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Navigating Electrification Risks in European Cities

Strategies for Sustainable Transition Amid Rising Demand and Geopolitical Challenges

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Abbreviations and acronyms

Acronym	Description
WP	Work Package

Summary

This deliverable addresses the electrification risks that cities in Europe face in the transition to sustainable, low-carbon energy systems. It explores key challenges such as rising energy demand, critical materials shortages, and the complexities of decarbonizing urban infrastructure while ensuring environmental and social equity. The deliverable provides an in-depth analysis of the risks associated with sourcing and production of clean energy technologies, environmental impacts, workforce shortages, and the financial barriers to the energy transition.

The report highlights opportunities for cities to mitigate these risks through strategies like urban mining, circular economy practices, skills development, innovative financing, and regional cooperation. It emphasizes that a coordinated approach across cities is essential to overcoming these challenges and achieving the EU's climate goals, particularly net-zero emissions by 2050.

Keywords

Electrification, Energy transition, Resource Security, Circular economy, Green technologies, Urban mining, Skills development, Financial mechanisms, Climate targets, Geopolitical risks, Workforce shortages,

1 Introduction and Objectives

The need for European cities to transition towards clean energy sources is undeniable. However, the processes, as well associated benefits, opportunities, trade-offs, risks accompanying this transition are crucial to consider to design and implement societally equitable and truly environmentally sustainable pathways. This piece of work aims to contribute to increased understanding of the transition complexity helping cities better strategize on ways forward, goals, and decision-making processes.

The following questions are explored:

- **Which sectors account for the highest energy use** in European cities, and how do they relate to the greatest opportunities for adaptation?
- How can cities **address increasing energy demand while urgently reducing greenhouse gas emissions** (2.2.)?
- Which concepts, products, components, and materials are central to the energy transition, and why is it important to capture their systemic implications (2.4.)?
- What are the risks of sourcing and producing (3.1.), as well as environmental (3.2.), social (3.3.), and economic (3.4.) implications of these concepts, products, and materials?
- And what are the **key findings and key takeaways (4.0),** that could support **pathways for European cities (5.0)**?

2 Context

The EU's total remaining built environment carbon budget for limiting warming to 1.5°C is around 15 Gt CO2e (Friedlingstein et al., 2022). This means Europe must reduce its CO2 emissions by approximately 40% by 2030, necessitating a drastic acceleration in reduction efforts.

Achieving these goals demands **tripling the current renovation rates with a focus on deep energy-saving retrofits that cut building energy use by at least 60%** (International Energy Agency, 2021).

The EU's Renovation Wave initiative aims to upgrade 35 million buildings by 2030, simultaneously boosting green jobs and tackling energy poverty (European Commission, 2024). Realizing these goals requires a holistic strategy that integrates demand reduction, energy efficiency, and renewables, supported by robust enforcement, monitoring, and digital tools like renovation passports. Balancing the growing energy demand driven by comfort, climate extremes, and technological growth with this finite carbon budget—and geopolitical uncertainties over energy supply—creates a formidable challenge. Yet, coordinated, ambitious action across Europe's cities and countries is indispensable to secure a sustainable, resilient energy future consistent with net zero by 2050.

Furthermore, the Russia's invasion of Ukraine and the resulting disruption of relations with Russia have placed Europe's **energy security under severe pressure, exposing the risks of dependence on a limited number of external suppliers.** This shock accelerated the **urgency for diversification of energy sources** and highlighted the **geopolitical dimension of the clean energy transition.**

Many European cities now face the dual challenge of ensuring a reliable and affordable energy supply in the short term, while simultaneously pursuing long-term sustainability goals. The fragmentation of global trade, combined with volatile fossil fuel markets and competition for critical clean energy technologies, further complicates this task (International Monetary Fund, 2023).

In this context, electrification (among others of heating through heat pumps, combined with expanded renewable electricity such as solar PV) is critical (European Climate Foundation, 2022).

Mandatory Minimum Energy Performance Standards (MEPS), **nationally tailored renovation plans**, and aligned financial incentives must drive widespread uptake, ensuring **equitable access** particularly for vulnerable households (Climate Bonds Initiative, 2023).

For urban centers—where consumption is most concentrated—this means navigating a tight balance between securing immediate energy needs and investing in the infrastructure that will enable decarbonization. Without a coordinated approach at both national and municipal levels, cities risk being locked into expensive stopgap solutions, undermining the resilience and equity of Europe's transition to a sustainable energy system.

2.1 An Overview of Energy Consumption in European Cities and Associated Decarbonization Impact

European cities rely heavily on a stable and affordable energy supply to meet the demands of diverse sectors, including heating and cooling, transportation, agriculture, industry, and electricity provision. Despite substantial progress in renewable energy adoption, a significant portion of the EU's energy consumption remains fossil-fuel based, contributing notably to greenhouse gas emissions and climate change challenges (European Environment Agency, 2023) (Fig 1.).

