IMK

Macroeconomic Policy Institute

The IMK is an institute of the Hans-Böckler-Stiftung

# WORKING PAPER

No. 228 • May 2026 • Hans-Böckler-Stiftung

# INDUSTRIALIZATION AND ENERGY DEMAND: IMPLICATIONS FOR CLIMATE CHANGE MITIGATION

Gregor Semieniuk[1]

## ABSTRACT

Industrialization is key for economic development but how it interacts with climate change mitigation is insufficiently understood. However, this relationship is important for scenarios of climate change mitigation, such as reviewed by the International Panel for Climate Change (IPCC), that seek to show pathways for simultaneous economic development and mitigation in the coming decades. This paper examines the hypothesis that industrialization tends to go hand in hand with a rising energy intensity of GDP (energy/GDP). Analysis of 16 development successes in the 19th, 20th and 21st century shows that all relied on structural change toward manufacturing almost universally accompanied by a growing energy intensity of GDP for decades. In contrast, all scenarios in the most recent assessment report by the IPCC project historically unprecedented, fast GDP growth for the (least industrialized and affluent) Africa region out to 2050, but with a fast-falling energy intensity, at odds with any historical development experience. The underlying models arrive at these implausible growth trajectories by relying on an assumption of automatic income convergence of low-income to high-income countries, without explaining how it is achieved or conditioning energy demand. If economic growth is indeed going to be as successful as projected, climate models may be underestimating the future demand for energy in developing countries and the effort it takes to decarbonize. Or conversely, if the projected reduction in energy use is in fact materializing, then much lower GDP growth rates are likely.

[1] University of Massachusetts, gsemieniuk@umass.edu

**Industrialization and Energy Demand: Implications for Climate Change Mitigation***

Gregor Semieniuk[1]

This version: 17 March 2026

Abstract: Industrialization is key for economic development but how it interacts with climate change mitigation is insufficiently understood. However, this relationship is important for scenarios of climate change mitigation, such as reviewed by the International Panel for Climate Change (IPCC), that seek to show pathways for simultaneous economic development and mitigation in the coming decades. This paper examines the hypothesis that industrialization tends to go hand in hand with a rising energy intensity of GDP (energy/GDP). Analysis of 16 development successes in the 19th, 20th and 21st century shows that all relied on structural change toward manufacturing almost universally accompanied by a growing energy intensity of GDP for decades. In contrast, all scenarios in the most recent assessment report by the IPCC project historically unprecedented, fast GDP growth for the (least industrialized and affluent) Africa region out to 2050, but with a fast-falling energy intensity, at odds with any historical development experience. The underlying models arrive at these implausible growth trajectories by relying on an assumption of automatic income convergence of low-income to high-income countries, without explaining how it is achieved or conditioning energy demand. If economic growth is indeed going to be as successful as projected, climate models may be underestimating the future demand for energy in developing countries and the effort it takes to decarbonize. Or conversely, if the projected reduction in energy use is in fact materializing, then much lower GDP growth rates are likely.

Keywords: industrialization, structural change, climate change mitigation, energy intensity, decoupling, integrated assessment models

JEL codes: N10, N70, O14, O47, Q43

---

* I thank three anonymous reviewers for feedback on an earlier version of this manuscript, Karla Cervantes Barron, Navroz Dubash, Léonce Ndikumana and Isabella Weber for discussions about this manuscript and the participants at the CIVICA-Bocconi workshop on energy and food demand for comments on early results. I also thank the Groningen Growth and Development Centre and various energy historians for maintaining easily accessible data collections on historical GDP, manufacturing and energy demand patterns that enabled the research in this paper.
[1] University of Massachusetts and World Bank. gsemieniuk@umass.edu

## 1. Introduction

Industrialization is key for economic development but how it interacts with climate change mitigation is insufficiently understood. Since industry (mining, manufacturing, utilities and construction) tends to be more energy intensive than agriculture or services, the rate and pattern of industrialization matters for the magnitude of future energy demand. Most energy is still derived from fossil fuels, whose combustion causes about two thirds of current global greenhouse gas emissions (IPCC 2022). Therefore, reducing overall energy demand is one of three main ways of reducing climate-changing emissions from fossil fuels. The other two are the decarbonization of energy supply and carbon dioxide removal (IPCC 2022). To the extent that energy demand is driven up by the pattern of industrialization, reducing energy demand becomes harder. This paper uses historical data to shed light on the past co-evolution of industrialization and energy demand. It then compares the historical record with assumptions about the energy intensity of industrialization in influential projections used to assess global climate change mitigation.

Mitigation projections that consider the sources of emissions and how to reduce them are provided in scenarios calculated by integrated assessment models (IAMs) – integrated because they combine climate, energy, economic and other models to assess mitigation options.[2] More than a thousand scenarios produced by models that passed peer review have recently been reviewed in the International Panel on Climate Change's (IPCC) assessment report. The conclusions drawn in this report and the scenarios going into it are the authoritative source for how much and via which channels mitigation can and should proceed, and to some extent also which policies should be used to activate these channels (Hermansen et al. 2023; Pollitt et al. 2024; Vasileiadou et al. 2011). For instance, the scenarios reviewed in the report have been used to calculate that current climate policy pledges – if implemented – may be sufficient to hold global warming just below 2C of warming (Meinshausen et al. 2022). Naturally such projections must have a robust depiction of future economic development to be accurate.

But looking at how GDP per capita in developing countries (a very crude but not altogether irrelevant indicator of material wellbeing) is correlated with energy demand in IAM scenarios is likely to raise the eyebrows of researchers on economic development. Fig. 1

---

[2] It is important to distinguish IAMs, with thousands of equations seeking to depict the transformation of the economy as it mitigates, from highly stylized cost-benefit analyses produced by economists that are also often called IAMs (e.g. Barrage and Nordhaus 2024). The latter abstract from the actual mitigation process and have been widely criticized for their lack of realism and misrepresentation of climate impacts (Keen et al. 2022; N. Stern et al. 2022). This paper only considers the large IAMs depicting mitigation in detail and that are also called 'detailed process' or 'process-based' IAMs to distinguish them.

depicts how the ensemble of scenarios reviewed in the most recent 2022 IPCC assessment report that achieve the Paris agreement goal of decarbonization project this correlation for the Africa region. Africa has the lowest average GDP per capita of any region and about half of all employment in agriculture compared with a quarter for the world as a whole (International Labour Organization 2026).[3] So the question of industrialization in economic development looms particularly large. Economic development in Africa is highly successful in all of these scenarios: within a quarter of a century, the region's average GDP per capita is projected to rise to close to or even surpass the current world average (or about the GDP per capita of China) from less than a third of it today. Simultaneously, projected African per person energy demand rises to less than half the world's current average per person energy demand, however, or even stagnates or falls. What industrial development process is envisaged for Africa and other developing regions in these scenarios and how does it compare with the energy demand patterns during past industrialization episodes in other regions?

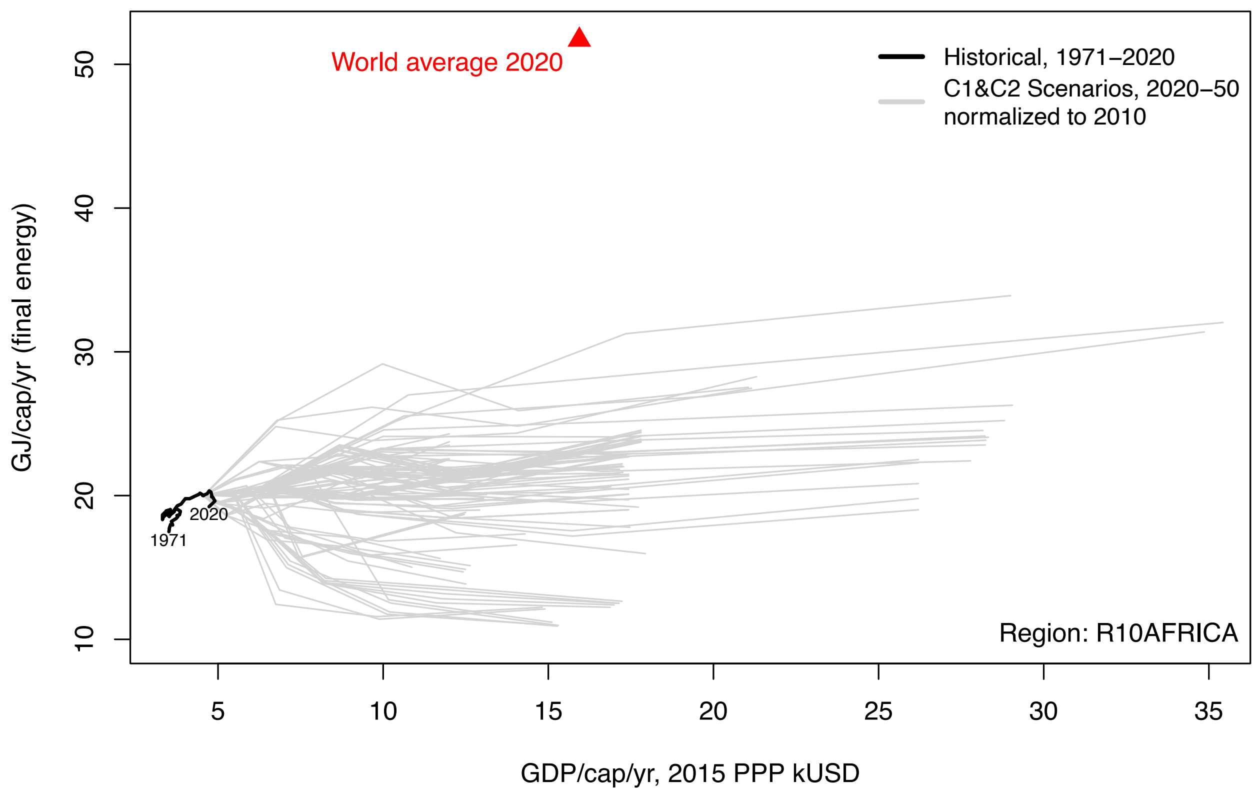



Fig. 1 | Trajectories of GDP per capita and final energy demand per capita 2010 to 2050 for the Africa region in scenarios of the 6th IPCC Assessment Report that successfully mitigate climate change (>50% chance of limiting warming to 1.5°C after low (C1) or high (C2) overshoot) in grey, and the historical trajectory in black

[3] These average should not obscure the fact that the continent is home to very heterogeneous economies, both in terms of affluence and economic structure (Chang et al. 2016; Mensah et al. 2023).

and the 2020 average world position in red. Final energy considers only energy reaching end users, thereby avoiding energy demand changes as an artifact of fuel switches.

This article analyzes the plausibility of mitigation scenario growth trajectories in developing regions, using the example of Africa as the region that starts from the least industrialized initial position. The guiding hypothesis is that rapid economic growth from low levels, i.e. industrialization, requires not only a structural transformation towards industry via manufacturing but also substantial increases in energy throughput because of the structural change toward more energy-intensive production patterns. In particular, the hypothesis is that industrialization is typically accompanied by a rising energy intensity. This hypothesis is derived from considering broad historical as well as theoretical evidence.

The paper first substantiates the claim that successful economic development has been generally achieved by industrialization, which is in turn tightly coupled with energy demand in section 2 with a literature review. This growth comes both from the more energy-intensive production processes that structural change from primary to secondary sectors implies, and from increasing final demand by households who become more affluent and purchase additional types of consumer durables that need more energy to be powered. Empirical evidence for the coupling of energy with GDP growth when manufacturing is brought from 19$^{th}$, 20$^{th}$ and 21$^{st}$ century industrialization successes and shown in section 4 after section 3 introduces the method and data. Section 5 shows that these ubiquitous patterns are wholly absent in current scenarios reviewed in the IPCC's 6th assessment report for Africa, even though their ubiquity makes them the most likely driver of near future projected African economic development. In the models underlying the scenarios, fast GDP growth instead happens automatically, by a Solow-type convergence assumption. Simultaneously, the energy intensity of GDP declines at arbitrarily fast rates allowing the result in Fig. 1. Since these models either do not include an economic growth model or one that does not feature structural transformation as part of the growth process, they are blind to industrialization and its energy consequences. The section also reviews arguments why fast growth may now be less energy intensive. The concluding section 6 discusses the consequences for climate mitigation in a growing global economy, as well as those for policy advice based on optimist scenarios. Unless a new development model or goal emerges, near-term decarbonization may have to take place in a more energy and resource using economy than is often assumed. Developing countries will either consume more energy, putting pressure on mitigation by other means, or they will simply not grow as fast.

