



ORIGINAL PAPER

Energy Output and (De)industrialisation: Redefining the Socio-Economic and Cultural Fabric of the World's Three Major Blocs (EU, US and China)

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Abstract:

Energy production has become a decisive factor shaping the economic competitiveness and industrial development of major global powers. This paper examines the relationship between energy output and processes of industrialisation and deindustrialisation in the world's three major economic blocs: the European Union, the United States, and China. While the United States has strengthened its position through increased domestic energy production, particularly in oil and natural gas, China continues to expand its energy capacity to sustain large-scale industrial growth. In contrast, the European Union faces significant challenges related to energy dependency, rising costs, and energy transition policies, which may influence its industrial competitiveness. These differences in energy availability and strategy are redefining not only industrial production but also the broader socio-economic and cultural fabric of these regions. The study argues that energy output and energy policy will play a crucial role in shaping future patterns of industrial development, labour markets, and geopolitical influence among these three global economic blocs.

Keywords: *the European Union, the United States, China; industrialisation; global economy; energy policy.*

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1. Energy, Industrial Capacity and the Changing Logic of Global Competition

Energy has always been a fundamental component of industrial development, but its strategic significance has increased considerably in the twenty-first century. The international economy is simultaneously undergoing electrification, digitalisation, decarbonisation and geopolitical fragmentation. Each of these processes increases the importance of reliable energy systems. Industrial competitiveness therefore depends not simply on the quantity of energy available, but on the interaction between output, cost, accessibility, technological capability, infrastructure and security of supply. The comparison between the European Union, the United States and China illustrates three markedly different approaches to this problem.

Industrialisation historically required concentrated sources of energy capable of sustaining manufacturing at scale. Coal supported the first industrial revolution, while petroleum, natural gas and electricity became indispensable to subsequent phases of industrial development. In the contemporary economy, the relationship has become more complex. An advanced economy can reduce the energy intensity of each unit of GDP while simultaneously increasing its dependence on electricity for data centres, semiconductor production, electric vehicles, artificial intelligence, advanced manufacturing and the electrification of transport and heating. Energy efficiency does not consequently eliminate the strategic importance of energy output. It changes the form in which energy is required.

A comparison of the three blocs must also distinguish between deindustrialisation as economic evolution and deindustrialisation as loss of productive capacity. In wealthy economies, manufacturing employment may decline naturally as productivity rises and services expand. Such structural change need not represent economic weakness. A more serious form occurs when economically viable production is displaced because firms face persistently higher input costs, inadequate infrastructure, regulatory uncertainty or insufficient access to energy. The distinction is particularly important in Europe. Research examining European economies after the energy shock associated with the war in Ukraine identifies the possibility that energy-intensive industries may relocate outside Europe and stresses the danger of secondary effects when these firms occupy important positions within manufacturing supply chains (Grömling et al., 2023, p. 212).

Energy must therefore be considered an industrial ecosystem variable. A steelworks, chemical complex, battery factory or semiconductor facility does not respond simply to national energy production figures. It responds to predictable prices, grid capacity, continuity of supply, transport networks, environmental requirements, taxation and investment conditions. An energy-rich economy may fail to translate resources into industrial advantage if its infrastructure is deficient. Conversely, an energy-importing economy can remain highly competitive through technological specialisation and energy efficiency. Nevertheless, large differences in energy prices and availability become increasingly important in industries where energy constitutes a substantial share of production costs.

The three blocs examined here embody different configurations. The United States combines enormous hydrocarbon output with nuclear power and rapidly expanding renewable electricity. China combines unparalleled industrial scale with equally ambitious expansion across coal, nuclear, hydroelectric, solar and wind capacity. The European Union possesses significant technological expertise and increasingly large

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renewable capacity, but it has fewer indigenous fossil-energy resources, considerable variation among member states and a recent history of exposure to imported-energy shocks. The result is not a simple division between winners and losers. Rather, energy is contributing to the creation of three different models of economic organisation, with consequences that extend from factories to employment, regional identities, universities and vocational education.

