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Michael G. Pollitt

Abstract

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Green growth and net zero policy in the UK: some conceptual and measurement issues[1]

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October 2022

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1. Introduction

Climate change remains one of the biggest and most complicated issues facing the modern world. Reducing emissions greenhouse gases (GHG) requires a major policy response that alter energy mix (high- vs. low-emission sources) in order to mitigate the change in the global climate. Getting GHG emissions down to zero (net) by 2050 is the stated policy of the UK and the European Union and net zero targets have been announced by China (by 2060) and India (by 2070). There is a renewed attention on net-zero emissions energy systems to achieve deep decarbonization of the power sector as the sector will play a fundamental role in decarbonizing energy systems to lower emissions. One major strategy being championed to speed up the net zero transition of the energy system is a Green New Deal which is aimed at fuelling large-scale clean energy investments, with the purpose of stimulating continuous growth (Mastini et al., 2021).

Opinions are divided whether sustainable economic growth can be achieved in the face of such deep decarbonisation (Fankhauser and Jotzo, 2018; Neves, Marques and Fuinhas, 2018; Pollin, 2018). Nevertheless, national and international efforts are currently geared towards green growth as a panacea for the urgent climate change and economic challenges. Indeed, green growth builds on the concern for sustainable development which dates back several decades, which has generated a range of views around the role of conventional GDP growth in reducing poverty and inequality vs the short- and long-term health and environmental consequences of economic development driven by fossil fuel.

In recent years, the concept of green growth has been recognized by policymakers as sustainable growth that delivers win-win outcomes for society based on the assumption that it fosters environmental protection while at the same time speeds up (or does not reduce) the pace of economic growth. In essence, green growth primarily straddles both economic policy and sustainable development policy, and it is more desirable due to the potential complementarity between environmental preservation and economic growth, spurred by innovation and productivity. Thus, the increasing acceptance of the green growth concept rests on its tendency to circumvent the potential trade-offs between short-term economic benefits and future environmental sustainability (Bowen and Fankhauser, 2011; Jacobs, 2013). As such, the concept is popular among environmentalists and politicians.

Several definitions have been advanced to conceptualise green growth but there is no consensus given that these varied definitions originate from different philosophical, analytical and operational perspectives (Bowen and Hepburn 2014; Jacobs, 2013). In the same vein, Florino (2018) discusses several sources of influence on the emergence of the green growth concept arising from academic thinkers in the areas of ecological modernization, ecological economics, and its application in business eco-efficiency. Brand (2012) argues that green growth is potentially, if not inevitably, an oxymoron. Nevertheless, the description of green growth by multilateral development institutions is geared towards sustainable development, with different degrees of emphasis placed on sustainability. According to the Organisation for Economic Co-operation and Development (OECD), green growth implies "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD, 2011, p.18). Meanwhile, the World Bank describes green growth as "growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters" (World Bank, 2012, p.30). Although both the OECD and the World Bank definitions give prominence to growth, the OECD concept of green growth underscores a more stringent 'sustainability' level compared with the World Bank (2012) which is somewhat equivocal about the extent of environmental preservation.

Furthermore, the United Nations Environment Programme (UNEP) adopts 'green economy' instead of green growth and defines it as one that simultaneously grows income and improves human well-being 'while significantly reducing environmental risks and ecological scarcities' (UNEP 2011, p.16). This definition appears more encompassing in that it stresses the reduction of environmental impact and ecological scarcities, as well as 'rebuilding natural capital'. As a matter of fact, the term 'green economy' was first coined in a pioneering 1989 report commissioned by the United Kingdom Government and authored by a group of leading environmental economists, entitled *Blueprint for a Green Economy* (Pearce, Markandya and

Barbier, 1989)[2]. Although, green economy was not explicitly defined in the report. Against this background, UNEP advocated the notion of "green stimulus packages" following the financial crises and identified specific areas where large-scale public investment could kick-start a "green economy" to drive global recovery (Atkisson, 2012).