## 2. Literature review: Economic growth through structural transformation and energy demand

### 2.1. Economic Growth through structural transformation

The readership of *Development and Change* does not need reminding that structural change is an essential component of economic development and growth. Nevertheless, it is useful to briefly recap the main elements of such a 'structural transformation' (Chenery et al. 1986) and highlight the role of manufacturing. That is not least because knowledge about the character of these structural transformations has recently declined in the wider development community (Hauge 2018; Cherif and Hasanov 2019; Chang and Andreoni 2021).

Industrialization is the sine qua non condition for economic development (e.g. Bairoch 1982; Chenery, Robinson, and Syrquin 1986; Amsden 1990). The eponymous industrial revolution that catapulted Britain to become the world's predominant economic and military power is indicative. Social change in agriculture (enclosures) set free labor, and technological progress in the industrial sector employed these workers at higher productivity (Marx 1867). The pattern of expanding the industrial sector and the shift in economic activity from agriculture to industry was therefore termed 'modern economic growth' by Simon Kuznets (1966; 1971). The importance of the shift to the industrial sector, and its contribution via labor productivity growth has been confirmed for more recent growth successes (Ocampo et al. 2009).

Growth in manufacturing in turn is the key condition of industrialization, so much so that dating and pace of industrialization are routinely measured by manufacturing per capita or manufacturing shares in the economy (Bairoch 1982; Perkins and Tang 2017). Manufacturing is key for its ability to increase productivity and – to a lesser extent – provide employment. From the demand side, economic growth has been said to drive productivity growth specifically in manufacturing, so-called Kaldor-Verdoorn effects (Kaldor 1966; Magacho and McCombie 2018; Tregenna 2009; Deleidi et al. 2023). The key mechanism are static and dynamic economies of scale, enabled by a larger market. A recent example is the remarkable cost decline in several renewable energy generation technologies, where tight correlations between cumulative installed capacity (larger market) and unit prices declines have held for decades, also called Wright's law (Nagy et al. 2013; Way et al. 2022). From the supply side, manufacturing sectors have been recognized as having more spillover effects for productivity growth in other sectors (Young 1991). And richer countries have tended to be more proficient at exporting manufacturing goods than poorer countries in both the 19th and 20th century (Weber et al. 2022). The importance of manufacturing as a driver of industrialization has held up in more recent development experiences (Haraguchi et al. 2017; Kruse et al. 2023). Indeed, while there has been no overall convergence in incomes across countries (Johnson and Papageorgiou 2020), manufacturing sector labor productivity has been converging across countries, meaning that if countries achieve structural transformation towards the manufacturing industry, they can achieve productivity and hence income levels comparable with high income countries (Rodrik 2013).

Naturally, growth in other sectors also propels aggregate growth, today notably in business services, transport, and infrastructure (construction). However, they tend to grow in combination with manufacturing – part of Young's (1991) superior spillovers – as manufacturing processes need substantial administration, shipping and utility inputs. This relationship is also reflected in manufacturing jobs having the highest indirect job multipliers (Winkler et al. 2023). One recognition of the relatedness of these sectors to manufacturing has been their label as "social overhead" (Chenery et al. 1986). Of course, this label disregards the essential role that both paid and unpaid services provide in sustaining the entirety of manufacturing activity (Folbre 2021; Fraser 2022).

Today, it is often noted that services tend to create most of the incomes in the economy. But that is only because manufacturing is so productive that its output has become cheap relative to services: it requires fewer workers to make all the good that are demanded. Since wages need to be coherent within a country, rising manufacturing wages tend to increase service wages alongside them, increasing the volume of incomes and hence value added in the service sector relative to manufacturing. Thus, it is precisely services' low productivity that make them appear large in income shares (Baumol 1967), a pattern that Baumol later decided to label a "cost disease" (Baumol 1993), even though productivity in care and education services is notoriously difficult to measure, since the output, and changes in its quality, is hard to capture (Folbre 2023). Looking at constant price time series corrects for this effect and shows that the change toward a service economy tends to be smaller than suggested by current price snapshots (Tregenna 2009).

Overall, it remains unclear whether service exports to higher income countries that tend to pay good wages in business and digital services relative to other sectors can lift the wages in the rest of the economy, and manufacturing has tended to remain the driver of growth (Hauge 2023).[4] Therefore (premature) deindustrialization has been a particular focus of development analysts for presenting an unresolved challenge of identifying alternative pathways to higher living standards for broad swathes of people (Tregenna 2009, 2014;

[4] India, often noted as a country for service-led development, has recently been shown to be led by manufacturing, i.e. the share of manufacturing in constant-price GDP has increased by 16 percentage points between 2003 and 2018 (Goldar and Das 2024). As always with sectoral growth, one must deflate sectors with appropriate, and sector-specific price indices to reveal the growth in their volume of production.

Rodrik 2016; Sato and Kuwamori 2024; Tregenna 2016 reviews earlier contributions in the 1970s and onwards). In particular, the lower employment intensity in recent manufacturing growth demonstrates that it is more difficult to generate high incomes for the many via this traditional route (Felipe et al. 2019).[5]

### 2.2. Structural transformation and energy demand

The rest of this literature review will cover the research on the role of energy in structural transformations. It will show that while there is good historical research on energy in industrialization for individual countries in the 19th century, the same cannot be said of the 20th century.

The role of energy in the British industrial revolution is a well-covered topic. The steam engine and coal for powering it have become its symbol. Edward Anthony Wrigley (1962, 2010) emphasizes how fossil fuels enabled societies to overcome the reliance on current photosynthesis, which varied with the seasons in Northern latitudes, and allowed Britain to develop from a peripheral country to the foremost military and economic power in the world. In his words, Britain transitioned from an advanced organic to a mineral-based economy.[6] Kenneth Pomeranz (2000) uses the Wrigleyan interpretation of the industrial revolution to also explain the 'great divergence' with China in the 19th century: Britain had coal (and colonies), and China didn't.

Following Wrigley's early studies, several historians have analyzed quantitatively the role of energy, and its correlation with GDP in a number of European countries. Inevitable, energy demand increased dramatically as countries industrialized and machinery required fuel, and the composition of sources changed from human and animal muscle power, wood, and wind and water for ships and mills, to fossil energy (Fouquet 2008; Kander et al. 2014). But while these studies paid minute attention to measuring energy and recognizing the importance of industrialization, they did not associate their energy demand with specific sectors, notably manufacturing.

Students of the history of structural transformation in the 20th century paid less attention to resources and energy as inputs into the changing structure of the economy. For instance, neither Kuznets nor Chenery and Syrquin, who carefully trace the patterns of structural change and development, list energy in the index of their above-mentioned books. Part of this neglect may have been an abundance of energy in the post-World War 2 atmosphere of already industrialized countries, that was abruptly shattered with the oil embargo by OPEC

---

[5] However, part of the apparent decline in manufacturing jobs may also be a reclassification to service jobs as companies outsource accounting, information technology and other services (Berlingieri 2013).

[6] The motives behind the switch from water mills to steam engines by British capitalists – namely the better ability to control labor – are described by Andreas Malm (2013).

in 1973 (Mork and Hall 1980). As a result, detailed energy statistics started to be collected by the newly founded International Energy Agency (Scott 1994). But at the same time as these statistics became long enough to be studied for energy demand patterns implied by structural change, say in the 1990s, the attention to structural transformation as the engine of growth disappeared from the agenda of mainstream development discourse.[7]

Therefore, the analysis of energy demand with structural change tends to be dissociated from the larger development narrative about structural transformation. On the one hand, there is – to the best of my knowledge – little analysis whether energy demand increases faster when an economy moves toward manufacturing than otherwise (Semieniuk 2018). On the other, there are innumerable decomposition studies of the extent to which the variation in the energy intensity of GDP (an index of energy demand divided by GDP) is due to technological progress and to structural change. But they largely abstract from the specific industries between which the change occurs and how this may hang together with where countries are in the process of economic development (e.g. Ang, Liu, and Ong 1992; Croner and Frankovic 2018). Moreover, the industries are usually much more finely disaggregated so that the question is more about structural change within manufacturing (e.g. from energy-intensive industries such as paper or metal manufacturing to less energy-intensive ones such as textiles). As a result, as we will see, the discussion of which specific sectors are associated with a modeled decline in energy intensity is paid little attention in current integrated assessment modeling. The exception is a general reference to an increase in the service sector's weight in the economy, which has however been debunked as using current rather than constant prices, thereby overstating the decline in energy intensity to be expected from such structural change (Henriques and Kander 2010). The next section examines patterns of energy, manufacturing and GDP rates of change to begin to fill this lacuna.

What has been better highlighted in recent research however is the indirect energy demand generated by industrialization. Energy demand need not only increase in the production process, but the higher incomes in a quickly industrializing country also allow people to buy more material amenities that in turn require energy to run. For instance, in many developing countries, rising incomes will enable households to purchase their first white goods, TV, air conditioning or passenger car or a larger house – energy increases at the extensive margin (Wolfram et al. 2012). In addition, adaptation to climate change can also lead to an increase in energy consumption in low latitude developing countries, notable from residential air conditioning (Davis and Gertler 2015), although this may be offset at

---

[7] Exceptions in terms of earlier attention are Schurr and Netschert (1977) and Cleveland et al. (1984) for the United Sates, and, more recently, Ocampo, Rada and Taylor (2009) for developing countries.

the global level by lower energy demand for heating in higher latitude countries (Labriet et al. 2015). The following analysis looks at aggregate energy demand, so these indirect consequences of industrialization for energy demand via higher incomes are included.

### 2.3 Hypothesis: energy demand in industrialization

Taking together the evidence reviewed here, fast and sustained economic growth over several decades from low towards high levels of GDP per capita has historically required a structural transformation from agriculture to industry, for which there are theoretical reasons having to do with the nature of the manufacturing industry. Hence it is common to refer to this growth process as industrialization and to high per capita income countries as industrialized countries. In the following when we will use the term industrialization to mean this type of growth spurt with a structural transformation of the economy. A change in the structure of the economy under industrialization to more energy-intensive activities in turn requires additional energy inputs all else equal; however, the connection between industrialization and energy demand isn't sufficiently empirically explored. Therefore the guiding hypothesis for the following analysis is as follows.

Hypothesis: Industrialization is driven not only by (i) structural change towards manufacturing, but also (ii) an intensification in the use of energy. Claim (i) can be operationalized as an index of manufacturing gross value added growing faster than an index of aggregate gross value added or GDP over a period of decades. Claim (ii) can be operationalized by an index of energy consumption growing faster than GDP, a rising 'energy intensity' of GDP for a period of decades.

After introducing method and data in the next section, section 4 examines this hypothesis for a broad range of historical data. Subsequently we will apply the insights gained to hypothetical growth scenarios for the Africa region in IPCC scenarios of climate change mitigation.

## 3. Method and historical data

This section justifies the selection of countries for historical cases of industrialization, and introduces the method of analysis and the historical data sources.

### 3.1. Country case selection

The choice of countries is informed by data availability and salience. For the cases pre-1950, data scarcity helps pick the Netherlands, Sweden, the United States and Japan.[8]

[8] While not in Western Europe or North America, Japan started industrializing in the late 19th century and by the onset of World War 2 its industrial structure already largely resembled that of leading Western industrialized countries (Perkins and Tang 2017).

Several other industrialized countries lack energy data reaching back to the 19th century or changing territorial size makes it difficult to construct consistent time series (see below for data sources). There are few successful industrializers since World War 2, and those countries were selected that Szirmai (2012, Table 1) identifies with fast growth periods, and for which long continuous sectoral data is available.[9]

Data become much more widely available after 1971 (energy) and 1980 (sectoral value added data). For this period, the cases were selected from Szirmai that are ongoing (India, Vietnam, Malaysa) as well as based on reviewing grey literature on recent additional industrialization success yielding Bangladesh (World Bank Group 2021) and Botswana as a case in Africa with very high growth since 1971 – boosted by diamond exports rather than industrialization – and left out of Szirmai's table. Moreover, 3 African countries that are touted as recent growth successes – Ethiopia, Rwanda and Uganda – are included, even if their individual trajectories are quite heterogeneous (Mensah et al. 2023).[10] In interpreting their results one must consider that as of 2025, they all remain low-income countries according to the World Bank's classification, meaning their industrialization is incipient and the results can only be interpreted as characterizing its initial phase. This is also why the projections for the Africa region studied later in the paper are so significant: they project most or the entirety of the process of industrialization and thus the historical data from other regions can be used for a comparison more easily.

