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Green jobs, scarce talent: How the green transition intensifies labor shortages

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Green Jobs, Scarce Talent: How the Green Transition Intensifies Labor Shortages

Ronald Bachmann, David Fischer, Sibylle Gausing,
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Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

Bergische Universität Wuppertal, Schumpeter School of Business and Economics
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Green Jobs, Scarce Talent: How the Green Transition Intensifies Labor Shortages

Ronald Bachmann (RWI, Heinrich-Heine University Düsseldorf, IZA)
David Fischer (TU München, Stiftung Familienunternehmen)
Sibylle Gausing (Stiftung Familienunternehmen)
Roman Klauser (RWI, Heinrich-Heine-University Düsseldorf)
Timo Rammert (RWI, University of Duisburg-Essen)

21 May 2026

Abstract

This paper examines the extent and characteristics of labor shortages in the context of the green transition of the German labor market and discusses potential strategies to mitigate them. Using online job vacancy data, a firm survey, administrative employment and apprenticeship data, and measures of occupational greenness and labor shortages from the German Federal Employment Agency, we provide a comprehensive picture of green labor demand, supply, and shortages. We show that green labor demand has increased along both the extensive and intensive margins and identify the occupations and skills most relevant to the green transition. While green occupations are represented among both shortage and non-shortage occupations, firms increasingly expect the green transition to exacerbate skill and labor shortages. At the same time, the German apprenticeship system appears to play an important role in alleviating these shortages: although green occupations face shortages of apprentices, they remain comparatively attractive to applicants. Finally, firms predominantly rely on internal adjustment mechanisms – particularly training and increased technology use – rather than external recruitment strategies, such as hiring from abroad, to address changing labor demand.

JEL-Classification: J23, J24, Q52

Keywords: green transition, labor demand, firm adjustment, green skills, labor shortages

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1 Introduction

The German economy is undergoing several structural transformations. Alongside digital transformation, demographic change and disruptions in international trade flows, the green transition is reshaping production processes, products and services. This transition is driven primarily by policies to reduce CO_2 emissions and by changes in consumer behavior (OECD 2023).

The green transition affects the labor market by changing both product demand and production processes. As demand shifts away from environmentally harmful products and towards more sustainable alternatives, firms adjust the occupations and skills they require. The resulting greening of employment occurs through two main mechanisms: first, an increase in employment in green occupations and a decrease in employment in brown occupations, which shifts occupational employment shares; and second, changes over time in the tasks workers perform within occupations. (Bachmann et al. 2026b). These two mechanisms imply that labor demand for occupations and skills is changing.

These changes in labor demand are taking place in a labor market characterized by a general shortage of skilled workers and labor (OECD 2025). A significant shortage of skilled workers is also evident in many green occupations. For example, the demand for workers with green skills is growing much faster than the supply of such workers in many countries (LinkedIn 2023). If labor shortages in green occupations become severe, they could slow the greening of the labor market. Indeed, an analysis of the green components of the US American Recovery and Reinvestment Act (ARRA) shows that net job creation was much higher in US commuting zones with a larger share of workers with green skills (Popp et al. 2022).

Despite the importance of skill shortages for the economy, there is very little evidence on the extent and characteristics of labor shortages in green skills and occupations, and on potential solutions to reduce such shortages. Previous research has however explored the skills and occupations that are needed for the green transition. For example, Vona et al. (2018) identify 16 green skills and cluster them into four occupational groups of green skills: i) engineering and technology, ii) operations management, iii) monitoring, and iv) science. However, what is missing is a link between these identified skills and occupations and the literature on skill shortages.

The present study aims to fill this gap by answering the following research questions for the German labor market. First, how does the demand for green labor develop and what are the most important green occupations and skills? And how do firms expect the green transition to change labor demand and contribute to further labor shortages? Second, which green

occupations are most affected by labor shortages? Third, how can labor shortages be prevented in the green transition? In this context, we consider both the supply of green labor provided by the German apprenticeship system and the strategies firms use to meet their labor demand. To answer these research questions, we use several data sources: online job vacancy data, a firm survey, administrative data on employment and dual education, a measure of green occupations, and a measure of labor shortages provided by the German Federal Employment Agency.

The results of our analysis provide important information for relevant actors navigating the current green transition. In particular, companies face the challenge of identifying at an early stage which occupations and skills will play an important role in the green transition and where skills and labor shortages are already emerging. This has implications for human resource policies (hiring and firing) as well as for employee training. For policymakers, the green transition poses a challenge because education and labor market policies need to be designed such that a sufficient supply of appropriately skilled workers can be ensured, for example by promoting dual education, training, and higher education in relevant fields.

While the green transition poses important challenges for workers, firms and policymakers, it also offers economic opportunities. An empirical study of Swedish firms shows that they responded to the introduction of a CO_2 tax by significantly increasing their innovation activities (aus dem Moore et al. 2025). Although such an approach usually increases costs in the short run, it can strengthen the (international) competitiveness of companies in the long run. Similar opportunities exist for German family businesses, which are playing a pioneering role in areas such as environmental technology (Stiftung Familienunternehmen (Hrsg.) 2023b). Employees can also benefit from such developments, as shown by the increased demand for labor in the wake of the energy transition in Germany (Büchel et al. 2025).

This paper therefore analyze the challenges and opportunities of the green transformation of the labor market with a specific focus on labor shortages. We do so in the following way. Section 2 describes the data and methods, Section 3 analyzes green labor demand, Section 4 examines firms' responses to labor shortages, and Section 5 concludes with implications.

2 Data and methods

For our analysis, we draw on a combination of administrative employment records, online job advertisement data, and firm-level survey data. To analyze the labor-market implications of the green transition within these data sources, a key prerequisite is to identify and quantify the environmental relevance of different occupations and skills.

Several approaches exist to measure this environmental relevance, including classifications based on industry-level emissions (Südekum and Rademacher 2024) or sectoral affiliation (Becker and Shadbegian 2009, Elliott and Lindley 2017). In this paper, we adopt a task-based approach, which conceptualizes occupations as bundles of activities rather than fixed job titles. This framework allows environmental relevance to be linked directly to the content of work and therefore to the actual tasks performed on the job. Task-based measures have been widely used in the literature on technological change and structural transformation (Acemoglu et al. 2025, Bachmann et al. 2026a) and have more recently been applied to study the labor market implications of the green transition (Vona 2021, Vona et al. 2019).

We measure occupational greenness using the Greenness of Jobs Index (GOJI) developed for the German labor market by Janser (2019, 2025). The index is constructed using detailed task descriptions from BERUFENET, the occupational information system of the German Federal Employment Agency. Individual tasks are classified according to their direct environmental impact into environmentally beneficial ("green"), environmentally harmful ("brown"), or environmentally neutral activities ("white"/"gray"). Given that occupations are bundles of tasks, occupational greenness is defined as the share of green tasks in all tasks performed within an occupation o in year t:

$$GOJI_{o,t}^{\text{green}} = \frac{\sum \text{green tasks}_{o,t}}{\sum \text{all tasks}_{o,t}} \quad (1)$$

Analogously, a brown task index can be constructed based on the share of environmentally harmful tasks within an occupation. The difference between the green and brown task shares yields the so-called net greenness index $GOJI_{o,t}^{net}$:

$$GOJI_{o,t}^{net} = GOJI_{o,t}^{\text{green}} - GOJI_{o,t}^{\text{brown}} \quad (2)$$

The net greenness index takes values between $GOJI_{o,t}^{net} \in [-1,1]$ and captures the balance between environmentally beneficial and environmentally harmful tasks within an occupation. Positive values of the $GOJI_{o,t}^{net}$ indicate that environmentally beneficial tasks predominate within an occupation, whereas negative values reflect a predominance of environmentally harmful tasks. Based on the $GOJI_{o,t}^{net}$, we further construct a binary classification of occupations following Bachmann et al. (2026b), defined as follows:

- Green occupations: $GOJI_{o,t}^{net} > 0.01$

- Brown occupations: $GOJI_{o,t}^{net} < -0.01$
- Neutral occupations: otherwise

The GOJI measures are available on an annual basis for the period 2012–2022 at the occupational group level (KldB-2010 3-digit × 5-digit, i.e. requirement level), covering 144 occupational groups across four requirement levels – helpers, skilled workers, specialists, and experts. The data are provided through the IAB Occupational Panel, an occupation-level dataset compiled by the Institute for Employment Research (IAB) (Grienberger et al. 2023).

