

The Twin Transition and Labor Market Transformation: A Conceptual Framework for AI-Enabled Green Growth

Suad MUVAKIT¹

ORCID: 0000-0001-6120-4021

DOI: 10.54752/ct.1973941

Abstract: The green and digital transitions do not automatically produce inclusive growth. They interact through distinct labour-market processes: green structural change reallocates employment across sectors and places, whereas artificial intelligence (AI) reorganises tasks and authority within workplaces. This article develops a process-based conceptual framework for examining when their interaction can support AI-enabled green growth. An integrative review brings together peer-reviewed research and recent comparative reports. The framework follows a directional sequence in which green restructuring and AI deployment generate sectoral reallocation and task/workplace reorganisation. Labour-market adjustment arrangements and structural context then shape how these mechanisms lead to environmental, productivity, employment, job-quality, and distributive outcomes. These elements are not specified as independent, dependent, mediator, or moderator variables because the article does not estimate a statistical model. The

¹ Dr. Gaziantep Üniversitesi, Sosyal Bilimler Enstitüsü. smuvakit@gantep.edu.tr

MUVAKIT, S., (2026) “The Twin Transition and Labor Market Transformation: A Conceptual Framework for AI-Enabled Green Growth”, Çalışma ve Toplum Sayı: 91, C.4, s.2423-2450

This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited. See <https://creativecommons.org/licenses/by/4.0/>
Makale Geliş Tarihi: 18.06.2026- Makale Kabul Tarihi: 07.10.2026

framework distinguishes an enabling pathway based on labour augmentation and shared productivity gains from an adverse pathway involving displacement, surveillance, unequal value capture, and ecological externalisation. Six propositions identify relationships for subsequent empirical examination. A renewable-electricity value-chain application illustrates why AI exposure and labour effects differ across manufacturing, construction, and operations. The contribution is a power-sensitive account that treats environmental improvement and decent work as joint and institutionally contingent outcomes.

Keywords: twin transition; artificial intelligence; labour-market adaptation; just transition; green growth.

İkiz Dönüşüm ve İşgücü Piyasasının Dönüşümü: Yapay Zekâ Destekli Yeşil Büyüme İçin Kavramsal Bir Çerçeve

Öz: Yeşil ve dijital dönüşümler kendiliğinden kapsayıcı büyüme üretmez. Bu süreçler farklı işgücü piyasası dinamikleri üzerinden etkileşir: yeşil yapısal değişim istihdamı sektörler ve bölgeler arasında yeniden dağıtırken, yapay zekâ (YZ) işyerlerindeki görevleri ve otoriteyi yeniden düzenler. Makale, bu etkileşimin hangi koşullarda YZ destekli yeşil büyümeyi destekleyebileceğini inceleyen süreç-temelli bir kavramsal çerçeve geliştirmektedir. Bütünleştirici inceleme, hakemli akademik çalışmaları güncel karşılaştırmalı raporlarla bir araya getirmektedir. Çerçeve, yeşil yeniden yapılanma ve YZ kullanımından sektörel yeniden tahsis ile görev/işyeri yeniden örgütlenmesine, oradan da çevresel performans, verimlilik, istihdama erişim, iş kalitesi ve bölüşüm sonuçlarına uzanan yönlü bir ilişki kurmaktadır. Beceri oluşumu, hareketlilik, iş tasarımı, çalışanların söz hakkı ve sosyal koruma gibi uyum düzenlemeleri ile sektörel ve kurumsal bağlam bu sürecin nasıl ilerleyeceğini belirlemektedir. Makale istatistiksel bir model tahmin etmediği için bu unsurlar bağımsız, bağımlı, aracı veya düzenleyici değişkenler olarak tanımlanmamaktadır. Çerçeve, YZ'nin emeği tamamladığı ve verimlilik kazançlarının paylaşıldığı olanak sağlayıcı yol ile iş kaybı, gözetim, eşitsiz değer paylaşımı ve ekolojik maliyetlerin dışsallaştırıldığı olumsuz yolu ayırmaktadır. Altı önerme, gelecekteki görgül araştırmalar için incelenebilir ilişkiler sunmaktadır. Yenilenebilir elektrik değer zinciri uygulaması ise emek etkilerinin imalat, inşaat ve işletme aşamalarında neden farklılaştığını göstermektedir.

Anahtar Kelimeler: ikiz dönüşüm; yapay zekâ; işgücü piyasası uyumu; adil geçiş; yeşil büyüme.

Introduction

Decarbonisation and digitalisation are changing production at the same time, but they do not constitute a single process. The green transition redirects investment, output, and labour away from carbon-intensive activities and towards low-emission systems. The digital transition changes how information is produced, decisions are made, and work is organised. Their interaction—often called the twin transition—can create complementarities, such as AI-assisted renewable-energy forecasting, or conflicts, such as additional electricity and material demand from digital infrastructure. Recent scholarship therefore cautions against treating green and digital change as naturally synergistic or measuring it only through technology adoption (Bruno et al., 2026: 1–3, 18–24; Kaack et al., 2022: 518–525; van Wynsberghe, 2021: 214–217).

The labour market is where many of these complementarities and conflicts become distributive outcomes. Green structural transformation changes the industrial and geographical location of jobs. AI, by contrast, primarily changes the task content and governance of work. A wind-turbine technician may use predictive-maintenance tools without the occupation disappearing; a data analyst may be newly employed to forecast grid congestion; and a worker in fossil-fuel extraction may face displacement even when national clean-energy employment increases. Treating these changes on one analytical plane obscures their mechanisms. This article therefore distinguishes sectoral reallocation from task and workplace reorganisation and explains how they interact.

Aggregate job counts alone cannot establish whether the transition is inclusive. Global renewable-energy employment reached at least 16.6 million in 2024, while total energy employment reached 76 million; yet employment remained geographically concentrated, skill shortages persisted, and technological innovation reduced labour intensity in some renewable segments (IEA, 2025: 5–7, 20–21; IRENA & ILO, 2026: 14–15, 19–20, 29–30). Micro-level evidence is equally cautionary. In US employment histories covering roughly 300 million job transitions, the probability that a worker leaving a carbon-intensive job entered a green job rose markedly between 2005 and 2021 but was still only 0.7% in 2021, with lower transition rates for older and non-degree workers (Curtis et al., 2024: 127–161; OECD, 2024: 83–88, 187–217). Expansion and access are thus different questions.

AI introduces another distributional divide. Exposure estimates are high in advanced economies, but exposure does not equal adoption, displacement, or productivity gain; outcomes depend on complementary capital, skills, firm strategy, and institutions (Cazzaniga et al., 2024: 3, 8–10, 20–23; Gmyrek et al., 2025: 45–48;

OECD, 2023: 93–140). Moreover, AI is not confined to automating tasks. It can allocate shifts, monitor pace, evaluate performance, and discipline workers. The same predictive system that reduces energy waste can also intensify work or move decision authority towards an opaque vendor-controlled model. Algorithmic management consequently links digital capability to workplace power, privacy, bargaining, and job quality (De Stefano & Taes, 2023: 23–31; Jarrahi et al., 2021: 2–10; Kellogg et al., 2020: 368–377).