### 3.2. Method

The method to study the hypothesis is straightforward: compare rates of growth in manufacturing sector value added, GDP and energy demand over multi-decade periods that correspond to industrialization, and other periods in countries' histories. This approach to examining and comparing growth patterns is inspired by Schurr and Netschert (1977), who compared manufacturing, GPD and its energy intensity as indices over subsequent multi-decade periods and compared the periods amongst them. This allowed Schurr and Netschert to conclude that the United States had had more energy-intensive growth 1885-1920 than 1920-1955 and that during the earlier period, its manufacturing (and mining) sector had also grown faster relative to GDP than in the latter. This paper does the same, including using their way of plotting the data – as indices starting at 1 in the first year of the period under consideration. One advantage that this method has over looking at compound annual growth rates is that – since periods of consideration vary across

[9] Several South East Asian countries whose growth spurt ended abruptly with the 1997 Asian Financial crisis and that Szirmai includes are excluded since they had not – unlike the Asian Tigers – reached high income status, nor did their subsequent trajectory put them on the path there.
[10] I thank an anonymous reviewer for suggesting these inclusions.

countries – they show the multiples by which an indicator has grown at the end of the period, rather than just an annual average.

### 3.3. Data sources and approach

Data for GDP and manufacturing in constant prices is mainly sourced through the historical national accounts portal as well as the 10-sector database versions from 2007 and 2014, and the Emerging Markets and Transition Countries database, all available the Groningen Growth and Development Centre.[11] The sources behind these collections are detailed in the documentations of the databases. Italian manufacturing and GDP data prior to 1970 is from Gomellini and Toniolo (2017). Economic and also energy data for the United States pre-1955 is from Schurr and Netschert (1977). Energy data for most countries pre-1960 is from the National Energy Accounts collection from the Joint Center for History and Economics at Harvard, and the detailed sources from which data is collected are again explained in the supplementary note, but most of them are analyzed in the above-mentioned Kander, Malanima and Warde (2014).[12] The energy data for Japan is from Fouquet (2009). The energy data after 1960 or 1971 is from the International Energy Agency.

To study GDP and energy projections, this paper uses the 10-region data from the scenarios database accompanying the 6th IPCC assessment report from 2022.[13] One of these regions is Africa, which cannot be disaggregated further based on the publicly available data. Naturally individual country situations differ from the continent's average (Mulugetta et al. 2022). The sample includes all C1 and C2 scenarios that have a >50% chance of limiting warming to 1.5°C after low (C1) or high (C2) overshoot, as well as the 5 illustrative mitigation pathways and two reference scenarios.

A note on the measure of energy used is in order.[14] Energy accounting distinguishes various stages of conversion at which energy could be measured, as well as conventions for aggregating different forms of energy (Brockway et al. 2024; Semieniuk and Weber 2020). To compare past with future projected patterns of energy demand, the measure of energy use should be robust to different forms of energy supply (e.g. from coal or solar photovoltaics). This robustness is achieved by measuring energy as close as possible to the actual service

[11] https://www.rug.nl/ggdc/structuralchange/
[12] https://histecon.fas.harvard.edu/energyhistory/energydata.html
[13] https://data.ene.iiasa.ac.at/ar6/#/about
[14] GDP data is an opportunistic collection of whatever long-run estimates are available. Due to changes in the definition and measurement of GDP between sources, conclusions should not be drawn that depend on exact quantitative comparisons between two country cases from two different sources (Semieniuk 2024). However, the qualitative results hold.

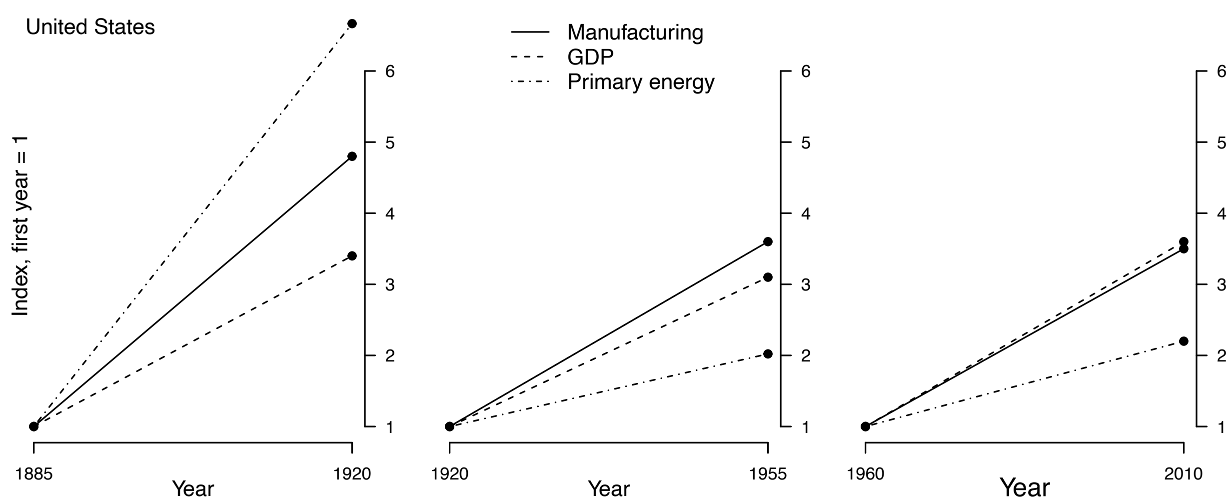
it provides, such as displacement of people and freight or illumination. In projections of future energy demand, the scenarios in the IPCC analyzed below consistently report final energy, i.e. energy available to end users, such as electricity at the plug or gasoline at the pump. This measure of energy is not uniformly available in the historical data. Instead, primary energy, i.e. energy when it just enters the economy such as the chemical energy content in mined coal or crude oil or the electricity from solar photovoltaics at the panel is available. It would be preferable to have final energy for past data, but in its absence, to make past primary with future final energy demand as comparable as possible, it is important to remove traditional biomass from the historical series. Biomass has a lot of primary energy, but since its conversion to final and useful energy is very inefficient, substituting coal and other fossil for biomass at the primary energy stage in the 19$^{th}$ and 20$^{th}$ century led to a large gain, not a 1:1 replacement in final energy and energy services. In other words, if wood was left in the series, the huge uptake of 'modern' industrial or commercial energy that goes along with industrialization would be obscured by a disproportional decline in the primary energy of traditional biomass. The same problem appears with the transition from fossil energy to renewables: renewables are much more efficient at generating electricity than coal or gas (Koomey et al. 2019), so primary energy would again not be a good measure. The IPCC final energy reporting takes care of that by directly measuring electricity instead of its source. By removing biomass (and muscle power) from the historical energy measures where possible, the modern primary energy of the past is more comparable to the final energy of the IPCC as conversion efficiencies within fossil energy remain relatively stable. However, it may lead to a slight overstatement of past energy growth rates, when biomass consumption falls quickly as the reduced final energy content of biomass slightly lowers growth the overall energy demand.

Table 1: Summary of data sources

| Country | Time | GDP, manufacturing | Energy pre-1960/71 |
|---|---|---|---|
| USA | 1885-2010 | Schurr and Netschert, Groningen | Schurr and Netschert |
| Sweden | 1870-2005 | Groningen | Harvard |
| Netherlands | 1870-2005 | Groningen | Harvard |
| Japan | 1885-2011 | Groningen | Fouquet |
| Italy | 1896-2005 | Gommelini/Toniolo, Groningen | Harvard |
| Korea | 1953-2018 | Szirmai, Groningen | Darmstadter |
| China | 1952-2018 | Groningen | Darmstadter, BP |
| Singapore | 1960-2012 | Groningen | Darmstadter, BP |
| All other countries have a start date of 1980 and later, use International Energy Agency balances for energy, and Total Economy Database from Groningen | | | |

## 4. Energy demand in past industrialization successes

We begin by looking at four advanced industrial countries whose industrialization began in the 19th century (Fig. 2). In the period 1870-1913 or 1885-1920, the United States, Netherlands, Sweden and Japan all displayed identical growth patterns in the manufacturing-energy-GDP space. Manufacturing at constant prices grew substantially faster than GDP. And primary energy demand grew substantially faster than both GDP and manufacturing. Contrast this with the most recent period, post 1973 or 1960: primary energy grew more slowly than manufacturing and GDP in all four economies, and it even fell a little in Sweden. GDP grew slightly faster than manufacturing in the United States, Netherlands and Japan, and slightly more slowly in Sweden. It is also evident that GDP grew much more slowly in the right panel than in the left – all countries had transitioned from industrialization to industrialized without catch-up and overtake opportunities to the 'technological frontier', that had been largely set by Britain in the 19th century. In other words, we see a clear correlation between fast economic growth powered overwhelmingly by manufacturing and rising energy intensity of GDP. We also see a clear correlation between lower growth in industrialized countries, only partly driven by manufacturing and a falling energy intensity – energy demand growing more slowly than GDP.




(figure continued overleaf)