There is **marked variation in energy consumption volumes across** European countries and urban areas, reflecting obvious differences in climate, economic structure, technological adoption, as well as cultural and lifestyle patterns. These disparities suggest differentiated decarbonization pathways and opportunities for energy demand reductions, balanced with human comfort needs and shifting behavioural patterns related to energy use (International Energy Agency, 2023) (Fig 2).

Furthermore, **shifting climatic zones, add to the further complexity** when considering decarbonization pathways, as the dynamically changing conditions need to be taken into account. For example, while Southern cities face continuously growing cooling requirements, Northern cities are now also experiencing increasing demand for cooling during ever warmer summers, having until recently focused primarily on heating needs.

Sectorally, the **mobility sector** stands out as a primary target for emissions reduction due to its substantial share in urban energy consumption and relatively **straightforward technological alternatives through electrification** and modal shifts. This sector shows some of the greatest differences in emissions across cities, largely shaped by infrastructure and policy choices (European Environment Agency, 2023; International Energy Agency, 2023g) (Fig 3). By contrast, household energy use, principally for space heating, cooling, and appliances presents a more complex challenge. It accounts for a similar scale of urban energy consumption and corresponding emissions, with significant potential for energy efficiency improvements and electrification of heating through heat pumps. Closely following is the industrial sector, where energy-intensive production processes demand targeted decarbonization strategies including process electrification, adoption of green hydrogen, and circular economy approaches (European Environment Agency, 2023; International Energy Agency, 2023).

Recognizing these sectoral dynamics and geographical variations is essential for designing decarbonization policies that not only reduce emissions but also address sufficiency and redefine what constitutes urban liveability in line with EU climate commitments.

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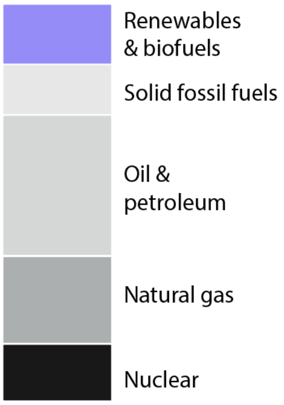
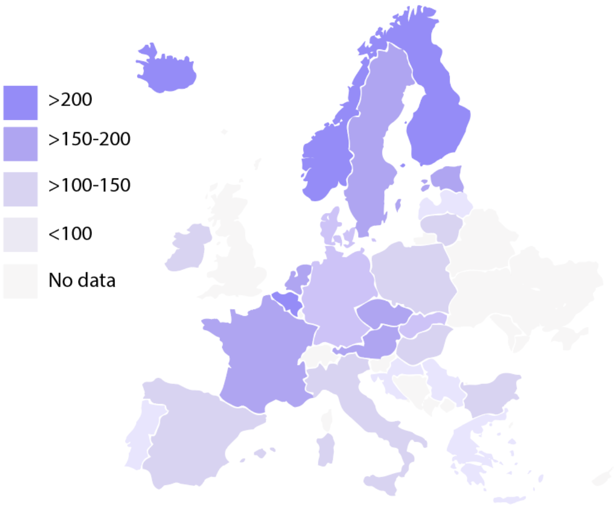




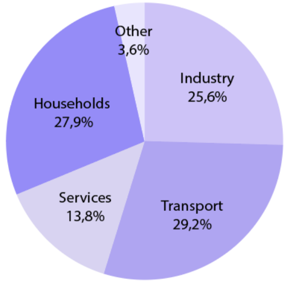


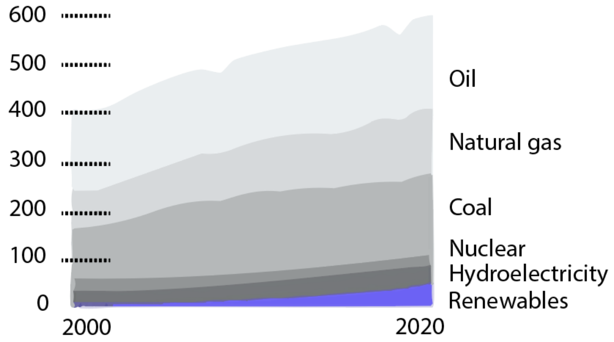
Fig 1. European Energy consumption per fuel

Fig 2. European Energy consumption (annual kWh/capita)

Fig 3. European Energy consumption by sector

2.2 Increasing Energy Demand in a Conflict with the Urgency to Reduce Emissions

In recent years, global energy **demand has risen at a pace exceeding the total installed capacity of renewable energy sources,** meaning renewables have so far only been able to meet the growing demand rather than surpass it (International Energy Agency, 2023) (Fig 4). Within this global context, the **European Union's per capita energy consumption still remains about twice the world average**, reflecting unique challenges in managing urban energy consumption while pursuing decarbonization (International Energy Agency, 2023) (Fig 5.).



