Ziele im Zusammenhang mit der Bewältigung wesentlicher negativer Auswirkungen, der Förderung positiver Auswirkungen [...]	

### 4.3 Datenbanklösungen und digitales Gebäudelogbuch

Aus den vorangegangenen Analysen leitet sich im Wesentlichen die folgende Erkenntnis ab: die Datenbestände eines Gebäudes, die im Zusammenhang mit der Gebäudeeffizienz-Richtlinie entstehen, sind auch für Nachweise im Zusammenhang mit der EU-Taxonomie Verordnung und der CSRD relevant. Es ist ersichtlich, dass Synergieeffekte in Bezug auf Datenerfassung, Auswertung und Nutzung bestehen. Allerdings ist der Bausektor ein fragmentierter Sektor mit vielen Beteiligten über den gesamten Lebenszyklus hinweg, das macht das Sammeln, Speichern, Teilen und Aktualisieren von Informationen schwierig. Aus diesem Grund hat die Europäische Kommission eine Studie in Auftrag gegeben, die die Entwicklung und Implementierung von digitalen Gebäudelogbüchern darlegt. (Ecorys et al. 2023) Der Aufbau der Gebäudelogbücher konzentriert sich demnach auf Anwendungen, die für strategische politische Entscheidungen, Finanzdienstleister, ausführende Unternehmen und Dienstleister (wie z.B. Energiedienstleister) notwendig sind.

Das digitale Gebäudelogbuch soll ein gemeinsamer Datenspeicher für alle relevanten Gebäudedaten sein, wo eine Vielzahl von Daten, Informationen und Dokumenten abgespeichert wird. Neben Veränderungen im Lebenszyklus eines Gebäudes, wie z. B. Eigentümer-, Besitz- oder Nutzungswechsel, werden Instandhaltungs- und Renovierungsmaßnahmen sowie andere Eingriffe dokumentiert. Des Weiteren soll die Rückverfolgbarkeit von Baumaterialien und Leistungsdaten, wie Energieverbrauch im Betrieb, Umweltqualität in Innenräumen, Potenzial für intelligente Gebäude und Lebenszyklus-Emissionen, sowie Links zu Gebäudebewertungen und -zertifikaten

sichergestellt werden. Ziel ist die effiziente Bewirtschaftung, die auch die zukünftigen Möglichkeiten der Kreislaufwirtschaft ausschöpft. (Ecorys et al. 2023)

Für die Implementierung des digitalen Gebäudelogbuchs sind daher die technischen Datenformate, die wirtschaftliche Datennutzung und die gesetzlichen Rahmenbedingungen (Eigentumsrechte und Datenschutz) zu bestimmen. Es ist ein langfristiges Vorhaben, das nach der Gebäudeeffizienz-Richtlinie eine stabile Grundlage für fundierte Entscheidungsfindungen bilden wird und den Informationsaustausch innerhalb des Bausektors, und zwischen Gebäudeeigentümern und Bewohnern, Finanzinstituten und öffentlichen Einrichtungen erleichtern wird.

Das in Wien elektronisch zu führende Bauwerksbuch (§ 128a Abs.5 BO für Wien) kann als Zwischenschritt zum digitalen Gebäudelogbuch angesehen werden. Nach Auskunft der Baupolizei (2024) müssen Pläne für das Bauwerksbuch nicht zwingend maßstäblich sein. So sind z.B. leichte Verzerrungen, die beim Abfotografieren entstehen können, tolerierbar, solange der Plan als solches lesbar bleibt. Dieser Anspruch an das Bauwerksbuch deckt sich somit nicht vollständig mit der angedachten Herangehensweise für die Erstellung des Gebäudelogbuchs.

Das Bauwerksbuch hat jedenfalls nach §128 a Abs.3 folgende Teile zu beinhalten:

- die das Gebäude betreffenden Baubewilligungen und Fertigstellungsanzeigen oder Benützungsbewilligungen;
- die Bezeichnung der Bauteile, die einer regelmäßigen Überprüfung zu unterziehen sind;
- den Zeitpunkt der erstmaligen Überprüfung sowie die Intervalle, in denen die Überprüfungen in der Folge durchzuführen sind;
- die Voraussetzungen, die die überprüfenden Personen jeweils zu erfüllen haben;
- die Ergebnisse der durchgeführten Überprüfungen mit Ausnahme jener Überprüfungen, die für Bauteile nach anderen bundes- oder landesgesetzlichen Vorschriften durchzuführen sind;
- ein aktuelles Verzeichnis der Baugebrechen sowie einen Plan zu deren Behebung, wenn im Zuge einer Überprüfung solche festgestellt wurden;
- eine Dokumentation der Maßnahmen oder Änderungen gemäß § 118 Abs. 3.

Nach § 128 der Wiener Bauordnung ist für bestehende Gebäude ein Bauwerksbuch bis zu folgenden Stichtagen zu erstellen:

- bis zum 31.12.2027 für Gebäude, die vor dem 1.1.1919 errichtet wurden,
- bis zum 31.12.2030 für alle Gebäude, die zwischen dem 1.1.1919 und dem 1.1.1945 errichtet wurden.