The article addresses two research questions. First, through which distinct labour-market mechanisms do green structural transformation and AI deployment interact? Second, under which sectoral, geographical, and institutional conditions does this interaction support environmentally effective and socially inclusive growth? The argument is organised as a process: the two transitions initiate sectoral reallocation and task/workplace reorganisation; adjustment arrangements and structural context shape how those changes are translated into environmental, economic, and labour outcomes.

The article separates reallocation across sectors from reorganisation within jobs and treats labour adjustment as more than training. Mobility, job design, worker voice, and social protection are considered alongside skills, corporate power, and algorithmic control. This gives the analysis a clearer route from the two research questions to the enabling and adverse pathways developed later in the paper. The comparative figures and the renewable-electricity discussion provide context for that argument; they are not presented as new causal estimates. Section 2 explains the review design, Section 3 sets out the theoretical foundations, Section 4 identifies the labour-market mechanisms, and Section 5 presents the framework and its directional relationships. Section 6 applies the argument to renewable electricity, while Sections 7 and 8 discuss policy implications and limitations.

Methodology: Integrative Conceptual Review

The study uses an integrative conceptual review designed for theory synthesis rather than a systematic effect estimate. Conceptual articles can contribute by clarifying constructs, connecting previously separated literature streams, and developing relationships that guide empirical research (Jaakkola, 2020: 18–26). This design is appropriate because the relevant evidence spans transition studies, labour economics, employment relations, energy justice, geography, and sustainable AI; a single meta-analytic outcome would not capture their different levels of analysis. The method nevertheless requires a transparent boundary around source selection and a traceable chain from evidence to constructs.

The literature base was assembled through searches of scholarly indexes, publisher databases, and institutional repositories, followed by DOI checks and backward citation searches. The main emphasis was on work published between 2000 and 15 September 2026. Earlier studies were retained when they remained important for defining a theoretical argument. Search terms combined the twin or green transition with AI, automation, labour-market change, skills, algorithmic management, just transition, collective bargaining, value chains, and geography.

Selection was guided by relevance to the two research questions and by the contribution a source made to a concept, mechanism, or contextual difference. Peer-reviewed studies carry the theoretical discussion. Reports from the IEA, ILO, IMF, IRENA, and OECD are used for recent comparative indicators and institutional evidence. Journalistic commentary, duplicate items, and documents that did not add a distinct analytical or evidential contribution were left out. The final reference base contains 28 academic works and six institutional reports.

The synthesis developed in three steps. The literature was first organised around transition pressures, labour-market mechanisms, adjustment arrangements, structural context, and outcomes. Claims were then compared across levels of analysis, including the contrast between aggregate employment growth and individual job transitions, and between task augmentation and algorithmic control. Finally, recurring relationships were stated as propositions that can be examined in later empirical work.

This is an integrative conceptual review rather than a systematic review, and it does not claim exhaustive coverage or use a PRISMA protocol. Table 1 provides recent background figures that establish the scale and unevenness of labour-market change. The figures are contextual evidence, not results produced by this article. Because renewable-energy employment, electricity employment, and total energy employment use different sectoral boundaries, they are discussed separately.

Table 1. Updated contextual evidence for the labour dimension of the twin transition

Indicator	Latest observation	What the observation establishes	Source
Renewable-energy employment	At least 16.6 million direct and indirect jobs in 2024; +2.3% from 2023	Employment is expanding, but more slowly than capacity because productivity, scale, and automation can reduce labour intensity.	IRENA & ILO (2026: 14–15)
Geographical concentration	China accounted for 43.9% of global renewable-energy jobs in 2024	Job creation depends on industrial capability and value-chain location, not deployment alone.	IRENA & ILO (2026: 29–30)
Total energy employment	76 million jobs in 2024; +2.2%, versus 1.3% economy-wide employment growth	Energy remains a large and growing labour system that includes both low- and high-carbon activities.	IEA (2025: 5, 11)
Electricity-sector expansion	+3.9 million jobs during 2019–2024; solar PV produced half of additions	Electrification is the main source of net energy-job growth, but technologies contribute unevenly.	IEA (2025: 5)
Applied technical shortages	More than half of 700 surveyed firms, unions, and educators reported critical hiring bottlenecks	Transition capacity is constrained by occupational pipelines and job quality, not only abstract “skills gaps”.	IEA (2025: 6, 20–21)
Current AI–manual task boundary	Energy-sector AI-skill concentration about 40% below selected knowledge-intensive sectors; current use does not materially replace most construction, operations, and maintenance roles	AI exposure varies strongly by task and physical work context.	IEA (2025: 7)

Theoretical Foundations

Three theories perform distinct functions in the framework. Socio-technical transition theory explains system-level green restructuring; task-based technological change explains how AI alters labour demand and work content; and just-transition political economy explains how power and institutions distribute gains and costs. Keeping these functions separate avoids treating technology, skills, governance, and outcomes as equivalent components.

Socio-technical transitions and green structural change

Socio-technical transition theory understands transformation as a reconfiguration of technologies, infrastructures, regulations, user practices, markets, and cultural meanings rather than a one-for-one replacement of devices (Geels, 2002: 1257–1263; Markard et al., 2012: 956–960). Environmental policy can destabilise carbon-intensive regimes while opening space for renewable generation, electrification, efficiency, and circular production. Because regimes are embedded in supply chains and places, the process changes the location and composition of labour demand. It is therefore a theory of structural direction and coordination, not a prediction that every low-carbon investment creates a net job gain.

Later transition research explicitly highlights agency, politics, and geography. Incumbent firms may defend assets and standards; new entrants may challenge them; governments select infrastructures and subsidies; and communities contest the distribution of costs (Köhler et al., 2019: 4–12). Geographic scholarship adds that location, territoriality, scale, and spatial embeddedness shape which regions host extraction, manufacturing, construction, and high-value services (Bridge et al., 2013: 331–337). These insights make sectoral reallocation a driver of differentiated opportunity rather than a uniform national shock.

This foundation also separates environmental output from social outcome. A project can reduce operational emissions while reproducing insecure subcontracting, land conflict, or uneven regional development. Conversely, protecting every incumbent job indefinitely can slow decarbonisation. The conceptual problem is not to maximise a single indicator, but to explain the conditions under which environmental effectiveness and decent work become compatible.

Task-based technological change and algorithmic management

Task-based accounts distinguish occupations from the activities performed within them. Automation substitutes for labour in some tasks, complements workers in others, and can create new tasks whose labour-demand effect offsets displacement (Acemoglu & Restrepo, 2019: 3–8, 21–25; Autor, 2015: 5–12). Robot adoption demonstrates that productivity gains and local displacement can coexist: technology may raise output while reducing employment and wages in exposed labour markets (Acemoglu & Restrepo, 2020: 2194–2200). AI should therefore be analysed by task, adoption strategy, and local adjustment capacity rather than by occupational labels alone.