2. Three Energy-Industrial Models: The United States, China and the European Union

The American energy position has changed significantly since the expansion of shale oil and gas production. Horizontal drilling and hydraulic fracturing transformed resources that had previously been uneconomic into commercially exploitable reserves. This development altered the relationship between the United States and global energy markets. It reduced dependence on imported hydrocarbons, expanded export capacity and provided domestic industry with access to comparatively inexpensive natural gas. The importance of this development is especially visible in industries in which gas functions both as an energy source and as a feedstock, including chemicals, petrochemicals and fertilisers.

Research on the US shale transformation suggests that lower American natural-gas prices relative to European prices contributed to an increase of approximately 3 per cent in industrial activity and approximately 2 per cent in investment, even though the overall effect across the entire manufacturing sector was more limited than claims of a complete manufacturing renaissance might imply (Kirat, 2020, p. 1). Energy abundance therefore does not automatically reverse decades of industrial restructuring, automation or offshoring. What it does provide is a favourable platform upon which industrial policy can operate.

This distinction has become increasingly significant as the United States attempts to strengthen domestic production in strategically important industries. Semiconductor fabrication, battery manufacturing, electric vehicles, artificial intelligence infrastructure and advanced materials require enormous investments in physical assets and electricity networks. Domestic energy resources provide the country with a form of strategic flexibility. Policymakers can promote electrification and renewable generation while retaining substantial oil and natural-gas production. This creates tensions in environmental policy, but it also permits a gradual transition in which conventional and low-carbon energy systems coexist.

China represents a different model. Its economic rise has been inseparable from rapid industrialisation, urbanisation and extraordinary growth in energy consumption. Unlike the United States, China remains heavily dependent on imported oil and gas, while coal continues to provide an important domestic foundation for its energy system. Yet China has responded to vulnerability not through a single energy source but through diversification and scale. It has expanded coal generation while simultaneously becoming the world's central manufacturing base for many renewable-energy technologies. Solar panels, batteries, electric vehicles, wind equipment and important elements of clean-energy supply chains have consequently become part of Chinese industrial strategy.

The relationship between energy and Chinese industrial growth is visible empirically. A study of 37 Chinese industrial sectors found a long-run equilibrium relationship between energy consumption and industrial economic growth, estimating that a 1 per cent increase in energy consumption was associated with a 0.871 per cent increase

in real industrial value added (Hu et al., 2015, p. 9400). This does not mean that industrial output must permanently grow at the same rate as energy consumption. Efficiency, technological change and changes in industrial structure can weaken that relationship. It does demonstrate why energy security occupies such a prominent position in China's development strategy.

China's approach also challenges the assumption that decarbonisation necessarily implies deindustrialisation. The country has attempted to transform the energy transition itself into an industrial opportunity. Renewable generation requires factories, minerals, transmission systems, batteries, power electronics and extensive construction. The transition therefore generates new forms of energy-intensive manufacturing even while seeking to reduce the carbon intensity of the energy consumed. This helps explain why Chinese energy policy often appears contradictory when evaluated solely through emissions. Coal can provide near-term energy security while renewables, nuclear power, storage and electrification support a longer-term transformation of the productive system.

The scale of energy-intensive industry remains economically significant. Research using Chinese provincial data from 2000 to 2019 estimated that 23.96 per cent of the effect of economic growth on energy consumption was transmitted indirectly through the development of energy-intensive industries (Ji et al., 2022, p. 12). China's challenge is consequently not whether to choose between industrial development and energy transformation in absolute terms, but how to upgrade industrial production while preventing energy demand, pollution and resource dependency from becoming constraints on future growth.