To analyze the evolution of green employment, we combine the GOJI measures with administrative employment records from the German Federal Employment Agency. We use a special data extract covering the number of employees subject to social security contributions by 3-digit occupations for the period 2013–2024 (yearly reference date: June 30). The information is based on mandatory employer notifications to the social security system and therefore provides a highly reliable measure of employment. We link employment counts to occupational greenness measures at the 3-digit level of the KldB classification.

While the administrative employment data captures the supply side of the labor market, analyzing the green transition also requires information on evolving labor demand and skill needs. To this end, we draw on a large dataset of online job advertisements (OJA). The OJA data is provided by Palturai GmbH / Finbot AG and consists of systematically scraped vacancy postings enriched with firm-level information from the commercial register (see e.g. Bachmann and Storm 2024). Our dataset covers approximately 14.5 million job postings from 285,379 firms over the period January 2017 to December 2024.

We process the full-text vacancy data using natural language processing (NLP) techniques to extract information on occupations, regional location, and requested skills. The raw postings undergo several preprocessing steps, including the removal of duplicates and the standardization of occupational titles. This ensures that vacancy postings can be consistently assigned to occupational groups (KldB-2010, 3-digit level). In addition, to improve the reliability of skill extraction, we clean and structure unstructured text fields, such as profile and task sections and remove boilerplate content. To identify skill requirements mentioned by employers, we parse the vacancy texts via a keyword-based approach.

A key advantage of vacancy data lies in their granularity and timeliness: they reflect firms' actual recruitment needs and allow labor demand to be observed at high frequency. As such, they provide a forward-looking measure of labor market dynamics that expands the stock-based perspective captured in administrative employment records.

To complement the administrative and vacancy-based evidence, we conducted an online firm survey in cooperation with the ifo Institute. The survey targeted managers and human resources staff and was conducted between May 5 and May 31, 2025, with a total of 594 participating firms. The questionnaire collected information on firms' exposure to the green transformation, recruitment challenges, and strategic responses in terms of hiring, training, and organizational adjustment. In addition, firms were asked to report on perceived challenges in the training of their workforce in green skills. This survey-based evidence provides a firm-level perspective on how the green transition translates into changing skill needs and complements the quantitative insights obtained from employment and vacancy data.

Taken together, the combination of administrative employment records, vacancy data, and firm-level survey evidence allows us to capture multiple dimensions of labor market adjustment to the green transition.

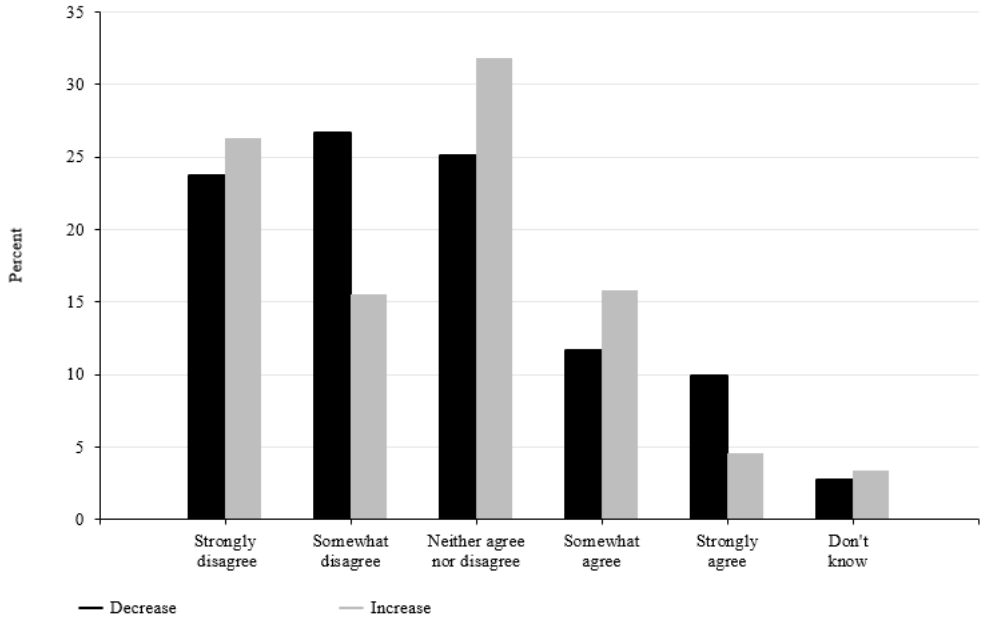
3 Labor demand in the green transition

3.1 Firms' employment expectations and labor demand

To analyze changes in labor demand, we begin by providing firms' expectations regarding the evolution of employment in the green transition. To do so, we asked firms to what extent they expect employment (i) to decrease and (ii) to increase. As becomes apparent in **Fehler! Verweisquelle konnte nicht gefunden werden.**, the picture is mixed. Regarding employment declines, about a fifth of the companies expect a decrease in employment ("somewhat agree" and "strongly agree"), but about half of the companies disagree with the statement: "The green transition will lead to a decline in employment" ("strongly disagree" and "somewhat disagree"), and around one quarter of companies do not anticipate any substantial negative effects on employment ("neither agree nor disagree"). Therefore, there are far more companies that expect no decrease in employment than companies that expect such decreases.

Employment increases are expected by nearly one quarter of companies, around a third do not expect substantial increases ("neither agree nor disagree"), and more than 40% disagree or strongly disagree with the statement "The green transformation will lead to an increase in employment". Taken together, the results on firms' employment expectations indicate that perceived risks and opportunities are relatively equally balanced between firms.

Figure 1 **Consequences of the green transformation: increase/decline in employment**



Source: ifo employment survey.

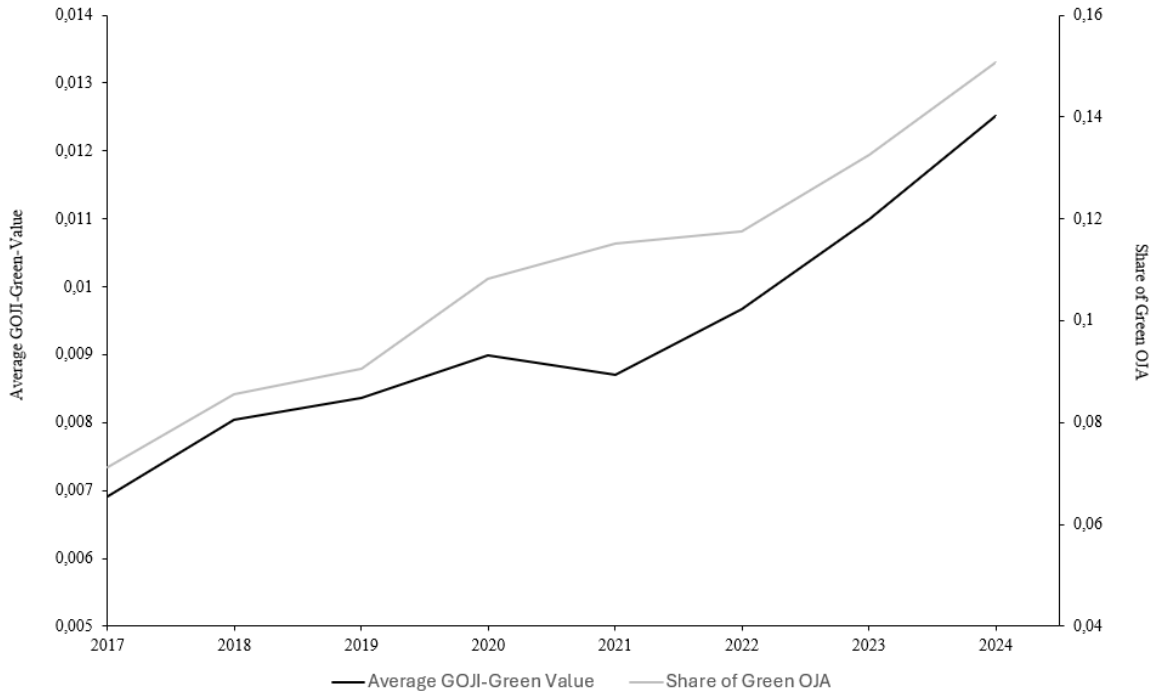
Labor demand is an important potential driver of the employment effects of the green transition. To analyze labor demand, we start by analyzing the evolution of the environmental content of job postings over time. To do so, each vacancy is assigned the GOJI value of the occupation it targets. Based on this mapping, we compute the average greenness of all job advertisements for each year of our period of analysis. The development of this green labor demand is depicted in Figure 2.