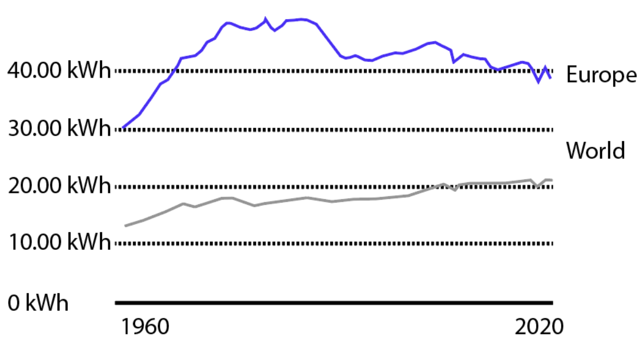


Fig 4. Global increase in demand is higher than all renewables installed (TWh)

Fig 5. European energy use per capita is double compared to world average

European cities face a complex dilemma: **rising standards of comfort, technological advancements, and industrial growth consistently elevate energy demand.** This trend is further intensified by increasingly extreme weather patterns, leading to augmented heating and cooling needs to maintain indoor climate conditions conducive to health and productivity.

- **Buildings** are major consumers of energy in European cities, representing approximately 40% of the EU's total energy use. This energy is largely devoted to heating, cooling, lighting, and operating appliances. Since 2000, the building stock in Europe has grown by about 300%, while the energy demand per building continues to rise at an annual rate of approximately 4% (International Energy Agency, 2023).
- **Cooling** services, driven by urban heat and climate change, currently account for nearly 10% of global energy demand and can constitute over 50% of the total energy consumption during peak summer months in warmer regions—trends also manifesting across Southern European cities (International Energy Agency, 2023b). Notably, global energy consumption for indoor cooling has more than tripled over the last three decades, with forecasts indicating continued acceleration as temperatures rise.
- **Heating**, encompassing space heating and water heating, remains the largest contributor to building energy use globally, accounting for nearly 50%. Electrification of heating is progressing, with projections indicating that the share of electricity in heating will

approximately double by 2030. Moreover, recent extreme cold spells have driven spikes in winter energy demand, further exacerbating challenges for urban energy systems (International Energy Agency, 2023b).

These dynamics create periods of **extreme peak demand**, especially during very hot summers or harsh winters. Such peaks strain grid infrastructure and increase the risk of **power outages**, which in turn jeopardize public health and safety by exposing large urban populations to climate-related stress (International Energy Agency, 2023c).

Recent examples include the June 2024 blackout across parts of the Balkans during a heatwave that drove cooling demand to unprecedented levels, and the 2025 heatwave in Italy, where cable overheating and surging demand stressed the power system. While not directly climate-related, the Iberian Peninsula blackout of April 2025 — which cut 60% of Spain's electricity supply within seconds — further illustrates how fragile grids can become when faced with sudden shocks.

Balancing this mounting and volatile energy demand while accelerating emission reductions presents one of the key risks in the transition to net zero cities. Addressing this requires integrated energy planning, deployment of flexible, low-carbon heating and cooling technologies, and demand-side management strategies tailored to Europe's diverse, and changing climatic and urban contexts.

2.3 Current Predominating Systems and Products of the Green Transition

- **Electric Vehicles:** The rapid adoption of electric vehicles (EVs) represents a transformative step toward sustainable, low-carbon transportation and is a cornerstone technology in decarbonizing road transport. However, the production of EV batteries and motors requires several critical minerals and rare earth elements. Therefore, a holistic approach to electrification must consider the environmental and social implications of raw material extraction to ensure overall sustainability (International Energy Agency, 2023d).
- **Solar Panels:** Photovoltaic (PV) technology is expected to lead the transformation of the global electricity sector. In 2022, global solar capacity increased by 26% and must continue growing at this pace to meet the Net Zero Scenario goals. Solar panels rely on materials such as silicon, cadmium, tellurium, and rare earth elements, whose extraction can be linked to environmental degradation and supply chain vulnerabilities. Additionally, the majority of the PV value chain is geographically concentrated, with China dominating production, creating strategic and supply risks (European Commission, 2020).
- **Wind Turbines:** Wind power is one of the most cost-effective climate mitigation technologies. A key component of wind turbines is the generator, which demands rare earth elements and a variety of materials such as concrete, steel, plastics, composites, aluminium, chromium, copper, iron, manganese, molybdenum, nickel, and zinc. The typical wind turbine lifetime ranges between 25-30 years, raising concerns about waste management and emphasizing the importance of embedding circular economy principles in turbine design and end-of-life processing (European Commission, 2020).
- **Air Conditioning:** Approximately 2 billion air conditioning units are currently in operation worldwide, positioning space cooling as a major driver of increasing global building energy demand. Besides the electricity consumed, air conditioning contributes to greenhouse gas emissions through refrigerant leaks, with many refrigerants having a global warming potential thousands of times greater than CO_2 (International Energy Agency, 2023e).
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- **Heat pumps:** Heat pumps are indispensable for reducing emissions and natural gas use and are an urgent priority within the EU's climate strategy. Their rapid adoption will increase

electricity demand substantially, making the implementation of energy-efficient practices, demand response measures, and simultaneous improvements in building envelopes critical to mitigating impacts on power systems (International Energy Agency, 2023f).