The European Union confronts the opposite structural dilemma. European integration created one of the world's largest and most sophisticated industrial markets, with major strengths in automobiles, machinery, chemicals, pharmaceuticals, aerospace and specialised manufacturing. Yet Europe has historically depended substantially on imported fossil fuels. The disruption of Russian energy supplies after 2022 exposed the vulnerability created by this model. The consequences were particularly severe for natural-gas-intensive production because European manufacturers had to compete internationally against firms operating under very different energy-cost conditions.

Energy-price competitiveness had already attracted scholarly attention before the crisis. Faiella and Mistretta's analysis of European manufacturing found that energy purchases, which had represented roughly one seventh of labour costs in the first decade of the century, subsequently increased to more than one quarter. Their work also identifies final energy prices as a major contributor to increases in unit energy costs, despite improvements in energy efficiency (Faiella & Mistretta, 2020, p. 19). The European problem is thus not reducible to an absence of technological sophistication. Highly efficient production can still become vulnerable when competitors enjoy structurally cheaper energy.

Europe's energy transition may ultimately reduce this vulnerability. Expanded renewable generation, nuclear power where politically accepted, stronger interconnections, storage technologies, efficiency and electrification could lower dependence on imported hydrocarbons. The critical question is temporal. Industrial investment decisions are made in the present, whereas a fully transformed energy system requires years or decades to construct. If the transition period imposes significantly higher costs before abundant low-carbon electricity becomes available, industries may relocate before the benefits materialise. The strategic problem for Europe is therefore one of

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sequencing: decarbonisation, energy security and industrial competitiveness must advance together rather than successively.

3. From Energy Systems to Labour Markets, Social Structures and Geopolitical Power

Industrial change affects much more than national GDP. Manufacturing creates networks of suppliers, transport operators, engineers, technicians, research institutions and local services. Large industrial facilities frequently become anchors of regional economies. Their expansion or closure consequently alters employment patterns, tax bases, demographic movements and collective identities.

The United States illustrates how energy production can reshape regions. The expansion of shale development generated investment in areas connected to drilling, pipelines, processing, petrochemicals and associated manufacturing. At the national level, greater domestic production also changed the geopolitical position of the country. Energy exports became an instrument of foreign economic policy, while American LNG acquired particular strategic importance for European countries seeking alternatives to Russian gas.

Yet the social benefits of energy abundance should not be exaggerated. Modern energy production is capital intensive, and advanced manufacturing is increasingly automated. Reindustrialisation in the twenty-first century therefore cannot be expected to recreate the mass factory employment characteristic of the twentieth century. A new semiconductor plant or automated battery factory may be economically and strategically important without employing the numbers associated with earlier industrial complexes. The political vocabulary of "bringing manufacturing back" can consequently conceal a transformation in the kind of manufacturing that returns.

China faces another social configuration. Industrial expansion contributed to one of history's largest movements of people from rural to urban areas and created enormous manufacturing centres integrated into global value chains. Energy availability facilitated not merely economic output but a new social geography organised around cities, ports, industrial clusters and transport corridors. As wages rise and demographic growth slows, however, the sustainability of a model based predominantly on labour-intensive export manufacturing becomes weaker. China increasingly seeks to move toward automation, robotics, high-value manufacturing and technological leadership.

The cultural consequences are considerable. Industrial capacity is increasingly connected with narratives of national modernity and technological sovereignty. Electric vehicles, high-speed rail, nuclear reactors, batteries and renewable technologies are not merely commodities. They can be represented domestically as evidence of scientific capability and national advancement. Energy infrastructure therefore participates in the cultural construction of political legitimacy and collective confidence.

The European experience is more ambivalent. Post-industrial development has often been associated with higher education, services, environmental regulation and quality of life. Yet the decline of manufacturing in particular regions can weaken communities built historically around factories, mines, ports and engineering occupations. Industrial closure may therefore produce a form of cultural as well as economic dislocation. When a steel plant or chemical complex disappears, a region does not simply lose measured output. It can lose occupational traditions, apprenticeship networks, technical knowledge and an important element of local identity.

