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**Conference Paper — Manuscript Version (Preprint)**

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*Suggested Citation:* Samadi, Sascha; Fischer, Andreas; Verpoort, Philipp C.; Müller-Hansen, Finn; Ueckerdt, Falko (2025) : Synthesising Current Knowledge on the Renewables Pull: A Systematic Literature Review, Industrial decarbonization and hydrogen: The politics and economics of sustainable structural transformation, Potsdam, 28.10.2025 bis 29.10.2025, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg

This Version is available at:

<https://hdl.handle.net/10419/331736>

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# Synthesising Current Knowledge on the Renewables Pull: A Systematic Literature Review

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This article accompanies an oral presentation held at the conference on “Industrial decarbonization and hydrogen: The politics and economics of sustainable structural transformation” in Potsdam, Germany on October 28<sup>th</sup>, 2025.

## Abstract

With the transition to renewable energy, global production cost patterns for industrial materials and products are shifting, potentially creating what has been termed the renewables pull. This paper conducts a systematic review to identify and synthesise the growing body of scientific literature on this emerging topic. Out of 4,813 studies screened, 81 peer-reviewed journal articles were found to be relevant. Most of these were published after 2020, with the number of publications increasing every year since then – indicating rapidly growing research interest in the field. Most studies originate from countries such as Germany or Australia, which are also identified as a potential major importer or exporter, respectively, within newly emerging renewable-based trade patterns. In contrast, while Japan and South Korea are frequently identified as potential importers, relatively few studies originate from these countries. Most of the identified literature conducts techno-economic analysis assessing the location-specific production costs of hydrogen-based derivatives and materials such as ammonia, methanol or steel produced using solar and wind electricity. Overall, the existing literature regards the renewables pull as potentially significant, although several studies emphasise that its realised impact depends on complementary locational factors, such as financing costs and policy context. Future research should expand the methodological approaches applied to this young and rapidly evolving field to assess the implications of the renewables pull for global production locations and value chain configurations, trade dynamics, and broader macro- and socioeconomic as well as geopolitical developments.

## 1. Introduction

Achieving the goals of the Paris Agreement requires a significant and sustained global reduction in greenhouse gas (GHG) emissions. The largest progress toward decarbonisation has so far been achieved through the expansion of renewable energy sources, mainly in the form of electricity generated from solar PV and wind. Renewables not only provide low-carbon energy but have also become increasingly cost-competitive due to their decline in cost. According to the International Energy Agency (IEA), global electricity demand increased by 4.3% in 2024, and renewables made up almost three-quarters of the overall year-on-year increase in power generation (IEA 2025). However, energy costs remain a decisive factor in industrial production – especially of energy-intensive basic materials – and are expected to continue to play a key role in emerging green value chains. Historically, the trade of fossil fuels has mitigated the impact of spatial disparities in primary energy availability, as coal, oil, and gas could be transported over long distances at relatively low cost. However, long-distance transport of electricity and of renewable-based energy carriers such as hydrogen is considerably more expensive, as highlighted by Day (2022). Consequently, substantial regional differences in renewable energy costs may create strong locational advantages for energy-

intensive industries in regions endowed with excellent solar or wind resources. Such regions may therefore attract new investments in energy-intensive production processes, whereas regions with less favourable renewable energy conditions could depend on costly energy imports and could struggle to remain competitive.

Therefore, the increasing use of renewables in industry can be expected to result in economic impacts that vary considerably across regions. Electricity prices differ substantially between world regions already today, with for example European electricity prices remaining mostly above those in other parts of the world. The European Union continues to pursue its long-term target of achieving climate neutrality by 2050, as outlined in the European Green Deal. At the same time, industrial competitiveness hinges on low energy prices, which has sparked concerns in European policy debates. In contrast, other world regions are presented with new opportunities arising from abundant renewable energy resources and relatively low energy prices. These regional differences in renewable energy potential may generate a pull factor for the production of energy-intensive goods, whose production costs are largely driven by energy expenditures.

The term ‘renewables pull’ refers to the attraction of industrial production activities toward regions characterised by particularly low marginal renewable energy costs (Samadi et al. 2023). This incentive may induce regional shifts in industrial production, either through the relocation of existing facilities or through changes in investment patterns for new production sites. When such shifts occur primarily due to variations in the marginal costs of renewable energy or renewable-based secondary energy carriers (such as green hydrogen or synthetic fuels), this is referred to as “green relocation” (Verpoort et al. 2024). While such relocations remain largely hypothetical at present, they may become empirically observable as the global transition toward renewable energy systems accelerates.

The concept of green relocation shares certain similarities with carbon leakage, as both describe the relocation of industrial activities across regions. Yet, the mechanisms behind these processes differ. Carbon leakage arises when industrial production migrates to regions with weaker climate policies and lower CO<sub>2</sub> costs, thereby maintaining fossil-based competitiveness. In contrast, green relocation reflects a shift driven by economic advantages associated with low-cost renewable energy. Rather than escaping regulation, industries relocate to exploit abundant and cheap renewable energy resources, enabling the low-cost production of low-carbon goods. While the rising costs of fossil-based production due to increasingly stringent climate policy is a key driver of green relocation, such relocation may even occur in the absence of climate policy, e.g. when renewable-based products become cheaper than fossil-based products due to technical progress or significant growth of demand for green products.

A growing body of literature has begun to examine the phenomena of the renewables pull and green relocation. Earlier studies analysed regional cost advantages for renewable-based production of basic materials or synthetic fuels. For instance, Fasihi et al. (2017) project that green ammonia could achieve cost parity with conventional ammonia by 2030 in specific niche markets and by 2040 in a broader context, identifying regions with high solar and wind potential as possible future production hubs. Similarly, Demirhan et al. (2019) illustrate significant differences between production pathways and regions within the United States, while Armijo and Philibert (2020) highlight strong production cost advantages in certain regions of Chile. More recent studies have examined trade routes for energy-intensive intermediates such as green ammonia and hot briquetted iron (HBI). Cao et al. (2024) and Egerer et al. (2023), for example, estimate the cost benefits of importing such intermediates from Australia to Japan and Germany, respectively. Further studies extend this analysis to the global level. For example, Bilici et al. (2024) estimate global trade in green iron under various scenarios and demonstrated substantial cost reductions for global steel production through green relocation and international markets for green goods.

Given the rapid expansion of this research field, we here provide a comprehensive overview of the current state of knowledge on the renewables pull. Our review seeks to identify which aspects have been studied to date, how extensively they have been analysed, and where future research needs remain. To achieve this, a systematic literature review approach is employed to capture the scientific literature holistically and enable quantitative evaluations – such as, identifying the regions, products, and energy carriers most frequently studied and the disciplinary perspectives involved.

The remainder of this paper is organised as follows. Section 2 describes the systematic review methodology applied to identify and categorise the relevant literature. Section 3 presents the quantitative results of this analysis. Section 4 discusses these findings in detail, exploring conceptual, methodological, and empirical insights into the renewables pull. Finally, Section 5 concludes the paper and highlights key research gaps for future studies on the renewables pull topic.

## 2. Methods

Our approach to searching, screening, and synthesising findings from the scientific literature follows established procedures for systematic reviews (e.g. Kolaski et al. 2023). First, we refined the scope of the review and compiled an initial set of 27 articles we knew to be relevant to the subject area. Of the 27 articles, the majority was published in peer-reviewed academic journals, whereas 2 were under review at the point of developing the query. This corpus served as a validation set for developing and iteratively refining our search query to ensure that the vast majority of the 27 articles would be retrieved. Next, we defined clear inclusion and exclusion criteria to guide the screening process. Titles and abstracts were screened first to determine inclusion in the full-text review. As part of the review, we developed a coding framework to categorise and analyse the selected articles based on predefined characteristics, enabling structured mapping and analysis (see Results section). The following subsections provide detailed descriptions of each step.

### Search strategy

Based on a validation dataset of 27 hand-selected articles addressing the renewables pull, we developed and evaluated a boolean keyword-based search string for document retrieval (see below). The query consists of two parts: first it searches for the terms ‘renewables pull’, ‘green relocation’ and similar terms in publications that directly talk about this phenomenon; second it uses a combination of keywords from four groups to also capture papers that cover the topic without using specific terms: (1) keywords describing industry and energy-intensive sectors, (2) renewable energy keywords, (3) keywords related to cost comparison and economic development, and (4) decarbonisation and energy transition keywords.