- **Building envelope retrofit:** Since 2010, increased energy efficiency measures in building envelopes have contributed to a 4% global reduction in heating demand across advanced economies (European Environment Agency, 2022). Retrofitting building envelopes has the potential to reduce building energy consumption by 50–75%. Innovations in materials and adaptive envelope systems are therefore crucial components of effective retrofitting strategies. Importantly, embodied carbon and pollution impacts of insulation materials must also be carefully evaluated to achieve truly sustainable building upgrades (EU Smart Cities Information System, 2023; Greenspec, 2023).

2.4 The Importance of Capturing the Entanglements and Systemic Impacts of the Green Transition

Green transition is characterized by a complex entanglement of sectors, technologies, and **resource flows that cannot be understood or managed in isolation.** Energy demand from buildings, transportation, industry, and power generation is intricately linked with the deployment of diverse low-carbon technologies, each **relying on critical materials and supply chains that introduce systemic vulnerabilities**. These interconnections create feedback loops where changes or disruptions in one domain propagate across others, underscoring the need to analyze the entire system holistically to avoid unintended consequences.

Moreover, the **extraction and processing of critical minerals** essential for clean technologies such as electric vehicles and renewable energy infrastructure **carry their own environmental and social risks**. These resource dependencies highlight that sustainability challenges are not confined to carbon emissions alone but span ecological integrity, social welfare, and geopolitical stability. Addressing the green transition's challenges effectively requires capturing these multi-dimensional entanglements and adopting integrated strategies that reflect the full scope of risks and opportunities across interconnected domains.

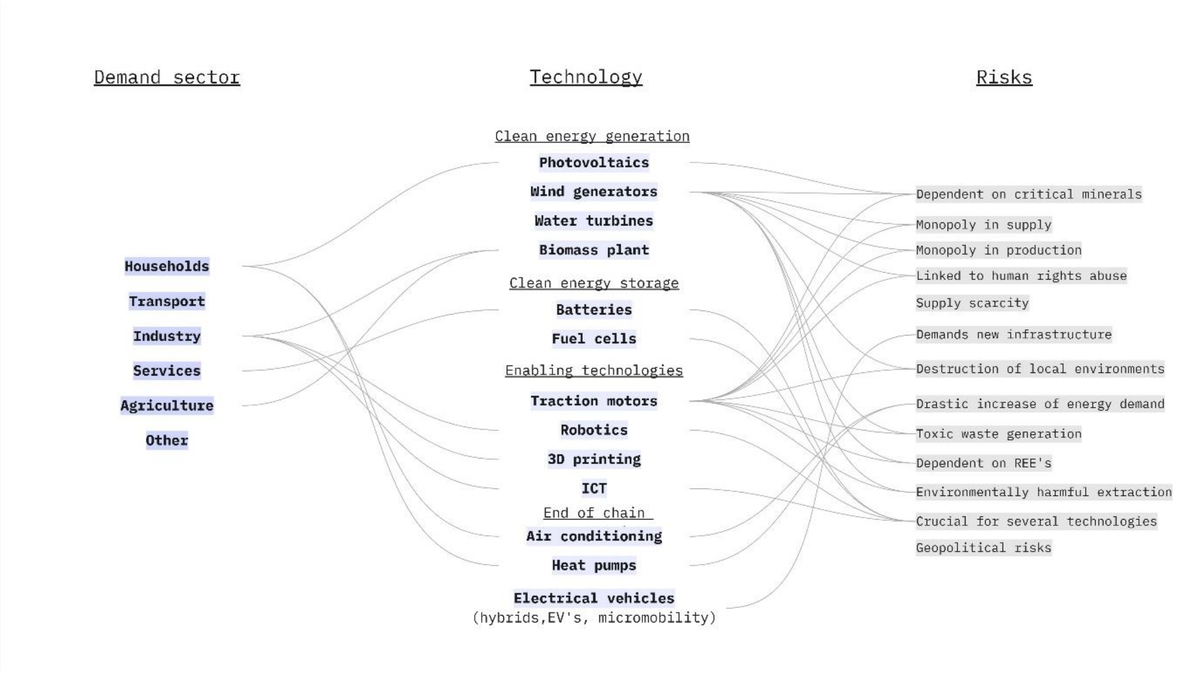

Fig 6. An overview of detected risks associated with the energy transition of cities (Graphic by Dark Matter Labs)