This helps explain why energy policy can become politically contentious. Consumers view energy through household bills, while industrial workers may view it

through employment security. Environmental groups may emphasise emissions reduction, whereas industrial communities may fear that rapid restrictions will transfer production abroad rather than eliminate global emissions. Governments must reconcile these perspectives if the energy transition is to maintain social legitimacy.

The concept of strategic autonomy further strengthens the relationship between energy and geopolitical power. The pandemic, war in Ukraine and growing US-China rivalry have encouraged governments to reconsider the assumption that economic efficiency should always be maximised through globally dispersed supply chains. Semiconductors, batteries, critical minerals, pharmaceuticals and energy technologies are increasingly treated as strategic assets. Industrial policy has consequently returned to political agendas after decades in which many advanced economies placed greater emphasis on liberalisation and market allocation.

Energy output becomes essential within this framework because reshoring or expanding industrial production raises domestic electricity demand. An economy cannot simultaneously electrify vehicles, heating and industry, construct energy-intensive data centres, expand semiconductor production and expect electricity requirements to remain static. Industrial strategy and energy strategy must therefore become integrated.

The divergence among the three blocs is likely to influence international power. The United States possesses strong advantages in resources, technology, finance and higher education. China possesses extraordinary manufacturing depth, infrastructure, scale and state capacity for large projects. The European Union possesses technological expertise, a wealthy integrated market and considerable regulatory influence, but must resolve the tension between ambitious environmental goals and the costs of maintaining industrial capacity during transition. The global balance will depend increasingly on which bloc can combine energy abundance with technological sophistication rather than on energy production alone.

4. Education, Skills and the Cultural Infrastructure of the Energy Transition

The educational implications of these industrial transformations are substantial because energy transitions are ultimately implemented by people. Engineers design grids and reactors, electricians install equipment, technicians maintain industrial machinery, chemists improve batteries, software specialists manage intelligent energy systems, and economists, lawyers and public administrators construct regulatory frameworks. Consequently, the competition among the EU, the United States and China is also a competition over human capital.

This has several implications for educational policy. First, vocational education is likely to regain strategic importance. Industrial economies require large numbers of technicians whose qualifications cannot be replaced simply by increasing university participation. Electricians, welders, specialised construction workers, maintenance technicians, machinists and operators will remain necessary even in highly automated environments. The clean-energy transition adds new specialisations in heat pumps, solar installations, wind turbines, battery systems, hydrogen technologies, smart grids and industrial electrification.

European research already identifies workforce availability as a potential bottleneck. A Joint Research Centre report on skills for the clean-energy transition argues that insufficient numbers of workers with appropriate skills in the appropriate locations can obstruct the green and digital transition. It also notes the continuing difficulty of

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incorporating standardised clean-transition content into mainstream university and vocational programmes (Czako, 2022, p. 3). This is particularly important for Europe because educational policy must support two transformations simultaneously: replacing declining industrial competencies where old technologies disappear and developing new capabilities fast enough for emerging industries to remain located within Europe.

Second, higher education will become more interdisciplinary. Energy can no longer be treated exclusively as a concern of electrical, mechanical or chemical engineering. The contemporary energy system intersects with artificial intelligence, cybersecurity, international relations, economics, environmental science, law and communication. Future university programmes are therefore likely to combine technical knowledge with systems analysis. An engineer working on an electricity grid may require knowledge of digital systems and cybersecurity. A lawyer working in energy regulation may require an understanding of carbon markets and electricity trading. Economists examining industrial policy must increasingly understand material supply chains and physical infrastructure. This transformation will also place greater pressure on language and communication education to adapt to increasingly specialised and technologically mediated professional environments. In her analysis of English for Specific Purposes, Maria-Magdalena Lăpădat emphasises that contemporary ESP instruction must respond to technological change, learner needs and real professional contexts, incorporating digital literacy and authentic communicative tasks rather than limiting instruction to conventional linguistic structures (Lăpădat, 2025, p. 61). This perspective is particularly relevant to the emerging energy economy. Engineers, energy specialists, technicians and researchers will increasingly operate within international and interdisciplinary environments in which technical expertise must be accompanied by the ability to communicate specialised knowledge, interpret digital information and collaborate across professional and linguistic boundaries.