Academic definitions include Bowen and Hepburn (2014) who capture societal objectives and describe green growth as increases in GDP in the long-term and possibly short-term, without an associated reduction in aggregate natural capital. In broader terms, Smulders et al. (2014) define green growth as a call for steadying longer-term investments in sustaining environmental wealth with nearer-term needs for growth to reduce poverty. Meanwhile, operational definition of green growth is GDP growth without emissions growth i.e. an absolute fall in emission intensity. In effect, the concept of green growth is evolving, with more definitions emerging as the concept is considered ‘new and still somewhat amorphous’ as noted by Smulders et al. (2014, p. 423).

The concept of green growth can be broadly grouped into two based on the perspectives of the proponents of green growth (Blaxekjaer, 2012). One concept of green growth advocates poverty reduction and global equity. This is well aligned with the UN Sustainable Development Goal (SDG) as it holds the potential of promoting income distribution and job creation through complementing environmental policies with social policy measures so as to reduce inequality and unemployment. The second concept places high priority on transformation in industry and energy, with public-private collaboration. This concept of green growth is hinged on the combination of energy policies and innovations incentives aimed at enhancing labour productivity and energy efficiency. It emphasizes the scaling up of cleaner energy sources in power generation as well as an increase in the proportion of electricity in the total energy mix. Closely related to the first perspective is a green growth concept that emphasizes directing growth towards achieving equity and inclusion (OECD, 2012), especially in developing countries where a large percentage of the population are usually excluded from economic gains.

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[2] The authors were tasked to advise the UK Government on the possibility of a consensus definition to the term "sustainable development”.

1.1 The feasibility of green growth

Despite the growing convergence around the concept of green growth and its crucial role in the policy space, the plausibility of green growth is contentious due to the perceived difficulty of continued GDP growth that preserves aggregate natural capital. The mere fact that economic expansion results in production and consumption, energy use, urbanization, land and water use, habitat loss, etc, are grounds for skepticism about green growth. However, proponents of green growth such as OECD, the United Nations Environment Program (UNEP), and the World Bank argue that promoting green growth can enhance both environmental performance and economic well-being in the long-run, as well as in the short-run. On the contrary, critics (see Latouche, 2009; Martínez-Alier, et al., 2010; Kallis, 2011) argue that green growth is a type of growth that is slower and less appealing compared with standard GDP growth given that natural capital transformation into other forms of capital is considered as a key aspect of economic growth. In a somewhat ironic expression, Schmalensee (2012) posits that the possibility of a continuous growth that is short of stretching, and at an indefinite time, breaching ecological limits seems like a conceivably great thing. In other words, green growth is viewed from a seemingly contradictory light as conventional economic growth will ultimately have to be stifled due to the environmental constraints required for sustainable growth (Bowen and Hepburn; 2014). In addition, Skidelsky and Skidelsky (2012) criticize the green growth concept as it focuses on economic growth rather than other outcomes of green growth upon which its effect could be objectively evaluated such as increases in consumption possibilities, reductions in environmental degradation, improvements in health and leisure etc[3]. Nevertheless, maintaining long-term growth within ecological limits would depend, in part, on factor-augmenting technical-change directed towards countervailing resource depletion (Smulders et al., 2014).

At the core of green growth in the developed economies is a reduced reliance on fossil fuels and a switch away from these dirty fuels to alternative zero-carbon energy sources such as wind, solar, hydro or nuclear power. Although a green growth policy could take different dimensions, it would be accompanied by a cut in fossil energy use in order to stymie carbon emissions accumulation while preserving the stock of fossil resources (Smulders et al., 2014). Therefore, green growth as