Später errichtete Gebäude sind bis dato nicht von dieser Erstellungspflicht erfasst. (Baupolizei, 2024)

Des Weiteren hat die Baupolizei (2024) klargestellt, dass das Bauwerksbuch zur Erfüllung der öffentlich-rechtlichen Vorgaben der Bauordnung dient, weshalb kein Anspruch auf eine vollständige Auflistung aller Schäden im Bauwerksbuch besteht. In der Regel werden im Zuge der gemäß ÖNORM B 1300:2018 und ÖNORM B 1301:2016 vorgenommenen Begehungen relevante Bauteile mit Gefährdungspotential erfasst und mit regelmäßigen Prüfroutinen versehen. Jedoch stimmen diese Zieldefinitionen und Qualitätsanforderungen mit jenen des Bauwerksbuchs gemäß der Wiener Bauordnung nicht immer überein, weshalb die Ergebnisse dieser Überprüfungen nur teilweise übernommen werden können. Ähnlich verhält es sich auch mit von Eigentümern oder Hausverwaltungen selbst festgelegten Prüfroutinen, auch hier obliegt es dem Bauwerksbuchersteller, diese für geeignet oder ungeeignet zu erachten. (Baupolizei, 2024)

## **5. Schlussfolgerungen**

Die neue Gebäudeeffizienz-Richtlinie verlangt zahlreiche Adaptierungen in der nationalen Gesetzgebung. Für die Implementierung des Renovierungspasses wird die OIB-Richtlinie 6 Energieeinsparung und Wärmeschutz (OIB 2023) überarbeitet werden müssen. Neue Schwerpunkte im Bereich Datenaustausch und Datennutzung eröffnen die Möglichkeit, den derzeit statischen Energieausweis zu einem dynamischen Energieausweis inklusive Renovierungspass weiterzuentwickeln, der auf Basis des Gebäudelogbuchs erstellt werden könnte. In weiterer Folge müsste auch das Energieausweisvorlagegesetzes (EAVG 2012) adaptiert werden, denn inwieweit die Ersteller für die Richtigkeit eines dynamischen Ausweises belangt werden können, sei dahingestellt.

Es empfiehlt sich auch für die Umsetzung der zu erfüllenden Bestimmungen wesentliche Herangehensweisen im MRG und WEG 2002 zu verankern, um

eventuelle Interessenkonflikte zwischen Vermietern und Mietern sowie innergemeinschaftliche Kontroversen zu vermeiden.

Jedenfalls sind die Mindestvorgaben für die Gesamtenergieeffizienz ein wesentlicher Beitrag, um das langfristige Ziel eines bis 2050 dekarbonisierten Gebäudebestands sicherzustellen. In diesem Zusammenhang ist es auch wichtig zu diskutieren, wie man zukünftig mit der Gesamtenergieeffizienz des unkonditionierten Gebäudebestands (z.B. Logistikimmobilien, Parkgaragen etc.) umgehen wird.

In Abschnitt 4 konnte gezeigt werden, dass die im Zuge der neuen Gebäudeeffizienz-Richtlinie generierten Datenbestände als Informationsquellen für Nachweispflichten im Zusammenhang mit den Anforderungen der EU-Taxonomie-Verordnung und der CSRD dienen können. Die real erschließbaren Synergiepotenziale werden von der Ausgestaltung der inhaltlichen, organisatorischen und rechtlichen Rahmenbedingungen für die Implementierung des Gebäudelogbuchs (im Sinne der Gebäudeeffizienz-Richtlinie und der DG GROW) abhängen. Erste Digitalisierungsansätze wie das Wiener Bauwerksbuch bieten diesbezüglich Anknüpfungspunkte, machen aber auch die Entwicklungserfordernisse deutlich.

Für das Facility Management jedenfalls ergeben sich zukünftig vielfältige Aufgaben. Facility Manager werden eine Schlüsselrolle im Datenmonitoring einnehmen und damit über die Wirksamkeit der Richtlinien, Verordnungen und Gesetzesvorgaben wachen. Im Anwendungsbereich Mensch und Organisation werden sie hinsichtlich der Information und Kommunikation wesentlich zur Umsetzung und Akzeptanz von Energieeffizienzmaßnahmen beitragen. Darüber hinaus stellen die enormen Anforderungen und damit verbundenen Dokumentationspflichten der EU-Taxonomie Verordnung sowie die Realisierung des Gebäudelogbuchs ein großes Betätigungsfeld für Facility Manager dar. Auch die in Zukunft zu implementierenden Technologien für erneuerbare Energien werden fachkundige Personen benötigen, um den ordnungsgemäßen Betrieb zu gewährleisten.

Das Gebäudelogbuch kann eine zentrale Rolle bei der Erfüllung von Dokumentations- und Berichtspflichten spielen. Dazu müssen Datenfelder und die Prozesse für den Dateninput und Datenaustausch definiert werden, sowie Eigentums- und Zugriffsrechte geregelt werden. Im Facility Management werden bereits relevante Betriebsdaten erfasst und Routinen ausgeführt, die als Grundlage für die detaillierte

Entwicklung eines Gebäudelogs genutzt werden könnten. Die Erstellung und das kontinuierliche Updaten von Gebäudelogs könnte eine zentrale neue Aufgabe des Facility Managements werden.