The results for the overall greenness of labor demand indicate a relatively low level, but a clear upward trend: In 2017 the average GOJI green value across all job postings was around 0.007, rising to a value exceeding 0.012 by 2024. Other studies looking at the greenness of employment find similarly low levels for the greenness of employment. For instance, Vona et al. (2018) find a total greenness across occupations of 0.023. An OECD assessment of the European labor market also documents a comparable positive trend in the greening of employment across countries with an initially low level of greenness for Germany (below 0.02 percent) (Vandeplas et al. 2022).

This pattern is further supported when applying the binary classification of occupations into green and non-green categories based on the $GOJI^{net}$ as outlined in Section 2. The share of job postings associated with green occupations in all job postings increases steadily over the observation period (Figure 2). By 2020, more than one in ten job advertisements were linked to

an occupation classified as environmentally relevant, pointing to a growing role of green occupations in firms' recruitment activities.

Figure 2 The extensive and intensive margin of green labor demand over time



Source: Palturai/Finbot Online Job Advertisements (OJA), own calculations. Notes: The graph shows the extensive margin (share of green OJA in all OJA) and intensive margin (GOJI-Green-Value of OJA) of green labor demand over time.

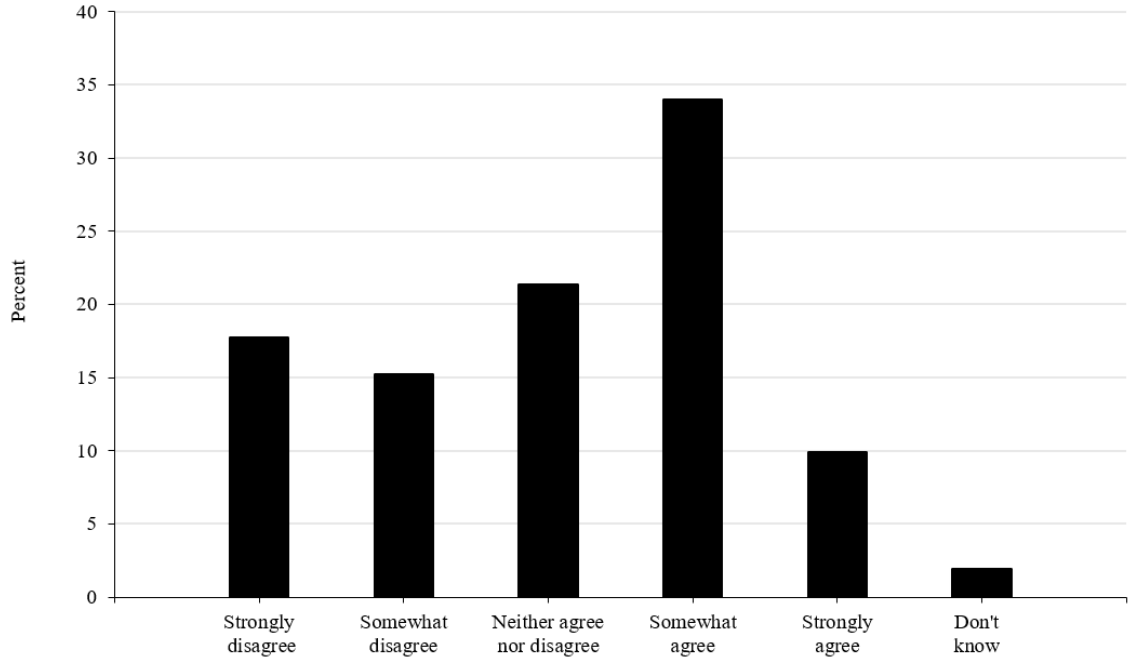
Taken together, these findings suggest that the green transition is increasingly reflected in firms' hiring behavior. While green occupations still represent a minority of overall labor demand, their relevance has expanded noticeably over time, both in terms of their average environmental task content and their share among newly advertised positions.

3.2 Skills and occupations most in demand

Given the increase in the overall demand for green skills, the question arises how strongly the demand for green skills and occupations is changing. To answer this question, in a first step we again asked firms about their expectations regarding these changes. As it turns out (cf. figure 3), more than 40% of the surveyed firms expect that the green transition leads to a change in skill requirements ("somewhat agree" or "agree strongly"). Only a third of firms expect the

green transition not to have consequences for their skill requirements ("Disagree", "Somewhat disagree"). These firm expectations are in line with the expectations of employees, the majority of whom expect that they will need to acquire new competences in the course of the green transition (Bachmann et al. 2025). In the following, we therefore investigate which skills and occupations are most in demand in the green transition.

Figure 3 Consequences of the green transition: Are skill requirements changing?



Source: ifo business survey

Regarding the greenness of occupations, Table 1 shows the ten occupational groups with the highest average GOJI-green values in 2022.[1] These occupations are characterized by a particularly high proportion of environmentally friendly activities. Occupations in environmental management and environmental protection technology rank at the top, reflecting their direct involvement in the planning, implementation, and monitoring of environmentally relevant measures.

The occupational group of "Environmental Protection Administration and Environmental Protection Consulting" features the highest GOJI-green value. Its activity profile encompasses

[1] Since GOJI values are only available up to and including 2022, extending the analysis to 2024 is not informative, as projected values are based on the 2022 levels and would therefore mechanically reproduce the same ranking of occupations.

regulatory and legal domains (e.g., environmental law, waste law, emissions protection law), classical environmental protection aspects (e.g. water and nature conservation), advisory functions (e.g. environmental and energy consultancy) as well as ecological balancing. Rather than being primarily engaged in the operational implementation of green transition measures, these professions predominantly perform steering, coordination, and strategic governance functions.

Table 1 Top 10 Occupational Groups with the Highest Green GOJI Scores (2022)

Rank	Occupational Group	Green GOJI	Number of Employees
1	Environmental protection management and environmental protection consulting	0.503	18,550
2	Environmental protection engineering	0.332	18,502
3	Drivers of vehicles in railway traffic	0.251	37,138
4	Forestry and hunting, landscape preservation	0.225	35,361
5	Building services and waste disposal	0.221	190,916
6	Gardening	0.128	259,378
7	Traffic surveillance and control	0.125	60,762
8	Geology, geography, and meteorology	0.109	12,906
9	Occupational health and safety administration, public health authority, and disinfection	0.108	15,945
10	Drivers of vehicles in road traffic (also bus and tram)	0.100	964,599

Source: Special employment data extraction by the Federal Employment Agency, own calculations

The activity profile of the occupation “Environmental Protection Engineering” is structured differently. It includes advisory and monitoring tasks but also numerous operative-technical activities with direct reference to the implementation of the green transition, including planning and commissioning of plants for waste and wastewater treatment, as well as biotechnological processes for CO_2 recycling or carbon capture and storage systems. In this group, family businesses are particularly strongly represented (Stiftung Familienunternehmen (Hrsg.) 2023a).