Third, the meaning of "green skills" itself requires careful consideration. Stroud, Antonazzo and Weinel argue that educational systems should not conceptualise green skills simply as narrow packages of new competencies. Their study of vocational education and the European steel transition emphasises that successful "greening" emerges through the broader functioning of vocational systems, institutions and pedagogical practices (Stroud et al., 2024, p. 343). This interpretation is particularly valuable because the energy transition will modify existing occupations as often as it creates entirely new ones.

The three blocs are likely to follow distinctive educational paths. In the United States, the interaction among universities, private firms, federal laboratories, community colleges and state-level training systems may support rapid specialisation in areas receiving industrial investment. The principal challenge will be geographical and institutional coordination. A new factory cannot depend on national averages of educational attainment. It needs electricians, engineers and technicians in the region in which it operates. Industrial subsidies without local training capacity may therefore encounter labour shortages.

China is likely to continue using the scale of its education system to strengthen engineering, applied sciences and technologically intensive industries. Its enormous manufacturing base provides an additional educational advantage because skills can develop through production itself. Manufacturing knowledge is partly tacit. It consists of experience accumulated by engineers, suppliers and workers in solving practical production problems. Maintaining dense industrial ecosystems therefore creates a

feedback mechanism between education and industry. Universities supply knowledge to firms, while industry provides practical problems, employment pathways and technical experience to educational institutions.

Europe possesses world-class universities and strong vocational traditions in several member states, but fragmentation can complicate the alignment of education with industrial strategy. The greatest risk would be a circular process of industrial decline. If industries contract, fewer students may choose technical occupations associated with them; training institutions may reduce specialised programmes; the supply of skilled labour then falls; and firms considering new investments may encounter additional reasons to locate elsewhere. Deindustrialisation can therefore destroy educational capacity as well as productive capacity.

The reverse is also possible. Energy transition can become a mechanism for educational revitalisation. Universities can develop programmes in energy engineering, battery chemistry, advanced nuclear technologies, hydrogen, carbon management, energy economics and grid digitalisation. Vocational schools can form direct partnerships with employers. Micro-credentials and continuing education can permit mid-career workers to adapt without completing entirely new degrees. Industrial regions can transform their technical heritage rather than abandon it.

By the 2030s, successful education systems are therefore likely to treat energy literacy as a broader competency. This does not imply that every student must become an engineer. Citizens will increasingly encounter public debates concerning electricity prices, grid expansion, nuclear energy, renewable generation, carbon taxation, industrial subsidies and energy security. Basic understanding of the economic and environmental trade-offs involved could become an important component of civic education. Energy is becoming sufficiently central to social organisation that energy literacy may eventually occupy a position comparable to digital literacy.

5. Future Trajectories: Energy Abundance, Industrial Strategy and the Reorganisation of Society

The emerging competition among the EU, United States and China suggests that twenty-first-century industrial power will depend on the ability to combine abundant energy, reliable infrastructure, technological innovation and human capital. None of these variables is sufficient independently. Energy without technological capability can leave an economy dependent on commodity exports. Technology without sufficient energy can make advanced production expensive or physically difficult to expand. Industrial subsidies without skilled labour can produce factories that struggle to recruit. Education without productive investment can generate skilled workers who migrate toward stronger industrial ecosystems.