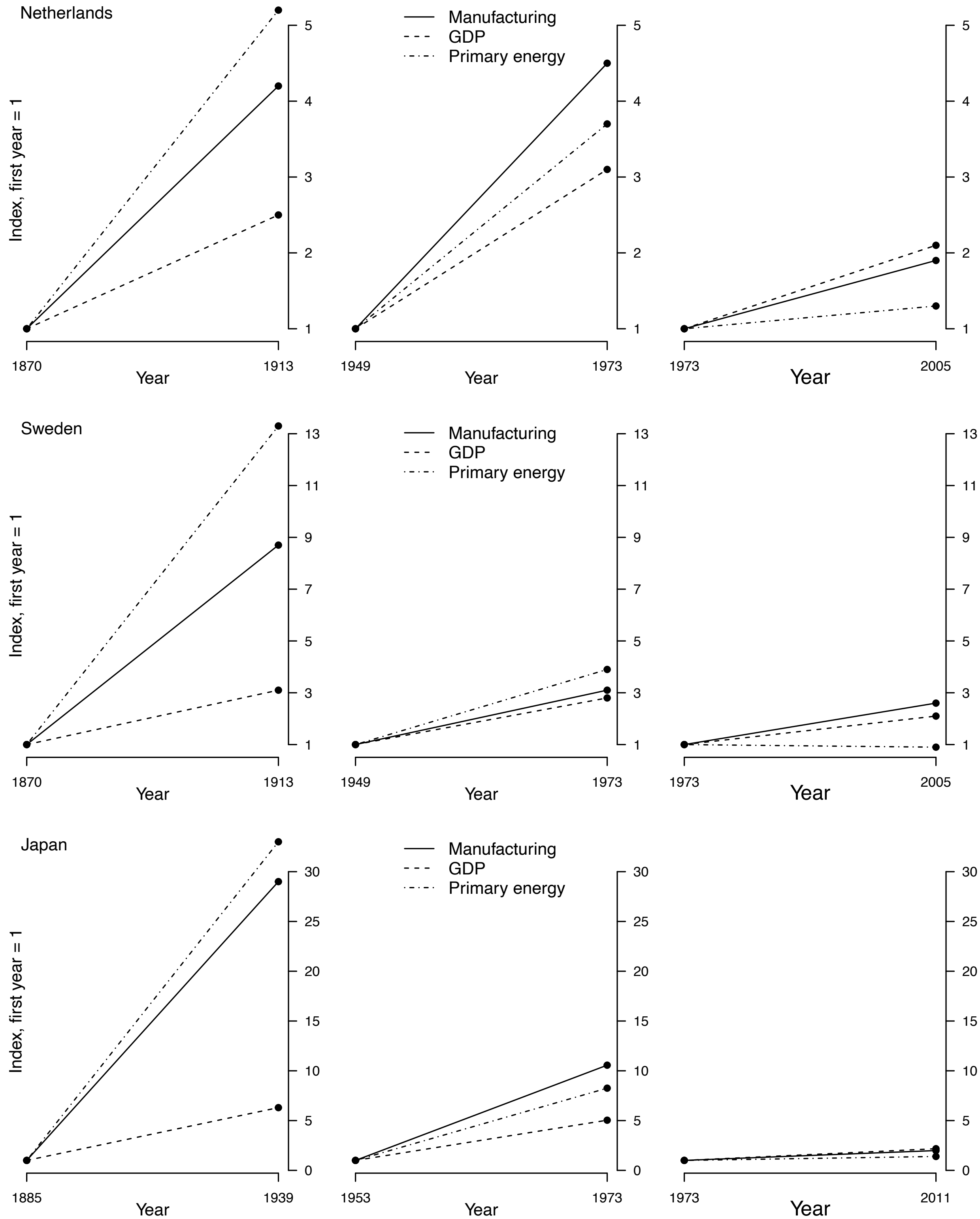
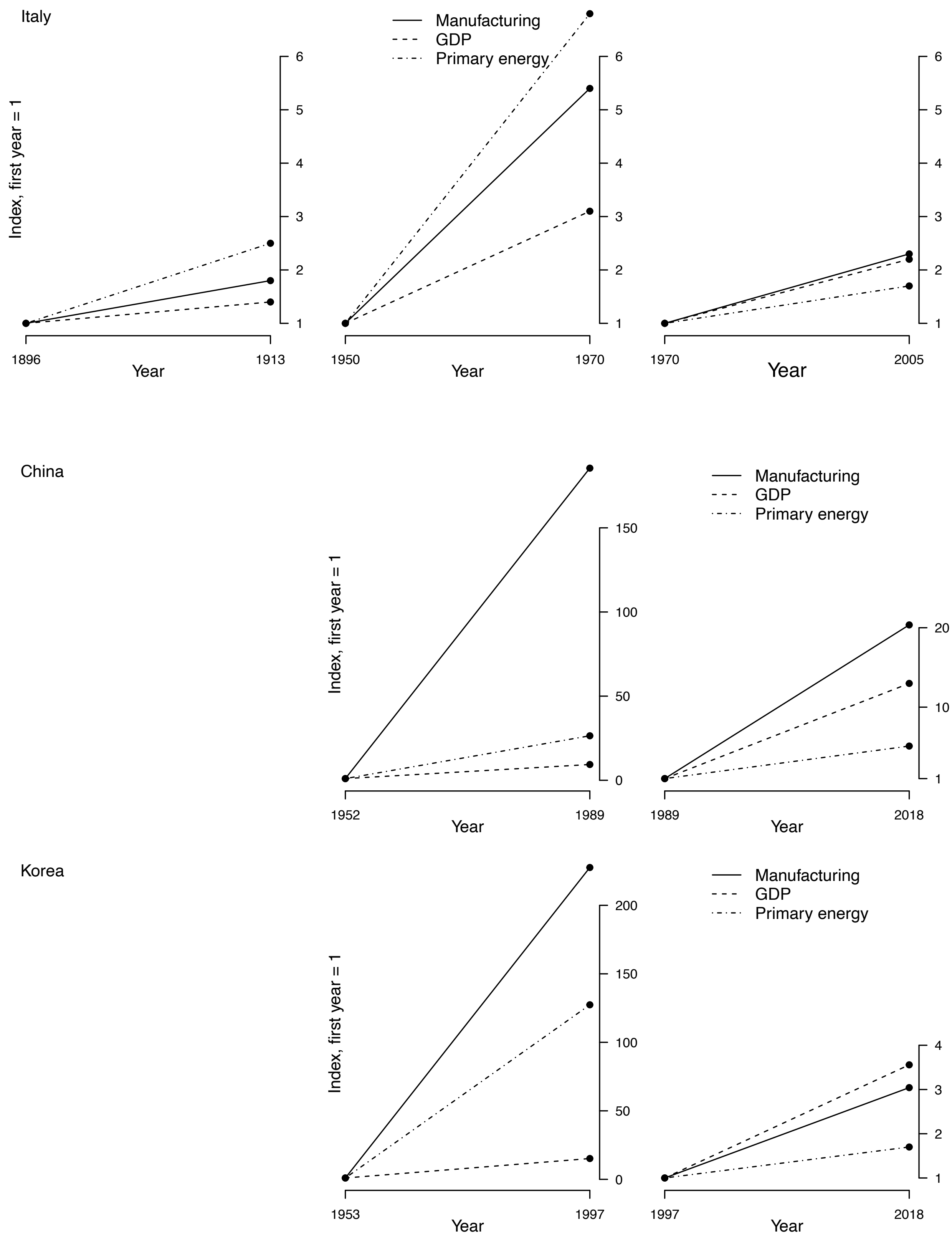



Figure 2 | Manufacturing, GDP, and primary energy index for the United States, Netherlands, and Sweden for 3 time periods: the turn of the 20th century, mid-century before 1973, and most recent period.

The middle period in Fig. 2 largely continues the pattern of the first period: it is a period of transition and of post-war boom. For United States, which has different start and end dates, the period includes the Great Depression and war mobilization. In the United States, energy already grows more slowly than manufacturing and GDP. The country takes over as the most advanced economy from Britain, and Schurr and Netschert also attribute the pattern to an already relatively complete industrialization. In the Netherlands, manufacturing grows faster than energy, and energy grows faster than GDP. One explanation may be the discovery of gas and the subsequent quick scale-up of the energy-intensive petrochemical industry (Lubbers and Lemckert 1980; Dekker and Missemer 2024). Sweden maintains its pattern that sees energy grow faster than manufacturing and GDP (see the appendix Fig 1A for a long-run graph for Sweden that shows that this qualitative pattern was also maintained in the long period 1870-1949. Japan continues its rapid industrialization with structural change toward manufacturing that grows tenfold continuing, and the energy intensity of GDP growing. The middle period reinforces the uniformity of patterns during industrialization (energy-intensive, manufacturing-led fast growth) and after industrialization (slower, less energy-intensive growth).

A second set of economies hadn't industrialized as much as our first four economies by the time of the onset of World War 1. Italy had greatly caught up with Northern Europe by 1913, but only in some regions, and its industrialization can be said to stretch until 1970 (Gomellini and Toniolo 2017). China's quest to re-industrialize started after the civil war and the socialist revolution. Although, it's most impressive growth spurt started when the economy grew into the market (Weber 2021), China's industrialization is a much longer process, and industrial growth rates in China were faster than Japan's throughout most of the 20$^{th}$ century (Brandt et al. 2017). Korea's industrialization took off in the 1960s (Perkins and Tang 2017), and its fastest sustained growth covered the period 1952-1997 according to Szirmai (2012). Similar patterns are reported by Szirmai for Singapore, both countries being recognized as "Asian Tigers" for the successful industrialization in the second half of the 20$^{th}$ century. As a result, these four economies are treated as having passed through an important phase of industrialization by differing cutoff periods in the late 20$^{th}$ century. The results are summarized in Fig. 3.


Italy
Manufacturing
GDP
Primary energy
Index, first year = 1
1896
1913
1950
1970
1970
2005
Year
China
Index, first year = 1
1952
1989
1989
2018
Korea
Index, first year = 1
1953
1997
1997
2018

Singapore

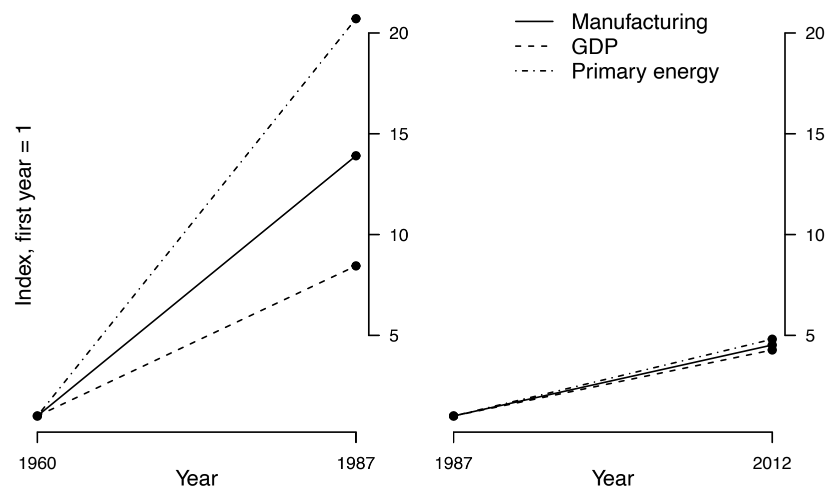



Figure 3 | Manufacturing, GDP, and primary energy indices for Italy, China, Korea and Singapore for two periods: mid-century before 1973, and most recent period. Italy also has the turn of the 20th century period. China and Korea: two periods have different scales on the y-axis.

The evidence for this second era of industrialization is clear: in all but the last period, both manufacturing and energy indices grow faster than GDP, and in the latest period, manufacturing slows to around GDP growth rates while energy demand grows substantially slower than the economic value indices in all countries. Energy grows faster than manufacturing in the pre-1913 period in both Italy and Japan and also in the 1950-70 period in Italy, and slower than manufacturing in the other cases, but bearing in mind the difficulty of pinning down energy consumption because of the shift in energy sources discussed above, it is sufficient to say that energy grew at rates close to that of manufacturing, and substantially faster than GDP. All of the historical industrialization cases reviewed so far therefore support the hypothesis that structural transformation driven by manufacturing was energy intensive to such a degree that it pushed economywide energy consumption up faster than GDP.

This leaves the current period. Eight economies are analyzed. Three of them are included in Szirmai's post 1950-industrialization list, and Vietnam and Malaysia stand in for some other relatively fast-growing Southeast Asian economies (Perkins et al. 2022). Bangladesh and Botswana are also included. Botswana is one of the highest per capita income countries in Africa bar small islands, and its success in this dimension has been attributed partly to onshoring the manufacturing of diamonds, even though it has seen uneven development of its industrial structure over the period (Owusu and Ismail Samatar 1997; Moyo 2016). Bangladesh has recently experienced relatively fast growth thanks especially to its expanding textile industry. In addition, three fast-growing African economies are included that are classified as low-income in 2025, meaning their industrialization is only incipient and the patterns cannot be used to conclude much about their overall growth pattern. Nevertheless, the patterns are informative early-stage growth spurts.

The first five results confirm earlier studies (Table 2). Vietnam, Botswana, Bangladesh and Malaysia all fit the previous pattern of faster energy and manufacturing growth than GDP, with quantitative variation but qualitative similarity, which have to do with the more detailed industry structure and in Malaysia's case with the relatively high energy intensity of the economy in 1970 due to its domestic oil industry. India appears to achieve robust manufacturing growth with its energy consumption 'only' growing as fast as GDP. Nevertheless, and granted India still is very much in the process of industrialization, the overall pattern is robust. Fast GDP growth in developing countries coincides with a shift to manufacturing and a non-declining and typically growing energy intensity.

Table 2: Recent GDP growth successes

| | | **Index in last year (first year = 1)** | | | | **Compound annual growth rate** | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | Period | Manu-factu-ring | GDP | Modern primary energy | Memo: all primary energy | Manu-factu-ring | GDP | Modern primary energy |
| **Botswana** | 1971-2018 | 39.8 | 26.1 | 46.2 | 15.1 | 8.2 | 7.2 | 8.5 |
| **Malaysia** | 1971-2018 | 36.0 | 15.4 | 20.4 | 16.5 | 7.9 | 6 | 6.6 |
| **India** | 1980-2018 | 17.4 | 13.4 | 13.1 | 6.9 | 7.8 | 7.1 | 7 |
| **Bangladesh** | 2000-2018 | 4.6 | 2.9 | 3.2 | 2.3 | 8.9 | 6.1 | 6.7 |
| **Vietnam** | 2003-2018 | 3.2 | 2.2 | 3.7 | 2.4 | 8.1 | 5.3 | 9.1 |
| **Recent African growth successes (all countries were still classified as low-income in 2025)** | | | | | | | | |
| **Uganda** | 1990-2018 | 8.0 | 2.6 | 7.2 | 2.8 | 7.7 | 3.4 | 7.3 |
| **Ethiopia** | 2005-2018 | 5.3 | 3.6 | 3.1 | 1.5 | 13.7 | 10.4 | 9 |
| **Rwanda** | 2006-2018 | 1.9 | 2.3 | 2.0 | 1.4 | 5.4 | 7.3 | 6 |

Note: total primary energy grows more slowly due to lesser growth or decline in the use of fuel wood for household consumption, an important share of energy in pre-industrial societies.