Occupational groups related to vehicle operation, particularly in rail and road transport, are also represented among the top-ranking occupations. These aggregated groups include public transport representing a more environmentally compatible transportation form. These groups also show a more pronounced greening over time (Bachmann et al. 2026b). Remaining occupations, such as ‘Gardening’ as well as ‘Geology, geography and meterology’, are closely linked to environmental sustainability through their roles in resource conservation and the sustainable management of natural ecosystems.

Overall, our results on the most important green occupations in Germany are in line with findings for the US where occupations related to engineering and technology, operations management and monitoring play a key role for the green transformation of the labor market (Vona et al. 2018).

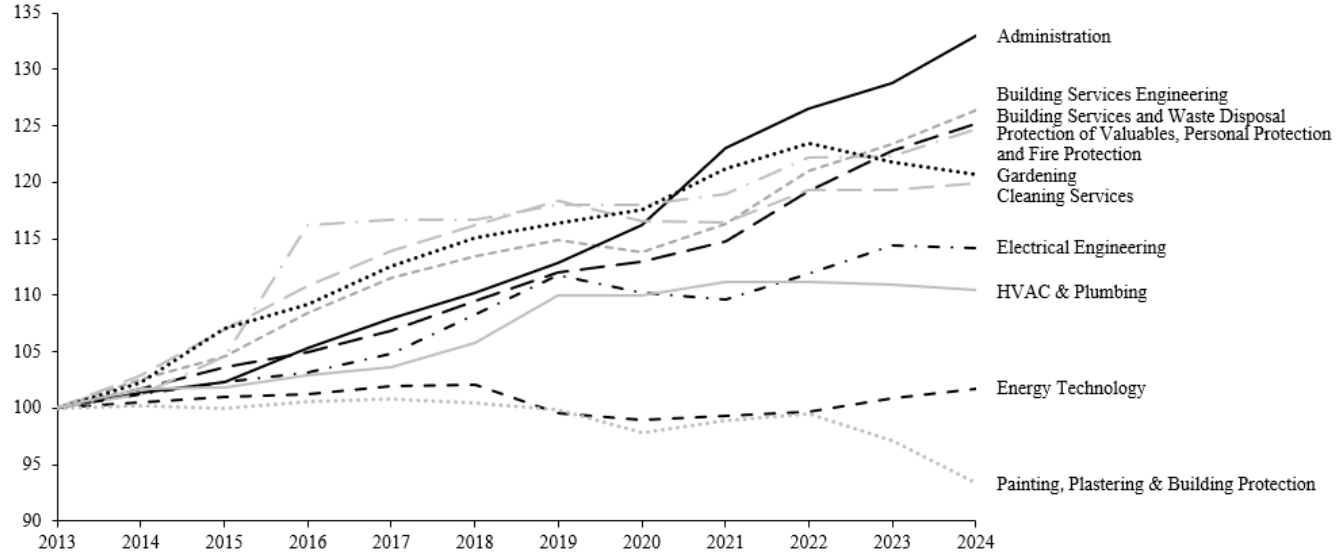
To identify green occupations with both high greenness and high labor market relevance, we carry out a supplementary analysis taking into account both the greenness of occupations and the number of employees in an occupation (cf. Table A1).[2] Between the top ten green occupational groups with the highest employment (Table A1) and the ranking of the greenest occupations (Table 1), there is only one overlap: Occupations in building services and waste disposal. This group plays a central role in the circular economy and recycling. Apart from that, the occupational groups differ significantly. Among the top ten green occupational groups, "Occupations in public administration" has by far the highest number of employees (Table A1). Although this may appear unexpected at first glance, it can be explained by the broad level of occupational aggregation, which encompasses public sector employees engaged in municipal environmental and sustainability matters and thus performing a non-negligible share of green activities.

Given that these occupational groups account for the largest share of green employment, it is informative to examine how their employment levels have evolved over time. Figure 4 therefore traces the development of these occupations between 2013 and 2024. Interestingly, some of the ten largest groups, such as "Energy Technology" and "Painting, Plastering & Building Protection" exhibit little to no employment growth, or even declining employment over the period. These are mainly classical vocational training occupations experiencing a general decline in applicants, an issue analysed in detail in Section 4.1. The remaining groups record employment growth between 11% ("HVAC & Plumbing") and 33% ("Administration").

Overall, the German workforce has become increasingly green over the past decade. Although green employment remains modest in aggregate terms, the transformation has gained momentum over time. Especially occupational groups characterized by high greenness intensity or sizeable employment levels show disproportionately strong employment growth.

[2] For this purpose, the binary classification of green occupations was used, which is based on defined threshold values of the GOJI-net. Subsequently, those occupations with the highest employee numbers were filtered out from the green occupations.

Figure 4 **Employment Development of the 10 Green Occupational Groups with the Highest Employment**



Source: Special employment data extraction by the German Federal Employment Agency, own calculations.

Up to this point, the analysis has looked on employment stocks, which typically evolve only gradually over time. To complement this perspective, we now turn to labor demand, which provides a more forward-looking view of how the green transformation reshapes occupational structures and skill requirements. Table 2 reports the ten most in-demand green occupational groups in 2024, measured by the number of job advertisements classified as green under our binary classification.

Table 2 **Top 10 Green Occupational Groups with Specific Qualification Levels with the Highest Number of Job Postings (2024)**

Rank	Occupation	Rank	Occupation
1	Energy Technology, Skilled Workers	6	Building Services Engineering, Skilled Workers
2	Electrical Engineering, Specialists	7	Building Services and Waste Disposal, Skilled Workers
3	Technical Research and Development, Experts	8	Machine-Building and-Operating, Experts
4	Cleaning Assistants	9	HVAC & Plumbing Skilled Workers
5	Electrical Engineering, Experts	10	Real Estate and Facility Management, Specialists

Source: Finbot/Palturai OJA data, own calculations

Demand for green occupations is dominated by specialized and technical occupational groups such as Energy Technology, engineering-oriented activities (Electrical Engineering, Building

Services Engineering, Machine-building), building technology, facility management specialists and skilled workers in plumbing, sanitary, heating and air conditioning technology. These occupations focus on increasing energy efficiency in buildings and technical implementation of emission reduction measures.

The analysis of online job vacancies also allows us to identify the green skills that are most in demand (Table A2).[3] In 2024, the most frequently mentioned skill is "Energy Supply". In light of recent energy policy uncertainties and challenges, this topic has become increasingly important. Other energy-related competences, such as "Renewable Energies" and "Energy Management" are also prominently presented.

Only three of the ten most demanded green skills are not directly related to energy. First, "Environmental Protection" represents a broad competence relevant to many dimensions of the green transformation. Second, "Waste Management / Disposal" is closely linked to the previously identified high-demand occupational group "Occupations in building services and waste disposal." Third, "ESG" (Environmental, Social, Governance) reporting has gained importance as a competence for monitoring sustainability goals and managing the green transformation, while also reflecting increasing regulatory requirements related to sustainability reporting.

4 Firms' Reactions to Labor Shortages

The results in the preceding section showed that labor demand is becoming greener, and that green skills are increasingly required. For firms, the green transition has created a dual challenge: on the one hand, they have to adapt production, on the other hand they need to secure skilled workers to implement these changes. In the following, we therefore explore how firms deal with the challenge of attracting workers with the necessary skills. This includes dual vocational education as well as internal (e.g. on-the-job training) and external (e.g. hiring new workers) responses to labor shortages.

4.1 Dual Education in the Green Transition

The dual vocational education system plays an indispensable role in preparing workers for occupations central to the green transition. While higher education provides the necessary engineers and scientists, the practical implementation of green technologies, such as the

[3] To this end, we count the number of keyword matches associated with each green skill across all job vacancies.

installation of heat pumps, the maintenance of wind turbines, or the energy-efficient renovation of buildings, relies heavily on the skilled trades and technical professions which acquire their skills in the vocational system. In the following, we therefore analyze the number of apprenticeship positions, the number of applicants, and the number of started apprenticeships.