We tested the query initially with the Scopus (Elsevier 2025) bibliographic database and then translated it to also search Web of Science (Clarivate Analytics 2025) and OpenAlex (Priem et al. 2022). We ran the search on July 2nd, 2025. The query yielded 2,035 results for Scopus, 1,299 results for Web of Science and 1,209 results for OpenAlex. After deduplication, our dataset for title and abstract screening contained 2,803 publications. The results of the query contained 23 of the 27 articles of the validation set. Of the 4 articles not contained in the query results, 2 were preprints and were therefore likely unknown to the index of the bibliographic databases.

Search string:

```
(
  "renewable* pull" OR "green relocation*" OR "green industr*
  relocation*" OR "green leakage" OR "renewable* leakage"
) OR
(
  (ammonia OR methanol OR iron OR steel OR "energy-intensive
  industr*" OR "green industry" OR "chemical industry" OR
  "industrial sector" OR "hydrogen industry" OR "low carbon
  industry" OR "industrial production") AND

  (renewable* OR wind OR pv OR biomass OR bio-energy OR
  bioenergy OR geothermal OR geo-thermal OR "solar thermal" OR
  hydro OR "green hydrogen" OR "zero-carbon hydrogen" OR "clean
  energy" OR "green energy" OR "energy endowment*" OR "energy
  resources") AND

  (cost* OR "regional development" OR "industrial development"
  OR "development path*" OR "export-oriented development" OR
  "export opportunity" OR "industrial location" OR "competitive
  advantage" OR "supply chain*" OR "value chain*" OR "economic
  transformation") AND

  (decarb* OR "low carbon" OR "climate neutral" OR "climate
  neutrality" OR "energy transition*" OR "green transition*" OR
  "net zero" OR "CO2 pric*" OR "carbon pric*" OR "climate
  policy" OR "carbon footprint*")
)
```

This query was run on titles, abstracts and author keywords (TITLE-ABS-KEY()) for Scopus, TS = for Web of Science). For OpenAlex, the query was slightly modified to spell out variations of keywords captured by the asterisks ("\*").

## Screening for eligibility

We use a set of inclusion and exclusion criteria to screen the titles and abstracts of all search results. Publications that directly analyse the renewables pull in a broad sense are included. Furthermore, publications that contain relevant information for analysing the renewables pull are also included. These comprise studies with a focus on the cost of tradable energy-intensive products or basic materials, such as ammonia or methanol, as well as studies analysing renewable energy costs as a location factor. We exclude studies that only focus on electricity, heat or hydrogen, and studies that only consider non-renewable energy sources or do not discuss costs (e.g. life-cycle analyses and analyses of other locational factors such as weighted average cost of capital (WACCs)).

In an initial training phase, we screened a small set of titles and abstracts to further refine and reach a common understanding of the criteria for inclusion and exclusion. Each record is screened by two authors. When an author is unsure about the relevance of a study, it is marked as MAYBE. Differences in the double coding and ambiguous cases are first discussed in pairs of coders and elevated to the entire author team when the interpretation of inclusion criteria requires further coordination and specific rules for edge cases.

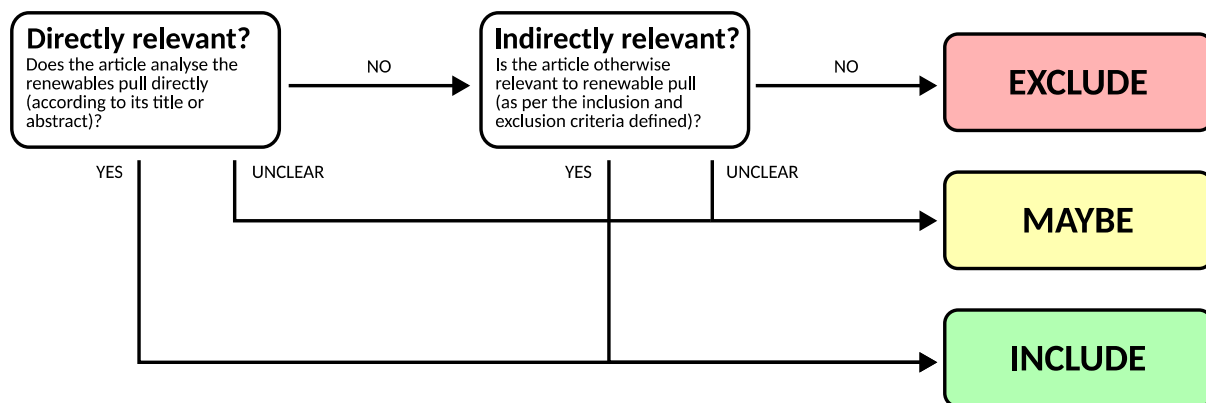


Figure 1 — Decision tree for the inclusion and exclusion of the literature sources found via the database queries.

## Inclusion criteria

Include articles that are

- **directly relevant:** analyse or discuss “renewables pull” in a broader sense, i.e. articles that meet all of the following criteria:
  - analyse or discuss locational economic attractiveness of OR economic development potential of OR export opportunity associated with
  - one or more locations for producing
  - renewable-based (electricity OR heat OR hydrogen OR fuels/feedstocks)
  - energy-intensive basic materials OR further refined intermediate products OR (final) industrial and refinery products
  - as a function of a location’s renewable energy conditions

OR

- **indirectly relevant:** are otherwise relevant to the renewable pull, i.e. articles that meet at least one of the following criteria:
  - focus on the cost of tradable energy-intensive basic materials or products (including ammonia or methanol) that are produced with renewable energy (electricity OR heat OR hydrogen) for more than one location OR
  - analyse/discuss economic attractiveness of renewable-based commodities or products of one location if advantage over other locations is at least discussed OR
  - analyse or discuss renewable energy costs as a location factor (including hydrogen, heat and electricity).

## Exclusion criteria

Studies limited solely to the production of renewable-based hydrogen, electricity, or heat, without extending to a globally tradable industrial commodity or product (e.g., ammonia or methanol) are excluded. Furthermore, articles are excluded, if they do not analyse or discuss “renewables pull” in the broad sense defined above AND

- focus on non-renewable energy sources for energy-intensive products

- conduct a general analysis of locational factors, including the impact of (general) energy costs (unless renewable energy costs are specifically discussed as a locational factor)
- analyse regional weighted average cost of capital (WACCs)
- analyse regional life cycles (LCA), but not costs (even for renewable-based materials across regions)
- only mention the renewables pull in the full text, without analysing it or being otherwise relevant

The decision about inclusion or exclusion is operationalised with the following decision tree for the first screening of abstracts and titles (see also Fig. 1):

**Directly relevant?**

- o YES → code INCLUDE
- o UNCLEAR → code MAYBE
- o NO → **Indirectly relevant?**
  - YES → code INCLUDE
  - NO → code EXCLUDE
  - UNCLEAR → code MAYBE

We code articles as MAYBE when it is unclear from title and abstract whether inclusion or exclusion criteria apply. In those cases, a closer examination of the full text would be necessary to assess the relevance of an article. Articles coded as MAYBE have not yet been analysed as part of this conference article, but are planned to be analysed at a later stage.

## **Data extraction and synthesis**

We document our selection in a PRISMA flow chart below (see Fig. 2). A full list of the 81 articles selected for this review can be found in the Appendix. For this conference article, we restrict our search to English-language peer-reviewed publications, while we plan to analyse academic books and book chapters, as well as grey literature (pre-prints, conference papers, working papers, theses, and dissertations) that we discovered through our search at a later stage. As mentioned above, we do not further consider the 154 articles that we coded MAYBE, which we plan to analyse at a later stage. Moreover, we included 2 articles contained in the validation set that were not found by the query but were published before the date of running the query (July 2nd, 2025).