## 5. Structural Transformation in climate modeling

How does the historical evidence compare with model projections? Before looking at evidence, it is instructive to study the model structure. Scenarios of future climate change mitigation alongside economic growth and development are typically studied in detailed process integrated assessment models (IAMs). These have many submodules to study the energy system, land, food, the macroeconomy, and calculate their emissions and resulting forcing and temperature changes. The scenarios are submitted to and reviewed every roughly seven years by the IPCC's assessment report on mitigation, working group 3. To be included, scenarios must pass a vetting process that checks whether key climate variables are modeled in sufficient detail. As a result, only a small number of models supply the scenarios shown in the IPCC graphs and statistics.[15] This also means that a small number of macroeconomic models determines how economic growth and energy demand hang together.

One way to study the structure of the models is to go through them one by one, which shows that they either have exogenous GDP growth taken from OECD projections or a version of neoclassical, mostly one-sector growth models (Semieniuk et al. 2021). Another approach is to look at the modeling community's statement about how it sees economic growth in their models, which can be found in the shared socioeconomic pathways (SSPs). In 2014, key IAM modelers and IPCC report authors presented the SSPs "as reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or climate policies" (O'Neill et al. 2014). These five pathways with varying barriers to mitigation or adaptation were then characterized in detail in a special issue of *Global Environmental Change,* in which all the major IAM modeling teams participated as co-authors. Three papers treat macroeconomic growth and GDP, and can be considered a relatively authoritative statement of the thinking that went into the scenarios modeling reviewed by the most recent IPCC assessment report.

One paper is by the OECD modeling team, whose GDP outputs several other teams use. The key driver of growth in Dellink et al. (2017) is economic convergence whereby countries at the technological frontier grow at the exogenous total factor productivity frontier rate, and others catch up to the frontier, i.e. they grow faster than the frontier country – they converge. Trade openness and factor endowments modulate rate and level of convergence, so-called conditional convergence. But convergence takes place in all cases. And the lowest income countries will be projected to grow fastest, all else equal. This hypothesis comes out of the (single-sector!) Solow-Swan growth model that sees countries grow faster if they have low capital-labor ratios, until they converge to their steady state.[16] Empirically, the historical evidence for convergence is scant (Johnson and Papageorgiou 2020; Brussevich et al. 2022). The years since COVID-19 and the increasing instability of the

[15] In the most recent assessment report, those that fail the vetting can nevertheless be accessed in the IPCC's scenario database.

[16] In the Solow (1956) model, the relatively low capital stock combined with an imperfect substitution production function implies a high marginal product of capital, output to capital ratio and investment. Other versions of the convergence hypothesis rely more on technology diffusion and higher productivity of newer vintages of capital stock (Abramovitz 1986).

international system, including the second fossil energy crisis in 4 years starting in 2026 as this manuscript is revised, do not bode well for accelerated developing country catch-up.

The OECD paper does not mention the terms ‘structural change’ or ‘structural transformation’ once. [17] It does mention industrialization once and only in its model appendix when it justifies the assumption of a u-shape of the energy efficiency parameter as a function of per capita GDP. The explanation given supports the evidence in the previous section:

> “commercial energy consumption is low for low-income countries and then rises rapidly with industrialisation (associated with increased incomes); as countries become richer, access to advanced technologies and further structural shifts towards the services sector imply higher energy productivity.” (Dellink et al. 2017, p. 214)

Clearly the authors understand heightened energy demand underpinning industrialization. But since IAMs relying on GDP from the OECD (which does not have its own IAM) use their own energy models, they inherit the OECD’s GDP convergence but not its u-shape constraints on energy efficiency.

The other two papers are similar. One focuses on how an integrated world leads to more trade and income convergence (Leimbach et al. 2017). No mention is made of structural change except once where it appears to refer to changes in behavior (p. 223). Industrialization isn’t mentioned either, and the dominant driver of developing countries’ GDP per capita is once again a convergence assumption. The last paper looks at GDP from the income side and once again discusses income growth in terms of conditional convergence (Crespo Cuaresma 2017). Structural change or industrialization do not appear in this paper.

In sum, the models informing the IPCC-reviewed scenarios do not see industrialization and structural change as key drivers of their growth scenarios. However the energy efficiency assumptions in Dellink et al. (2017) suggest that their Solow-type convergence models could nonetheless mimic the energy patterns we saw in the historical evidence. We turn to their projections next.

While the IPCC’s 6th assessment report reviews over 1,000 scenarios, it does select five ‘illustrative mitigation pathways’ as well as two reference scenarios without or with moderate climate action “to illustrate key themes that form a common thread in the report”

---

[17] The paper hints at a changing sectoral composition once, when it predicts that PPP exchange rates converge to market exchange rates in the course of the 21st century “as productivity gains affect the structure of domestic economies” (p. 205).

(IPCC 2022, p. 309). Fig. 4 reports GDP and final energy indices for each of these scenarios for the Africa region for 2020-2050. Uniformly, these scenarios depict a vast improvement in GDP in the Africa region – faster than the United States, Netherlands or Sweden in the 40 years pre-World War 1 or Italy's catch-up in 1950-1970. The 30-year growth projected is about as fast as Japan's growth multiple over the period 1885-1939, Vietnam's explosive growth over 26 years from 1992 to 2018 or China's unprecedented growth success 1997-2018 (Fig. A1). The projected growth rates cannot be called anything but highly successful, especially given the continent's past growth performance that was often only fast enough to keep per capita GDP constant except in the commodity super cycle decade 2000-2010 (see Fig A2 in the appendix). Data on manufacturing isn't part of the public database; moreover, most models do not generate this data.

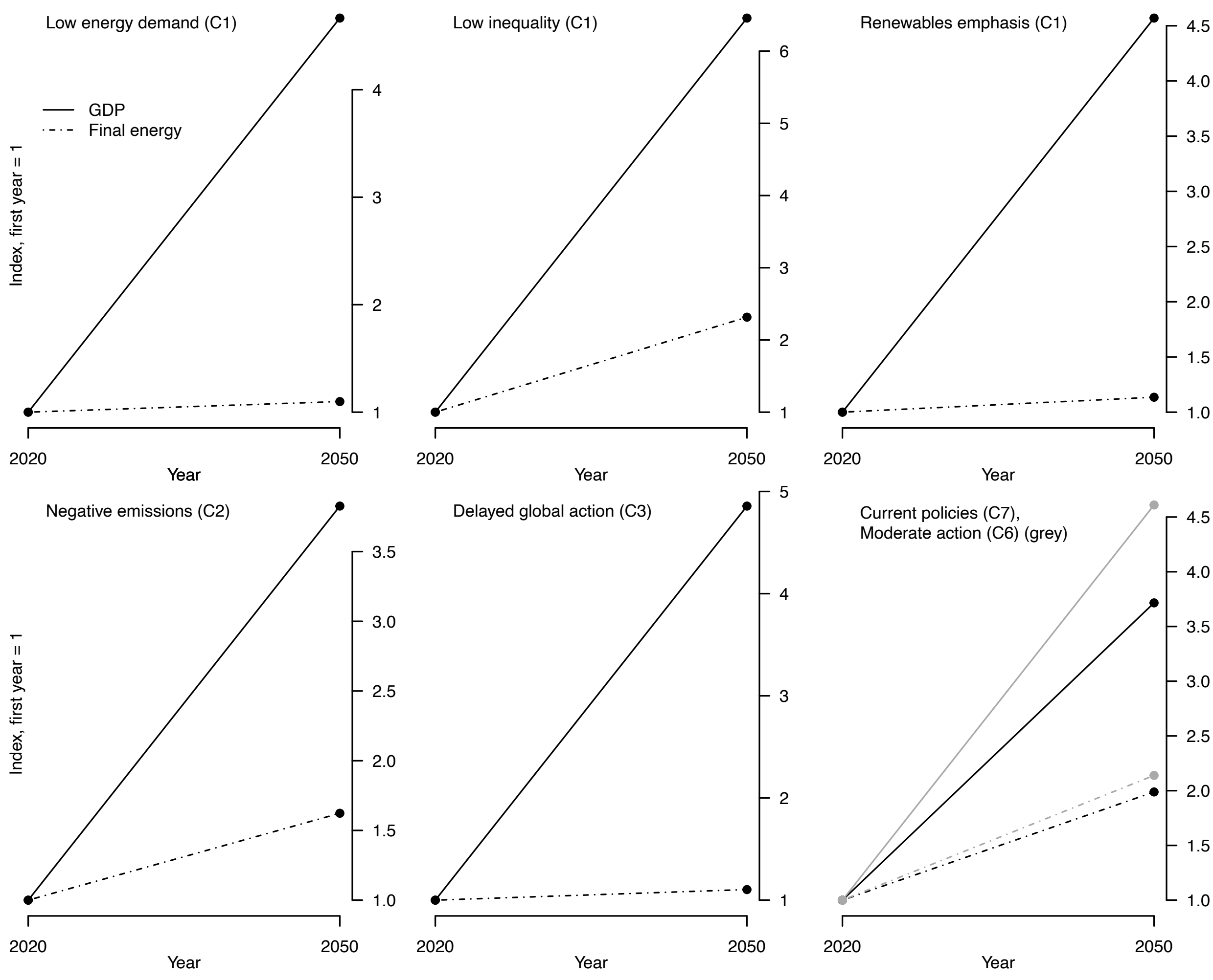



Figure 4 | Manufacturing, GDP, and final energy indices for the Africa region in 5 illustrative mitigation pathways in the IPCC and two reference scenarios (bottom right). C1 is the best mitigation outcome and C7 the worst. Y-axes scales are scenario-specific.

Final energy meanwhile stagnates or rises only a small fraction of the GDP index in Figure 5. It is hard to overstate how ahistorical this growth pattern is. In all but one case of rapid growth during industrialization, energy demand rose faster, or at least as fast as GDP. One illustrative mitigation pathway called “low inequality”, that models the simultaneous achievement of all sustainable development goals (Soergel et al. 2021), sees energy grow 2.5-fold. But it also has substantially faster GDP growth than all other scenarios (6.5-fold, implying a 6.4% annual growth rate). In three others total final energy demand hardly changes. Not even the reference scenarios without climate policy that might maximize energy efficiency bear resemblance to typical historical trajectories.[18] It does not look like an energy efficiency u-curve plays a role. Rather, it appears that there are a priori assumptions of fast convergence and energy-intensity reduction, without inquiring how the Africa region might achieve this historically unprecedented GDP growth.

A skeptic might say that Africa, given its initial position, might still be at relatively low GDP per capita levels by 2050, and hence at pre-industrialized levels of affluence. The historical data for Ethiopia in Table 2 showed at least a slightly faster GDP growth than energy growth in its low-income phase. But Fig. 1 showed that this growth would bring the Africa region to roughly the GDP per capita level of where the world average at purchasing power parity is today (e.g. close to where China is, and 50% higher than Vietnam), which means substantial industrialization must have occurred in those 30 years.

Another way to look at the results for all successful mitigation scenarios (C1 & C2), is to compare them with the 2050 GDP frontier – where Africa would be in 2050 it if it grew at the 1971-2020 average – as well as with recent estimates of the energy consumption to meet basic needs. Fig. 6 shows that African GDP growth far surpasses the 2050 GDP frontier in every single scenario that passed vetting. There is no projection of slow growth in the Africa region – the convergence assumption dominates. At the same time, this growth is achieved while hardly ever crossing the lower boundary for what Lamb and Rao (2015) calculate is the per capita energy consumption to meet basic needs at 25 GJ/person/year. For comparison, European Union citizens currently consume 84 GJ/person/year on average.

[18] The lack of final energy growth in reference scenarios is significant because part of the additional decline in policy scenarios is caused by increasing the final-to-useful energy conversion efficiency by moving e.g. from internal combustion engines to electric motors for transport. That is, energy services aren’t affected by that decline in final energy. Unfortunately, total useful energy figures, or for industrial use are not reported in the IPCC database.