Table 3 shows the ten green occupations with the highest number of started apprenticeships in 2022. These occupations strongly overlap with the occupations for which we identified the highest labor demand above. Energy technology ranked first among the occupations with the highest demand in 2024 (as measured by OJA), and also ranked first among recognised training occupations. Electrical engineering ranked second among the most demanded occupations and ranked fifth among recognised training occupations. Similarly, waste disposal, plumbing, sanitation, heating and air conditioning technology and real estate management all appeared among the occupations with the highest demand and among the top ten green recognised training occupations. This strong overlap suggests that the dual vocational education system responds to scarcity signals from green labor demand and helps equip workers with relevant skills to high-priority technical fields of the green transition.

Table 3 Top 10 Apprenticeship Occupational Groups with the Highest GOJI-net Values (2022)

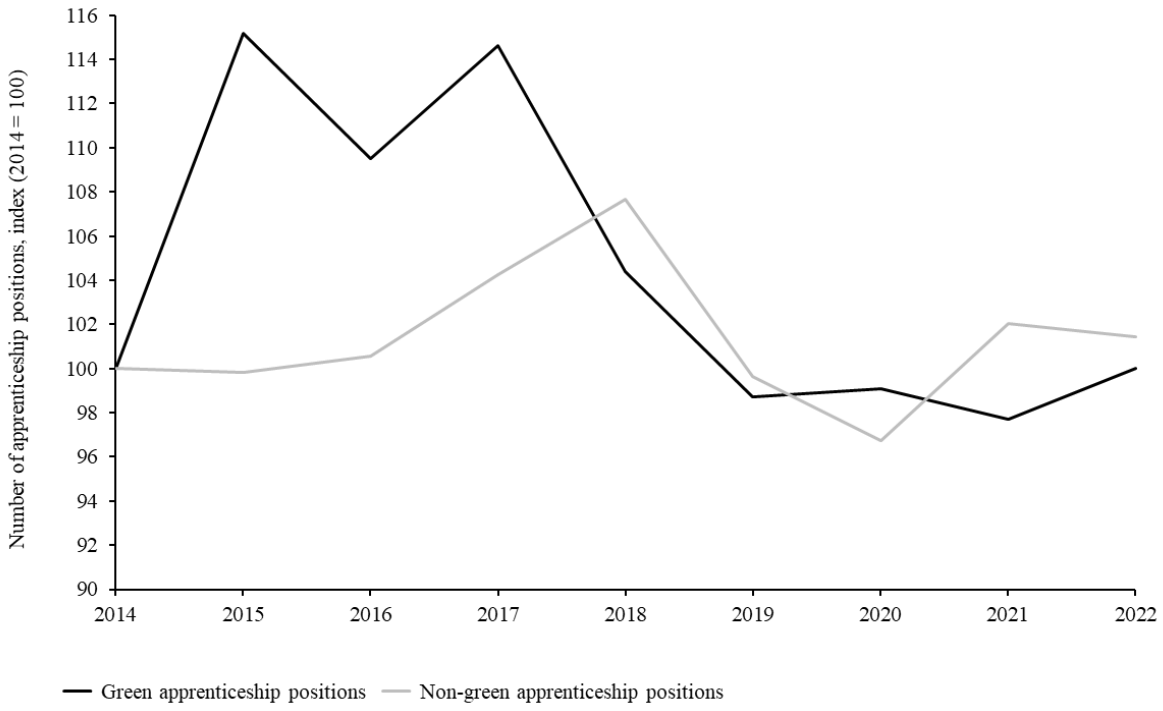
Rank	Occupational Group	GOJI-net	Number of Trainees
1	Energy technology	0.056	9,397
2	Plumbing, sanitation, heating and air-conditioning technology	0.044	6,651
3	Administration	0.020	5,305
4	Painting, varnishing, plastering, water proofing of buildings, preservation of structures and wooden building components	0.032	3,157
5	Electrical engineering	0.026	3,093
6	Gardening	0.128	1,939
7	Building services and waste disposal	0.213	1,733
8	Sales of drugstore products and pharmaceuticals, medical supplies	0.023	1,526
9	Real estate management and facility management	0.013	972
10	Physical security, personal protection, fire protection and workplace safety	0.012	965

Source: Special apprenticeship data extraction by the Federal Employment Agency, own calculations.

Although the apprenticeship system apparently responds to labor demand, the evolution of apprenticeship positions reveals complex dynamics. Figure 5 shows that green apprenticeship positions experienced a significant increase in the mid-2010s, reaching a peak in 2015 and 2017, indicating a rapidly growing firm-side demand for qualified green workers. This was followed by a noticeable decline to just below the baseline by 2020 and remaining stable until 2022. Non-green positions, in contrast, remained relatively stable until 2016, rose moderately to about 108 by 2018, and then experienced a less pronounced decline, stabilizing slightly above the baseline

by 2022. This differential development indicates that the supply of green training positions underwent a more dynamic development compared to the broader market.

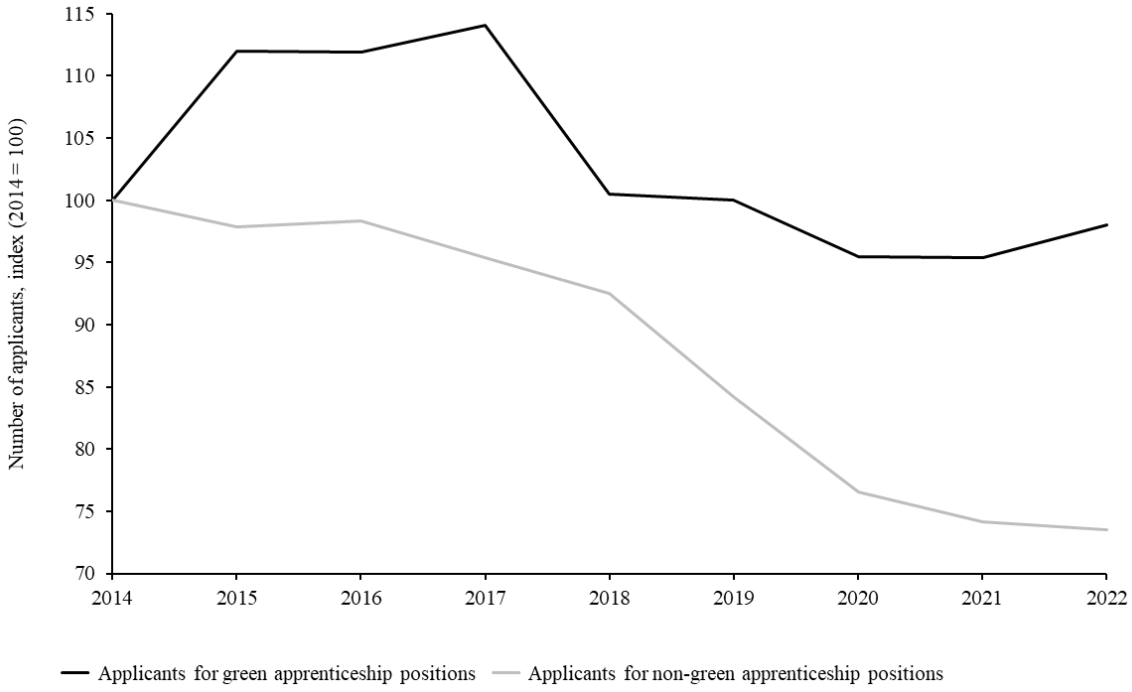
Figure 5 Number of Apprenticeship Positions Over Time



Source: Special apprenticeship data extraction by the Federal Employment Agency, own calculations.