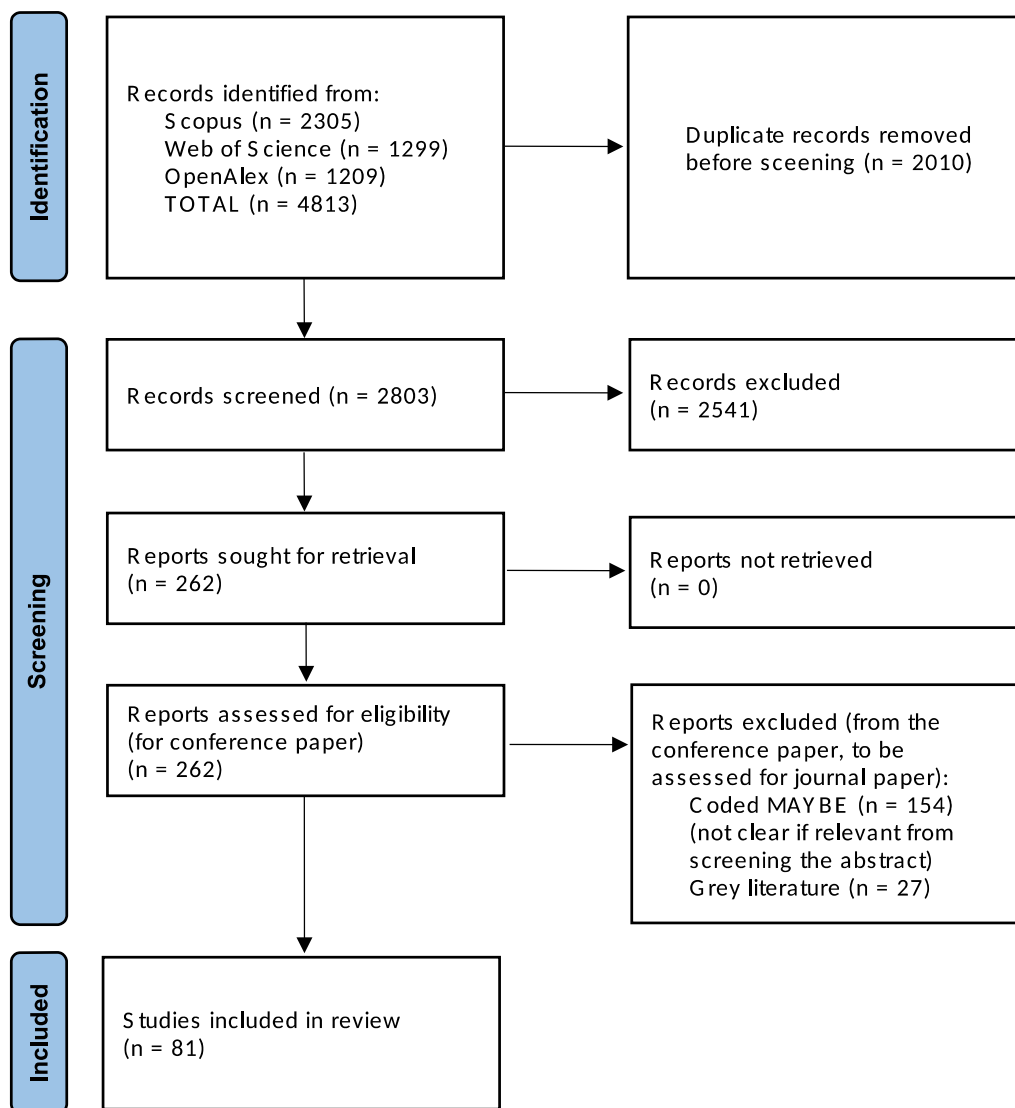


Figure 2 — Illustration of the literature selection and inclusion process using a PRISMA flow diagram (Page et al. 2021).

### 3. Results – Mapping of literature

Of the 2,803 articles yielded by the query, we found 81 peer-reviewed articles to be relevant for the renewables pull (see query and screening criteria in Methods). Here we map these articles with respect to different properties based on a harmonised codebook.

#### **A growing field of research** (Fig. 3a–b)

The renewables pull has recently received increasing attention, as observable through the growing number of annually published peer-reviewed journal articles (Fig. 3a). Of the articles identified as relevant for this review, about a third (35 %) have the renewables pull as their main focus, whereas it is only a side focus (29 %), a topic of indirect relevance (29 %), or merely a side note (8 %) in the remaining articles (Fig. 3b). This demonstrates that the topic is a direct subject of study but is also increasingly receiving attention in other related research.

#### **Countries involved in and relevant for studying the renewables pull** (Fig. 3c–f)

Germany clearly dominates among the author countries (i.e. countries of the article authors' institutions). Germany is a country known for its substantial energy-intensive industry and limited



renewable energy potential and land availability. Australia and Sweden follow as the countries with the second and third most authors. Both countries are rich in renewable and raw-material resources. Other notable countries of author institutions are the USA, the UK, China, Finland, the Netherlands, Chile, and South Africa. Interestingly, while Japan and South Korea are frequently identified as potential importers, relatively few studies originate from these countries (Fig. 3c). Countries most often studied or mentioned as potential future importing countries are Japan, Germany, Europe more generally, South Korea, and China (Fig. 3d). Countries most often studied or mentioned as potential exporting countries are Australia, Chile, Morocco, Saudi Arabia, and South Africa (Fig. 3e). While about two thirds (68 %) of articles focus on global effects, the remaining third consider national or regional relocation (Fig. 3f).

#### **Industrial sectors studied (Fig. 4a)**

The vast majority of articles focus on the ammonia and fertiliser sector (43 articles) and the steel sector (34 articles). This is likely due to the high transportability, existing trade exposure, product homogeneity, and clear transformation pathways of these two sectors, and, especially in the case of steel, due to the high share of all final energy consumption and the high share of total greenhouse gas emissions. Methanol (13 articles), naphtha (1 article), HVCs (1 article), ethylene (1 article), plastics (1 article) and chemicals more generally (8 articles) are also studied frequently, which we summarise as “carbonaceous fuels & feedstocks” in Fig. 4. Other less-often studied sectors include aluminium (2 articles) and cement (1 article).

#### **Used methods (Fig. 4b)**

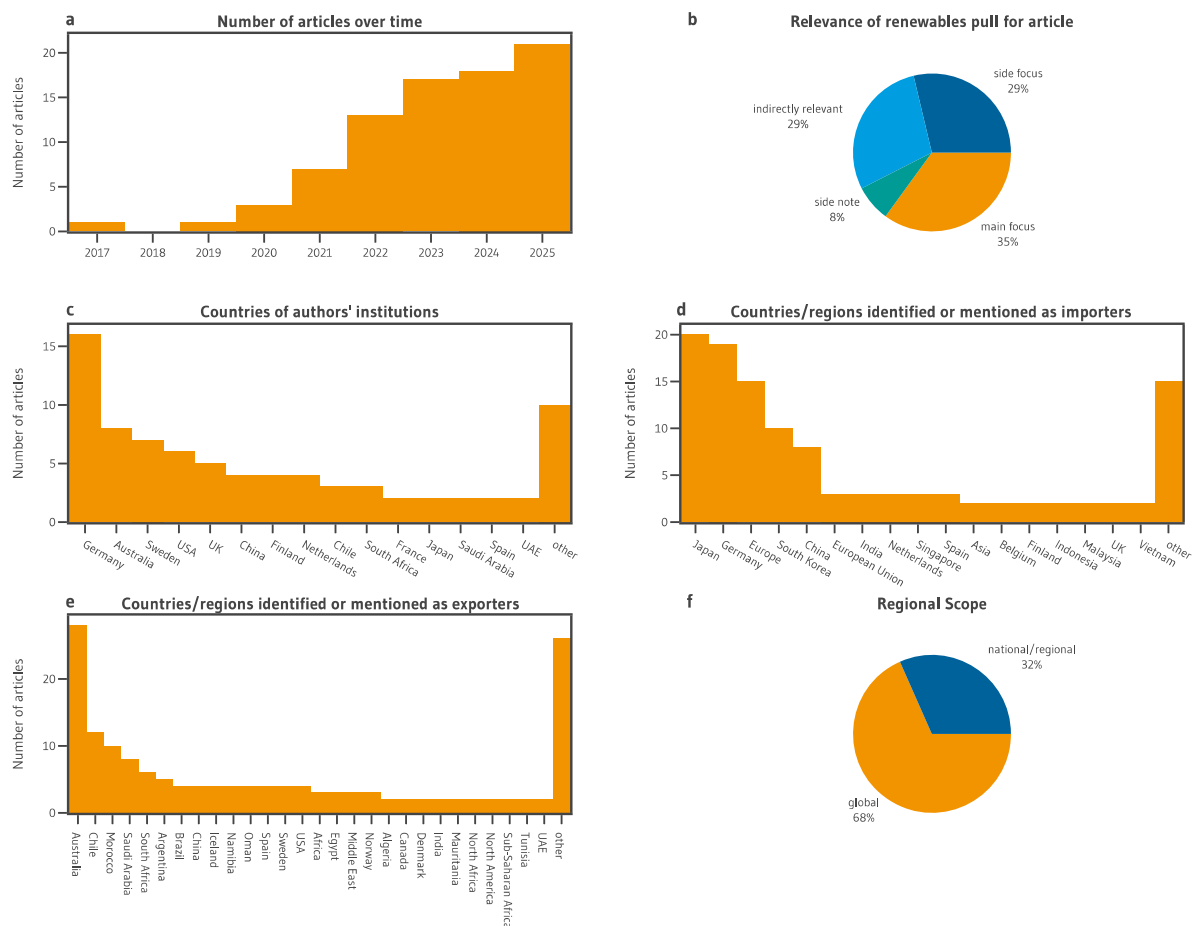
Within the methods used in the selected literature, we find a dominance ( $\geq 80$  %) of techno-economic assessments (TEA), often comparing different production sites and supply chains of hydrogen-based derivatives. One reason for the dominance of this method may be that TEAs are a rather simple but still meaningful approach to derive comparative results and insights for green products. Other methods are more complex and thus less represented in the young research strand on the renewables pull and green value chains. These include the comprehensive assessment of production locations accounting for locational factors other than production costs, scenario or energy system or production network modeling with endogenous trade or supply chain configurations (most importantly Neumann et al. 2025), as well as conducting economic modeling to study potential future macroeconomic effects of green relocation.