In green production, AI can forecast renewable output, optimise grids, detect equipment failure, model material flows, and support environmental monitoring (Kaack et al., 2022: 518–525; Vinuesa et al., 2020: 1–8). These applications may complement engineering, maintenance, and planning tasks. Yet the capability to deploy them is uneven and their ecological balance is not automatically positive. “AI for sustainability” must be evaluated alongside the energy, hardware, and material requirements of AI itself (van Wynsberghe, 2021: 214–217). The relevant outcome is net environmental productivity after rebound and infrastructure effects, not digital intensity as such.

The task lens is incomplete unless managerial tasks are included. Algorithms can recommend or restrict action, record and rate performance, and influence reward or replacement. Such systems may improve coordination and safety, but they can also increase opacity, surveillance, pace, and asymmetry between the organisation that controls data and the worker who is evaluated by it (Jarrahi et al., 2021: 2–10; Kellogg et al., 2020: 368–377). Collective bargaining and worker consultation are therefore not policy add-ons; they shape how the technology is specified, audited, contested, and redesigned (De Stefano & Taes, 2023: 23–31).

Accordingly, the AI driver has two analytically distinct channels. A production channel changes prediction, optimisation, and technical task allocation. A control channel changes scheduling, monitoring, evaluation, and authority. Either channel can augment or displace labour. Their joint effect on job quality cannot be inferred from productivity alone.

Just transition and the political economy of power

Just-transition research asks who participates in decisions, who receives new opportunities, and who bears the costs of decarbonisation. Early political-economy

formulations emphasised that transition pathways are negotiated among states, firms, labour, and communities, not selected by a neutral planner (Newell & Mulvaney, 2013: 134–138). Labour organisations have promoted different versions of “just transition”, ranging from managed reform to deeper transformations of production and ownership (Stavis & Felli, 2015: 31–39). The concept therefore cannot be reduced to retraining after a closure decision has already been made.

Energy-justice scholarship distinguishes distributional, procedural, and recognition concerns. It asks how costs and benefits are allocated, who has decision-making voice, and whether historically marginalised groups are recognised (Carley & Konisky, 2020: 570–574; McCauley & Heffron, 2018: 2–6). Political accounts add that mobilisation and coalition-building affect whether transition policy can overcome incumbent interests and produce durable public support (Barry & Healy, 2017: 452–457; Cha & Pastor, 2022: 2–10). These dimensions enter the framework through worker voice, social dialogue, ownership, and corporate concentration.

Corporate concentration matters at two points. Concentrated energy firms influence investment, supply-chain location, and employment conditions; concentrated digital vendors influence access to data, models, cloud infrastructure, and standards. Where a small number of actors control both transition assets and informational infrastructure, productivity gains can be captured without proportional wage, employment, or local-development benefits. This does not mean concentration always prevents innovation, but it changes bargaining positions and the distribution of rents.

A global value-chain perspective further reveals that low-carbon consumption in one region can depend on mineral extraction, component manufacturing, or waste disposal elsewhere. Evidence from African cobalt production and e-waste sites illustrates how environmental harm and precarious labour may be displaced upstream or downstream (Sovacool et al., 2020: 1–3, 12–16). Global North estimates cannot therefore be generalised without considering informality, fiscal capacity, technology ownership, industrial depth, and exposure to extractive externalities.

Labour-Market Mechanisms of the Twin Transition

This section moves from theory to mechanism. Section 3 explained why systemic reallocation, task change, and power belong in the framework; Section 4 specifies how these processes generate observable labour-market effects.

Sectoral and occupational reallocation

Environmental regulation, investment, and demand alter relative output across high- and low-carbon activities. Labour demand consequently expands in some industries and contracts in others. “Green employment”, however, is not a binary occupational class. Jobs differ by the extent to which their outputs or tasks improve environmental performance, and many familiar occupations become greener through changing tasks (Bowen et al., 2018: 264–270; Consoli et al., 2016: 1048–1055). A construction worker installing insulation and a power-systems engineer integrating storage participate in the transition through different skills, contracts, and mobility requirements.

Skill relatedness affects the cost of moving between jobs. Green occupations tend to place greater weight on engineering, technical, managerial, and problem-solving capabilities, but requirements vary across sectors (Vona et al., 2018: 720–730). Climate policy can therefore be skill-biased within industries, favouring technicians while disadvantaging some manual workers even when aggregate employment changes little (Marin & Vona, 2019: 3–13). A policy centred only on the number of vacancies misses wage loss, credential barriers, seniority, and the transferability of tacit knowledge.

Reallocation is also spatial. Carbon-intensive assets and their suppliers are often clustered, whereas new projects may arise elsewhere. Moving residence is costly because workers have housing, family, and community ties. The US transition evidence shows very low direct movement from carbon-intensive to green jobs and substantial variation by age, education, and location (Curtis et al., 2024: 127–161). Thus, place-based industrial diversification and income security are as important as individual training.

Task and physical-workplace reorganisation

AI exposure varies with the codifiability, data intensity, and physical embeddedness of tasks. Forecasting, documentation, design, diagnostics, and scheduling are more readily supported by current AI than climbing a turbine, wiring a building, repairing a transmission line, or handling irregular materials on a construction site. In the energy sector, current AI applications have not removed the principal shortages in applied technical roles because many tasks remain manual, site-specific, safety-critical, and dependent on embodied expertise (IEA, 2025: 5–7, 20–21).

Manufacturing lies between these poles. Vision systems and predictive maintenance can automate inspection and reduce downtime, while robotics can change assembly tasks. Yet adoption depends on production scale, product variety,

capital cost, and industrial relations. Agriculture is different again: precision systems can improve input targeting, but their labour effects depend on farm size, connectivity, land tenure, and whether technologies are owned by farmers, contractors, or platform providers. Sector-specific task architecture therefore conditions any claim about AI substitution.

Algorithmic management changes physical workplaces even when production tasks remain human. Sensor data can determine routes, maintenance priorities, output targets, break timing, and safety alerts. These systems may prevent hazards, but poorly designed metrics can shift risks to workers, intensify pace, or penalise behaviour that is hard to measure. A just digital transition consequently requires *ex ante* worker participation, intelligible criteria, human review, limits on surveillance, and channels to contest decisions (De Stefano & Taes, 2023: 23–31; Jarrahi et al., 2021: 2–10).

Adaptation: skills, mobility, job design, voice, and protection

Labour-market adaptation is defined here as a multi-dimensional capacity, not as reskilling alone. Its five components are: (i) skill formation and recognition; (ii) occupational and geographic mobility; (iii) job redesign that combines human and machine capabilities; (iv) worker voice in technological and restructuring decisions; and (v) income and social protection during adjustment. These components are complementary. Training has little effect without vacancies, mobility support, credible credentials, or income during participation; mobility can be socially costly without place-based alternatives; and AI augmentation can deteriorate job quality without voice.

Skill policy must distinguish entry pipelines from transitions by incumbent workers. Apprenticeships and vocational programmes develop long-term supply, while modular training and recognition of prior learning can help experienced workers transfer. Employers must reveal task requirements and provide paid learning time. Public authorities can coordinate qualifications across regions and ensure that smaller firms and informal workers are not excluded. The objective is capability to move and bargain, not simply individual responsibility to remain “employable”.