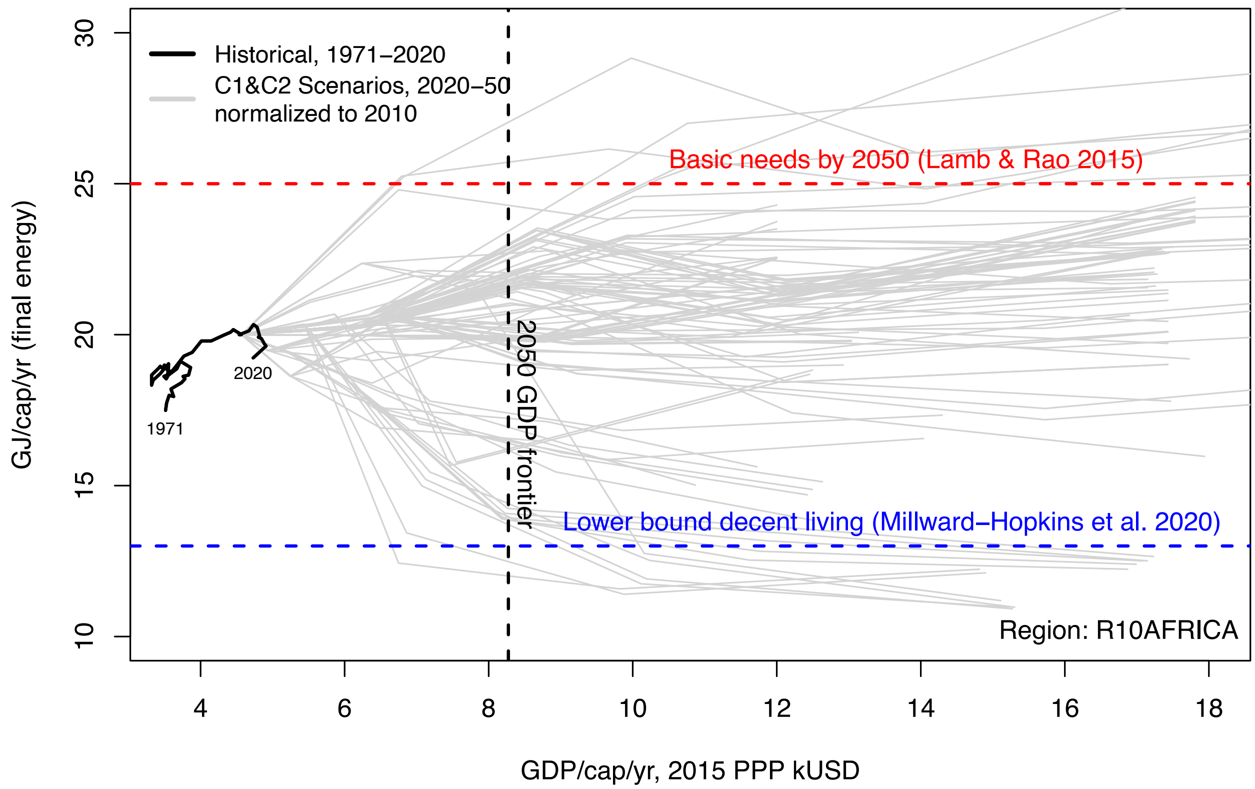



Figure 6 | Trajectories of GDP per capita and final energy demand per capita 2010 to 2050 for the Africa region in scenarios of the 6th IPCC Assessment Report that successfully mitigate climate change (>50% chance of limiting warming to 1.5°C after low (C1) or high (C2) overshoot) in grey, the historical trajectory in black. The GDP frontier indicates the horizontal position of the African trajectory in 2050 if GDP growth were to continue at the rate of 1971-2020.

Millward-Hopkins et al. (2020) have calculated an even lower bound for 'decent living'. Most IPCC scenarios skirt just above it, and so does the historical African average energy demand. To be clear, Millward-Hopkins et al. assume no fast economic growth, let alone additional industrialization. On the contrary, they consider sufficiency combined with advanced technology transfer around the world to make that sufficiency maximally energy efficient. Such a future is far removed from any of the SSPs on which the scenarios reported in the IPCC are predicated; indeed, it presupposes an economic paradigm shift (Hofferberth 2025).

In sum, projections are vastly different from any historical experience. A frequent reaction to pointing out such differences is that historical experience is a poor guide to the future; after all, the energy transition is supposed to change how things are going to be from how they were. Rodrik (2018) sketches scenarios for agriculture or service-led growth in African countries (although he remains skeptical that these can be realized). Perhaps the proposed rapid structural change implied by climate mitigation itself might alter patterns of structural change. There also some evidence for 'energy leap-frogging', i.e. latecomers to adopting technology may be able to skip some energy-intensive steps that earlier industrializers had to take (Liddle and Huntington 2021). A favorite example is not having to dig up the ground for phone cables when starting with wireless telephony in the first place; more generally, more energy efficient machines may be used in production. An important counterargument to higher energy efficiency is that of the energy rebound effect – whereby the very efficiency improvement leads not only to economic growth but also a more extensive use of these more efficient machines 'bringing back' some of the energy thought saved. Recent evidence suggests the economy-wide rebound effect may be upwards of 50%, meaning higher efficiency –e.g. through energy leap-frogging to more efficient technologies – leads to less than half the nameplate savings (D. I. Stern 2020; Brockway et al. 2021).

All in all, claims of the irrelevance of history lack – like the models themselves – an explanation how the relationship between the quantity of energy contingent on the quality of economic production and growth may change from past patterns for an entire continent. Indeed, the convergence assumption itself neither has a an explanation of growth nor is it backed by good historical evidence (Johnson and Papageorgiou 2020). In contrast, the method applied here, that is, confronting model projections with historical reference cases that serve to delineate feasibility spaces, is a well-founded methodological approach rooted in the literature of decision making based on risky prospects (Jewell and Cherp 2023). The results of such confrontations should therefore be considered as one important sense check on models' maps of the future.

## 6. Concluding discussion

This analysis has shown that IAM scenario projections of energy demand for a fast-growing developing region, Africa, are starkly at odds with any historical experience. Historical growth spurts were driven by industrialization and coincided with an increase in the constant-price manufacturing share in GDP as well as with a growing or at least non-decreasing primary energy intensity of GDP. IAM scenarios instead show a growth spurt driven by a convergence assumption with a dramatically falling final energy intensity of GDP. Manufacturing data is not reported. In other words, based on historical experience the scenarios systematically underestimate the energy demand coming with the growth spurt they project. The case study in this article was Africa, which presents perhaps the clearest picture of fast growth from low levels. However, the same problem applies to all other developing regions modeled to converge with rich countries in integrated assessment models.

This means that if developing countries collectively do achieve the rates of growth shown in the IAM scenarios, energy demand will be higher, and the challenge to supply it from low-carbon sources more difficult to meet. Decarbonization requires more effort on average. Failure to understand this can complicate decarbonization efforts. The additional salience of this is that if energy demand were really limited as the scenarios depict, it would curtail Africa's or other developing regions' economic growth. It seems unlikely in today's world that any developing country would sacrifice economic growth to meet a low energy demand goal, but there could be pressure from abroad.

To illustrate such pressure, consider negotiations at the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP). Ahead of COP27, the Nigerian President Muhammadu Buhari wrote an angry op-ed in the Washington Post, demanding Western countries not deny African countries the use of natural gas to meet their comparatively small energy demand (Buhari 2022). This followed the pledge by 34 countries at COP26 in 2021 to end overseas public financing and shift it to low-carbon energy in the Clean Energy Transition Partnership, with checkered results on the low-carbon support two years into the program (Jones et al. 2024), and with evidence mounting that this partnership constrains the very industrial policy space that is supposed to bring about a structural transformation (Bradlow and Swamidurai 2026). Bringing more clarity on the sources of growth in the energy transition debate for developing countries could help develop multilateral policy proposals that are consistent with the economic development challenges on the ground.

## Bibliography

Abramovitz, Moses. 1986. “Catching Up, Forging Ahead, and Falling Behind.” *The Journal of Economic History* 46 (2): 385–406. https://doi.org/10.1017/S0022050700046209.

Amsden, Alice H. 1990. “Third World Industrialization: ‘Global Fordism’ or a New Model?” *New Left Review*, no. I/182 (August): 5–31.

Ang, B. W., X. Q. Liu, and H. L. Ong. 1992. “Sector Disaggregation and the Effect of Structural Change on Industrial Energy Consumption.” *Energy* 17 (7): 679–87. https://doi.org/10.1016/0360-5442(92)90075-B.

Bairoch, Paul. 1982. “International Industrialization Levels from 1750 to 1980.” *Journal of European Economic History* 11 (2): 269–333.

Barrage, Lint, and William Nordhaus. 2024. “Policies, Projections, and the Social Cost of Carbon: Results from the DICE-2023 Model.” *Proceedings of the National Academy of Sciences* 121 (13): e2312030121. https://doi.org/10.1073/pnas.2312030121.

Baumol, William J. 1967. “Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis.” *The American Economic Review* 57 (3): 415–26.

Baumol, William J. 1993. “Health Care, Education and the Cost Disease: A Looming Crisis for Public Choice.” In *The Next Twenty-Five Years of Public Choice*, edited by Charles K. Rowley, Friedrich Schneider, and Robert D. Tollison. Springer Netherlands. https://doi.org/10.1007/978-94-017-3402-8_3.

Berlingieri, Giuseppe. 2013. *Outsourcing and the Rise in Services*. Working Paper No. CEPDP1199. London School of Economics and Political Science. Centre for Economic Performance. http://cep.lse.ac.uk/_new/publications/series.asp?prog=CEP.

Bradlow, Benjamin H., and Aishwarya Swamidurai. 2026. “The ‘Power to Pollute’ and ‘Post-Neoliberal’ Climate Finance.” *Socio-Economic Review*, March 16, mwag015. https://doi.org/10.1093/ser/mwag015.

Brandt, Loren, Debin Ma, and Thomas G. Rawski. 2017. “Industrialization in China.” In *The Spread of Modern Industry to the Periphery since 1871*, edited by Kevin Hjortshøj O’Rourke and Jeffrey Gale Williamson. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198753643.003.0009.

Brockway, Paul E., Matthew Kuperus Heun, Zeke Marshall, et al. 2024. “A Country-Level Primary-Final-Useful (CL-PFU) Energy and Exergy Database: Overview of Its Construction and 1971–2020 World-Level Efficiency Results.” *Environmental Research: Energy* 1 (2): 025005. https://doi.org/10.1088/2753-3751/ad4e39.

Brockway, Paul E., Steve Sorrell, Gregor Semieniuk, Matthew K. Heun, and Victor Court. 2021. “Energy Efficiency and Economy-Wide Rebound Effects: A Review of the Evidence and Its Implications.” *Renewable & Sustainable Energy Reviews* 141 (December 2020): in press-in press. https://doi.org/10.1016/j.rser.2021.110781.

Brussevich, Mariya, Shihui Liu, and Chris Papageorgiou. 2022. “Income Convergence Or Divergence in The Aftermath of the COVID-19 Shock?” *IMF Working Papers* 2022/121.

Buhari, Muhammadu. 2022. “Muhammadu Buhari: How Not to Talk with Africa about Climate Change.” *Washington Post* November 9.

Chang, Ha-Joon, and Antonio Andreoni. 2021. "Bringing Production Back into Development: An Introduction." *The European Journal of Development Research* 33 (2): 165–78. https://doi.org/10.1057/s41287-021-00359-3.

Chang, Ha-Joon, Jostein Hauge, and Muhammad Irfan. 2016. *Transformative Industrial Policy for Africa*. United Nations Economic Commission for Africa.

Chenery, Hollis, Sherman Robinson, and Moshe Syrquin. 1986. *Industrialization and Growth: A Comparative Study*. World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/714961468135943204/Industrialization-and-growth-a-comparative-study.

Cherif, Reda, and Fuad Hasanov. 2019. "The Return of the Policy That Shall Not Be Named: Principles of Industrial Policy." *IMF Working Papers* 2019/074. https://www.imf.org/en/Publications/WP/Issues/2019/03/26/The-Return-of-the-Policy-That-Shall-Not-Be-Named-Principles-of-Industrial-Policy-46710.