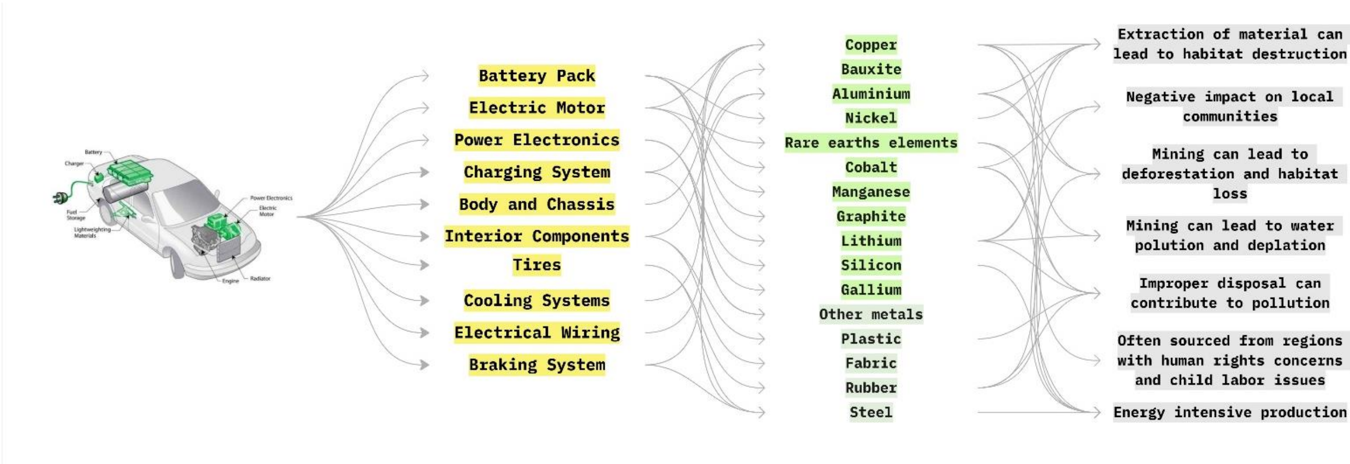

Fig 7. Example: Risks associated with electric car production (Diagram by Dark Matter Labs)

3 Risks

3.1 Sourcing and Production Risks: Escalating Demand for Critical Materials and Supply Chain Vulnerabilities

Components for clean energy technologies generally require a larger number of resources and energy to produce compared to conventional fossil-fuel based alternatives (International Institute for Sustainable Development, 2018).

> *"A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant."* (International Energy Agency, 2021).

According to the International Energy Agency's latest report, efforts aligned with meeting the goals of the Paris Agreement are estimated to require a 400% increase in mineral demand by 2040. Accelerating this further to hit global net-zero by 2050 would mean an increase in mineral input demand by 600% in 2040 compared with today's levels—a surge in demand for critical minerals such as cobalt, lithium, and rare earths, given their crucial role in manufacturing wind turbines, electric vehicles, and energy storage batteries (International Energy Agency, 2022).

> *"In total, between 2022 and 2050, the energy transition could require up to 6.5 billion tonnes of materials cumulatively, of which 95% is accounted for by steel, copper, and aluminum"* (International Energy Agency, 2022).

The capacity for mining and refining in a sustainable way and at the speed required is limited. The International Energy Agency estimates the average duration of mining projects from discovery to initial production is approximately 16.5 years, making it difficult for the supply side to rapidly respond to sudden surges in demand (International Energy Agency, 2021b).

Another pressing risk for mineral supply stability is climate change. Several critical minerals needed for the energy transition are sensitive to climate impacts. Copper and lithium are both highly susceptible to water stress. More than 50% of current production for these minerals occurs in regions with high water stress and climate vulnerabilities, such as Australia, China, and Africa, raising uncertainty about supply reliability (International Institute for Sustainable Development, 2018).

3.2 Environmental Impact Risks: Embodied Carbon, Pollution, and Waste in Clean Energy Systems

Transitioning to clean energy technologies will undoubtedly be a driving force in the shift to a low-carbon economy. However, it is crucial to adopt a holistic perspective and account for potential negative side effects that could arise (International Institute for Sustainable Development, 2018).

- **The mining industry** has been identified as the second-most-polluting industry globally, and the green energy transition risks catapulting it to the number one position. This means our planned green transition is far from perfectly green. Rare earth elements are crucial for clean energy, but current mining methods significantly damage communities and surrounding environments through heavy metal discharges, acid rain, and water contamination (Nayar, 2023).
- **Energy sourcing** in cities substantially influences greenhouse gas emissions and contributes to the emergence of urban heat islands. For example, indirect greenhouse

gas emissions related to cooling technologies have nearly tripled and continue to rise despite energy efficiency improvements and less carbon-intensive energy production (International Energy Agency, 2023).

- **Waste and end-of-life management** pose major challenges: high-demand minerals currently suffer from poor end-of-life collection and recycling rates. Mining rare earth elements produces large amounts of toxic waste hazardous to human health and the environment. “For every ton of rare earth produced, the mining process yields 13 kg of dust, 9,600–12,000 cubic metres of waste gas, 75 cubic metres of wastewater, and one ton of radioactive residue… Overall, for every ton of rare earth, 2,000 tons of toxic waste are produced” (Nayar, 2023).
- **Improvements in recycling technology** are vital, but so far no technology has proven economically viable compared to raw material extraction. Modifying accounting systems to reflect the entire systemic impact could incentivize circularity patterns, currently estimated at around 7% and declining (Circularity Gap Report, 2023).

Another pressing issue is **the lack of recycling capacity**, which contributes to intensive waste generation. Enhancements in this sector are crucial for reducing waste and limiting environmental impacts by curbing demand for virgin materials (International Institute for Sustainable Development, 2018).