Social protection changes workers’ ability to accept technological and sectoral risk. Wage insurance, unemployment protection, pension bridging, relocation assistance, and regional investment can reduce the private cost of decarbonisation. Collective bargaining can negotiate redeployment, training rights, data governance, monitoring limits, and productivity sharing. Together, these

arrangements help determine whether a nominally green and digital job is also stable, safe, and adequately paid.

Sectoral and geographical heterogeneity

The same policy produces different outcomes across manufacturing, construction, agriculture, and energy services. Manufacturing is capital-intensive and exposed to automation and trade; construction is locally delivered and physically variable; agriculture often combines climatic risk, informality, and unequal land or platform ownership; and professional energy services are more data-intensive and geographically mobile. Comparing sectors therefore requires task-level indicators, contract type, occupational composition, and local supply-chain depth.

Development level changes both opportunity and constraint. Advanced economies typically possess deeper digital infrastructure, finance, social protection, and high-skill labour pools, but may offshore material- and labour-intensive stages. Many emerging and developing economies have strong renewable resources and young workforces yet face financing costs, infrastructure gaps, informality, and dependence on imported equipment or proprietary systems. A 155-country analysis finds markedly stronger alignment between job matching and emissions reduction in wealthier high-latitude countries than in poorer low-latitude countries, underscoring the danger of universalising advanced-economy pathways (Zhao et al., 2025: 2–10).

Value-chain position is more informative than a simple North–South binary. A country that manufactures components, owns intellectual property, and provides engineering services captures different rents and learning effects from a country that only hosts resource extraction or final deployment. The framework therefore examines development level, geography, and value-chain position as related but distinct parts of the structural context.

A Process-Based Conceptual Framework for AI-Enabled Green Growth

Architecture and construct relationships

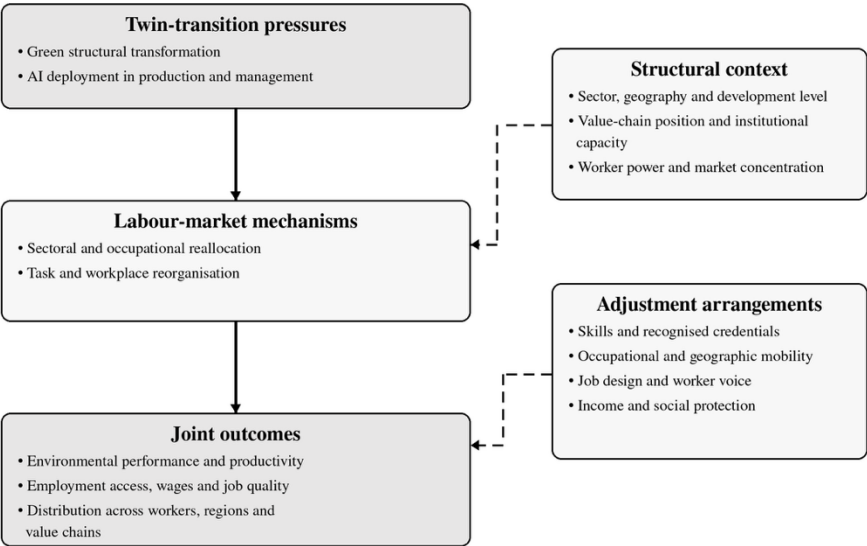
The framework is organised as a sequence rather than as a set of statistical variables. Green structural transformation and AI deployment create two kinds of labour-market change: reallocation across sectors and occupations, and reorganisation of tasks and workplace authority. Skills, mobility, job design, worker voice, and social protection form the adjustment arrangements through which workers and firms respond. Sector, geography, development level, value-chain

position, institutional capacity, worker power, and market concentration make up the structural context. The sequence ends with environmental, productivity, employment, job-quality, and distributive outcomes.

AI-enabled green growth is defined as productivity and income growth in which AI contributes to a net improvement in environmental performance and the associated labour-market adjustment is consistent with decent work and broad access to opportunity. The definition is deliberately conjunctive. Efficiency without net environmental gain is digitally enabled growth but not green growth; emissions reduction achieved through severe unprotected displacement is not inclusive; and rising green employment that depends on ecological and labour harm elsewhere is not a complete success.

Because the article does not estimate relationships, it does not assign independent, dependent, mediator, or moderator-variable status to these elements. Figure 1 shows the proposed direction of the argument. The solid arrows connect transition pressures, labour-market mechanisms, and joint outcomes. The dashed arrows indicate where structural context and adjustment arrangements shape the pathway. They are theoretical links for later examination, not estimated correlations or effects.

Figure 1. Directional structure of the process-based conceptual framework



Solid arrows show the proposed sequence; dashed arrows show conditions shaping the pathway.

Table 2 translates the figure into analytical questions and indicative observations. It also identifies the interpretive error most likely to arise at each stage. Outcomes can feed back into political support, investment decisions, and the subsequent pace of both transitions, but the article does not claim to quantify that feedback.

Table 2. Process-based conceptual framework: stages, questions, and observations

Stage	Role in the argument	Indicative observations	Main interpretive risk
Transition pressures	Green restructuring changes sectoral demand; AI deployment changes prediction, optimisation, automation, and managerial control.	Low-carbon investment; emissions regulation; AI adoption; data and compute access.	Assuming that technology adoption determines labour or environmental outcomes.
Labour-market mechanisms	Reallocation operates across industries and places; task and workplace reorganisation operates within jobs and organisations.	Job creation and destruction by sector; job-to-job flows; task shares; algorithmic scheduling and monitoring.	Equating aggregate job growth with worker access, or task exposure with job loss.
Adjustment arrangements	Skills, mobility, job redesign, worker voice, and social protection influence how workers and firms respond to change.	Recognised credentials; placement; mobility support; bargaining coverage; benefit access; job redesign.	Reducing adjustment to individual training while ignoring labour demand and adjustment costs.
Structural context	Sector, geography, development level, value-chain position, institutions, worker power, and concentration shape available choices.	Industrial depth; informality; regional alternatives; ownership; union coverage; platform and supplier concentration.	Generalising one national or sectoral pathway to settings with different institutions and capabilities.
Joint outcomes	Environmental, economic, and labour results are evaluated together and across groups and places.	Net emissions and material use; productivity; employment and wages; safety, autonomy, surveillance; regional gaps.	Counting gross jobs or efficiency gains while externalising ecological and social costs.
Feedback	Experienced outcomes affect political support, investment choices, and the later speed of the two transitions.	Public support; policy continuity; investment commitments; industrial and labour responses.	Reading a one-way sequence as a closed model without institutional learning or political reaction.

Enabling and adverse pathways

In the enabling pathway, environmental policy creates credible demand for low-carbon investment; AI is deployed to complement human judgement and improve system performance; training and mobility institutions connect workers to new tasks and sectors; and worker participation constrains harmful control practices. Productivity gains are shared through wages, shorter or safer work, and expanded employment. Digital infrastructure is powered and designed in ways that preserve net environmental benefits. Under these conditions, adaptation increases both economic capability and political support for faster decarbonisation.