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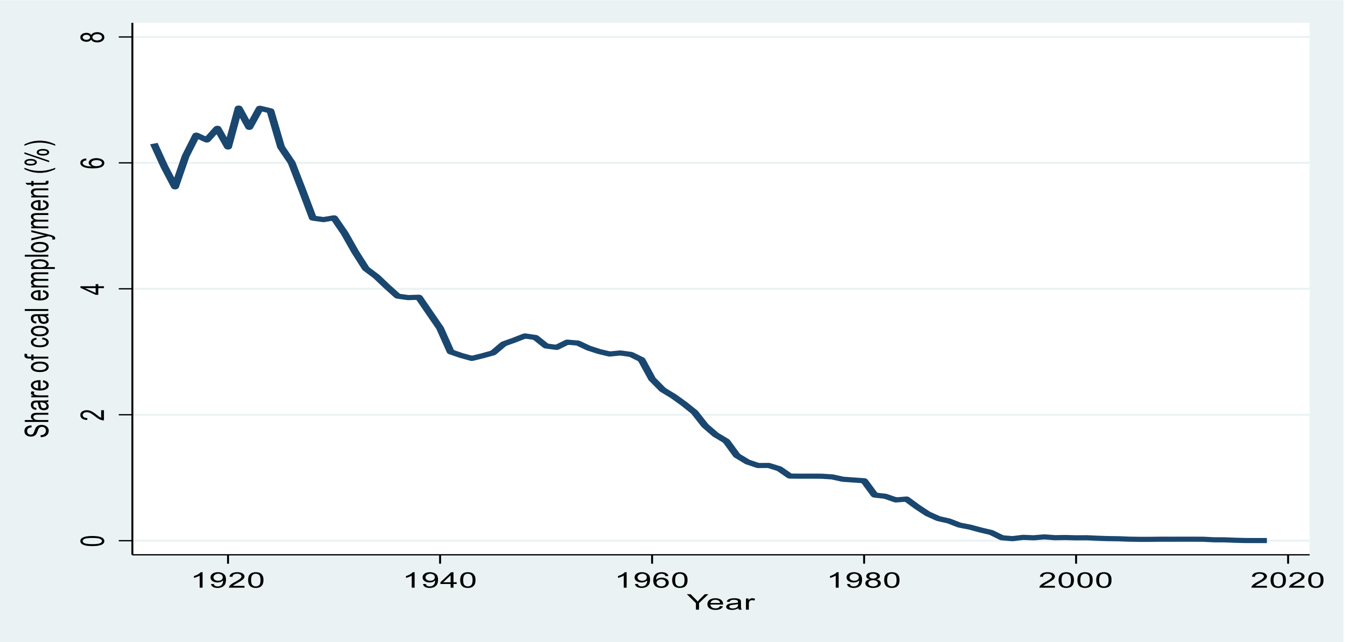
[3] Detailed discussion on some limitations of green growth has been provided by Jakob and Edenhofer (2014), especially from the standpoint of its failure to offer compelling explanation for how human well-being can be achieved in the face of environmental scarcities.

a form of GDP growth without emissions would mean absolute decoupling such that the rate of decline in emissions intensity is greater than the rate of GDP growth, as opposed to a relative decoupling which implies a decline in carbon emission intensity, usually at a slower rate. Put simply, decoupling GDP from the flow of emissions is different from decoupling economic activity from the environmental and material resource use on which continued economic expansion relies.

As an illustration of both how significant fossil fuels can be in an economy and how they can be phased out, the case of coal in the UK is a good case study. Coal is the most carbon intensive fossil fuel. It has lost its appeal in the UK and phasing it out completely is key to achieving the emissions reductions. Using coal employment as indicative of gross value added of coal (or contribution to GDP), Fig. 1 shows the share of coal production employment as a percentage of total employment in the UK, averaging 2.3% p.a. between 1913 to 2018. This indicator shows that, if anything, the value added of coal increased until mid-1920s, at a growth rate of 6.38% p.a. (if we use increase in employment as a measure of value added) but the share of coal employment plummeted steadily afterwards. Coal employment is now negligible and coal is barely used in the UK energy system, with coal contributing just 1% of the UK's energy mix in 2020 (ONS, 2021).

Fig. 1 : Share of coal employment in total employment in UK.



Source: BEIS and ONS Databases (2021)

However, switching away from coal has invariably given rise to high preference for gas as it is relatively cheaper than coal, partly due to carbon price per GWh being higher for coal (ONS, 2021). Coal did not run out in the UK, it was simply left in the ground as being too high cost to be worth extracting. At the global level, McGlade and Ekins (2015) argue that in order to meet global temperature targets under the Paris Agreement, about 33 percent of oil reserves, 50 percent of gas reserves and more than 80 percent of proved recoverable coal reserves must remain unburned. Attaining sufficient absolute decoupling in the United Kingdom that is capable of preventing climate breakdown would require a yearly reduction in carbon emissions at a rate well over 20%, alongside a net zero[4] target that should be attained not later than 2030, with negative emission technologies responsible for not more than 5% of the reduction in the emissions (Jackson, 2019). Therefore, oil, gas and energy intensive industries which are at the heart of stock markets and pay disproportionate dividends as well as whose operation and income rely on fossil fuel production or utilisation will suffer losses (Leaton, 2011; van der Ploeg and Rezai, 2020). Thus, the end of the carbon economy could imply financial value destruction.