3.3 Social Impact Risks: Geopolitical Challenges and Workforce Shortages in the Energy Transition\

3.3.1 Geopolitical and social risks due to high geographical concentration of material supply

Much of the minerals needed for clean energy transitions are **highly geographically concentrated**, with **China playing a predominant role in both extraction and production stages**. This concentration raises social distress and geopolitical risks, creating vulnerable and fragile supply chains (International Institute for Sustainable Development, 2018).

In nations with high political instability and weak governance in the mining sector, **mineral extraction has been associated with increased violence, conflict, and human rights abuses** (International Institute for Sustainable Development, 2018). Several critical minerals needed for the energy transition are also sensitive to climate change, with considerable risks of supply chain disruptions. For example, **copper and lithium** are highly susceptible to water stress, and more than 50% of the current production of these minerals occurs in regions facing high water stress and extreme heat waves such as Australia, China, and Africa (International Energy Agency, 2021b).

3.3.2 Risks of lack of workforce for implementation of energy transition

Worker shortages alongside an inadequately trained and aging workforce create substantial challenges for sourcing personnel needed for sustainable building activities, including both renovations and new construction - an existing major obstacle for the building sector (Euractiv, 2021). Without making this industry more attractive and inclusive, securing adequate numbers or quality of workers becomes impossible. Migration patterns will complicate this situation further, as they may not align with labour demands regarding timing or location. Climate and conflict-related displacement will not necessarily bring people to regions designated for planned retrofits or green construction programs. Even where this alignment occurs, competing labour priorities will emerge, including caregiving responsibilities and food security improvements. As these competing demands intensify, decisions about allocating workers to building renovations versus other essential tasks will likely become a major strategic issue.

Estimates suggest that **some three to four million construction workers in Europe alone need to upgrade or diversify** their skills to meet the ambitious targets set by EU energy policies, including the Energy Efficiency Directive, Energy Performance of Buildings Directive, and Renewable Energy Directive (European Climate, Infrastructure and Environment Executive Agency, 2023).
This substantial skills gap poses both a major bottleneck and an opportunity to reshape Europe's labor market towards greener, more sustainable jobs.

Demographic trends and an aging workforce, particularly in construction and energy engineering sectors, further intensify the shortages at a time when demand for labor to build and maintain new energy infrastructure is surging (Clean Energy Wire, 2025). The transition also requires integration of emerging technologies such as heat pumps, renewable heating and cooling systems, and advanced performance contracting, highlighting the need for specialized training and cross-border recognition of skills and qualifications (European Climate, Infrastructure and Environment Executive Agency, 2023).

To address these challenges, EU-wide initiatives such as the BUILD UP Skills initiative and the European Construction Blueprint have been developed, providing comprehensive toolkits and roadmaps to upskill the workforce. Funding programs like Erasmus+ and LIFE Clean Energy Transition (CET) underpin these efforts by supporting member states in labor market adaptation, skills mapping, and targeted education and training programs (European Climate, Infrastructure and Environment Executive Agency, 2023). Yet, despite these efforts, the integration and coordination of workforce development policies at the national level remain critical to closing the gap timely and efficiently.

Experts stress that recognizing the workforce as a strategic asset and fostering collaboration among policymakers, educational institutions, and industry stakeholders are vital for overcoming the workforce shortages threatening Europe's journey to climate neutrality. Flexible training models such as micro-credentials and modular learning can accelerate the reskilling of the existing workforce, while attracting younger generations to green careers is essential to sustain long-term labor supply (InnoEnergy, 2025). Failure to act decisively risks delaying deployment schedules, escalating costs, and ultimately undermining the EU's net-zero ambitions (European Commission, 2025).

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3.4 Economic Risks: Escalating Costs and Financial Barriers to the Energy Transition

Cities, as the primary hubs of energy consumption, economic activity, and population density in the European Union, face acute economic challenges due to the high costs associated with the green transition. Urban areas account for the majority of energy use and greenhouse gas emissions, especially from buildings, transport, and infrastructure, making them crucial battlegrounds for achieving climate targets. However, increasing capital expenditures for deep building renovations, renewable energy infrastructure, and sustainable transport solutions may strain municipal budgets and investment capacities (European Central Bank, 2025).

Unlike national governments, cities often have more limited fiscal autonomy and borrowing capacity, which can constrain their ability to finance large-scale projects needed for rapid decarbonization. Without adequate financial support schemes, including grants, subsidies, and blended financing mechanisms, many cities—particularly small and medium-sized ones—may struggle to implement costly retrofit programs or to upgrade public transport and energy infrastructure on the timescale required (Pisani-Ferry et al., 2025).

The impending end of EU-wide recovery funding such as the Recovery and Resilience Facility (RRF) in 2026 poses a critical risk for cities reliant on this support to leverage private investments. The projected funding gap of approximately €180 billion for 2024-2030 could disproportionately impact urban areas that need sizable upfront investments to modernize energy systems and reduce carbon emissions efficiently (European Central Bank, 2025).