#### **Terminology used (Fig. 4h)**

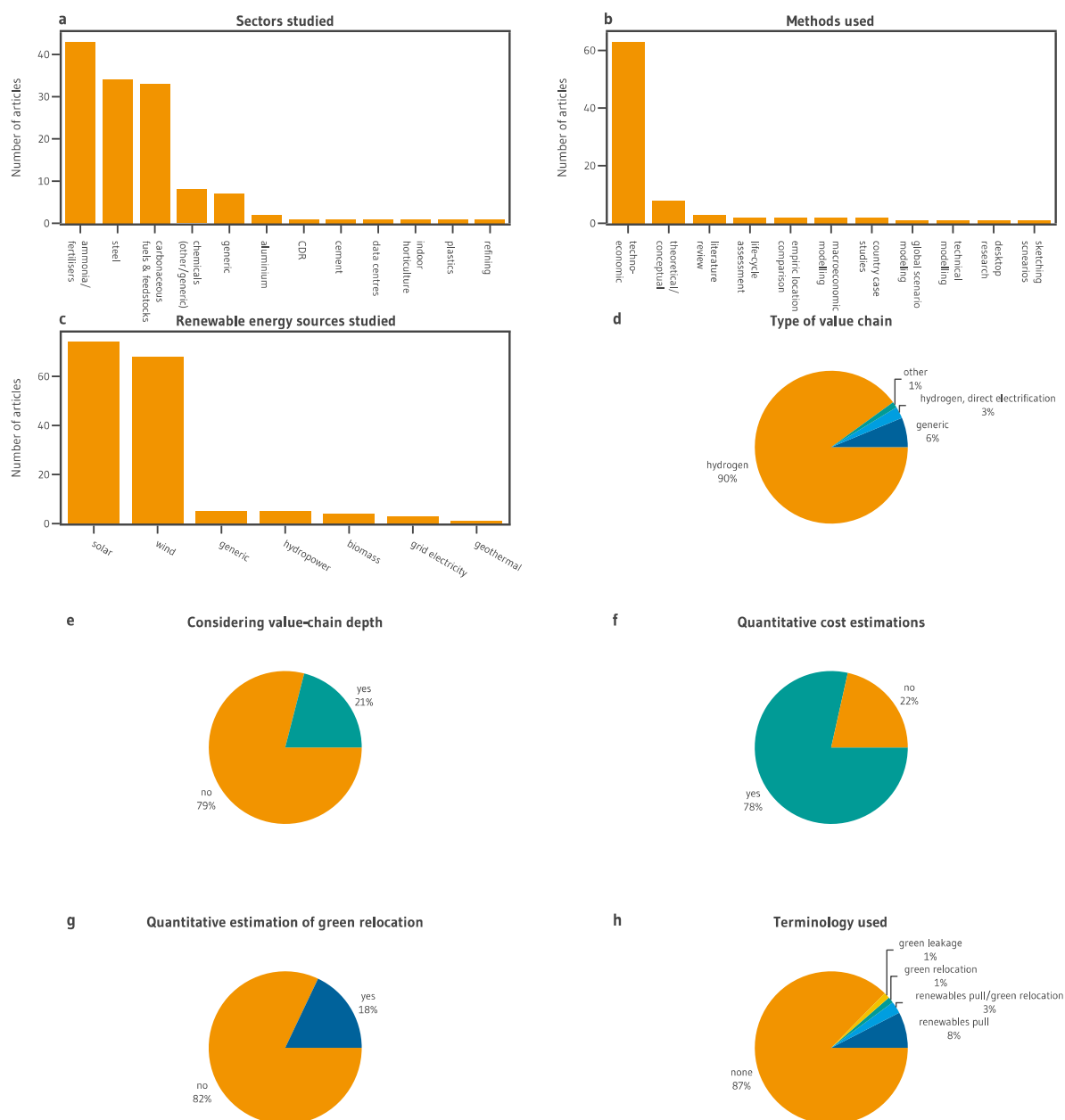
Only 13 % of articles use specific terminology such as (only) “renewables pull” (8 %), (only) “green relocation” (1 %), both “renewables pull” and “green relocation” (3 %), or the term “green leakage” (1 %). The other 87 % of articles describe the two phenomena without using specific terms or by using generic terms, such as “industrial dislocation” (Crawford 2024) or “cost-effective geographic location” (Bataille et al. 2021).

#### **Renewable energy sources and types of value chains (Fig. 4c and d)**

It is little surprising that the vast majority of papers focus their analysis and discussion on solar and wind electricity, as these sources are broadly acknowledged as the backbone of future net-zero energy systems. More interestingly, most articles (90%) focus on value chains that produce hydrogen as an intermediate energy carrier or feedstock, while there are only very few studies that study direct electrification routes in the context of the renewables pull (Burke et al. 2022; Crawford 2024).



**Figure 3 — Quantitative analysis of article codings (Part 1).** **a**, Number of articles published over time. **b**, All articles differentiated by the relevance that the renewables pull has in studied articles. **c**, Countries of article authors' main institutions. **d**, Importing countries studied or mentioned in articles. **e**, Importing countries studied or mentioned in articles. **f**, Share of articles having a global or a national/regional scope.



**Figure 4 — Quantitative analysis of article codings (Part 2).** **a**, Counts of sectors studied in articles. **b**, Counts of methods used in articles. **c**, Counts of renewable-energy sources studied in articles. **d**, Share of articles studying different types of value chains. **e**, Share of articles considering value-chain depth (e.g. imports of HBI vs. imports of steel). **f**, Share of articles quantitatively estimating cost of affected energy-intensive production or activities. **g**, Share of articles quantitatively estimating green relocation (i.e. actual geographic change of production patterns). **h**, Terminology used in articles.

#### **Value chain configurations (Fig. 4e)**

Most articles (~80%) do not differentiate between value chain configurations, as they analyse or discuss production at only one defined level within a specific value chain. In other words, they implicitly or explicitly assume an integration of certain production steps such as those of green steel via H<sub>2</sub>-DRI-EAF at one location. 17 articles compare or discuss different configurations of value chains. While most articles of the selected references analyse ammonia, the sector for which value chain configurations are most often differentiated is steel production (13 articles) — likely because HBI is a valid break point for separating the energy-intensive production of green iron from steelmaking and downstream refinement. For ammonia, the different value-chain configurations with respect to its use in the fertiliser or other chemical industry (e.g. trading ammonia or trading fertilisers such as urea) are discussed in 7 articles.

#### **Estimations of costs and relocation (Fig. 4f–g)**

79 % of articles estimate the cost of energy-intensive products and activities. Such estimates can serve to understand the strength of the renewables pull. However, only 18 % of all articles study the potential future green relocation resulting from the cost differences and the renewables pull, i.e. the shift in the patterns of production and associated production capacities.