Figure 6 reveals unfavorable long-term applicant trends. The number of applicants for green apprenticeship positions rose moderately from 2014 to 2017 (peak at about 115 compared to the baseline value of 100 in 2014), then declined sharply to about 95 by 2020 – reflecting COVID-19 disruptions – before recovering slightly to just under 100 by 2022. Applicants for non-green apprenticeship positions followed a worse trajectory: after remaining stable near 100 through 2016, they entered a sustained decline to about 75 by 2022. This divergence between green and non-green apprenticeship applications demonstrates that while non-green vocational training experienced a substantial decline in applicants, caused by demographic change and a generally falling interest in entering dual education (Brixy et al. 2023), green apprenticeship positions perform much better and therefore seem to exhibit a resilient appeal to potential applicants.

Figure 6 Number of Applicants Over Time



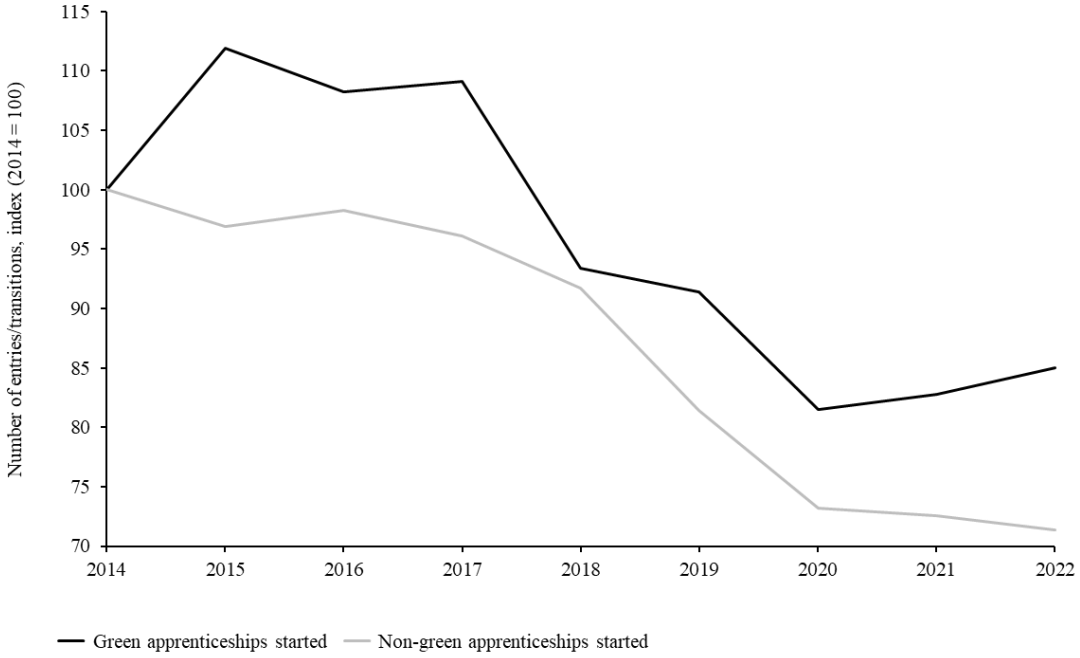
Source: Special apprenticeship data extraction by the Federal Employment Agency, own calculations.

Figure 7 presents commenced apprenticeships, representing realized matches. The data for successful matches closely tracks the underlying applicant dynamics: transitions into green apprenticeships grew between 2014 and 2016 but subsequently declined to about 80 by 2020. By 2022, the data show a mild recovery, settling at a value of roughly 85, indicating on average constant matching efficiency. Conversely, non-green commenced apprenticeships remained stable until 2017 before contracting sharply and continuously, ultimately reaching a level of about 70 by 2022. The persistence of this gap underscores differential resilience: green occupations managed to avoid the strong decline that severely affected the broader apprenticeship market, which is in line with existing evidence, Brixy et al. (2023).

Across all three metrics, green occupations demonstrate greater stability than non-green occupations. However, a disparity emerges when comparing applicants and started apprenticeships. While the number of applicants for green apprenticeship positions recovered to near its baseline level by 2022, started apprenticeships lagged behind. This suggests that steady interest among potential apprentices does not fully translate into filled apprenticeship positions. This discrepancy could indicate either insufficient demand from firms or a mismatch of supply and demand in the vocational education and training market, an issue pointed out by Wicht et al. (2024). The analysis of apprenticeship positions, applicants, and started

apprenticeships thus reveals both encouraging alignment between training and green labor demand and concerning contraints on future labor supply.

Figure 7 Number of Apprenticeships Started Over Time

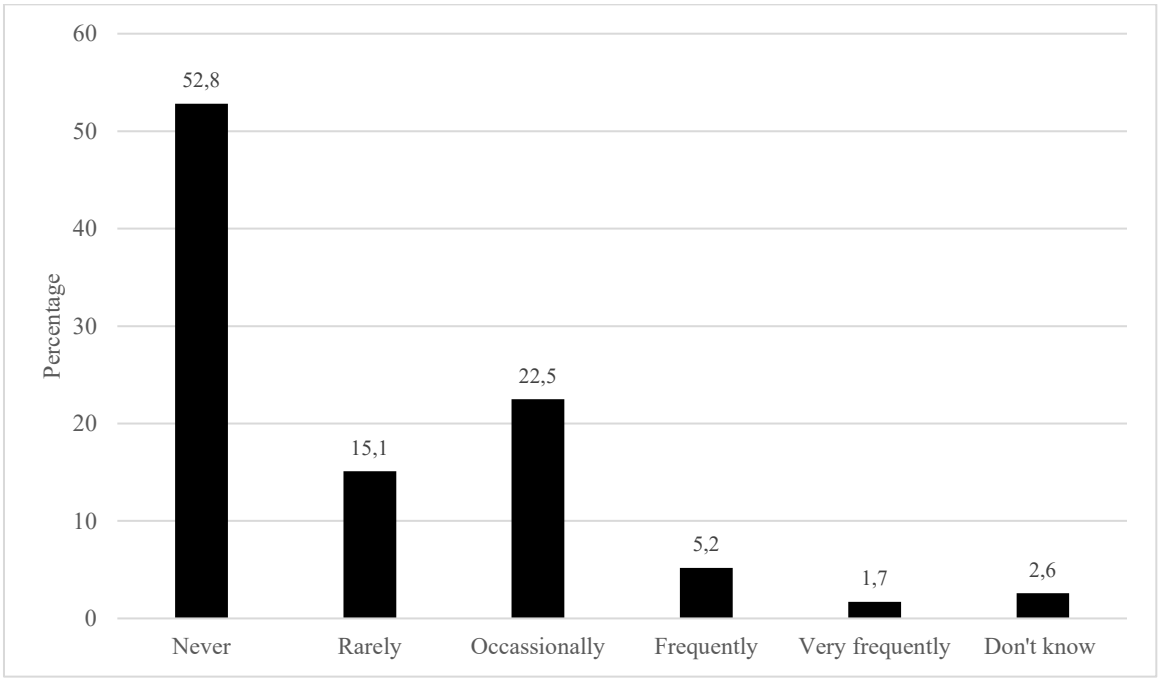


Source: Special apprenticeship data extraction by the Federal Employment Agency, own calculations.

4.2 Firms React Mainly Using Internal Solutions

Given the structural constraints and insufficient applicant numbers in the dual vocational system, the question arises which other strategies firms use to meet the rising skill demands of the green transition. The results of our firm survey are informative in this respect. Figure 8 shows that 52.8% of firms never recruit new suitable personnel to address shortages caused by the green transition, while only 6.9% do so (very) frequently.

Figure 8 **Measures Against Skilled Labor Shortages: Recruitment of Suitable Personnel**



Source: ifo employment survey.