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## **Förderhinweis**

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# High-Performance Climbing Plants for Urban Climate Improvement: Maintenance Strategies for Climbing Plants in Vertical Greening Systems

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## **Abstract:**

Vertical Greening Systems (VGS) in urban areas play a crucial role in urban climate adaptation, energy efficiency, and biodiversity, but their sustaining benefits depend on species-specific care and maintenance. This study focuses on ground- and planter-based VGS with climbing aids for woody, deciduous plants, introducing the concept of High-Performance Climbing Plants (HPCP): species with superior growth, resilience and greening efficiency. Tailored interventions from planting through preservation maintenance are essential to optimise Plant Coverage (PC) and Wall Leaf Area Index (WLAI), enabling effective cooling and bioshading that directly impact these ecosystem services. Maintenance strategies were systematically developed, tested, and demonstrated under real-site conditions, integrating species selection, structural design, plant training, and pruning techniques. Practical recommendations and checklists, based on national and international guidelines, support the sustainable management of VGS. The study underscores the link between maintenance quality and Green Infrastructure (GI) performance, providing a practical framework for building owners, planners, and facility managers to maximise environmental, economic, and aesthetic benefits.

## **Keywords:**

High-Performance Climbing Plants, Vertical Greening Systems, plant training, maintenance strategies

## **Acknowledgments:**

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## **1. Introduction**

Urban GI has become an essential strategy for mitigating the impacts of climate change in densely built and settlement environments (European Commission, 2013; UN-Habitat, 2011). VGS have the potential to counteract the problem of high solar irradiation as plants act as a natural external shading layer and solar filter (Stangl et al., 2022). Reducing solar irradiation impact on the building envelope substantially decreases the building's surface temperatures) and thus helps to improve indoor thermal comfort (Cetiner et Özkan, 2005; Hoelscher et al., 2016).

This paper introduces the concept of ground- and planter-based HPCP, addressing deciduous, woody species with rapid growth and high biomass production capacity. Therefore, these plants offer a good base for high shading and cooling properties for VGS applications. This work focuses on care and maintenance needs as well, which are often neglected or underestimated during planning and continuous functioning of VGS. It presents findings and insights from the Austrian research project GLASGrün from BOKU University which developed, implemented and evaluated VGS specifically for large-scale glass facades in commercial buildings (Stangl et al., 2025). While VGS has been widely applied to solid facades, solutions for fully glazed building facades remain limited. The GLASGrün research project addressed this gap by developing new VGS typologies tailored for glass facades and retrofitting.

The GLASGrün project implemented two real-life demonstration sites (Söll, Tyrol and Kreuzgasse, Vienna), where plant development and -physiology, microclimatic performance, and maintenance needs were systematically studied over three years.

The project started in August 2021, the implementation of the first study site in Tyrol took place in June 2022 and the monitoring continued up to December 2024. These insights form the basis for the care and maintenance strategies presented in this paper. Despite the growing popularity of VGS, there is still a lack of standardised care concepts that are adapted to the specific needs of different plant species, system designs, and facade materials. Without suitable maintenance, even well-designed systems can suffer from poor plant development, aesthetic loss, or technical failure. The GLASGrün project responded to this problem by developing comprehensive guidelines with a catalogue of variants for VGS on glass facades (Briefer et al., 2025) as well as a guideline for maintenance strategies for VGS (Poiss et al. 2025b).

The concept of HPCP, introduced in this work addresses a gap in practice-oriented research by highlighting that, although climbing plants are often chosen for aesthetic reasons, certain species have the traits needed to excel in supporting climate adaptation goals such as heat mitigation, microclimate improvement, and energy balance (Stangl et al., 2022). Care and maintenance are often underestimated in VGS, though success relies on targeted interventions such as pruning, training shoots, controlling growth, ensuring structural integrity, and safe access for workers. Based on the findings of the GLASGrün monitoring phase, transferable care guidelines with structured phases for establishment, development and preservation linked to vegetation targets set during planning were developed (Poiss et al., 2025b).

Based on this framework, this concept study investigates following research questions:

- RQ1: How can the HPCP Concept be conceptualized to open new perspectives for the planning and implementation of VGS?
- RQ2: How can maintenance strategies align with the HPCP Concept ensure rapid establishment, sustained functionality, and consistent delivery of ecosystem services in VGS?

## **2. Methodology**

### **2.1 Site Design and System Setup**

The GLASGrün Project represents real-site applications of VGS for glass facades, addressing both technical and vegetation-specific challenges. As part of this applied research initiative, two demo systems were implemented in different climatic regions of Austria in central Europe – Söll in Tyrol (Figure 1) and Kreuzgasse in Vienna (Figure

2) – to develop and test tailored VGS solutions under practical conditions. The facts about both Demo sites are included in Table 1. The systems included ground- and planter-based plantings combined with customised climbing aids for retrofit.