In the adverse pathway, firms automate cost-reduction tasks without creating complementary work, concentrate data and decision authority, and use algorithmic management to intensify performance. Workers and regions facing carbon-intensive decline receive training without credible vacancies or protection. High-value digital and manufacturing stages remain concentrated elsewhere, while extraction, disposal, and unstable project work are externalised. Environmental efficiency may improve at the firm level even as rebound, energy demand, or material burdens weaken system-level gains.

These pathways can coexist. A single firm may augment engineers while surveilling technicians; a country may gain deployment jobs while importing high-value equipment; and global emissions may fall while local extraction burdens increase. The framework therefore predicts heterogeneity rather than a universal net effect.

Testable propositions

Proposition 1 (reallocation and accessibility)

Workers will move more readily from contracting carbon-intensive activities into expanding green occupations where skills are related, jobs are geographically accessible, and prior learning is recognised; otherwise, gross green-job growth can coexist with displacement and local scarring.

Proposition 2 (augmentation and job quality)

AI deployment is more likely to improve green productivity and job quality when it complements worker judgement and is accompanied by job redesign and skill investment; substitution-focused or surveillance-intensive deployment is more likely to increase displacement risk, work intensity, and inequality.

Proposition 3 (adjustment arrangements)

Training alone is unlikely to secure inclusive outcomes. Its contribution will depend on whether workers also have mobility support, influence over job design, access to social protection, and realistic employment opportunities.

Proposition 4 (power and value capture)

Higher corporate and digital-infrastructure concentration will weaken the translation of productivity gains into wages, local employment, and knowledge diffusion, while collective bargaining and participatory governance will strengthen it.

Proposition 5 (development and value-chain position)

Countries and regions with deeper productive capabilities and higher-value positions in green–digital value chains will capture larger and more durable employment gains than locations limited to extraction or final deployment, conditional on domestic linkages and labour standards.

Proposition 6 (net environmental condition)

AI's contribution to green growth will diminish as the energy, material, water, and rebound effects of digital infrastructure increase; lifecycle measurement and low-carbon infrastructure are therefore necessary to assess the net result.

Illustrative Application: The Renewable-Electricity Value Chain

Renewable electricity is used to examine how the proposed relationships differ along one value chain. The discussion covers upstream materials and component manufacturing; project development, construction, and installation; and operations, grids, and maintenance. These segments differ in location, task content, capital intensity, and exposure to digital control. The comparison organises existing evidence around the framework and is not presented as a new case study or causal test.

Upstream production includes mineral extraction, refining, cells, modules, turbines, batteries, and power electronics. AI may support exploration, process control, quality inspection, and supply-chain optimisation. At the same time, capital intensity and scale can reduce labour per unit, while concentrated ownership can limit local value capture. Extraction and end-of-life processing may impose pollution, safety, and informal-work burdens, especially where regulation

and bargaining are weak (Sovacool et al., 2020: 1–3, 12–16). A national count of installation jobs cannot reveal these transboundary effects.

Construction and installation include civil works, electrical installation, logistics, and commissioning. Many tasks occur in variable outdoor environments, require licensing and team coordination, and are difficult to automate with current AI. Digital tools can improve planning, safety, and quality, yet workers may also be monitored through location and productivity data. Labour shortages in electricians and other applied technical roles indicate that current AI capability is not a substitute for vocational pipelines and attractive working conditions (IEA, 2025: 5–7, 20–21).

Operations, maintenance, grid management, and energy services contain more data-intensive tasks. Forecasting, fault detection, predictive maintenance, and dispatch support are plausible areas of augmentation. These roles may combine domain knowledge with data literacy. The article uses “hybrid green–digital occupations” as an author-defined analytical category—not an official occupational classification—to denote occupations whose core tasks directly support environmental performance and require material digital or AI capability. Examples include smart-grid analysts, renewable forecasting specialists, predictive-maintenance technicians, building-energy managers, and precision-agriculture specialists. Classification should be operationalised through task data, not job titles alone (Bowen et al., 2018: 264–270; Consoli et al., 2016: 1048–1055).

The value-chain comparison clarifies why sector-neutral claims fail. A forecasting specialist may experience AI complementarity, an assembly worker may face automation, an installer may face labour scarcity and digital monitoring, and a mining community may face externalised costs. The relevant policy package consequently differs by segment.

Table 3. Applying the framework to renewable-electricity value-chain segments

Value-chain segment	AI-enabled uses	Likely labour mechanism	Power and justice risk	Priority institutional response
Materials and component manufacturing	Process control, inspection, robotics, logistics, demand forecasting	Automation and task redesign; possible productivity-led expansion; changing technician demand	Concentrated ownership; weak local linkages; extraction, safety, and pollution burdens shifted to low-regulation locations	Supplier and labour standards; local capability and linkage policies; environmental due diligence; bargaining rights
Project development, construction, and installation	Siting, permitting support, scheduling, safety analytics, quality control	Strong demand for site-specific applied technical work; partial digital augmentation rather than broad substitution	Subcontracting, temporary work, surveillance, unsafe pace, licensing and geographic bottlenecks	Apprenticeships; portable credentials; procurement job-quality clauses; worker data protections; regional mobility support
Operations, grids, maintenance, and energy services	Renewable forecasting, grid optimisation, fault detection, predictive maintenance, customer-energy management	Hybrid green-digital tasks; augmentation of engineering and technical judgement; some administrative automation	Vendor lock-in; opaque decisions; skill polarisation; control of operational data and cyber dependence	Human oversight; joint technology design; continuous paid training; auditability; public-interest data governance

Discussion and Policy Implications

What the framework changes analytically

The framework replaces the simple proposition that “AI plus green investment produces inclusive growth” with a sequence of relationships that can vary across settings. The distinction between reallocation and reorganisation explains why an economy can simultaneously report green-job growth, difficulty moving displaced workers, and AI-driven changes inside expanding occupations. Treating adjustment arrangements and structural context explicitly also explains why skills are necessary but insufficient and why institutions belong within the analysis rather than in an after-the-fact policy list.

It also changes the unit of evaluation. Occupational exposure is not an outcome; it is a potential for task change. Gross employment is not access; it may be geographically or educationally distant from displaced workers. Firm-level efficiency is not net sustainability; it may generate rebound or externalise resource costs. Finally, training provision is not adaptation unless it results in recognised capability, mobility, income security, and influence over job design.

The power-sensitive account does not presume that all firms oppose inclusion or that all concentrated industries perform poorly. It identifies mechanisms through which ownership and bargaining affect value capture. Empirical research can therefore test whether similar technology produces different wage, retention, safety, and productivity outcomes under different bargaining arrangements or supplier structures.

An integrated policy sequence

First, governments should conduct anticipatory workforce planning at the sector–occupation–region level. This requires linking decarbonisation pathways and procurement pipelines to task-based demand, training capacity, retirements, and local supply chains. National aggregate forecasts should be complemented by transition-flow indicators that reveal who actually moves into new work. Public dashboards should distinguish gross job creation, vacancies, hires, retention, wages, and job-to-job transitions.