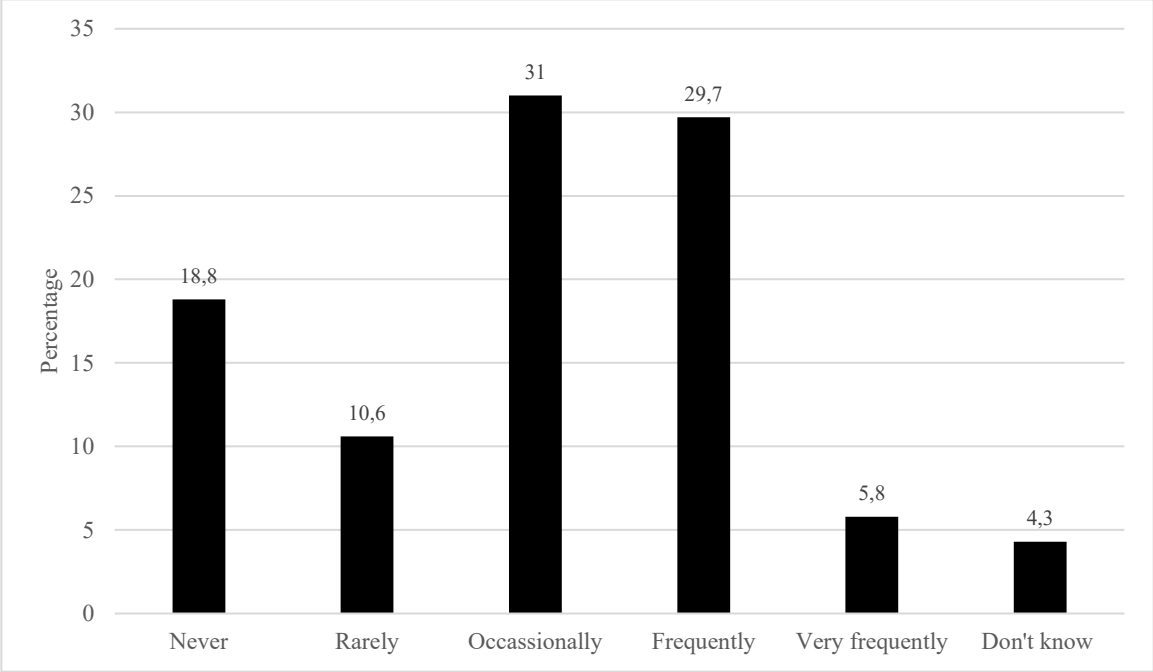
International recruitment is even rarer: 75.8% of firms never seek workers abroad (Figure A1). Production relocation proves least common, with 81.3% of firms never considering it.

This lack of external hirings could reflect multiple barriers. International recruitment may face practical obstacles, including credential recognition and language barriers. The aversion to relocation could stem from deep regional embeddedness, particularly among family enterprises that have been rooted in specific localities for generations (Bichler et al. 2022). In contrast, technology adoption and training dominate firm responses. Figure A2 indicates that nearly half of firms (48.5%) at least occasionally rely on robotics and automation to substitute for labor, while only 34.0% never do so. This aligns with findings showing firms anticipate increased R&D investment for green transition, manifesting in technology-intensive production (Figure A3). However, the 34.0% of firms that never adopt such technologies may face financial constraints or operate in sectors with limited automation potential. As a result, labor shortages may place a disproportionate burden on smaller firms and less automatable sectors.

Employee training emerges as the most utilized strategy. Figure 9 shows that 66.5% of firms use training at least occasionally, substantially higher than any alternative. Training offers strategic advantages: filling competency gaps without navigating external markets, developing firm-specific skills difficult to find externally, and strengthening organizational loyalty. Klauser and Tamm (2026) show that participating in training is associated with reduced employee mobility, underscoring the “binding” effect of such initiatives. Furthermore, they show that the

introduction of new technologies in the workplace is associated with a higher likelihood of participating in workplace training. This result is consistent with the firm-level survey responses, which likewise emphasize technology adoption and employee training as key channels.

Figure 9 **Measures to address the skilled labor shortage: further training of existing employees**



Source: ifo employment survey

5 Summary and conclusions

Our analysis adds to the growing literature on the labor-market effects of the green transition, focusing on changes in the required skills, potentially increasing labor and skill shortages in Germany, and on measures that could reduce such shortages. We first show that green labor demand has increased significantly since 2017, both at the extensive (share of green job ads) and the intensive margin (greenness of given job advertisements). We also show that firms expect the green transition to change their skill requirements.

Second, we identify the most important green occupations and skills for the German labor market. These occupations are mainly related to engineering and technology, operations management, and monitoring, which is in line with evidence from the US. These results suggest that green employment growth is driven primarily by technical and operational occupations and skills, but there has also been a significant growth in occupational groups that are closely associated with corporate reporting obligations. Our results also show that the green skills in

highest demand are mostly connected to the transition towards renewable energies which could therefore be a potential driver for future employment growth.

Third, regarding skill and labor shortages, we find that green occupations are represented both in shortage occupations (e.g., plumbing, heating, and air conditioning technology) and in occupations without a pronounced shortage of skilled workers (e.g., environmental management and consulting). The proportion of green occupations among shortage occupations has hardly changed since 2013. This may, however, change in the future as firms expect the green transition to increase labor shortages.

Fourth, we show that the supply of workers trained for green occupations through the German apprenticeship system plays an important role in alleviating labor shortages. This role appears to be stronger in green occupations than in non-green occupations. Nevertheless, failure to substantially increase the number of apprentices despite growing demand may indicate binding applicant-side constraints – demographic factors, educational preferences shifting toward academic pathways, or insufficient apprenticeship attractiveness.

Fifth, analyzing the strategies used by firms to meet their labor demand, we show that firms mostly rely on internal strategies, such as training and greater use of technology, to cope with changing labor demand, rather than external strategies such as domestic and international recruitment.

Our results have several policy implications. First, the demand for green occupations and skills in the German labor market is growing, with firms expecting a further increase in labor shortages. Early identification of (potential) shortage areas should therefore be a policy priority. Second, the green transition should be framed not only as an economic adjustment challenge, but as a strategic employment and growth opportunity. To unlock these labor market gains, policymakers must provide long-term regulatory certainty through clearly communicated CO_2 targets and stable funding frameworks that enable firms to undertake the investments required for the transition. Third, a sufficient number of apprentices in green occupations is a basic prerequisite for the success of the green transition. As regional matching problems are likely to play a role in this context, appropriate information should be provided to potentially interested parties by all actors in the dual training system: chambers of skilled trades, chambers of commerce and industry, trade unions, and the Federal Institute for Vocational Education and Training. Furthermore, companies should intensify their efforts to recruit apprentices interregionally and further develop regional training offerings according to needs. Such a strategy could be successful because there is a renewed increase in applicants' willingness to

relocate for employment following its decline during the COVID-19 pandemic (Fischer et al. 2025).

In general, the successful management of the green transition of the labor market requires coordinated efforts in the areas of education, the supply of skilled workers, and framework conditions. It is only through a combination of attractive educational offerings, improved provision of information on labor-market trends, improved regional mobility and long-term planning certainty that the opportunities of the green transition can be realized.

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7 Appendix

Table A1 Top 10 Green Occupational Groups with Specific Qualification Levels with the Highest Number of Employees (2024)

Rank	Occupational Group	GOJI-green	Number of Employees
1	Administration	0.021	938,881
2	Cleaning Services	0.046	883,769
3	Electrical Engineering	0.0278	503,052
4	Energy Technology	0.057	431,210
5	Protection of Valuables, Personal Protection and Fire Protection	0.020	345,624
6	Building Services Engineering	0.061	325,264
7	Gardening	0.128	259,378
8	HVAC & Plumbing	0.070	248,150
9	Building Services and Waste Disposal	0.221	190,916
10	Painting, Plastering & Building Protection	0.038	169,910