Table 4: Facts About the two Demo Sites from the GLASGrün Project (Briefer et al., 2025)

	<i>Demo Site Söll, Tirol</i>	<i>Demo Site Kreuzgasse, Vienna</i>
<b>Location</b>	6306 Söll, Dorf 140, AUT	1180 Vienna, Kreuzgasse 74, AUT
<b>Architecture</b>	RATAPLAN-Architektur ZT GmbH	lichtblauwagner architekten zt gmbh
<b>Planting Concept</b>	BOKU IBLB	BOKU IBLB
<b>Client</b>	MPREIS Supermarket	TB Obkircher
<b>Planning Phase:</b>	August 2021 – May 2022	November 2021 – June 2023
<b>Completion</b>	June 2022	July 2023
<b>Greened Glass</b>	154 m <sup>2</sup>	77.5 m <sup>2</sup>
<b>Exposition</b>	south-east	south-south-west



Figure 1: Demonstration site in Söll, Tirol – GLASGrün bioshading based on a 3D flat steel climbing support in front of a glass facade - 3 years after implementation (Auer, 2024)



Figure 2: Demonstration site at Kreuzgasse, Vienna – GLASGrün bioshading based on a tubular steel frame climbing support in front of a glass facade - 2 years after implementation (Briefer, 2024)

Both study sites lie within the Central European temperate zone, characterised by four distinct seasons. According to the Köppen-Geiger classifications (Table 2), Vienna exhibits a temperate oceanic climate (Cfb) 220 meters above sea level, while Söll, Tyrol is classified as in the middle between ocean climate (Cfb) and humid continental (Dfb), reflecting its alpine surroundings and elevation of 703 meters above sea level (Kottek et al., 2006; GeoSphere Austria, 2025).

**Table 5: Temperature Zone Location Analysis of the Demo-Study Sites (Kottek et al., 2006; GeoSphere Austria, 2025)**

<i>Location</i>	<i>Temperate Zone</i>	<i>Köppen-Geiger Classification</i>	<i>Climate Type</i>	<i>Description</i>
<b>Söll, Tyrol</b>	Central European	Cfb – Dfb	Temperate Oceanic Climate – Humid Continental Climate	cold winters with snow and warm summers; year-round precipitation; alpine influence
<b>Kreuzgasse, Vienna</b>		Cfb	Temperate Oceanic Climate	mild and dry winters, warm summers, no complete dry season, even distribution of rain

## **2.2. Elaboration of the HPCP Concept**

The concept of HPCP was developed through a literature-based identification of key plant physiological parameters relevant for VGS. Parameters such as PC, WLAI, BSC, stomatal conductance, plant life cycle, climbing mechanism, biomass accumulation, and leaf retention type were defined following established sources. Based on these criteria, species suitable for Central European climates were pre-selected from botanical literature and guidelines. Their performance was subsequently validated at the GLASGrün demo-site in Söll (Tyrol) through monitoring of PC and WLAI between 2023 and 2024. Species were classified as HPCP if they combined rapid facade coverage, structural adaptability, and resilience under local climatic and maintenance conditions.

## **2.3. Monitoring Parameters Supporting the Maintenance Framework**

Monitoring data from the two demo sites were collected during the first three years after installation. The key parameters assessed included:

- yearly growth rates,
- PC development and foliage density, respectively WLAI over time,
- shading performance via the Bioshading Coefficient (BSC) through species-specific solar transmission in the VGS (Poiss et al. 2025a),
- plant vitality, stomatal conductance,
- maintenance effort, frequency, and complexity of interventions.

At the Söll site, two maintenance interventions were conducted in 2022: one during implementation and a second in autumn. In 2023 and 2024, maintenance was performed four times per year – in spring, early summer, late summer, and autumn. At the Kreuzgasse site, two maintenance interventions took place during the year of implementation (2023) as well. In 2024, the same seasonal maintenance cycle of four interventions per year was applied.

#### **2.4. Maintenance Framework for Vertical Greening Systems**

Effective maintenance strategies include three core phases and are adopted from BMDW (2021) and Poiss et al. 2025b for this study:

1. establishment phase (Year 1): supports rooting, survival, and early structure formation.
2. development phase (Years 2–3): shapes the growth toward the defined target coverage and structural form.
3. preservation phase (Year 3+): ensures the sustaining stability and aesthetics/functionality of the system.

#### **2.5. Regulation and Requirement Basis**

The care concept developed and tested within the GLASGrün project is based on national and German up-to-date guidelines and best practices in vegetation engineering. All recommendations are aligned with national and international standards, including:

- ÖNORM L1120 (2016) – Maintenance and Conservation of Green Areas.
- ÖNORM L1136 (2021) – Vertical Greening in Outdoor Spaces.

- ÖNORM B2241 (2013) – Standard Contract Conditions for Landscape Works.
- FLL Guidelines (2018) – Facade Greening Standards for Planning, Execution, and Maintenance.

These standards form the backbone of the GLASGrün maintenance protocol, which includes checklists, scheduling tools, and performance indicators.

### 3. Results

#### 3.1. Identification and Selection of High-Performance Climbing Plants (HPCP)

Initial findings confirmed that early, intensive care significantly accelerated the achievement of target vegetation structures. Species identified as HPCP – characterised by vigorous yet manageable growth, environmental resilience, and structural adaptability – demonstrated superior performance in both greening efficiency and maintenance responsiveness. Table 3 outlines the key plant physiological parameters used to define and monitor HPCP. These parameters allow for the identification of species most suitable for the optimal development of VGS, ensuring extensive coverage, vertical growth—provided that appropriate maintenance practices are applied.