Second, adaptation policy should finance institutions as well as courses. Sectoral training partnerships, apprenticeships, paid learning leave, recognition of prior learning, relocation support, and place-based diversification address different constraints. Employers benefiting from transition subsidies can be required to disclose occupational needs and contribute to training and adjustment funds.

Procurement and industrial policy can attach standards for wages, safety, apprenticeships, local supplier development, and worker representation.

Third, algorithmic systems used at work should be governed through purpose limitation, data minimisation, intelligibility, human review, and collective consultation. Workers and their representatives need information about the criteria used in allocation and evaluation, access to correction and appeal, and protection against retaliation. Productivity-sharing agreements can link measurable AI gains to wages, time reduction, staffing, or training. These provisions make worker voice part of adjustment practice rather than treating “responsible AI” as a voluntary principle.

Fourth, competition and infrastructure policy must address dual concentration. Interoperability, switching rights, public or shared data infrastructures, audit access, and support for smaller firms can limit dependency on a few digital vendors. Energy policy should assess supply-chain concentration and local capability alongside capacity additions. Where public finance de-risks investment, public authorities can negotiate knowledge transfer, domestic linkages, and social returns.

Fifth, international policy should prevent a green–digital transition in the North from externalising costs to the South. Due-diligence standards, traceability, technology and finance partnerships, and support for formalisation and labour inspection can improve conditions along mineral and equipment chains. These measures should not become protectionist barriers that deny development opportunities; their design requires representation from producing countries, communities, and workers.

Finally, measurement should be joint. A minimum evaluation set combines lifecycle environmental indicators; productivity and diffusion; employment flows and wages; job quality, safety, autonomy, and surveillance; and distribution by gender, education, age, region, and value-chain position. Recent work on twin-transition metrics similarly argues for input–process–outcome coherence and context-sensitive measurement (Bruno et al., 2026: 1–3, 18–24).

Empirical research agenda

The propositions can be tested through matched employer–employee data linked to firm AI adoption, environmental performance, collective-bargaining coverage, and regional labour-market characteristics. Difference-in-differences designs around subsidy, procurement, plant conversion, or algorithmic-management adoption could distinguish production and control channels. Task-level vacancy text can identify hybrid green–digital demand, but validation against worker-

reported tasks is necessary because titles may overstate both “green” and “AI” content.

Comparative sectoral case studies are especially valuable. A most-similar design could compare renewable projects using similar technology but different ownership, bargaining, and local-content arrangements. Global value-chain research could track where wages, intellectual property, emissions, mineral burdens, and discarded hardware occur. Worker surveys and qualitative research should examine autonomy, pace, safety, and contestability, which administrative employment counts cannot capture.

The renewable-electricity application offers a starting point rather than a substitute for fieldwork. Future research should test the framework in manufacturing, construction, agriculture, and energy services across both Global North and Global South contexts. Such studies can determine which relationships travel and which require sector-specific revision.

Conclusion

The twin transition is not a single technological wave. Green structural transformation reallocates employment across sectors and places, while AI reorganises production tasks and managerial authority within workplaces. Their interaction can improve renewable integration, resource efficiency, and productivity, but it can also displace workers, intensify monitoring, concentrate value, and externalise ecological costs. Labour-market outcomes cannot be inferred from investment, exposure, or gross job counts alone.

The process-based framework connects twin-transition pressures to outcomes through sectoral reallocation and task/workplace reorganisation. Skills, mobility, job redesign, worker voice, and social protection are treated as adjustment arrangements, while sector, geography, development level, institutions, bargaining power, value-chain position, and concentration constitute the structural context. This approach locates workers and organisations within political-economic structures rather than assigning adjustment responsibility to individuals.

The central implication is precise: AI-enabled green growth exists only when AI contributes to net environmental improvement and when adjustment produces broad access to decent work. The six propositions and renewable-electricity mapping provide a disciplined basis for comparative empirical testing. The article’s limitation is also clear: it is a conceptual synthesis, not a causal evaluation. Its contribution lies in specifying what future research must measure and what policy must coordinate if the green and digital transitions are to reinforce rather than undermine one another.

Genişletilmiş Özet

Bu çalışma, yeşil dönüşüm ile dijital dönüşümün kesişimini işgücü piyasası üzerinden açıklayan koşullu bir kavramsal çerçeve geliştirmektedir. Literatürde “ikiz dönüşüm” çoğu zaman karbonsuzlaşma ile dijitalleşmenin birbirini doğal olarak desteklediği varsayımıyla ele alınmaktadır. Oysa YZ’nin yenilenebilir enerji tahmini, akıllı şebeke yönetimi, çevresel izleme ve kaynak optimizasyonuna katkısı kadar; veri merkezlerinin enerji ve malzeme talebi, algoritmik gözetim, iş yoğunlaşması ve teknolojik kapasitenin büyük şirketlerde ve gelişmiş ekonomilerde toplanması da önemlidir. Bu nedenle çalışma, YZ destekli yeşil büyümeyi teknolojik benimsemenin otomatik sonucu olarak değil, kurumsal ve politik-ekonomik koşullara bağlı bir kalkınma yolu olarak tanımlamaktadır.

Makalenin iki araştırma sorusu bulunmaktadır: Yeşil yapısal dönüşüm ile YZ kullanımı hangi farklı işgücü piyasası mekanizmaları üzerinden etkileşmektedir? Bu etkileşim hangi sektörel, coğrafi ve kurumsal koşullarda çevresel olarak etkili ve toplumsal olarak kapsayıcı büyümeyi desteklemektedir? Çalışmanın temel savı, yeşil dönüşümün istihdamı sektörler ve bölgeler arasında yeniden dağıttığı, YZ’nin ise esas olarak meslek içindeki görevleri ve işyerindeki yönetsel otoriteyi yeniden düzenlediğidir. Bu iki mekanizmanın ayrıştırılması, toplam yeşil istihdam artarken belirli çalışanların yeni işlere geçememesi veya büyüyen bir sektörde YZ kaynaklı iş yoğunlaşmasının ortaya çıkması gibi eşzamanlı gelişmeleri açıklamayı mümkün kılmaktadır.

Yöntem olarak bütünleştirici kavramsal inceleme kullanılmıştır. 2000–15 Eylül 2026 dönemine odaklanan taramada ikiz dönüşüm, karbonsuzlaşma, YZ, otomasyon, algoritmik yönetim, yeşil işler, beceriler, hareketlilik, adil geçiş, güç, toplu pazarlık, değer zinciri ve coğrafya kavramlarının bileşimleri aranmıştır. Daha eski çalışmalar, kuramsal tartışma açısından önemlerini koruduklarında incelemeye alınmıştır. Kuramsal iddialarda hakemli akademik çalışmalara öncelik verilmiş; IEA, ILO, IMF, IRENA ve OECD raporları güncel karşılaştırmalı göstergeler için kullanılmıştır. Çalışma sistematik derleme veya meta-analiz iddiasında bulunmamakta; kaynakları dönüşüm baskıları, işgücü piyasası mekanizmaları, uyum düzenlemeleri, yapısal bağlam ve sonuçlar etrafında bir araya getirmektedir.