Just as coal was once synonymous with the UK economy, apparently, green growth would be associated with a fundamental alteration to the composition of GDP, with less priority on increased material throughputs. Hence, green growth can be regarded as being axiomatic of a steady state economy where increasing throughputs in the economic system is no longer the objective (Daly, 1971). Thus, a steady-state economy opposes continuous GDP growth but maintains the lowest feasible flows of matter and energy consumption between the first and last stages of production. Therefore, decarbonising the economy would require addressing the problem of increasing resource throughput in order to drive economic growth. This raises the challenge of decoupling GDP growth from material throughput and carbon emissions in a relatively short period of time (Hickel and Kallis, 2020). This also reinforces the divided views about whether a permanent decoupling might guarantee an endless economic growth. Hence, the question remains whether green growth is a guaranteed route to continuous economic growth or a route to economic value destruction.

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[4] Net zero emissions means that there is a balance between all anthropogenic greenhouse gas emissions removed from the atmosphere and their removal through natural and artificial sinks.

1.2 UK Green Industrial Revolution

Green industrial policy is currently on the front burner in the UK national programmes designed not only to fast-track economic recovery from the COVID-19 pandemic but also for promoting sustainable growth. This is in spite of the checkered history of industrial polices in the UK. Ill-fated attempts to rationalize UK electrical engineering in the 1960s (GEC), support the car industry in the 1970s (BL) and promote the computer industry in 1980s (ICL) are cases in point among several botched UK industrial policy actions on the pretext of supporting industries for the future. However, green industrial policy is premised on the need to complement environmental and energy policies with strategic measures to reduce inequality and unemployment in the country. The Ten Point Plan for a Green Industrial Revolution as set out by the UK Prime Minister in 2020 spans energy, transport and industry, including the mobilisation of government funding, amounting to £12 billion (HM Government, 2020). This represents an ambitious policy agenda that focuses on driving a green recovery, levelling up the country, and supporting jobs throughout the UK in the transition to a net zero economy by 2050. In general, the Plan is centered on the combination of energy policies and innovation incentives aimed at boosting labour productivity and energy efficiency.

In specific terms, the Ten-Point Plan are enumerated in points from 1-10 as follows; *advancing the offshore wind; driving the growth of low hydrogen; delivering new and advanced nuclear power; accelerating the shift to zero emission vehicles; green public transport, cycling and walking; jet zero and green ships; green buildings; investing in carbon capture, usage and storage; protecting our natural environment; and green and finance and innovation*. In as much as the Plan recognises the reduction of the negative impact of businesses and human activities on the environment, the scaling up of cleaner energy sources in power generation as well as the enormity of the task required to decouple the economy from fossil fuels consumption, on the back of which the British economy has been growing since the first industrial revolution, there remains some valid concerns about the ability of the Plan to facilitate any far-reaching green industrial revolution in the country. It is doubtful, if not unlikely, that some of the Plan's objectives like promoting green public transport, cycling and walking, greener buildings and protecting our natural environment are going to promote British economic growth. If anything, they are about non-market activity and efficient uses of existing assets. On other elements of the Plan, there is no evidence that the UK industry is well placed to benefit from first mover investments in hydrogen, nuclear power and carbon capture, usage and storage which are projected to facilitate the green growth as these technologies all require scale for success, which may be best realized in other countries.

Furthermore, green policies incidentally affect labour markets via supply chain disruption and reduction in overall demand (Bowen and Kuralbayeva, 2015). It is widely acknowledged that green jobs is connected with potential job losses in traditional carbon-intensive sectors, particularly in sectors such as oil and gas due to the necessary decline (under net zero) in demand for their goods or services arising from the contraction of fossil fuel-intensive activities. Although the Plan is expected to create other jobs in carbon-neutral industries to outweigh the total job lost, workers in the carbon-intensive sectors will need to adapt and potentially transition to these new sectors, with significant transition costs. Studies have shown that the UK oil and gas sector lost over 70,000 direct jobs in addition to those in the supply chain between 2014 and 2017, with about 80,000 workers projected to exit the sector between 2018 and 2035 as result of natural attrition (OPTICO, 2018).