**Table 6: Key Plant Physiological Parameter Used for HPCP Definition and Monitoring**

<i>Parameter</i>	<i>Definition / Description</i>	<i>Unit</i>	<i>Reference</i>
<b>Projected Plant Coverage (PPC)</b>	Percentage of vertical surface area occupied by vegetation, measured as vertical projection (of a measurement frame e.g., 0.5 m <sup>2</sup> ) of above-ground plant parts onto the wall; accordingly, describes vegetation density projected onto a frame (0 – 100 %).	[%]	Law et al., 2020 Seyrekşik et al., 2022 Li et al., 2023
<b>Target Plant Coverage (TPC)</b>	Percentage of vertical surface area occupied by vegetation, measured by plant coverage of a predefined target area (e.g. total glass facade area or climbing aid in front of a facade) on percent; accordingly, describes the vegetation density on a target (0 – 100 %).	[%]	Koyama et al., 2013  Poiss et al., 2025a*  *here classified as PC

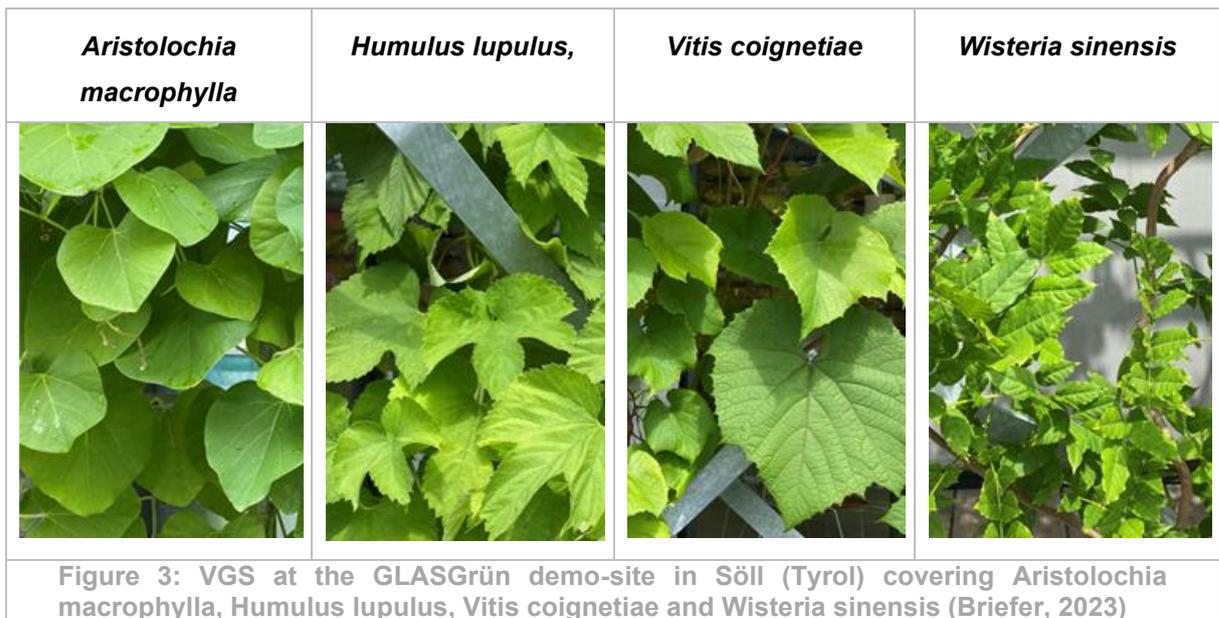
<b>Wall Leaf Area Index (WLAI)</b>	Total one-sided leaf area per vertical facade area; indicates canopy density and potential for evapotranspiration and shading.	dimensionless	DeBock et al., 2023 Pérez et al., 2017
<b>Bioshading Coefficient (BSC)</b>	Fraction of incident solar radiation intercepted by the plant canopy under standard solar geometry; indicates shading efficiency.	[0 – 1]	Ip et al., 2010 Poiss et al., 2025a
<b>Stomatal Conductance</b>	Rate of gas exchange per unit leaf area, reflecting plant physiological activity and cooling potential.	[mmol m <sup>-2</sup> s <sup>-1</sup> ]	Li et al., 2022 Lin, 2015
<b>Plant Life Cycle</b>	Divides plants into two main types based on the duration and pattern of their life cycle. Annual plants complete their entire life cycle within one growing season and then die off. Perennial plants live for multiple years and typically reproduce multiple times throughout their lifespan.	annuals and perennials	Friedman, 2020
<b>Climbing Mechanism</b>	Climbing plants use active or passive mechanisms, with specialised features, to attach and ascend climbing aids.	twiners, tendrils, adhesive roots, hooks and spines, scramblers	Mahabadi et al., 2018
<b>Biomass Accumulation</b>	Increase in plant dry mass over time, reflecting growth and productivity.	[g per plant or g per area]	Wyka et al., 2019
<b>Leaf Retention Type</b>	Categorisation of plants based on whether they retain or shed leaves seasonally	deciduous and evergreen	Elosegi, 2005

Building on the physiological parameters defined in Table 3, Table 4 lists climbing plant species that align with these criteria and are suitable for Central European climate conditions. Species highlighted in bold indicate those that were tested within the scope of this research.