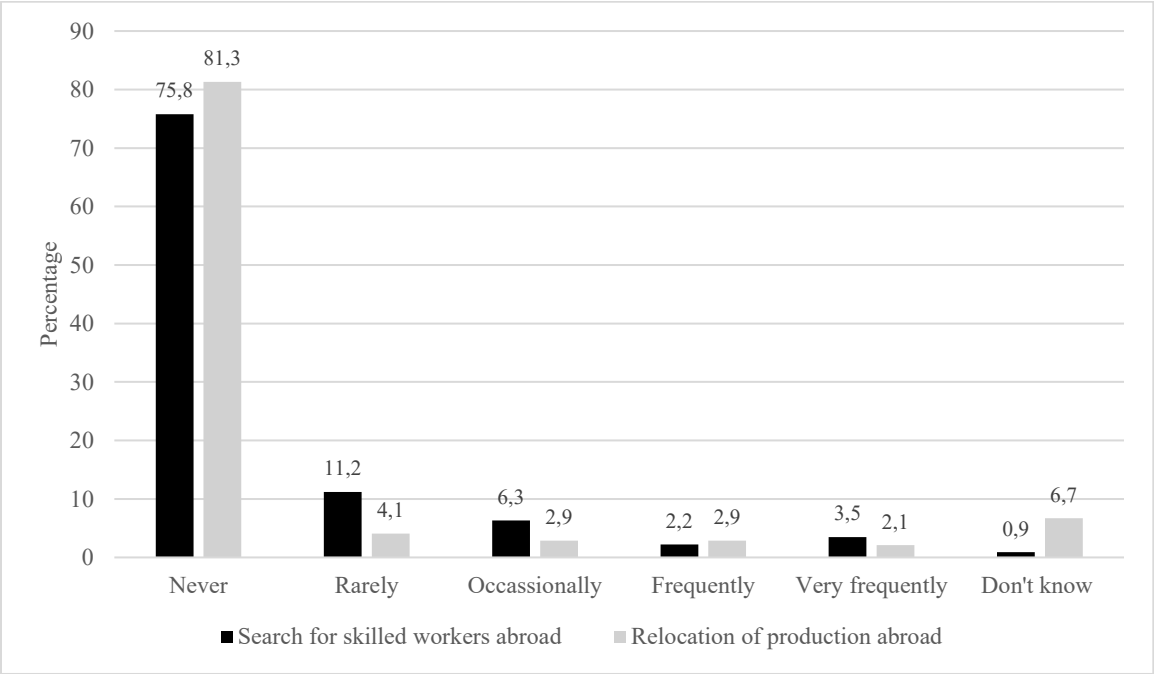
Source: Special employment data extraction by the German Federal Employment Agency, own calculations

Table A2 Top 10 Most In-Demand Green Skills (2024)

Rank	Green Skill	Rank	Green Skill
1	Energy Supply	6	Photovoltaics
2	Environmental Protection	7	Energy Management
3	Renewable Energy	8	Photovoltaics Systems
4	Waste Management / Disposal	9	ESG
5	Environmental Technology	10	Building Automation

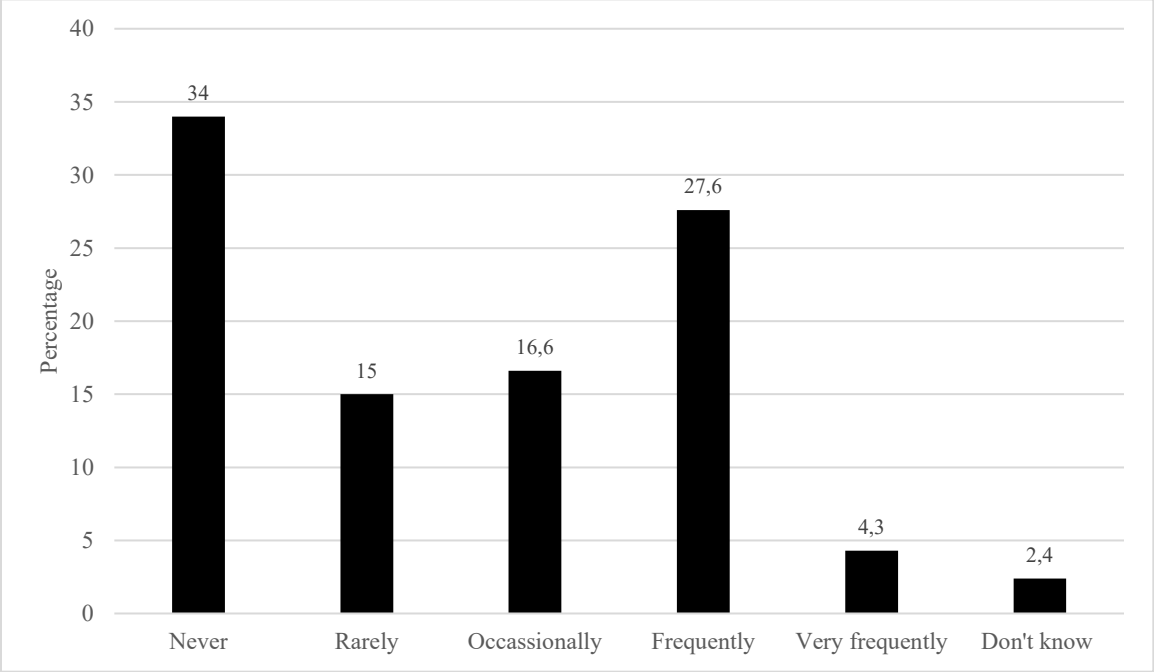
Source: Finbot/Palturai OJA data, own calculations

Figure A1 **Measures Against Skilled Labor Shortages: Search or Relocation Abroad**



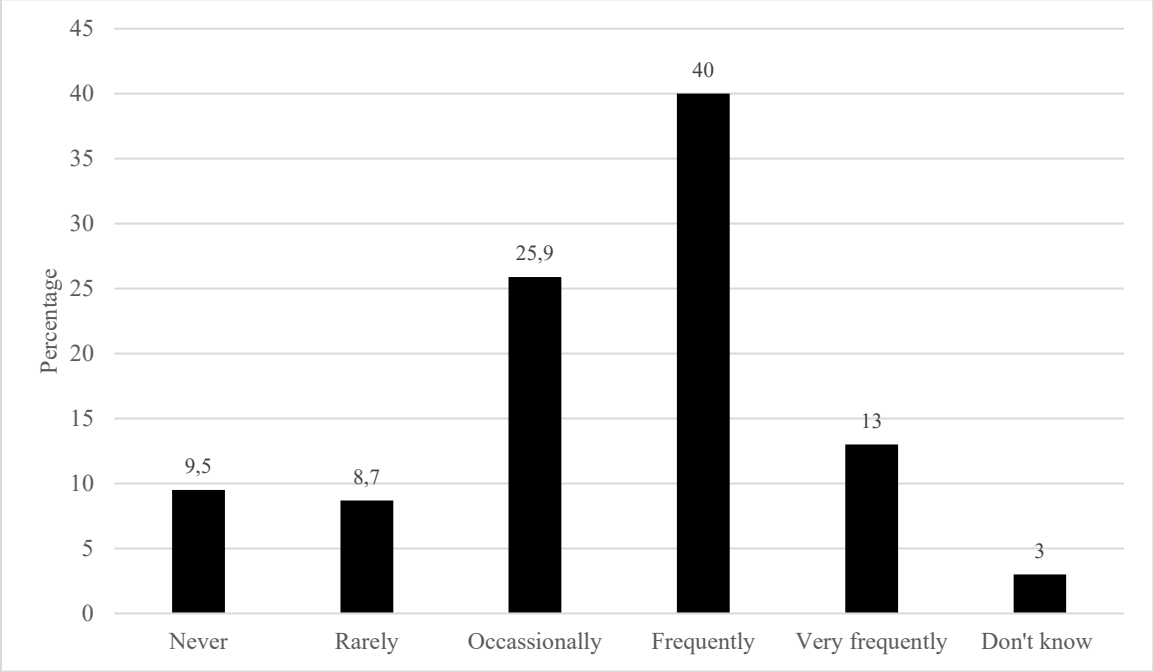
Source: ifo employment survey.

Figure A2 **Measures to address the skilled labor shortage: Increased use of technology**



Source: ifo employment survey.

Figure A3 Consequences of the green transformation: Requires increased investment in R&D



Source: ifo employment survey.