In addition, not many jobs can be created in new ‘green industries’ i.e. economic activities that seek to minimize impact to the environment. The International Energy Agency (IEA, 2020, p.40) provides some perspectives into this by separating construction and manufacturing jobs created into two types of measures: long-lived infrastructure - where jobs are given per million dollars of capital investment from government or private sources; and spending on final demand of energy or energy devices - where jobs are given per million dollars spent on final products. Supposedly, renewables are more labor-intensive than conventional energy, especially at the construction, manufacturing, and installation stage. However, with the exception of solar PV, IEA (2020, p.40) shows that renewable projects create the least jobs, between 1-2 jobs per million dollars of capital investment. The sectors with highest jobs per million dollars of investment are energy efficiency in buildings and industry together with solar PV, with an average between 10-15 jobs for every million dollars created by these sectors, perhaps due to lower unit labour costs, as well as lower capital costs.

Meanwhile, a plethora of studies on employment creation in the energy sector, including jobs in renewable energy, have been reviewed by Kammen at al. (2004), Wei et al. (2010), and Bacon and Kojima (2011), and their findings have been inconclusive. For instance, Wei et al. (2010), shows that renewable energy and low-carbon sectors generate more jobs per unit of energy delivered than the fossil fuel-based sector, with solar photovoltaics (PV) creating the most jobs per unit of electricity output, a position supported by Pollin et al. (2008). However, Lambert and Silva (2012) faulted the reliability of this assumption in their studies. Arguably, capital intensive renewables would imply higher input costs at time of lower revenues and hence lower measured TFP growth (of which more below).

2. Circular economy and green growth

The efficient use of limited natural resources has been considered as one of the potential solutions to end decades of consumer-driven economic expansion and climate change. Government policies like subsidies, regulations, and carbon pricing are therefore being directed toward cleaner technologies to sufficiently spur green growth. Low-carbon technologies such as installed solar PV capacity stood at 707 GW globally and combined on/offshore wind energy capacity amounted to 1418 GW in 2020 (BP, 2021). However, a major drawback associated with the growth of some renewable energy technologies and the proliferation of information and communication technologies associated with digitalisation is the increasing critical materials' consumption (Knoeri et al., 2013; Deetman et al., 2018). In other words, the rapid deployment of clean energy technologies as part of energy transitions means a significant rise in demand for certain rare minerals. Also, wind turbines have a typical operational lifespan of 20-25 years from commissioning, generating large volume of composite material waste from end-of-life blades when decommissioned (Leahy, 2019; Jensen et al., 2020) and this waste generation is a serious problem due to the type of materials used and their complex composition (Jensen and Skelton, 2018). Hence, the continuous use of minerals and elements essential for the low-carbon transition could possibly exacerbate social and environmental challenges (Sovacool et al., 2020). For example, demand for materials is projected to increase by 87,000% for electric vehicles, 1,000% for wind power, and 3,000% for photovoltaics (PV) between 2015 and 2060 (Sovacool et al., 2020). The dearth of material has also been linked to information and communication technologies

(ICT) growth (PWC, 2011). Although, efficiently priced investments in new technologies may efficiently curtail GHG emissions, but the production patterns of firms and economy are linear in nature, typically of a production–consumption–waste model where natural resources are used up and ecosystems are being destroyed, otherwise known as linear "take-make-use-dispose" economy (Lieder and Rashid, 2016, Stahel, 2016, Walzberg et al. 2021). Thus, switching away from fossil fuels may give rise to new resource constraints.