Kuramsal yapı üç ayrı yaklaşımı birleştirmektedir. Sosyo-teknik dönüşüm kuramı, teknolojilerin altyapı, düzenleme, piyasalar, şirketler ve kullanıcı pratikleriyle birlikte değiştiğini ve yeşil dönüşümün sektörel yönünü açıklar. Görev-temelli teknolojik değişim yaklaşımı, otomasyonun bazı görevlerde emeğin yerini aldığını, bazı görevlerde emeği tamamladığını ve yeni görevler yarattığını gösterir. Algoritmik yönetim yazını, YZ’nin yalnız üretim tekniği olmadığını; iş dağıtımını, izleme, performans değerlendirmesi ve disiplin yoluyla otorite ilişkilerini

değiştirdiğini ortaya koyar. Adil geçişin politik ekonomisi ise dağıtımsal adaletin yanında karar süreçlerine katılım, tanınma, mülkiyet, şirket yoğunlaşması ve toplu pazarlık gibi güç ilişkilerini analize dâhil eder.

Önerilen çerçeve istatistiksel değişkenler modeli olarak değil, yönlü bir süreç olarak kurulmuştur. Yeşil yapısal dönüşüm ve YZ kullanımı başlangıçtaki dönüşüm baskılarını oluşturur. Bunlar sektörler arası yeniden tahsis ile görev ve işyeri yeniden örgütlenmesi üzerinden işgücü piyasasına yansır. Beceri oluşumu, mesleki ve coğrafi hareketlilik, işin yeniden tasarımı, çalışanların söz hakkı ve sosyal koruma uyum düzenlemelerini oluşturur. Sektör, coğrafya, gelişmişlik düzeyi, değer zinciri konumu, kurumsal kapasite, toplu pazarlık ve şirket yoğunlaşması ise sürecin yapısal bağlamıdır. Çevresel performans, verimlilik, istihdama erişim, ücretler, iş kalitesi ve bölüşüm sonuçları birlikte değerlendirilir.

Çerçeve iki olası yol tanımlar. Olanak sağlayıcı yolda YZ çalışanların muhakemesini tamamlar, sistem performansını iyileştirir, eğitim ve hareketlilik kurumları çalışanları yeni görevlere bağlar, çalışan katılımı zararlı kontrol uygulamalarını sınırlar ve verimlilik kazançları ücret, güvenlik, çalışma süresi veya yeni istihdam biçiminde paylaşılır. Olumsuz yolda ise şirketler tamamlayıcı görev yaratmadan maliyet azaltıcı otomasyona yönelir, veri ve karar yetkisini yoğunlaştırır, algoritmik yönetimle çalışma temposunu artırır; karbon yoğun bölgeler ise gerçek iş olanakları ve koruma olmadan yalnızca eğitim programlarıyla baş başa bırakılır. Ayrıca yüksek değerli dijital ve imalat aşamaları belirli merkezlerde toplanırken çevresel ve emek maliyetleri başka coğrafyalara aktarılabilir.

Bu ilişkiler altı önermeyle incelenebilir hâle getirilmiştir. İşçilerin yeşil işlere geçişinin beceri yakınlığına, coğrafi erişime ve tanınan yeterliliklere bağlı olduğu; YZ'nin insan muhakemesini tamamlayan iş tasarımı ve beceri yatırımıyla birlikte kullanıldığında iş kalitesini geliştirme olasılığının arttığı öne sürülmektedir. Eğitim tek başına yeterli görülmemekte; hareketlilik desteği, çalışanların iş tasarımı üzerindeki etkisi, sosyal koruma ve gerçek iş olanaklarıyla birlikte ele alınmaktadır. Ayrıca şirket yoğunlaşmasının yerel değer paylaşımını zayıflatabileceği, toplu pazarlığın paylaşımı güçlendirebileceği; yüksek değer zinciri konumlarının daha kalıcı istihdam kazanımları sağlayacağı ve YZ altyapısının enerji, malzeme, su ve geri tepme etkileri arttıkça çevresel katkının azalacağı ileri sürülmektedir.

Yenilenebilir elektrik değer zincirine yönelik açıklayıcı uygulama, modelin sektör içi farklılaşmasını göstermektedir. Maden ve bileşen imalatında YZ süreç kontrolü ve kalite denetimini geliştirirken otomasyon, yoğunlaşma ve ekolojik dışsallaştırma riskleri doğurabilir. İnşaat ve kurulum işlerinde sahaya özgü fiziksel görevler YZ ile geniş ölçekte ikame edilemez; buna karşılık planlama, güvenlik ve izleme dijitalleşebilir. İşletme, bakım ve şebeke hizmetlerinde tahmin, arıza tespiti ve optimizasyon daha güçlü tamamlayıcılık yaratır. Çalışmada “hibrit yeşil-dijital

meslekler”, resmî bir sınıflandırma değil; çevresel performansa doğrudan katkı sağlayan ve kayda değer dijital/YZ yeterliliği gerektiren görevleri birleştiren yazar-tanımlı bir kategori olarak kullanılmaktadır.

Sonuç olarak YZ destekli yeşil büyüme, yalnızca YZ’nin düşük karbonlu üretimde kullanılmasını ifade etmez. Kavram, YZ’nin net çevresel iyileşmeye katkıda bulunduğu ve uyum sürecinin geniş kesimlerin insana yakışır işe erişimiyle uyumlu olduğu koşullu bir sonucu belirtir. Çalışmanın temel sınırlılığı, yeni nedensel tahmin veya birincil veri sunmayan kavramsal bir sentez olmasıdır. Buna karşılık kuramsal katkısı, gelecekteki karşılaştırmalı araştırmaların hangi mekanizmaları, güç ilişkilerini, sınır koşullarını ve ortak çevresel-emek sonuçlarını ölçmesi gerektiğini açık biçimde göstermesidir.

Beyanlar

Katkı Oranı Beyanı

Bu çalışma tek yazarlı olarak hazırlanmıştır. Makalenin kavramsal tasarımı, literatür taraması, kuramsal çerçevenin oluşturulması, analiz süreci, yazımı, düzenlenmesi ve son okuması yazar tarafından gerçekleştirilmiştir.

Çıkar Çatışması Beyanı

Yazar, bu çalışma kapsamında herhangi bir kişi, kurum veya kuruluş ile çıkar çatışması bulunmadığını beyan eder.

Finansman Beyanı

Bu çalışma herhangi bir kurum, kuruluş veya fon sağlayıcı tarafından finansal olarak desteklenmemiştir.

Etik Kurul Beyanı

Bu çalışma insan katılımcılar, deneysel veri, anket, mülakat veya kişisel veri içermeyen kavramsal bir araştırma niteliğindedir. Bu nedenle etik kurul izni gerektirmemektedir.

Destek ve Teşekkür Beyanı

Yazar, çalışmanın hazırlanması sürecinde herhangi bir kurumsal veya bireysel destek alınmadığını beyan eder.