**Table 7: Identified HPCP | IP = Invasive Plant acc. to Rabitsch et al., 2016; EU 2022/1203**

<b>Species</b>	<b>Climbing Mechanism</b>	<b>Avg. Growth Height (in m)</b>	<b>Shoot Diameter at Base (in cm)</b>
<b>Actinidia deliciosa</b>	twining	6–8	3–5
<b>Akebia quinata</b>	twining	8–10	2–3
<b>Aristolochia macrophylla</b>	twining	8–10	up to 3
<b>Celastrus orbiculatus (IP)</b>	twining	8-15	up to 10
<b>Clematis montana</b>	tendrill-like stems	8–10	2–3
<b>Clematis vitalba</b>	twining and scrambling hybrid	10–12	3–4
<b>Fallopia baldschuanica (IP)</b>	twining	12–15	4–6
<b>Humulus lupulus</b>	twining (annual)	5–7 / year	up to 1.5–2 (annual stem)
<b>Vitis coignetiae</b>	tendrill climber	8–12	up to 4–5
<b>Vitis vinifera</b>	tendrill climber	8–15	3–5
<b>Wisteria floribunda</b>	twining	10–12	up to 6–8
<b>Wisteria sinensis</b>	twining	15-30	up to 25

The HPCP-list reflects both botanical characteristics and performance criteria observed during the GLASGrün demo-study, which included *Aristolochia macrophylla*, *Humulus lupulus*, *Vitis coignetiae* and *Wisteria sinensis* (Figure 3). *Fallopia baldschuanica* and *Celastrus orbiculatus* are both considered invasive plants (IP) in parts of Europe. According to Rabitsch et al. (2016), *Fallopia baldschuanica* is an established neophyte and shows invasive behaviour in certain regions such as Austria and Bavaria. Although it is not listed in the official EU Regulation (EU) No. 1143/2014 on invasive alien species, it is recognised in regional strategies as potentially invasive. Similarly, *Celastrus orbiculatus* is included on the official EU list of invasive plant species under Regulation (EU) No. 2022/1203. Due to their invasive potential, neither species is recommended for use in vertical greening of buildings.



Monitoring data from the demo-site Söll (Tyrol) are presented in Table 5 on page 7. Including information about growth speed of different climbing species through the increases of PC development and WLAI from one monitoring to the next.

**Table 8: Monitoring Parameters Plant Coverage (PC) and Wall Leaf Area Index (WLAI) Supporting the Maintenance Framework (Stangl et al., 2025)**

<b>South-East from Söll, Tyrol</b>	<b><i>Vitis coignetiae</i></b>	<b><i>Humulus lupulus</i></b>	<b><i>Wisteria sinensis</i></b>	<b><i>Aristolochia macrophylla</i></b>
<b>Jun 23 PC [%]</b>	10.8	32.5	24.5	19.8
<b>Jun 23 WLAI</b>	0.9	1.3	1.0	1.0
<b>Sep 23 PC [%]</b>	57.7	70.5	79.6	67.1
<b>Sep 23 WLAI</b>	1.7	2.0	3.0	2.3
<b>Mai 24 PC [%]</b>	30.9	66.8	43.1	57.0
<b>Mai 24 WLAI</b>	1.2	2.5	1.6	1.9
<b>Jul 24 PC [%]</b>	78.8	95.0	83.5	91.3
<b>Jul 24 WLAI</b>	4.5	5.9	4.8	5.5
<b>Aug 24 PC [%]</b>	78.3	96.5	98.3	94.3
<b>Aug 24 WLAI</b>	3.0	4.3	4.3	4.1
<b>Sep 24 PC [%]</b>	67.2	91.0	92.9	92.3
<b>Sep 24 WLAI</b>	2.2	4.0	3.6	3.8

### **3.2. Maintenance Framework for Vertical Greening Systems**

The maintenance of VGS does not necessarily require high levels of effort, but intelligence and targeted interventions. In the context of GI, maintenance refers to the planned and regular steering of plant development rather than occasional large-scale corrections after neglect. Proper care enables optimal plant performance and reduces the likelihood of costly restorative interventions. The here applied framework was adopted from BMDW (2021) and extended by an additional phase:

#### ***Definition and Planning Phase***

A fundamental principle in vertical greening projects is that the target vegetation structure and coverage must be clearly defined during the planning phase. This target state forms the basis for the maintenance strategy. The target vegetation structure is defined by the dimensions of the support structure and climbing aids, which should be designed according to the desired shaded area. In line with Austrian Standard ÖNORM L1136:2021, at least 80 % PC of the target area must be achieved three years after installation for facade greening at a 4-story height. It is necessary to distinguish between plant coverage of the target area (as defined in ÖNORM L1136:2021, referring to the proportion of the designated facade area to be covered) and the projected PC, which refers to the proportion of vegetation within the vertical projection of a predefined frame (e.g., 0.5 m<sup>2</sup>) (Li et al., 2023; Law et al., 2020; Seyrekşik et al., 2022).