The United States appears well positioned because it can draw on extensive domestic energy resources while simultaneously expanding renewable electricity, nuclear technology and advanced manufacturing. Its principal advantage is optionality. It does not need to complete decarbonisation before providing substantial quantities of energy to expanding industry. The challenge is whether infrastructure, transmission networks and education can keep pace with investment and rising electricity requirements. Political changes may also produce shifts in energy and climate policy, creating uncertainty for long-term industrial projects.

China's principal strength is integration. Energy expansion, infrastructure construction and manufacturing development form part of a mutually reinforcing system.

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Its enormous internal market creates demand at a scale that can lower production costs and accelerate technological learning. However, this model faces important constraints, including dependence on imported fuels and raw materials, environmental pressures, demographic change, trade tensions and the possibility that other countries will increasingly protect strategic domestic industries. China's future competitiveness will therefore depend on improving energy efficiency and technological sophistication while reducing vulnerabilities created by its resource-intensive growth model.

The European Union faces the most difficult transition but also one with considerable transformative potential. Europe cannot realistically compete with the United States through equivalent hydrocarbon abundance or with China through identical manufacturing scale. Its comparative strategy must instead integrate efficiency, technological sophistication, low-carbon electricity, circular production and high-value manufacturing. Yet such a model remains viable only if energy costs permit industrial firms to remain internationally competitive.

European deindustrialisation is not inevitable. The danger lies in treating industrial policy, energy policy, environmental policy and education as separate domains. If renewable and nuclear generation, where nationally appropriate, are expanded alongside grids and storage, Europe can reduce external vulnerability. If carbon policy is accompanied by mechanisms that prevent simple relocation of emissions and production, decarbonisation can support rather than undermine strategic autonomy. If universities and vocational institutions are closely connected to emerging industries, technological transition can create new employment pathways rather than simply eliminate old ones.

This leads to a broader conclusion concerning the concept of industrialisation itself. Future industrial power should not be measured solely by the number of people working in factories or by manufacturing's percentage of employment. Advanced industry is increasingly embedded in research, software, logistics, design, services and education. The boundary between manufacturing and the knowledge economy is therefore becoming less clear. A semiconductor plant is simultaneously an industrial facility, an energy consumer, a research ecosystem and a centre of highly specialised human capital. A modern electricity grid is both physical infrastructure and a digital network.

For this reason, energy output is capable of reshaping cultural expectations as well as economic structures. Societies that expand industrial and energy systems may place renewed value on engineering, skilled trades and scientific education. Regions that experience industrial contraction may instead orient their labour markets toward services while confronting the cultural consequences of disappearing productive identities. These transformations influence how societies understand progress, environmental responsibility, work and national economic security.

The most plausible future is consequently neither a straightforward return to twentieth-century industrialisation nor the universal arrival of a post-industrial economy. The United States, China and Europe are entering a period of reindustrialisation under new technological and environmental conditions. Energy is central to that process because artificial intelligence, electrification, advanced manufacturing and decarbonisation all require large quantities of dependable power.

The strategic issue for the three blocs is thus not simply who produces the most energy. It is who can convert energy into durable productive capability while simultaneously maintaining social cohesion, environmental sustainability and educational adaptability. The United States possesses the advantage of resource abundance; China possesses the advantage of industrial scale; the European Union possesses sophisticated

institutions, technology and considerable potential for an integrated low-carbon industrial model. Their relative success will depend on how effectively each connects its energy system to manufacturing, labour-market policy, education and technological development.

Energy policy should therefore be understood as a form of social policy and educational policy as much as industrial policy. Decisions made about power generation today will influence where factories are constructed, which regions attract investment, what occupations young people enter, which competencies universities teach and how communities understand their economic future. Industrialisation and deindustrialisation are not merely changes in economic statistics. They reorganise the material and cultural foundations of society. In the emerging global order, the capacity to produce reliable and economically viable energy, and to educate a population capable of transforming that energy into technological and industrial value, will constitute one of the principal determinants of geopolitical power.

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