Furthermore, rising costs in clean technology sectors—for instance, manufacturing and installing heat pumps or solar panels—require cities to coordinate closely with regional and national governments to pool resources and integrate green infrastructure planning into broader urban development strategies. This coordination is essential to achieve economies of scale, reduce risks for investors, and prevent widening disparities between wealthier and poorer cities or neighborhoods (Bruegel, 2025).

Social equity concerns also intensify in urban environments, where vulnerable populations face heightened exposure to energy poverty and the socioeconomic effects of energy price increases related to green investments. Cities must balance ambitious climate actions with protecting residents from disproportionate cost burdens, requiring targeted subsidies, tariff structures, and stakeholder engagement to ensure a just transition (Pisani-Ferry et al., 2025).

In sum, cities are at the frontline of implementing the EU's green transition but face unique economic risks linked to financing capacity, cost escalation, and social equity. Strengthening urban financial instruments, fostering innovative funding models, and enhancing multi-level governance cooperation are critical to enabling cities to proceed at pace without sacrificing inclusivity or fiscal sustainability (European Central Bank, 2025; Pisani-Ferry et al., 2025).

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4 Key takeaways for cities

While European cities experience per capita energy use twice the global average, the global energy demand continues to **grow faster than the implementation of strategies** that would increase the renewable capacity. This trend, driven by **increasing comfort expectations** of ever greater parts of society, technological growth, or extreme climate events, intensifies the challenge of full decarbonization. Cities must address these **dual pressures** of both rising demand and meeting the climate targets.

Impacts of technologies, sourcing of resources, and energy demand are deeply entangled across sectors and geographies. Isolated interventions e.g. those which see electrification without critical mineral dependencies risk greenwashing and ineffective outcomes. Therefore, cities need to select and implement solutions based on comprehensive, science-based evaluations of their systemic impacts—climate, social equity, environmental, and economic.

Some of the municipalities Net Zero Cities consortium are implementing risk mitigation strategies that directly address electrification, circular economy while considering the transition risks mentioned. **These cities aim to e.g. reduce critical mineral dependencies, address the transition financing gaps, or retrain AEC (architecture, engineering, construction)** professionals through incentive mechanisms. The most successful are the blended approaches; those which combine **demand management (reduction)** with **innovative financing, workforce development, and regional cooperation to build resilient urban electrification** pathways.

4.1 Addressing Sourcing and Production Risks Through Urban Mining and Circularity

Europe's recycling and circularity capacity is critically underdeveloped compared to the scale of the challenge. When considering electrification through systemic lens, without embedding circular economy principles, cities may face supply chain vulnerabilities. Some of them, however, managed to initiate processes that demonstrate how urban areas can systematically reduce their dependence on virgin materials in electrification pathways while building local resilience muscle. Urban mining initiatives that treat cities as material reservoirs rather than consumption endpoint already exist.

For instance, Amsterdam, with its urban mining targets, is one of the leaders (see e.g. "Prospecting the Urban Mines" program that maps future materials from demolition and renovation (Metabolic, 2017; Amsterdam Smart City, 2024). The city has identified **nearly one third potential reduction in import dependency** through building material passports and urban material recovery systems. Their Urban Mining Factory specifically targets critical raw materials recovery from printed circuit boards (Circular Industries, 2024), while the Port Circular Strategy aims to generate an industrial ecosystem where one company's waste becomes another's raw materials across 116 active circular projects. Meanwhile at the Johan Cruijff ArenA, and, and Ikea store in Haarlem, food organic waste is turned into energy through container “plug-and-play” like system. **Furthermore, Barcelona's Zero Waste Plan 2021-2027** demonstrates systemic material reuse strategy at city scale (Etikord, 2024). The city operates 134 neighbourhood Green Point Networks for complex materials including electronics. The scheme is linked to incentive system for citizens through user card. It is linked to the household's water supply contract and enables discounts to be obtained for waste management charges. Similarly, **Vienna** targets 30% reduction in primary raw materials by 2030, with 80% reuse/recycling rates for demolition materials.

Multiple more grassroot organisations have committed to similar goals before and laid foundation for take-up by city authorities. These include

- Rotor DC: a cooperative in Belgium that organises the reuse of construction materials. They dismantle, process and trade salvaged building components.
- Mobius: a French organisation supporting material reuse in the construction industry by providing advice, sourcing and supplying reusable construction materials.
- Brda: a Polish cooperative focused on the reuse of recycled materials and circularity through projects, research and advocacy, workshops with citizens and competitions.

Finally, it is important to recognize that not only city-level but a regional coordination amplifies impact. The Cities are implementing shared material databases and cross-border secondary material flows, with Nordic countries developing collaborative circular economy systems in mining value chains (Newcastle University, 2024).