The friction between economic and ecological interests could be reconciled by implementing a so-called "circular economy" which provides concrete solutions to prevent further ecological degradation. The circular economy underscores an economic development with the minimum amount of harmful environmental impacts (Mavi & Mavi, 2019). Circular economy aims to foster economic prosperity followed by environmental quality, and its impact on social equity and future generation, enabled by business model and consumers. The origins of the circular economy can be traced to Boulding (1966); "*The Economics of the Coming Spaceship Earth*". Boulding (1966) conceptualises the earth as a single spaceship with limited reservoirs of anything, either for extraction or for pollution. More precisely, Boulding (1966) identifies the difference between the Cowboy economy and the Spaceman economy. The 'Cowboy economy' represents infinite horizons where more of both production and consumption are a good thing. The 'Spaceman economy' is where the economy is closed and can only rely on its existing capital and labour stock and its accumulated knowledge. In this economy more production and consumption are not necessarily possible or desirable. Thus, economic horizons are strictly finite, but success is measured in terms of "the nature, extent, quality, and complexity of the total capital stock" as opposed to economic throughput (Boulding, 1966, p. 9). This is analogous to Daly (1971) which considers the idea of the 'steady state' economy- one that stabilizes at a level consistent with planetary capacities - where increasing throughput in the economic system is no longer the objective. Daly (1991) compares the earth to a boat sinking because it is bearing too much weight of resource consumption.

A contemporary definition of circular economy is proposed by Geissdoerfer et al. (2017, p.759) who define the circular economy as "a regenerative system in which resource input and waste emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops"[5]. While the linear economy adopts the "take, make, use and dispose" perspective (Lieder and Rashid, 2016, Stahel, 2016), circular economy focuses on the 4R of reducing, reusing, recycling, and recovering materials[6] in production–consumption activities (Kirchherr et al., 2017; Anastasiades et al., 2020; Dyer et al., 2021). A circular economy has been estimated to potently generate about 1 trillion US$ globally per annum more GDP than the linear economy (Korhonen et al., 2018). More recently, the idea of the circular economy is gaining traction as a sustainable strategy for reducing waste and enhancing resource efficiency in many countries in the world including the United Kingdom, European Union (EU) and several national governments. For example, certain countries have developed strategies that are compatible with circular economic activities such as Japan, Austria, Germany, and the Netherland (Heck, 2006) and China, (see, e.g., Yuan et al., 2006; Geng et al., 2012). The European Commission estimated that transitioning to a circular economy would generate 600 billion euros annually in terms of net materials cost saving for the EU manufacturing sector (Deselnicu et al., 2018), in addition to latent energy saving between 8 and 15% of EU primary energy consumption due to resource efficiency originating from the adoption of CE concepts (Mehlhart et al., 2016).

A key indicator of the circular economy is resource productivity (Geng et al; 2012, Blomsma and Brennan 2017), as measured by material reuse, recycling rate and the rate of waste[7] (Moriguchi, 2007, Geng et al; 2012). Resource productivity is important given that growth within the economy is driven by many factors, among which is increases in the efficiency of input consumption to produce outputs, including the resources used and the waste generated. Resource productivity quantifies the relationship between the size of the economy and total amount of natural resources directly used in an economy by businesses for economic production and by households. It is expressed by the amount of GDP generated per unit of direct material consumed i.e. the ratio of a country's GDP to the domestic consumption of materials. Resource productivity offers insights if