Cleveland, Cutler J., Robert Costanza, Charles A. S. Hall, and Robert Kaufmann. 1984. *Energy and the U.S. Economy: A Biophysical Perspective*. 225 (4665): 890–97.

Crespo Cuaresma, Jesús. 2017. "Income Projections for Climate Change Research: A Framework Based on Human Capital Dynamics." *Global Environmental Change* 42 (January): 226–36. https://doi.org/10.1016/j.gloenvcha.2015.02.012.

Croner, Daniel, and Ivan Frankovic. 2018. "A Structural Decomposition Analysis of Global and NationalEnergy Intensity Trends." *The Energy Journal* 39 (2): 103–22. https://doi.org/10.5547/01956574.39.2.dcro.

Davis, Lucas W., and Paul J. Gertler. 2015. "Contribution of Air Conditioning Adoption to Future Energy Use under Global Warming." *Proceedings of the National Academy of Sciences* 112 (19): 5962–67. https://doi.org/10.1073/pnas.1423558112.

Dekker, Henk-Jan, and Antoine Missemer. 2024. "Resource Booms and the Energy Transition: What Can We Learn from Dutch Economists' Response to the Discovery of Natural Gas Reserves (1959–1977)?" *Energy Economics* 134 (June): 107636. https://doi.org/10.1016/j.eneco.2024.107636.

Deleidi, Matteo, Claudia Fontanari, and Santiago José Gahn. 2023. "Autonomous Demand and Technical Change: Exploring the Kaldor–Verdoorn Law on a Global Level." *Economia Politica* 40 (1): 57–80. https://doi.org/10.1007/s40888-023-00294-y.

Dellink, Rob, Jean Chateau, Elisa Lanzi, and Bertrand Magné. 2017. "Long-Term Economic Growth Projections in the Shared Socioeconomic Pathways." *Global Environmental Change* 42 (January): 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004.

Felipe, Jesus, Aashish Mehta, and Changyong Rhee. 2019. "Manufacturing Matters…but It's the Jobs That Count." *Cambridge Journal of Economics* 43 (1): 139–68. https://doi.org/10.1093/cje/bex086.

Folbre, Nancy. 2021. *The Rise and Decline of Patriarchal Systems: An Intersectional Political Economy*. Verso.

Folbre, Nancy. 2023. "Inflation and Paid Care Services in the U.S." *PERi Conference Paper*.

Fouquet, Roger. 2008. *Heat, Power and Light: Revolutions in Energy Services*. Edward Elgar Publishing Limited. papers3://publication/uuid/A0A65251-0F9E-4C22-A67F-7176AF450E17.

Fouquet, Roger. 2009. “A Brief History of Energy.” In *International Handbook on the Economics of Energy*. Edward Elgar Publishing. https://www.elgaronline.com/edcollchap/edcoll/9781847203526/9781847203526.00006.xml.

Fraser, Nancy. 2022. *Cannibal Capitalism: How Our System Is Devouring Democracy, Care, and the Planet—and What We Can Do about It*. Verso.

Goldar, Bishwanath, and Pilu Chandra Das. 2024. “Share of Manufacturing in India’s GDP: Stagnant or Increasing?” *Structural Change and Economic Dynamics* 68 (March): 75–85. https://doi.org/10.1016/j.strueco.2023.10.004.

Gomellini, Matteo, and Gianni Toniolo. 2017. “The Industrialization of Italy, 1861–1971.” In *The Spread of Modern Industry to the Periphery since 1871*, edited by Kevin Hjortshøj O’Rourke and Jeffrey Gale Williamson. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198753643.003.0006.

Haraguchi, Nobuya, Charles Fang Chin Cheng, and Eveline Smeets. 2017. “The Importance of Manufacturing in Economic Development: Has This Changed?” *World Development* 93 (May): 293–315. https://doi.org/10.1016/j.worlddev.2016.12.013.

Hauge, Jostein. 2018. “Manufacturing Still Matters: Five Reasons Why the IMF Is Wrong.” The Conversation, June 19. http://theconversation.com/manufacturing-still-matters-five-reasons-why-the-imf-is-wrong-96163.

Hauge, Jostein. 2023. “Manufacturing-Led Development in the Digital Age: How Power Trumps Technology.” *Third World Quarterly* 44 (9): 1960–80. https://doi.org/10.1080/01436597.2021.2009739.

Henriques, Sofia Teives, and Astrid Kander. 2010. “The Modest Environmental Relief Resulting from the Transition to a Service Economy.” *Ecological Economics*, Special Section: Ecological Distribution Conflicts, vol. 70 (2): 271–82. https://doi.org/10.1016/j.ecolecon.2010.08.010.

Hermansen, Erlend A. T., Elin L. Boasson, and Glen P. Peters. 2023. “Climate Action Post-Paris: How Can the IPCC Stay Relevant?” *Npj Climate Action* 2 (1): 1–8. https://doi.org/10.1038/s44168-023-00058-1.

Hofferberth, Elena. 2025. “Post-Growth Economics as a Guide for Systemic Change: Theoretical and Methodological Foundations.” *Ecological Economics* 230 (April): 108521. https://doi.org/10.1016/j.ecolecon.2025.108521.

International Labour Organization. 2026. “ILO Modelled Estimates Database, ILOSTAT.” https://ilostat.ilo.org/data/.

IPCC. 2022. *Climate Change 2022: Mitigation of Climate Change*. Cambridge University Press.

Jewell, Jessica, and Aleh Cherp. 2023. “The Feasibility of Climate Action: Bridging the inside and the Outside View through Feasibility Spaces.” *WIREs Climate Change* 14 (5): e838. https://doi.org/10.1002/wcc.838.

Johnson, Paul, and Chris Papageorgiou. 2020. “What Remains of Cross-Country Convergence?” *Journal of Economic Literature* 58 (1): 129–75. https://doi.org/10.1257/jel.20181207.

Jones, Nathalie, Claire O'Manique, Adam McGibbon, and Kate DeAngelis. 2024. *Out With the Old, Slow With the New: Countries Are Underdelivering on Fossil-to-Clean Energy Finance Pledge*. International Institute for Sustainable Development.

Kaldor, Nicholas. 1966. *Causes of the Slow Rate of Economic Growth of the United Kingdom: An Inaugural Lecture*. Cambridge University Press.

Kander, Astrid, Paolo Malanima, and Paul Warde. 2014. *Power to the People: Energy in Europe over the Last Five Centuries*. Princeton University Press. https://doi.org/10.23943/princeton/9780691143620.001.0001.

Keen, Steve, Timothy M. Lenton, Antoine Godin, Devrim Yilmaz, Matheus Grasselli, and Timothy J. Garrett. 2022. "Las estimaciones erróneas de los daños del cambio climático." *Revista de Economía Institucional* 24 (46): 249–98. https://doi.org/10.18601/01245996.v24n46.13.

Koomey, Jonathan, Zachary Schmidt, Holmes Hummel, and John Weyant. 2019. "Inside the Black Box : Understanding Key Drivers of Global Emission Scenarios." *Environmental Modelling and Software* 111 (August 2018): 268–81. https://doi.org/10.1016/j.envsoft.2018.08.019.

Kruse, Hagen, Emmanuel Mensah, Kunal Sen, and Gaaitzen de Vries. 2023. "A Manufacturing (Re)Naissance? Industrialization in the Developing World." *IMF Economic Review* 71 (2): 439–73. https://doi.org/10.1057/s41308-022-00183-7.

Kuznets, Simon. 1966. *Modern Economic Growth : Rate, Structure, and Spread*. With Internet Archive. New Haven : Yale University Press. http://archive.org/details/moderneconomicgr0000kuzn_z5q7.

Kuznets, Simon Smith. 1971. *Economic Growth of Nations; Total Output and Production Structure*. With Internet Archive. Cambridge, Mass. : Belknap Press of Harvard University Press. http://archive.org/details/economicgrowthof0000kuzn.

Labriet, Maryse, Santosh R. Joshi, Marc Vielle, et al. 2015. "Worldwide Impacts of Climate Change on Energy for Heating and Cooling." *Mitigation and Adaptation Strategies for Global Change* 20 (7): 1111–36. https://doi.org/10.1007/s11027-013-9522-7.

Lamb, William F., and Narasimha D. Rao. 2015. "Human Development in a Climate-Constrained World: What the Past Says about the Future." *Global Environmental Change* 33 (July): 14–22. https://doi.org/10.1016/j.gloenvcha.2015.03.010.

Leimbach, Marian, Elmar Kriegler, Niklas Roming, and Jana Schwanitz. 2017. "Future Growth Patterns of World Regions – A GDP Scenario Approach." *Global Environmental Change* 42 (January): 215–25. https://doi.org/10.1016/j.gloenvcha.2015.02.005.

Liddle, Brantley, and Hillard Huntington. 2021. "There's Technology Improvement, but Is There Economy-Wide Energy Leapfrogging? A Country Panel Analysis." *World Development* 140: 105259–105259. https://doi.org/10.1016/j.worlddev.2020.105259.

Lubbers, R. F. M., and C. Lemckert. 1980. "The Influence of Natural Gas on the Dutch Economy." In *The Economy and Politics of the Netherlands Since 1945*, edited by Richard T. Griffiths. Springer Netherlands. https://doi.org/10.1007/978-94-017-1382-5_4.

Magacho, Guilherme R., and John S. L. McCombie. 2018. “A Sectoral Explanation of per Capita Income Convergence and Divergence: Estimating Verdoorn’s Law for Countries at Different Stages of Development.” *Cambridge Journal of Economics* 42 (4): 917–34. https://doi.org/10.1093/cje/bex064.

Malm, Andreas. 2013. “The Origins of Fossil Capital: From Water to Steam in the British Cotton Industry.” *Historical Materialism* 21 (1): 15–68. https://doi.org/10.1163/1569206X-12341279.

Marx, Karl. 1867. *Das Kapital: Erster Band*. Otto Meissner.

Meinshausen, Malte, Jared Lewis, Christophe McGlade, et al. 2022. “Realization of Paris Agreement Pledges May Limit Warming Just below 2 °C.” *Nature* 604 (7905): 304–9. https://doi.org/10.1038/s41586-022-04553-z.

Mensah, Emmanuel, Solomon Owusu, Neil Foster-McGregor, and Adam Szirmai. 2023. “Structural Change, Productivity Growth and Labour Market Turbulence in Sub-Saharan Africa.” *Journal of African Economies* 32 (3): 175–208. https://doi.org/10.1093/jae/ejac010.

Millward-Hopkins, Joel, Julia K. Steinberger, Narasimha D. Rao, and Yannick Oswald. 2020. “Providing Decent Living with Minimum Energy: A Global Scenario.” *Global Environmental Change* 65 (November): 102168. https://doi.org/10.1016/j.gloenvcha.2020.102168.

Mork, Knut Anton, and Douglas E. Hall. 1980. “Energy Prices, Inflation, and Recession, 1974-1975.” *The Energy Journal* 1 (3): 31–63. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol1-No3-2.

Moyo, Theresa. 2016. “Promoting Industrialisation in Mauritius, South Africa and Botswana: Lessons for the Future.” *Africa Development* 41 (3): 3.

Mulugetta, Yacob, Youba Sokona, Philipp A. Trotter, et al. 2022. “Africa Needs Context-Relevant Evidence to Shape Its Clean Energy Future.” *Nature Energy* 7 (11): 1015–22. https://doi.org/10.1038/s41560-022-01152-0.

Nagy, Béla, J. Doyne Farmer, Quan M. Bui, and Jessika E. Trancik. 2013. “Statistical Basis for Predicting Technological Progress.” *PLOS ONE* 8 (2): e52669. https://doi.org/10.1371/journal.pone.0052669.

Ocampo, Jose Antonio, Codrina Rada, and Lance Taylor. 2009. *Growth and Policy in Developing Countries*. Cambridge University Press.

O’Neill, Brian C., Elmar Kriegler, Keywan Riahi, et al. 2014. “A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways.” *Climatic Change* 122 (3): 387–400. https://doi.org/10.1007/s10584-013-0905-2.