#### ***Establishment Phase***

The establishment phase is essential for root development, plant survival, and the initial structural setup of climbing plants. According to Austrian Standard ÖNORM B2241:2013, this period covers all maintenance measures between planting and handover. In the context of glass-based architecture, special attention is needed to guide plant growth in harmony with the building's design. Key actions during this phase include shoot training, tying to the trellis, pruning to stimulate branching, and checking technical systems such as irrigation systems and climbing supports.

## ***Development Phase***

Following the handover, the development phase begins (see ÖNORM L2241). This phase aims to ensure full PC, healthy growth, and proper integration into the vertical system. Depending on the species, growth rate, and defined target structure and area, development care may extend over several years.

Key maintenance activities include:

- regular inspection for pests, diseases, or nutrient deficiencies,
- removing dead plant parts,
- guiding shoots to close gaps and cover the facade evenly,
- clearing plants from technical components,
- performing structural and shaping cuts,
- fertilising as needed,
- replacing any dead or damaged plants.

## ***Preservation Maintenance***

The aim of preservation maintenance is to preserve the plant structure and develop it further in line with the defined goals (ÖNORM L1120:2016). To ensure the sustaining health, functionality, and visual quality of the planting system, several key maintenance actions must be regularly carried out. These are provided as Checklist in Table 6.

**Table 9: Checklist for Regular Preservation Maintenance Actions During the Preservation Phase (Poiss et al., 2025b)**

<b><i>Maintenance Task</i></b>	<b><i>Checklist</i></b>
<b>Water supply</b>	<ul style="list-style-type: none"><li>• manual watering or automated irrigation systems</li><li>• check and, if necessary, replacing of irrigation system components</li></ul>
<b>Removal of unwanted growth</b>	<ul style="list-style-type: none"><li>• manual removal of weeds and self-seeded plants</li><li>• removal of suckers from rootstock, trunk, or base shoots</li><li>• prevention of mechanical trimmers; protect plant stems with guards</li></ul>
<b>Soil loosening and mulching</b>	<ul style="list-style-type: none"><li>• careful loosening of soil in planting areas</li><li>• avoiding of damaging the root collar or fine roots</li></ul>

	<ul style="list-style-type: none"> <li>renewing mulch layer as needed, or underplanting with perennials</li> </ul>
<b>Fertilisation</b>	<ul style="list-style-type: none"> <li>application according to plant species and needs</li> <li>important in planters where root space and soil-fertility are limited</li> <li>regular nutrient replenishment required in older substrates</li> </ul>
<b>Pruning</b>	<ul style="list-style-type: none"> <li>performing maintenance and rejuvenation pruning as needed</li> <li>cutting back of overhanging or undesired shoots</li> <li>removing dead or diseased shoots</li> </ul>
<b>Check for trunk constriction</b>	<ul style="list-style-type: none"> <li>inspecting and loosening of plant ties if necessary</li> <li>checking for signs of stem strangulation or tight bindings</li> <li>inspecting and resecuring or removing of loose and unstable components</li> </ul>

## 4. Discussion

### 4.1 HPCP-Concept

Through the course of the demo-study, it became evident that not all climbing plants are equally suited to deliver the functional and ecological performance expected from contemporary VGS, particularly in urban contexts where shading, cooling, and space efficiency are crucial. This insight led to the idea of the development and introduction of the concept of HPCP, a term introduced and proposed for the first time within this study.

HPCP refer to a distinct group of species that fulfil a set of performance-based criteria addressing both ecological and technical dimensions of VGS design. Specifically, HPCPs should be able to:

- Provide substantial bioshading performance, effectively reducing solar heat gain on facades (Ip et al., 2010; Poiss et al., 2025a).
- Achieve rapid growth rates and vertical coverage, reaching up to 8 m in height within three years and delivering PC of the target area, as required by Austrian Standard ÖNORM L1136:2021 and min. 80 % projected PC within the period of 3 years after installation for highest possible shading performance
- Demonstrate resilience and vitality under typical urban stressors such as heat, drought, wind exposure, and air pollution (Gräf et al., 2021; Spörl et al., 2023).

- Integrate with structural systems, ensuring that both plant growth and support structures remain stable under biomass and wind loads (Stangl et al. 2025).
- Respond to structured maintenance routines, including pruning, guiding, and irrigation, which are essential to sustain the target vegetation state (Briefer et al. 2025).

In contrast to purely horticultural or aesthetic selection criteria, the HPCP concept emphasises quantifiable, performance-oriented outcomes such as growth and coverage rates, biomass production, and bioshading efficiency. The latter can be measured using the BSC introduced by Ip et al. (2010), allowing for objective comparison of species performance.

A key contribution of this study is the systematic definition and monitoring of plant physiological variables that operationalise the HPCP concept. These include PC, WLAI, BSC and Stomatal Conductance, which were measured across both demonstration sites over three growing seasons and are described in more detail in the project report (Stangl et al., 2025) and the research paper (Poiss et al. 2025a). Examples of HPCPs were identified and tested within the GLASGrün project all of which demonstrated strong vertical growth, high seasonal shading potential, and sustaining viability under proper care protocols. Growth and bioshading performance of *Aristolochia macrophylla*, *Humulus lupulus*, *Vitis coignetiae* and *Wisteria sinensis* were demonstrated and BSC data throughout the annual cycle are provided in Poiss et al. (2025a).