REFERENCES

- Acemoglu, D., & Restrepo, P. (2019). Automation and new tasks: How technology displaces and reinstates labor. *Journal of Economic Perspectives*, 33(2), 3–30. <https://doi.org/10.1257/jep.33.2.3>
- Acemoglu, D., & Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. *Journal of Political Economy*, 128(6), 2188–2244. <https://doi.org/10.1086/705716>
- Autor, D. H. (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*, 29(3), 3–30. <https://doi.org/10.1257/jep.29.3.3>
- Barry, J., & Healy, N. (2017). Politicizing energy justice and energy system transitions: Fossil fuel divestment and a “just transition”. *Energy Policy*, 108, 451–459. <https://doi.org/10.1016/j.enpol.2017.06.014>
- Bowen, A., Kuralbayeva, K., & Tipoe, E. L. (2018). Characterising green employment: The impacts of “greening” on workforce composition. *Energy Economics*, 72, 263–275. <https://doi.org/10.1016/j.eneco.2018.03.015>
- Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy*, 53, 331–340. <https://doi.org/10.1016/j.enpol.2012.10.066>
- Bruno, R. L., Jin, J., Korosteleva, J., Liu, Y., Radošević, S., & Wang, Z. (2026). A critical evaluation of digitalisation and green measures for advancing twin transition metrics. *Discover Sustainability*, 7, Article 1233. <https://doi.org/10.1007/s43621-026-03311-9>
- Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, 5, 569–577. <https://doi.org/10.1038/s41560-020-0641-6>
- Cazzaniga, M., Jaumotte, F., Li, L., Melina, G., Panton, A. J., Pizzinelli, C., Rockall, E., & Tavares, M. M. (2024). *Gen-AI: Artificial intelligence and the future of work (IMF Staff Discussion Note SDN/2024/001)*. International Monetary Fund. <https://doi.org/10.5089/9798400262548.006>
- Cha, J. M., & Pastor, M. (2022). Just transition: Framing, organizing, and power-building for decarbonization. *Energy Research & Social Science*, 90, Article 102588. <https://doi.org/10.1016/j.erss.2022.102588>
- Consoli, D., Marin, G., Marzocchi, A., & Vona, F. (2016). Do green jobs differ from non-green jobs in terms of skills and human capital? *Research Policy*, 45(5), 1046–1060. <https://doi.org/10.1016/j.respol.2016.02.007>
- Curtis, E. M., O’Kane, L., & Park, R. J. (2024). Workers and the green-energy transition: Evidence from 300 million job transitions. *Environmental and Energy Policy and the Economy*, 5, 127–161. <https://doi.org/10.1086/727880>

- De Stefano, V., & Taes, S. (2023). Algorithmic management and collective bargaining. *Transfer: European Review of Labour and Research*, 29(1), 21–36. <https://doi.org/10.1177/10242589221141055>
- Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31(8–9), 1257–1274. [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8)
- Gmyrek, P., Berg, J., Kamiński, K., Konopczyński, F., Ładna, A., Nafradi, B., Roslaniec, K., & Troszyński, M. (2025). *Generative AI and jobs: A refined global index of occupational exposure (ILO Working Paper No. 140)*. International Labour Organization. <https://doi.org/10.54394/HETP0387>
- International Energy Agency. (2025). *World energy employment 2025*. IEA. <https://www.iea.org/reports/world-energy-employment-2025>
- International Renewable Energy Agency & International Labour Organization. (2026). *Renewable energy and jobs: Annual review 2025*. IRENA and ILO. <https://www.irena.org/Publications/2026/Jan/Renewable-energy-and-jobs-Annual-review-2025>
- Jaakkola, E. (2020). Designing conceptual articles: Four approaches. *AMS Review*, 10, 18–26. <https://doi.org/10.1007/s13162-020-00161-0>
- Jarrahi, M. H., Newlands, G., Lee, M. K., Wolf, C. T., Kinder, E., & Sutherland, W. (2021). Algorithmic management in a work context. *Big Data & Society*, 8(2), 1–14. <https://doi.org/10.1177/20539517211020332>
- Kaack, L. H., Donti, P. L., Strubell, E., Kamiya, G., Creutzig, F., & Rolnick, D. (2022). Aligning artificial intelligence with climate change mitigation. *Nature Climate Change*, 12, 518–527. <https://doi.org/10.1038/s41558-022-01377-7>
- Kellogg, K. C., Valentine, M. A., & Christin, A. (2020). Algorithms at work: The new contested terrain of control. *Academy of Management Annals*, 14(1), 366–410. <https://doi.org/10.5465/annals.2018.0174>
- Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., Nykvist, B., Pel, B., Raven, R., Rohrer, H., Sandén, B., Schot, J., Sovacool, B. K., Turnheim, B., Welch, D., & Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, 31, 1–32. <https://doi.org/10.1016/j.eist.2019.01.004>
- Marin, G., & Vona, F. (2019). Climate policies and skill-biased employment dynamics: Evidence from EU countries. *Journal of Environmental Economics and Management*, 98, Article 102253. <https://doi.org/10.1016/j.jeem.2019.102253>

- Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), 955–967. <https://doi.org/10.1016/j.respol.2012.02.013>
- McCauley, D., & Heffron, R. (2018). Just transition: Integrating climate, energy and environmental justice. *Energy Policy*, 119, 1–7. <https://doi.org/10.1016/j.enpol.2018.04.014>
- Newell, P., & Mulvaney, D. (2013). The political economy of the “just transition”. *The Geographical Journal*, 179(2), 132–140. <https://doi.org/10.1111/geoj.12008>
- OECD. (2023). *OECD employment outlook 2023: Artificial intelligence and the labour market*. OECD Publishing. <https://doi.org/10.1787/08785bba-en>
- OECD. (2024). *OECD employment outlook 2024: The net-zero transition and the labour market*. OECD Publishing. <https://doi.org/10.1787/ac8b3538-en>
- Sovacool, B. K., Hook, A., Martiskainen, M., Brock, A., & Turnheim, B. (2020). The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa. *Global Environmental Change*, 60, Article 102028. <https://doi.org/10.1016/j.gloenvcha.2019.102028>
- Stavis, D., & Felli, R. (2015). Global labour unions and just transition to a green economy. *International Environmental Agreements: Politics, Law and Economics*, 15, 29–43. <https://doi.org/10.1007/s10784-014-9266-1>
- van Wynsberghe, A. (2021). Sustainable AI: AI for sustainability and the sustainability of AI. *AI and Ethics*, 1, 213–218. <https://doi.org/10.1007/s43681-021-00043-6>
- Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., Felländer, A., Langhans, S. D., Tegmark, M., & Fuso Nerini, F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature Communications*, 11, Article 233. <https://doi.org/10.1038/s41467-019-14108-y>
- Vona, F., Marin, G., Consoli, D., & Popp, D. (2018). Environmental regulation and green skills: An empirical exploration. *Journal of the Association of Environmental and Resource Economists*, 5(4), 713–753. <https://doi.org/10.1086/698859>
- Zhao, S., Shao, Q., Zhang, L., Zhou, X., Guo, H., & Mi, Z. (2025). Job seekers have more suitable job opportunities in decarbonization in the Global North than in the Global South. *Communications Earth & Environment*, 6, Article 272. <https://doi.org/10.1038/s43247-025-02230-3>