## **4. Discussion and literature synthesis**

### **Much of the literature on the renewables pull focuses on ammonia, iron and steel, and carbonaceous fuels and feedstocks**

The vast majority of the journal articles that we identified focus on the production of ammonia (e.g. Achour et al. 2025; Dabar et al. 2024; Fasihi et al. 2021; Lippkau et al. 2024; Toktarova et al. 2025; Fattahi et al. 2024), iron and steel (e.g. Bilici et al. 2024; Caiafa et al. 2025; Devlin et al. 2023; Lopez et al. 2023; Nurdawati et al. 2025; Nykvist et al. 2025; Toktarova et al. 2022; Verpoort et al. 2024) and synthetic carbon-based fuels and chemicals (e.g. Chavez-Angel et al. 2023; Florez et al. 2024; Karbassi et al. 2023; Shirizadeh et al. 2023; Uchida et al. 2025; Moritz et al. 2023; Arnaiz del Pozo et al. 2022). Our systematic literature search found only very few articles dealing with other energy-intensive industrial goods, such as aluminium (Burke et al. 2022) or cement (Toktarova et al. 2025). Not a single article was found that analyses the green relocation prospects for either glass or paper.

Several reasons may serve as explanation for the very limited amount of literature dealing with energy-intensive industries other than ammonia, iron and steel and synthetic carbon-based fuels and chemicals. 1.) The products of some other industries, such as cement or glass, have relatively high transport costs. 2.) Other energy-intensive industries such as paper, glass and aluminium are responsible for a considerably smaller share of greenhouse gas emissions, such that scholars put less focus on them. (While the share of greenhouse gas emissions from ammonia production is small today, ammonia may grow in importance due to its role as a fuel and energy carrier.)

Despite these reasons it is surprising to see that aluminium, for instance, is studied substantially less than steel even though aluminium is similarly trade-exposed and of similar strategic importance as steel. We conjecture that there may be a bias of recent literature towards hydrogen-based value chains due to the general attention and public debates that these value chains have received in recent years.

We note that the search string used for this systematic literature review may have introduced a certain bias into the articles yielded by our query (see Methods). The search string includes the terms 'ammonia', 'iron' and 'steel' to capture as many papers as possible from the validation set. It does not include references to other energy-intensive sectors.

### **Regional cost comparisons are often based on off-grid photovoltaic (PV) and wind-based electricity generation**

Many articles comparing the production costs of green ammonia and carbon-based fuels and chemicals base their calculations on off-grid systems consisting of a combination of solar PV and onshore wind to provide the electricity required to produce green hydrogen (e.g. Achour et al. 2025; Armijo and Philibert 2020; Dabar et al. 2024; Fasihi et al. 2021; Hampp et al. 2023; Shirizadeh et al. 2023; Toktarova et al. 2025; Wan et al. 2024; Chavez-Angel et al. 2023; Florez et al. 2024; Karbassi et al. 2023; Uchida et al. 2025). In these studies, battery backup is also typically assumed to be part of the dedicated electricity supply. However, some articles on green ammonia and green carbon-based fuels, as well as most articles on iron and steel production, assume that electricity from renewable sources can be obtained via the grid at a price that varies by region (e.g. Lippkau et al. 2024; Pawar et al. 2021; Wan et al. 2024; Caiafa et al. 2025; Cao et al. 2024; Jiang et al. 2025; Toktarova et al. 2025). Several other articles base their cost calculations on the assumption that dedicated renewable energy plants can be supplemented by purchasing additional electricity from the grid when needed (e.g. Bose et al. 2022; Kenny et al. 2024). Only a few articles explicitly consider other renewable energy sources besides PV and wind, such as hydropower (Runge et al. 2023; Crawford 2024), biomass (Pudi et al. 2022; Neumann et al. 2025; Demirhan et al. 2019), and geothermal energy (Runge et al. 2023). The focus on solar PV and wind energy reflects the widely held view that these two sources of renewable energy have the greatest potential for generating additional low-cost electricity from renewable sources in most regions of the world.

### **Many studies indicate a future relevance of the green relocation phenomenon**

Many of the identified journal articles conclude that regions with exceptional renewable energy conditions can produce renewable energy-based ammonia, iron and steel, and synthetic, carbon-containing fuels and chemicals at lower costs than renewable-constrained regions. Most of these articles also consider the costs of transporting green industrial goods from production sites to other regions of the world. They typically conclude that transport costs for green industrial goods are lower than the production cost advantages of renewable-rich sites, suggesting that much of the future energy-intensive green industrial production may be economically viable in renewable-rich regions around the world.

While many of the identified articles only compare the production costs of industrial goods based on renewable energy sources, some also include the costs of traditional, fossil fuel-based production (e.g. Gielen et al. 2020; Lopez et al. 2023; Nykvist et al. 2025; Armijo and Philibert 2020; Fasihi et al. 2021; Pawar et al. 2021; Sadiq et al. 2025; Allgoewer et al. 2024; Fasihi et al. 2017; Lopez et al. 2024). These articles generally conclude that green industrial production can become cost-competitive with fossil fuel-based production in the future. Fasihi et al. (2021) find that the cost of green ammonia production at the most suitable sites worldwide is expected to be lower than the cost of unabated natural gas-based ammonia production by around 2040, even without a CO<sub>2</sub> price. However, in most studies and for most industrial goods, green industrial production only breaks even with traditional production when a certain CO<sub>2</sub> price is assumed.

Some of the identified studies estimate the potential cost benefits of producing energy-intensive products in renewable-rich regions for different supply chain depths (e.g. Caiafa et al. 2025; Devlin and Yang 2022; Gielen et al. 2020; Kenny et al. 2024; Verpoort et al. 2024). These studies generally conclude that, for renewable-constrained regions, importing green industrial goods (such as direct reduced iron, steel or ammonia) from renewable-rich regions is more economical than importing green hydrogen and using it to produce green industrial goods domestically. A few articles (Verpoort et al. 2024; Cao et al. 2024; Egerer et al. 2024) also compare the cost advantages of importing energy-intensive intermediary products for use in the steel, urea and ethylene industries. They conclude that importing steel, urea and ethylene in their final forms from renewable-rich regions (so-called 'deep relocation') typically leads to the lowest procurement costs. However, much of the

total cost savings (relative to domestic production of these goods) could also be achieved by importing energy-intensive intermediates, such as DRI/HBI, ammonia and methanol, and refining them further domestically. Verpoort et al. (2024) emphasise that such imports of intermediates could enable importing countries to realise most of the cost savings while retaining a significant proportion of the value creation.

### **Green relocation can also occur within individual countries or regions**

While most studies that compare the cost of green industrial production focus on potential future global trade or specific interregional trade flows (e.g. between Europe and North Africa, or Australia and Japan), some also discuss how differences in renewable energy endowments could lead to green relocation within individual countries or regions. For instance, Toktarova et al. (2025) discuss the optimal future locations for the electrified steel, cement, chemical and petrochemical industries in Europe, Xiang et al. (2025) assess the potential future reallocation of ammonia production in China in the context of a carbon-neutrality target and Harahap et al. (2023) assess in what regions of Sweden which types of renewable marine fuel could be produced in the future.

### **Factors other than renewable energy endowment also influence companies' location decisions**

While most of the identified articles conclude that regional cost differences in green industrial production are significant and could result in the relocation of industrial activity in the future, many nonetheless emphasise that factors other than renewable energy potential are important for the economics of producing green industrial goods and for company decisions on where to establish future industrial production. This is true for the many identified articles that estimate regional production cost differences of green industrial goods, and also for articles that focus on conceptually discussing the renewables pull theory (e.g. Samadi et al. 2023; Day 2022; Verpoort et al. 2024; Crawford 2024).