4.2 Mitigating Environmental and Social Impacts Through Environmental Justice Frameworks

Social risks of decarbonization pathways should be taken into consideration and aim at mitigating energy poverty to prevent exclusion and inequity from undermining climate progress. Some of the examples of pathways are EU initiative include community owned solar installations on schools (Torreblanca district, POWERTY project) through which local residents see significant energy bill reductions, get energy education and unified under one community program (Euronews, 2024). Lyon's SLIM Program addresses energy poverty through systematic identification of households that struggle with their energy bills and guides them towards subsidies financing for housing renovations and energy upgrades (Eurocities, 2024). Whereas C40 Cities Clean Construction Accelerator committed to reducing embodied emissions by 50% in new buildings by 2030 in over 45 cities (GreenBiz, 2024).

4.3 Addressing Workforce Shortages through Comprehensive Skills Development

Cities are addressing the need for millions of European AEC workers to upgrade their skills through coordinated training programs that specifically target the demands of electrification, such as energy retrofits and renewable energy installations. Programs like EUCERT, which scales heat pump training across 14 countries with standardized certification (European Heat Pump Association, 2024), as well as initiatives such as SKILLSAFE-EU, the Domestic Heat Pump Installation Scheme, the European Solar Academy, and Energy Cities Network, are all working to bridge the skills gap and increase the attractiveness of green jobs. These efforts are part of a broader effort to equip the workforce for the clean energy transition. In this context, cities play a central role by facilitating local training programs, supporting the scaling of green job initiatives, and fostering partnerships with industry stakeholders.

4.4 Innovative Financing Mechanisms - Addressing the Funding Gap

Addressing the €180 billion funding gap for electrification and energy retrofits is a critical challenge for cities, especially as the EU Recovery and Resilience Facility (RRF) ends in 2026 with significant funds still to be disbursed (Socialists and Democrats, 2024). Innovative financing models are key to overcoming this gap. Amsterdam’s revolving fund model, which combines the Amsterdam Climate & Energy Fund (€45 million for commercial projects) and the Sustainability Fund (€40 million for smaller projects), demonstrates a successful strategy for scaling clean energy projects while ensuring financial returns for reinvestment (C40 Cities, 2024).

Additionally, citizen investment models, such as Local Climate Bonds, are enabling municipalities to engage the public in funding efforts, as seen in Camden and Islington, where low-cost borrowing options are being made available to communities (Green Finance Institute, 2024). The Climate City Capital Hub, launched in 2024, is further expanding financing opportunities by coordinating €2 billion in investments from the European Investment Bank (EIB) for consortium cities (NetZeroCities, 2024). These models show how blending public and private capital, alongside community engagement, is key to scaling the electrification efforts required for the energy transition.

4.5 Regional cooperation reducing supply chain vulnerabilities

Cities are coordinating regional approaches. Some of the strong incentives to do so, especially in current times of increasing geopolitical vulnerability in Europe, is to reduce dependence on foreign exporters control (e.g. China) over rare earth refining and long mining timelines. The NetZeroCities Twinning Learning Programme pairs 184 cities across 14 countries for 17-20 month exchanges, fostering collaborative resilience (NetZeroCities, 2025). Belfast and Galway focus on retrofits, while Soria, Cologne, and Vitoria-Gasteiz work on urban regeneration, sharing risk strategies among the partners.

Further examples include shared procurement through the CircularPSP Initiative (European Commission, 2024), demand management strategies such as the Amsterdam's Flexpower with its smart charging networks or Malmö's resource hub, optimizing renewable energy use and promoting material efficiency (NetZeroCities, 2025).

Further regional initiatives like the European Battery Alliance, aiming for €250 billion in annual domestic battery value (EBA250, 2024), and Solar Industry Regions Europe, building solar manufacturing clusters, drive energy sovereignty and supply chain diversification.

4.6 Systemic Implementation Pathways

Impacts of technologies, resource sourcing, and energy demand are deeply entangled across sectors and geographies. Isolated interventions risk greenwashing and ineffective outcomes. Cities need to select and implement solutions based on comprehensive, science-based evaluations of their systemic impacts—climate, social equity, environmental, and economic.

This section aimed at identifying clear replication pathways for consortium cities to address electrification risks **systematically (and systemically) rather than reactively.**

- **Immediate implementation opportunities** include adopting Amsterdam's €85 million revolving fund model with proven ROI metrics, expanding citizen investment platforms, and implementing EUCERT-style standardized training across all green technology sectors.
- **Medium-term coordination strategies** involve strengthening regional procurement cooperation following the CircularPSP model, scaling urban mining initiatives through shared material databases, and developing post-2026 financing strategies as traditional EU funding transitions.
- **Long-term resilience building** requires institutionalizing city climate funds following proven Bristol/Amsterdam models, formalizing multi-city cooperation for supply chain diversification, and embedding circular economy principles in all electrification planning to fundamentally reduce critical mineral dependencies.

These approaches provide practical alternatives to the potentially extractive model of electrification, showing how cities can achieve climate neutrality while building resilient communities and circular economies. Successful electrification risks mitigation requires integrated approaches combining demand reduction, social equity, innovative financing, and regional cooperation rather than addressing individual risks in isolation.

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Introduction

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