Owusu, Francis, and Abdi Ismail Samatar. 1997. “Industrial Strategy and the African State: The Botswana Experience.” *Canadian Journal of African Studies / Revue Canadienne Des Études Africaines* 31 (2): 268–99. https://doi.org/10.1080/00083968.1997.10751113.

Perkins, Dwight Heald, Rajah Rasiah, and Wing-Thye Woo. 2022. “Explaining Malaysia’s Past Economic Growth.” In *Malaysia’s Leap Into the Future: The Building Blocks Towards Balanced Development*, edited by Rajah Rasiah, Kamal Salih, and Cheong Kee Cheok. Springer. https://doi.org/10.1007/978-981-16-7045-9_2.

Perkins, Dwight Heald, and John P. Tang. 2017. "East Asian Industrial Pioneers: Japan, Korea, and Taiwan." In *The Spread of Modern Industry to the Periphery since 1871*, edited by Kevin Hjortshøj O'Rourke and Jeffrey Gale Williamson. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198753643.003.0008.

Pollitt, Hector, Jean-Francois Mercure, Terry Barker, Pablo Salas, and Serban Scrieciu. 2024. "The Role of the IPCC in Assessing Actionable Evidence for Climate Policymaking." *Npj Climate Action* 3 (1): 1–9. https://doi.org/10.1038/s44168-023-00094-x.

Pomeranz, Kenneth. 2000. *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Princeton University Press. https://doi.org/10.2307/j.ctt7sv80.

Rodrik, Dani. 2013. "Unconditional Convergence in Manufacturing *." *The Quarterly Journal of Economics* 128 (1): 165–204. https://doi.org/10.1093/qje/qjs047.

Rodrik, Dani. 2016. "Premature Deindustrialization." *Journal of Economic Growth* 21 (1): 1–33. https://doi.org/10.1007/s10887-015-9122-3.

Rodrik, Dani. 2018. "An African Growth Miracle?†." *Journal of African Economies* 27 (1): 10–27. https://doi.org/10.1093/jae/ejw027.

Sato, Hajime, and Hiroshi Kuwamori. 2024. "A Note on Premature Deindustrialization." *The Japanese Political Economy* 0 (0): 1–27. https://doi.org/10.1080/2329194X.2024.2367987.

Schurr, Sam H., and Bruce Carlton Netschert. 1977. *Energy in the American Economy, 1850-1975: An Economic Study of Its History and Prospects*. Greenwood Press.

Scott, Richard. 1994. *The History of the International Energy Agency, 1974-1994 : IEA, the First 20 Years*. With Internet Archive. Paris : OECD/IEA ; Washington, D.C. : OECD Publications and Information Centre [distributor]. http://archive.org/details/historyofinterna0000scot.

Semieniuk, Gregor. 2018. *Energy in Economic Growth: Is Faster Growth Greener?* Working Paper No. 208. Department of Economics, SOAS University of London, UK. https://econpapers.repec.org/paper/soawpaper/208.htm.

Semieniuk, Gregor. 2024. "Inconsistent Definitions of GDP: Implications for Estimates of Decoupling." *Ecological Economics* 215 (January): 108000. https://doi.org/10.1016/j.ecolecon.2023.108000.

Semieniuk, Gregor, Lance Taylor, Armon Rezai, and Duncan K. Foley. 2021. "Plausible Energy Demand Patterns in a Growing Global Economy with Climate Policy." *Nature Climate Change* 11 (4): 4. https://doi.org/10.1038/s41558-020-00975-7.

Semieniuk, Gregor, and Isabella M. Weber. 2020. "Inequality in Energy Consumption: Statistical Equilibrium or a Question of Accounting Conventions?" *The European Physical Journal Special Topics* 229 (9): 1705–14. https://doi.org/10.1140/epjst/e2020-900125-5.

Soergel, Bjoern, Elmar Kriegler, Isabelle Weindl, et al. 2021. "A Sustainable Development Pathway for Climate Action within the UN 2030 Agenda." *Nature Climate Change* 11 (8): 656–64. https://doi.org/10.1038/s41558-021-01098-3.

Solow, Robert M. 1956. "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economics* 70 (1): 65–94. https://doi.org/10.2307/1884513.

Stern, David I. 2020. "How Large Is the Economy-Wide Rebound Effect ?" *Energy Policy* 147 (July): 111870–111870. https://doi.org/10.1016/j.enpol.2020.111870.
Stern, Nicholas, Joseph Stiglitz, and Charlotte Taylor. 2022. "The Economics of Immense Risk, Urgent Action and Radical Change: Towards New Approaches to the Economics of Climate Change." *Journal of Economic Methodology* 29 (3): 181–216. https://doi.org/10.1080/1350178X.2022.2040740.
Tregenna, Fiona. 2009. "Characterising Deindustrialisation: An Analysis of Changes in Manufacturing Employment and Output Internationally." *Cambridge Journal of Economics* 33 (3): 433–66. https://doi.org/10.1093/cje/ben032.
Tregenna, Fiona. 2014. "A New Theoretical Analysis of Deindustrialisation." *Cambridge Journal of Economics* 38 (6): 1373–90. https://doi.org/10.1093/cje/bet029.
Tregenna, Fiona. 2016. "Deindustrialization and Premature Deindustrialization." In *Handbook of Alternative Theories of Economic Development*. Edward Elgar Publishing. https://www.elgaronline.com/display/edcoll/9781782544661/9781782544661.00046.xml.
Vasileiadou, Eleftheria, Gaston Heimeriks, and Arthur C. Petersen. 2011. "Exploring the Impact of the IPCC Assessment Reports on Science." *Environmental Science & Policy* 14 (8): 1052–61. https://doi.org/10.1016/j.envsci.2011.07.002.
Way, Rupert, Matthew C. Ives, Penny Mealy, and J. Doyne Farmer. 2022. "Empirically Grounded Technology Forecasts and the Energy Transition." *Joule* 6 (9): 2057–82. https://doi.org/10.1016/j.joule.2022.08.009.
Weber, Isabella M. 2021. *How China Escaped Shock Therapy: The Market Reform Debate*. Routledge.
Winkler, Deborah E., Hagen Kruse, Luis A. Aguilar Luna, and Maryla Maliszewska. 2023. "Linking Trade to Jobs, Incomes, and Activities : New Stylized Facts for Low- and Middle-Income Countries." *Policy Research Working Paper* 10635. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/en/099813412112341111.
Wolfram, Catherine, Orie Shelef, and Paul Gertler. 2012. "How Will Energy Demand Develop in the Developing World?" *Journal of Economic Perspectives* 26 (1): 119–38. https://doi.org/10.1257/jep.26.1.119.
World Bank Group. 2021. "Country on a Mission: The Remarkable Story of Bangladesh's Development Journey." https://www.worldbank.org/en/news/immersive-story/2021/09/16/country-on-a-mission-the-remarkable-story-of-bangladeshs-development-journey.
Wrigley, E. A. 1962. "The Supply of Raw Materials in the Industrial Revolution." *The Economic History Review* 15 (1): 1–16. https://doi.org/10.1111/j.1468-0289.1962.tb02224.x.
Wrigley, E. A. 2010. *Energy and the English Industrial Revolution*. Cambridge University Press. https://doi.org/10.1017/CBO9780511779619.
Young, Alwyn. 1991. "Learning by Doing and the Dynamic Effects of International Trade." *The Quarterly Journal of Economics* 106 (2): 369–405. https://doi.org/10.2307/2937942.

## Appendix

For China and Vietnam, it is instructive to begin the accounting later, after the countries had transitioned their national accounting systems to the System of National Accounts 1993, and away from the Material Product System. This is in 1997 for China, and the early to mid 2000s in Vietnam. The shorter periods in Fig. A1 confirms China's move to a post-structural transformation pattern with structural change away from manufacturing, and reaffirms Vietnam's structural transformation. Sweden, like the United States, has a consistent series of manufacturing that spans both world wars, allowing a look at its pattern in the first half of the 20th century, which shows a continuous structural transformation.

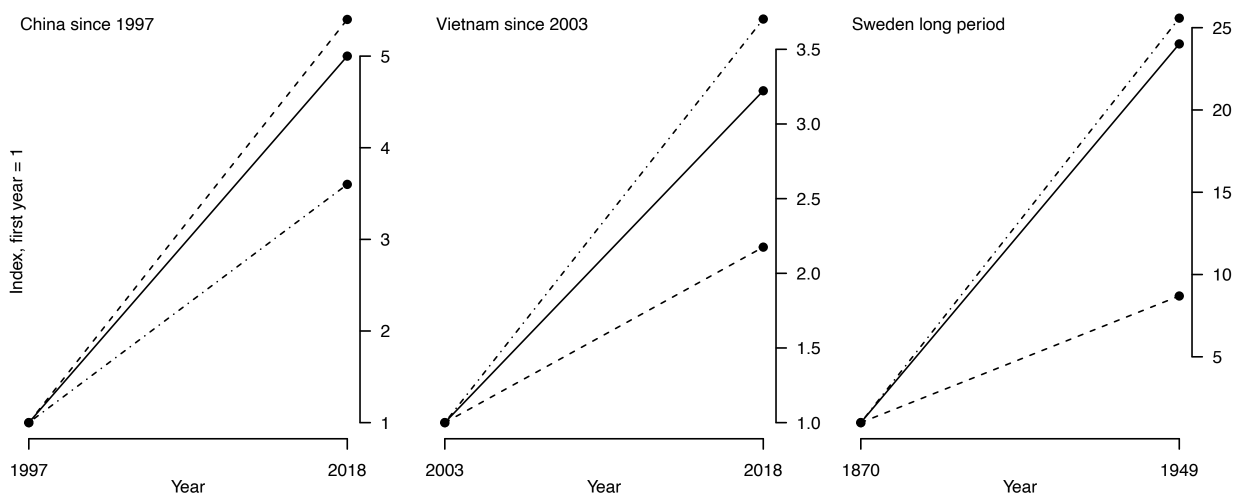



Fig A1 | Additional historical periods for China, Vietnam and Sweden. Manufacturing solid, GDP dashed and primary energy dot-dashed lines.

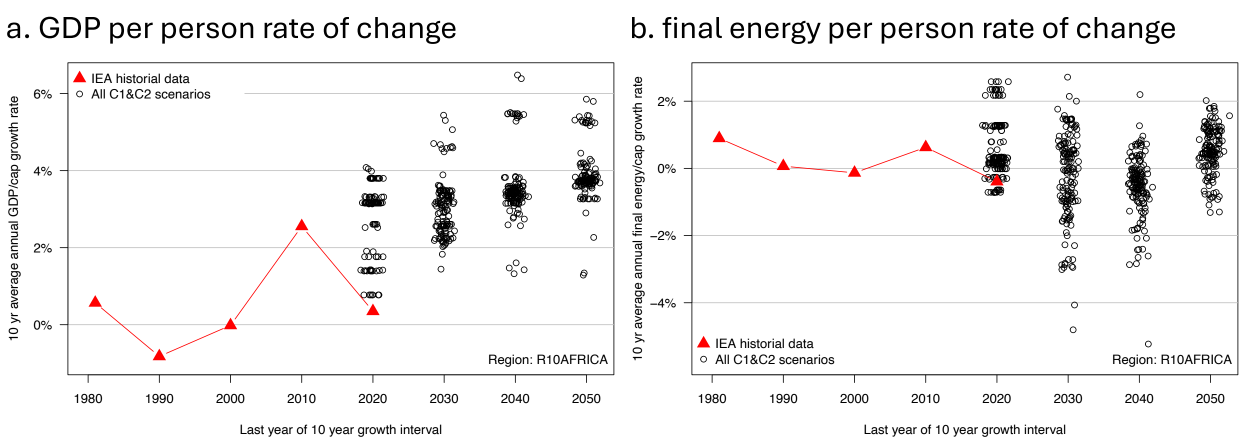



Fig A2 | Compound annual growth rates over the previous 10 years in GDP and final energy for all C1 & C2 scenarios for the Africa region.

## Imprint

**Publisher**
Macroeconomic Policy Institute (IMK) of Hans-Böckler-Foundation, Georg-Glock-Str. 18,
40474 Düsseldorf, Germany, phone +49 211 7778-312, email imk-publikationen@boeckler.de

**IMK Working Paper** is an irregular online publication series available at:
https://www.imk-boeckler.de/de/imk-working-paper-15378.htm



ISSN 1861-2199