Additional factors frequently cited in the literature include transport costs or the distance of potential production sites to large demand markets or ports (e.g. Devlin et al. 2023; 2024; Samadi et al. 2023; Toktarova et al. 2025; H. Wang et al. 2023; Crawford 2024), the cost of capital (e.g. Sadiq et al. 2025; Kountouris et al. 2025; Kaiser et al. 2021; Crawford 2024; Moritz et al. 2023), proximity to required natural resources other than renewable energy sources, such as iron ore deposits (e.g. Ellersdorfer et al. 2024; Reznicek et al. 2025; C. Wang, Walsh, Weng, et al. 2023; Toktarova et al. 2025), the availability of subsidies (e.g. Algers et al. 2025; Colen and Mohnen 2025; Reznicek et al. 2025; Devlin et al. 2023; Nykvist et al. 2025) and the level of wages (e.g. Devlin et al. 2023; 2024; Cotter 2024; Crawford 2024; Caiafa et al. 2025). These relevant location factors can either strengthen or weaken the case for green relocation. For example, green relocation in the steel industry may be more likely to occur because several renewable-rich regions also possess high-quality iron ore deposits. On the other hand, some renewable-rich regions have relatively high capital costs. Interestingly, according to Kaiser et al. (2021), the differences in capital costs between countries in the highly capital-intensive production of electricity-based green methanol and naphtha are of such great relevance that locations in Germany, a country with very low cost of capital, achieve lower production costs than locations in renewable-rich countries such as Chile or Argentina.

Some authors point out more generally that renewable-rich regions that wish to benefit from green relocation need to fulfil certain prerequisites in order to attract investment. Probably first and foremost among these is a stable legal and political environment (Colen and Mohnen 2025). According to Scheffler et al. (2025), countries aiming to transition to widespread green hydrogen use require place-based leadership, institutional entrepreneurship, and Schumpeterian innovative entrepreneurship. Similarly, Klagge et al. (2025) argue that such countries require what they term 'governance of future-making', meaning they need actors to 'coordinate their expectations about future economic development in different contexts and across scales over time'.

### **Some arguments also found in the literature for a limited future relevance of green relocation**

Colen and Mohnen (2025) focus on arguments why green relocation may be limited in the future. The authors highlight agglomeration and demand forces that could hinder relocation. They also emphasise that industrialised countries appear willing to provide substantial subsidies to retain at least some of their current industrial production. Furthermore, Colen and Mohnen (2025) highlight the need for renewable-rich regions to fulfil political, legal, environmental and social prerequisites, which is not always the case currently.

Some articles also suggest that producing low-carbon ammonia, methanol or steel using CO<sub>2</sub> capture and storage may be more economical than producing these goods using green hydrogen (Arnaiz del Pozo et al. 2022; Palandri et al. 2025; Arnaiz del Pozo et al. 2022; Nurdiawati et al. 2025). These findings highlight the fact that the competitiveness of low-carbon production options beyond renewable energy options may be an important factor in determining the future relevance of the renewables pull. Much of the literature identified does not include an assessment of the costs of low-carbon production options beyond those based on green electricity and green hydrogen. Interestingly, Xiang et al. (2025) find that the most cost-effective future production of low-carbon ammonia in China may include both green ammonia and ammonia based on nuclear power. The proportion of each method used would differ between Chinese provinces depending on factors including the regions' renewable energy conditions. Cao et al. (2024) find that, for low-carbon steel production, using carbon capture and storage may be more economical than using green hydrogen. However, due to the higher residual CO<sub>2</sub> emissions of carbon capture and storage, steel from this route is only found to have a cost advantage relative to green steel at low CO<sub>2</sub> prices.

### **Limited analysis conducted so far on how well individual renewable-rich countries are prepared to benefit from the renewables pull**

Only a small amount of the literature identified provides in-depth analysis of how well individual countries rich in renewable energy resources are prepared to benefit from the renewables pull in the future. Several articles focus specifically on Australia (Milani et al. 2022; Venkataraman et al. 2022; C. Wang, Walsh, Weng, et al. 2023; C. Wang, Walsh, Longden, et al. 2023; Cotter 2024). Both Venkataraman et al. (2022) and C. Wang, Walsh, Weng, et al. (2023) argue that future hydrogen production facilities and green steel manufacturing plants in Australia could benefit from being located near existing iron ore mining operations. C. Wang, Walsh, Longden, et al. (2023) point out that Australia possesses sites with excellent combined solar and wind resources, enabling these regions to become cost-competitive producers of green ammonia. The study also highlights that the complementary seasonal variability in the supply and demand of green ammonia in Australia and various locations in the Northern Hemisphere could significantly benefit a future green ammonia industry in Australia. In contrast, Cotter (2024) expresses doubt over whether Australia will attract energy-intensive industries and become an exporter of green industrial goods in the future. The author points to high wages and a relatively small domestic market in Australia. The small domestic market may prevent new industries from achieving economies of scale domestically and may therefore make it difficult to become internationally competitive. He also cites a lack of consensus among Australia's key political parties regarding the future role of renewables, which could hinder investment.

Scheffler et al. (2025) conduct interviews with stakeholders in Chile and Namibia to gain a better understanding of how prepared these two countries are to realise new development paths through green hydrogen. In both countries, the authors identify a lack of Schumpeterian entrepreneurial innovation, which they regard as a prerequisite for successful transformation. Similarly, (Klagge et al. 2025) conduct interviews with stakeholders in Namibia and South Africa to assess the effectiveness of the 'governance of future-making' in these two countries, i.e. how well actors coordinate their expectations about future economic development in different contexts and across scales over time.

## **Green relocation can support global climate action and a more even distribution of economic wealth**

Only a few of the identified articles focus on the potential ecological, macroeconomic, energy system and geopolitical effects of green relocation. Li et al. (2025) conclude, based on a cost-optimisation model for the Asian steel sector, that green HBI trade could lower the Asian steel sector's cumulative CO<sub>2</sub> emissions by 4 Gt by 2070. Gielen et al. (2020) estimate that green DRI exports from Australia to Asia could lead to CO<sub>2</sub> emission reductions of around 0.7 Gt per year by 2050. Burke et al. (2022) argue that Australia could contribute significantly to greenhouse gas emission reductions in the Asia-Pacific region by switching to the export of zero-carbon electricity, green hydrogen, green aluminium, and green steel. And Caiafa et al. (2025) find that relocating the Dutch steel industry to Brazil would lead to greater reductions in global greenhouse gas emissions than if the Netherlands imported green hydrogen and continued to produce steel domestically.

In regard to the macroeconomic effects of green relocation, Caiafa et al. (2025) find that relocating the Dutch steel industry to Brazil would result in stronger distributive impacts across global regions than if the Netherlands were to import green hydrogen from abroad. Trollip et al. (2022) and Dyantyi-Gwanya et al. (2025) emphasise the potential economic benefits of South Africa becoming an exporter of green industrial goods. Trollip et al. (2022) focus on green iron exports from South Africa and expect a 'substantial contribution to macroeconomic stability through a more sustainable export base and improved government finances through an expanded tax base'. Karbassi et al. (2023) conclude that producing green e-fuels for Europe in Africa could benefit only a few African countries if merely the most cost-effective production sites were chosen. The analysis suggests that accepting a moderate 10% increase in average fuel production costs would enable the economic benefits of green e-fuel production to be distributed much more evenly across the African continent. In regard to the macroeconomic effects of green relocation in regions affected by a loss of domestic industrial production, some authors (e.g. Crawford 2024; Trollip et al. 2022) point out that the employment effects are expected to be very limited – at least under the assumption that the less energy-intensive downstream production will remain in these regions.

Examining the repercussions for energy systems of green relocation in renewable-constrained regions, Neumann et al. (2025) find that importing green energy in various forms to Europe, including in the form of green steel and green ammonia, could reduce the annual costs of a carbon-neutral European energy system by €37 billion, equivalent to 4.4% of energy system costs. Both Crawford (2024) and Fattahi et al. (2024) also emphasise the cost savings in the European energy system if green hydrogen and green hydrogen derivatives such as ammonia and steel are imported to Europe from renewable-rich regions. Domestic industries as well as consumers could benefit from lower energy costs. The potential benefits of achieving lower energy system costs and obtaining access to lower-cost green industrial goods leads some authors (Crawford 2024; Verpoort et al. 2024) to argue that renewable-constrained countries should avoid providing massive subsidies to retain non-competitive green industrial production.

Eicke and De Blasio (2022) expect green relocation to have geopolitical implications, as countries and regions rich in renewables will increasingly compete with current industrial powers for jobs and market shares.

## **5. Conclusions and further research needs**

Our review of the existing literature indicates that the number of studies addressing the possibility and potential of the renewables pull – and the resulting phenomenon of green relocation – has increased significantly in recent years.