The HPCP concept is proposed as a transferable model for future GI projects and can support both simulation-based planning and building physical model calculations using BSC data, and real-world application of vegetation-based climate solutions. The results of the presented HPCP-concept study highlight critical considerations for the successful implementation and sustaining performance of VGS. For planners and designers, the findings emphasise the need to select appropriate climbing species based on growth form and maintenance requirements. Integrating species-specific behaviour into the very early planning phase supports structural integrity and maximises ecological benefits. Here a clear focus on the target vegetation scenario plays a key factor.

## 4.2 Maintenance Framework

Up-to-date and acknowledged maintenance regulations for VGS exhibit shortcomings for the GLASGrün systems tested and the purpose of explicitly provide bioshading using vertical greenery. Therefore, the GLASGrün-project requirements included the elaboration and testing of establishment and maintenance strategies and to provide a guideline for the new GLASGrün system and bioshading of glass facades. A guideline in this connex was presented in Briefer et al. (2025), and together with the results presented in Stangl et al. (2025) and in Poiss et al. (2025b) this was the basis for the here presented framework.

For facility management, the study underlines that VGS are not passive systems. Instead, and similarly to horizontal greenery, they require well-structured maintenance strategies including early establishment care, regular training of plant growth, and ongoing pruning, as defined in respective guidelines and used as starting point within this demo-study. Plant specific know-how is required, and involving gardeners qualified for VGS must be ensured. The checklists and tables provided are intended to serve as practical aids in daily operations and help to coordinate responsibilities.

Our results can directly improve existing facade and vertical greenery maintenance guidelines. Integrating the defined care phases—establishment, development, and preservation (BMDW 2021)—into project workflows ensures plant vitality and sustained ecosystem services like shading, cooling, and biodiversity. For bioshading, achieving high PC quickly requires focused plant training (e.g., shoot guiding and fixation), while species-specific pruning can stimulate additional shoot formation for faster coverage.

However, after the target PC has been achieved, pruning gains other significance in the preservation phase and beyond: (I) in order to stimulate biomass body and WLAI; (II) in terms of keeping shoots from undergrowing of building or facade elements (yearly but sensitive removal of shoots is necessary without harming the canopy and leaf body); (III) in terms of regulating light transmission. E.g. to promote full shading in peak summer, to avoid unwanted over-darkening, or to provide landscape views and indoor shading designs, pruning can be applied in season-specific frequencies and to a predefined extent. Efficient care means doing the right thing at the right time – based on a predefined goal, not maximum intervention.

## 5. Conclusions

In this contribution a concept and classification for HPCP and a maintenance framework for vertical greenery systems, built upon acknowledged strategies for greenery establishment, is presented. By combining empirical data from two demonstration sites with performance monitoring over three years, the following key insights were derived to answer the guiding research questions in Table 7.

**Table 10: Research Questions and Study Findings**

	<i>Main Findings</i>
RQ1: HPCP Concept	<ul style="list-style-type: none"> <li>• The HPCP Concept is a flexible framework emphasizing performance-based outcomes.</li> <li>• Core principles: rapid vertical coverage, urban stress resilience, structural integration, and maintenance responsiveness.</li> <li>• Supports early integration of plant-specific behavior into planning for ecological and technical optimization.</li> <li>• Transferable to other GI projects and supports simulation-based planning and real-world applications.</li> </ul>
RQ2: Maintenance Strategies for VGS	<ul style="list-style-type: none"> <li>• Maintenance as a strategic, phased based process: Definition and Planning, Establishment, Development, and Preservation Maintenance.</li> <li>• Early establishment care is critical for rapid coverage and bioshading.</li> <li>• Seasonal pruning regulates shading and light transmission while maintaining plant vitality.</li> <li>• Practical tools and qualified VGS expertise are essential for sustaining success.</li> <li>• Structured care regimes must be embedded into facility management plans to ensure sustaining bioshading effect, plant health, and ecosystem service delivery.</li> <li>• Maintenance strategies must align with project-specific goals and integrate into workflows from the start.</li> </ul>

From a sustainability perspective, maintenance must be viewed as a central component of GI, not a secondary task. Without regular and proper care on a yearly basis, plant systems lose functionality and could potentially develop shortcomings within the biomass structure or become damaging to building elements. As such, target structures with target areas and target PC must be defined, and budgeting and contracting for maintenance services should be a mandatory request in all vertical greening projects.

However, our study also features some limitations. It focuses primarily on a selected group of climbing species used in limited building contexts. Further research and

evaluation are needed on adult plant structures, species performance under extreme climatic and stress conditions, in mixed-plant systems, and across varying architectural typologies. Future work should also explore smart technologies for monitoring, irrigation purposes and assessing life-cycle costs more comprehensively.

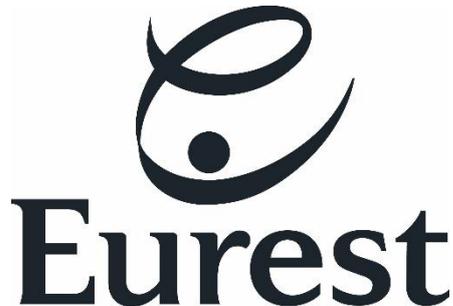
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