Many of these studies estimate regional differences in current or future costs of producing energy-



intensive industrial goods based on differences in renewable energy potential. Ammonia, iron and steel and synthetic carbonaceous fuels and chemicals are most frequently analysed. Among these studies, there is high agreement that some energy-intensive industrial goods can be produced at considerably lower costs in renewable-rich regions of the world. Most studies find that a relevant cost advantage remains when taking into account transport costs of these goods to other regions of the world. Many authors therefore conclude that in some industrial sectors green relocation is likely to become reality in the future, at least if climate policy continues to expand around the world.

However, many studies also stress that a number of other location factors are relevant when companies decide on where to produce industrial goods. In some cases, these additional location factors further amplify the renewables pull, in other cases they inhibit relocation. As some fundamental location factors are not well developed in several renewable-rich regions of the world, a number of authors argue that the relevance of green relocation may remain limited in the future. A smaller number of identified articles either look specifically at how individual countries could benefit from the renewables pull in the future, or examine the potential environmental, macroeconomic or geopolitical consequences of potential future green relocation. These studies generally find that if green relocation occurs, it can support global climate change mitigation efforts, reduce the overall costs of the transformation towards a climate neutral industry sector and contribute to more equitable economic development between regions.

Several areas of research remain underexplored based on the query derived for this review:

First, the quantification of green relocation requires further attention. While some recent studies have begun to estimate potential spatial distributions of future production capacities for green products such as methanol, ammonia or HBI to identify cost optimal international supply routes (Bilici et al. 2024; Neumann et al. 2025; H. Wang et al. 2023), the socio-economic consequences of such relocations remain largely unexplored. Future research should therefore adopt a broader perspective that also captures downstream value chains and assesses the wider economic and social implications for both exporting and importing regions. This includes analysing how the loss of energy-intensive production facilities in some countries could affect the international competitiveness of remaining domestic industries in the same countries through transforming upstream supply chains, higher transportation costs of intermediate goods, or the loss of cluster-based innovation dynamics.

Moreover, existing studies predominantly focus on a few specific energy-intensive intermediate products, particularly ammonia and potential energy carriers such as methane and HBI. Consequently, further research is required to identify additional energy-intensive sectors that may be significantly affected and to quantify the potential impacts along the entire value chains. This may include sectors outside conventional energy-intensive industries, such as carbon-dioxide removal, data centres, and indoor horticulture, which are mentioned but not studied in depth by existing literature (Crawford 2024). Additionally, long-term dynamics and transition processes remain insufficiently studied. For example, the timing of possible relocations, the development of previously inadequate infrastructure at locations with good renewable energy conditions, and dependence on the market ramp-up of green products have not yet been mapped out and quantified in detail.

Another promising research avenue lies in the evaluation of policy options for countries with differing renewable energy potentials. Although some studies have already outlined the possibility of exploiting regional location advantages by utilising high renewable potential, there have been few analyses of the policy options available to renewable-constrained countries, which may focus on strategies to mitigate relocation risks through accelerated renewable deployment (i.e. making sure the limited potential is used to its fullest extent), energy infrastructure expansion, or the strengthening of alternative locational advantages. Some studies (Colen and Mohnen 2025; Klagge et al. 2025) investigate the impact of policies and other factors on the occurrence of green relocation

through interviews with affected industries, but more empirical evidence is needed on how specific policy measures, such as carbon pricing or targeted subsidies, shape long-term location decisions in an increasingly renewables-driven global economy.

## Acknowledgements

This article accompanies an oral presentation held at the conference on “Industrial decarbonization and hydrogen: The politics and economics of sustainable structural transformation” in Potsdam, Germany on October 28<sup>th</sup>, 2025. The conference was jointly organised by the German Institute of Development and Sustainability (IDOS), the Centre for Sustainable Structural Transformation (CSST), and the Research Institute for Sustainability (RIFS). We thank the organisers of the conference for accepting our work for oral presentation and for the fruitful discussion.

This work was developed within the research projects SCI4climate.NRW and Kopernikus-Ariadne. SCI4climate.NRW is funded by the Ministry of Economic Affairs, Industry, Climate Action and Energy of the State of North Rhine-Westphalia. Ariadne is funded by the German Federal Ministry of Education and Research (grant nos. 03SFK5A0-2).

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## Appendix

Table: 81 studies selected for the review.

	Author(s)	Title	Year	DOI
1	Achour et al.	Techno-economic assessment of large-scale power-to-ammonia plant: Integrating hybrid energy storage system (gravity and battery) and advanced day-ahead forecasting algorithms	2025	10.1016/j.ijhydene.2025.04.102
2	Akimoto et al	Analyses on Transitions to Net-Zero Emissions in Asian Countries	2025	10.64289/iej.25.0206.4131845
3	Algers et al.	Competition and climate policy in the steel transition: Comparing costs and subsidies in the US and the EU	2025	10.1016/j.enpol.2025.114507
4	Allgoewer et al.	Cost-Effective Locations for Producing Fuels and Chemicals from Carbon Dioxide and Low-Carbon Hydrogen in the Future	2024	10.1021/acs.iecr.4c01287
5	Armijo & Philibert	Flexible production of green hydrogen and ammonia from variable solar and wind energy: Case study of Chile and Argentina	2020	10.1016/j.ijhydene.2019.11.028
6	Arnaiz del Pozo & Cloete	Techno-economic assessment of blue and green ammonia as energy carriers in a low-carbon future	2022	10.1016/j.enconman.2022.115312
7	Bararzadeh Ledari et al.	Greening steel industry by hydrogen: Lessons learned for the developing world	2023	10.1016/j.ijhydene.2023.06.058
8	Bataille et al.	Industry in a net-zero emissions world: New mitigation pathways, new supply chains, modelling needs and policy implications	2021	10.1016/j.egycc.2021.100059



9	Bilici et al.	Global trade of green iron as a game changer for a near-zero global steel industry? - A scenario-based assessment of regionalized impacts	2024	10.1016/j.egycc.2024.100161
10	Bose et al.	Spatial variation in cost of electricity-driven continuous ammonia production in the United States	2022	10.1021/acssuschemeng.1c08032
11	Burke et al.	Contributing to regional decarbonization: Australia's potential to supply zero-carbon commodities to the Asia-Pacific	2022	10.1016/j.energy.2022.123563
12	Caiafa et al.	Macroeconomic and environmental impacts of two decarbonization options for the Dutch steel industry: green relocation versus green hydrogen imports	2025	10.1016/j.enpol.2025.114726
13	Cao et al.	Prospects of regional supply chain relocation for iron & steel industry decarbonization: A case study of Japan and Australia	2024	10.1016/j.resconrec.2024.107804
14	Chavez-Angel	Exploring the Potential of Green Hydrogen Production and Application in the Antofagasta Region of Chile	2023	10.3390/en16114509
15	Colen & Mohnen	Unpacking the Renewables Pull Effect: Conditions for green industrial relocation	2024	10.1002/bse.4301
16	Cotter	"The Vision Splendid": Greening Australia Felix.	2024	10.25120/jre.4.2.2024.4152
17	Crawford	The Green Transition and European Industry	2024	10.1080/00396338.2024.2309078
18	Dabar et al.	Techno-economic and environmental assessment of green hydrogen and ammonia production from solar and wind energy in the republic of Djibouti: A geospatial modeling approach	2024	10.1016/j.egy.2024.09.037
19	Day	Why industrial location matters in a low-carbon economy	2022	10.1016/j.strueco.2022.10.004
20	Demirhan et al.	Sustainable ammonia production through process synthesis and global optimization	2019	10.1002/aic.16498
21	Devlin & Yang	Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation	2022	10.1016/j.enconman.2022.115268
22	Devlin et al.	Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits	2023	10.1038/s41467-023-38123-2
23	Devlin et al.	Techno-economic optimisation of steel supply chains in the clean energy transition: a case study of post-war Ukraine	2024	10.1016/j.jclepro.2024.142675

24	Dyantyi-Gwanya et al.	Exploring Economic Expansion of Green Hydrogen Production in South Africa	2025	10.3390/su17030901
25	Egerer et al.	The economics of global green ammonia trade - "Shipping Australian wind and sunshine to Germany"	2023	10.1016/j.apenergy.2023.120662
26	Egerer et al.	The industry transformation from fossil fuels to hydrogen will reorganize value chains: Big picture and case studies for Germany	2024	10.1016/j.apenergy.2023.122485
27	Eicke & De Blasio	Green hydrogen value chains in the industrial sector—Geopolitical and market implications	2022	10.1016/j.erss.2022.102847
28	Ellersdorfer et al.	Unlocking new export opportunities: An open-source framework for assessing green iron and steel supply chains	2024	10.1016/j.ijhydene.2024.10.163
29	Elsheikh et al.	Renewable hydrogen based direct iron ore reduction and steel making with grid assistance	2023	10.1016/j.enconman.2023.117544
30	Fasihi et al.	Global potential of green ammonia based on hybrid PV-wind power plants	2021	10.1016/j.apenergy.2020.116170
31	Fasihi et al.	Long-Term Hydrocarbon Trade Options for the Maghreb Region and Europe - Renewable Energy Based Synthetic Fuels for a Net Zero Emissions World	2017	10.3390/su9020306
32	Fattahi et al.	Opportunities of hydrogen and ammonia trade between Europe and MENA	2024	10.1016/j.ijhydene.2024.08.021
33	Fernández et al.	Achieving Decentralized, Electrified, and Decarbonized Ammonia Production	2024	10.1021/acs.est.3c10751
34	Florez et al.	Optimizing islanded green ammonia and hydrogen production and export from Saudi Arabia	2024	10.1016/j.ijhydene.2023.12.075
35	Gielen et al.	Renewables-based decarbonization and relocation of iron and steel making: A case study	2020	10.1111/jiec.12997
36	Hampp et al.	Import options for chemical energy carriers from renewable sources to Germany	2023	10.1371/journal.pone.0281380
37	Harahap et al.	Renewable marine fuel production for decarbonised maritime shipping: Pathways, policy measures and transition dynamics	2023	10.1016/j.jclepro.2023.137906
38	Ishimoto et al.	Large-scale production and transport of hydrogen from Norway to Europe and Japan: Value chain analysis and comparison of liquid hydrogen and ammonia as energy carriers	2020	10.1016/j.ijhydene.2020.09.017

39	Jiang et al.	Transition Pathways for Low-Carbon Steel Manufacture in East Asia: The Role of Renewable Energy and Technological Collaboration	2025	10.3390/su17104280
40	Kaiser et al.	Environmental and economic assessment of global and German production locations for CO <sub>2</sub> -based methanol and naphtha	2023	10.1039/D1GC01546J
41	Karbassi et al.	Diversifying the African energy system: Economic versus equitable allocation of renewable electricity and e-fuel production	2023	10.1016/j.apenergy.2023.121751
42	Kenny et al.	A techno-economic analysis of global renewable hydrogen value chains	2024	10.1016/j.ijhydene.2024.06.377
43	Klagge et al.	Governance of future-making: Green hydrogen in Namibia and South Africa	2025	10.1016/j.geoforum.2025.104244
44	Kountouris et al.	Renewable hydrogen and ammonia production: Location-specific considerations and competitive market dynamics in Europe	2025	10.1016/j.apenergy.2025.126168
45	Li et al.	Expanding the emissions trading system coverage can increase the cost competitiveness of low-carbon ammonia in China	2025	10.1038/s43247-025-02056-z
46	Li et al.	Decarbonizing the Asian steel industries through green Hot Briquetted Iron trade	2025	10.1016/j.resconrec.2025.108275
47	Lopez et al.	Towards defossilised steel: Supply chain options for a green European steel industry	2023	10.1016/j.energy.2023.127236
48	Lopez et al.	Assessing European supply chain configurations for sustainable e-polyethylene production from sustainable CO <sub>2</sub> and renewable electricity	2024	10.1016/j.enconman.2024.118295
49	Milani et al.	Green pathways for urea synthesis: A review from Australia's perspective	2022	10.1016/j.scca.2022.100008
50	Moritz et al.	Estimating global production and supply costs for green hydrogen and hydrogen-based green energy commodities	2023	10.1016/j.ijhydene.2022.12.046
51	Müller et l.	Can green hydrogen drive economic transformation in Saudi Arabia? – An input-output analysis of different Power-to-X configurations	2024	10.1016/j.ecmx.2024.100798
52	Neumann et al.	Green energy and steel imports reduce Europe's net-zero infrastructure needs	2025	10.1038/s41467-025-60652-1
53	Nurdiawati et al.	Prospective environmental and economic assessment of green steel production in the Middle East	2025	10.1016/j.resconrec.2025.108277

54	Nykvist et al.	Renewables pull and strategic push - What drives hydrogen-based steel relocation?	2025	10.1016/j.apenergy.2025.126189
55	Palandri et al.	Blue vs. Green: A comparative analysis of ammonia production and export in Western Canada and Australia	2025	10.1016/j.renene.2024.121953
56	Pawar et al.	Potential of green ammonia production in India	2021	10.1016/j.ijhydene.2021.05.203
57	Pozo et al.	Techno-economic assessment of long-term methanol production from natural gas and renewables	2022	10.1016/j.enconman.2022.115785
58	Pudi et al.	Modular and intensified-Reimagining manufacturing at the energy-chemistry nexus and beyond	2022	10.1016/j.cep.2022.108883
59	Rezneck et al.	Techno-Economic Analysis of Low-Carbon Hydrogen Production Pathways for Decarbonizing Steel and Ammonia Production	2025	10.1016/j.crsus.2025.100338
60	Roos	The cost of production and storage of renewable hydrogen in South Africa and transport to Japan and EU up to 2050 under different scenarios	2021	10.1016/j.ijhydene.2021.08.193
61	Runge et al.	Economic comparison of electric fuels for heavy duty mobility produced at excellent global sites-a 2035 scenario	2023	10.1016/j.apenergy.2023.121379
62	Sadiq et al.	Comprehensive techno-economic assessment of Green-Ammonia@Scale production	2025	10.1016/j.clet.2025.100964
63	Salmon & Bañares-Alcántara	A global, spatially granular techno-economic analysis of offshore green ammonia production	2022	10.1016/j.jclepro.2022.133045
64	Salmon and Banares-Alcantara	Green ammonia as a spatial energy vector: a review	2021	10.1039/d1se00345c
65	Salmon et al.	Impact of grid connectivity on cost and location of green ammonia production: Australia as a case study	2021	10.1039/d1ee02582a
66	Samadi et al.	The renewables pull effect: How regional differences in renewable energy costs could influence where industrial production is located in the future	2023	10.1016/j.erss.2023.103257
67	Scheffler et al.	Techno-economic and environmental assessment of renewable hydrogen import routes from overseas in 2030	2025	10.1016/j.apenergy.2024.125073

68	Scholvin et al.	New development paths through green hydrogen?: An ex-ante assessment of structure and agency in Chile and Namibia	2025	10.1016/j.erss.2024.103904
69	Shirizadeh et al.	Towards a resilient and cost-competitive clean hydrogen economy: the future is green	2023	10.1039/d3ee02283h
70	Toktarova et al.	Interaction between electrified steel production and the north European electricity system	2022	10.1016/j.apenergy.2022.118584
71	Toktarova et al.	Design of Clean Steel Production with Hydrogen: Impact of Electricity System Composition	2021	10.3390/en14248349
72	Toktarova et al.	Electrification of the energy-intensive basic materials industry – Implications for the European electricity system	2025	10.1016/j.ijhydene.2024.08.016
73	Trollip et al.	How green primary iron production in South Africa could help global decarbonization	2022	10.1080/14693062.2021.2024123
74	Uchida et al.	E-fuels in IC engines: A key solution for a future decarbonized transport	2025	10.1177/14680874251325296
75	Venkataraman et al.	Zero-carbon steel production: The opportunities and role for Australia	2022	10.1016/j.enpol.2022.112811
76	Verpoort et al.	Impact of global heterogeneity of renewable energy supply on heavy industrial production and green value chains	2024	10.1038/s41560-024-01492-z
77	Wan et al.	International trade of green hydrogen, ammonia and methanol: Opportunities of China's subregions	2024	10.1016/j.renene.2024.121294
78	Wang et al.	Ammonia-based green corridors for sustainable maritime transportation	2023	10.1016/j.dche.2022.100082
79	Wang et al.	Green steel: Synergies between the Australian iron ore industry and the production of green hydrogen	2023	10.1016/j.ijhydene.2023.05.041
80	Wang et al.	Optimising Renewable Generation Configurations of Off-Grid Green Ammonia Production Systems considering Haber-Bosch Flexibility	2023	10.1016/j.enconman.2023.116790
81	Xiang et al.	Regional reallocation of zero-carbon ammonia production in China with carbon neutrality targets	2025	10.1016/j.accre.2025.01.001