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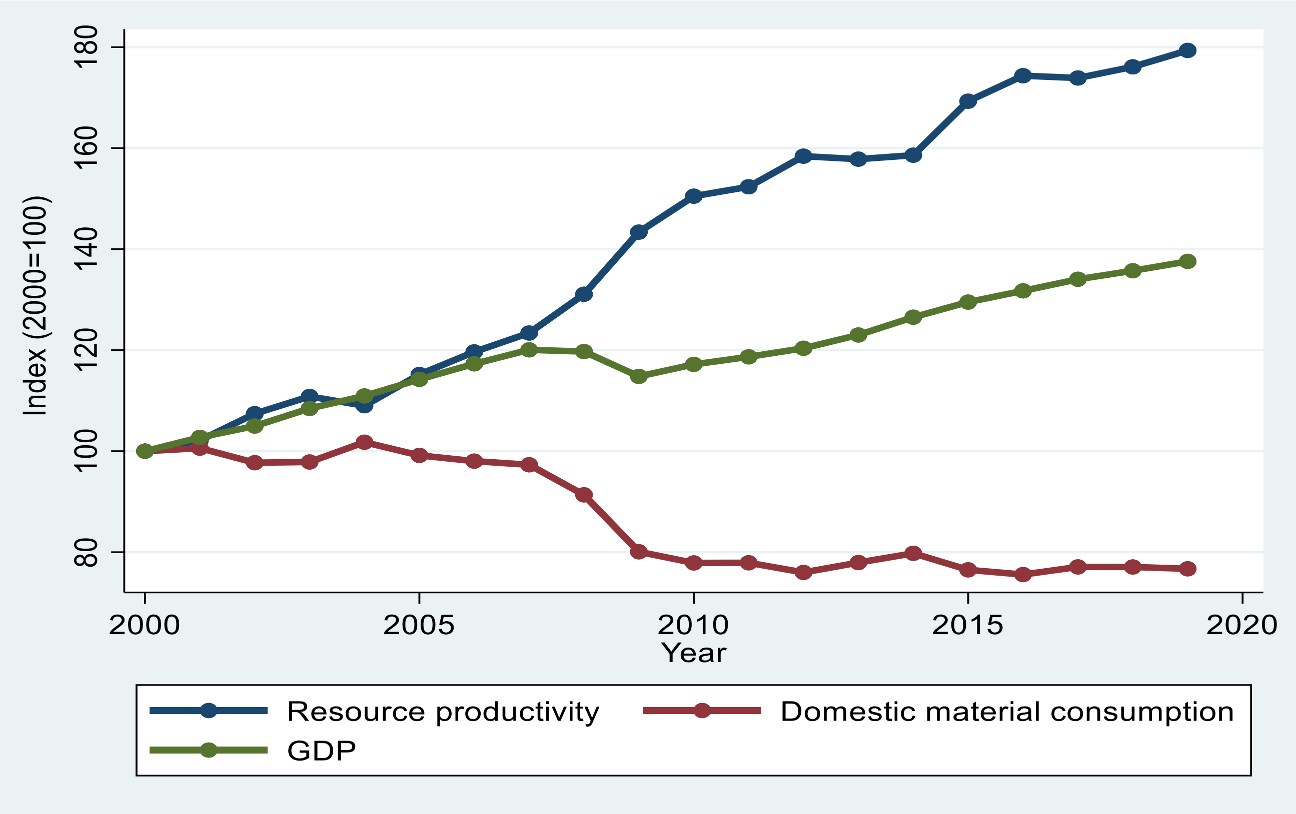
[5] Kirchherr et al. (2017) gathered about 114 circular economy definitions which were coded on 17 dimensions. However, this definition is the most appropriate for our purpose.

[6] The European Union Waste Framework Directive is a 4R framework which covers 'recover' as the fourth R as opposed the standard 3R framework (reduce, reuse, recycle) of circular economy.

[7] Arguably, resource productivity remains the standard indicators as there are contentions as to the widely accepted definition of other indicators such as recycling rate as well as data challenges associated with imported hidden flows. See Moriguchi, 2007 for details.

there is any meaningful progress in decoupling economic growth from natural resources depletion. The value of resource productivity will increase if the economy is growing at a faster rate than the consumption of raw materials. Fig 2 shows the index values of resource productivity, domestic material consumption and GDP from 2000-2019 based on data obtain from the European Statistics, Eurostat (2021). The resource productivity of the UK economy witnessed a staggering absolute growth of 83% for whole period, 2000 to 2019. The upsurge in resource productivity growth became quite remarkable in years during and following the global financial crisis 2007-2008, whereas the trend resource productivity remained relatively steady prior to these periods. While there was an appreciable decline in domestic material consumption, GDP increased, suggesting that there has been some decoupling of material use from rising output in the economy.

Fig 2: UK Index values of resource productivity, domestic material consumption and gross domestic product.



Source: European Statistics, Eurostat, 2021

The transition to circularity can promote positive economic and environmental changes (Ellen MacArthur Foundation, 2013), creating green growth, eco-innovation and resource efficiency (Avilés-Palacios and Rodríguez-Olalla; 2021, Das et al, 2019) but it cannot necessarily be guaranteed (Cheng et al., 2019). Although, there is a dearth of literature on the productivity implications of a transitions a circular economy, a few existing studies have focused on circular economy's impacts on growth in the European countries including Busu (2019); Busu and Trica (2019), Hysa et al; (2020).

Adopting an autoregressive distributed lag (ARDL) approach for a panel data of 28 EU member states a time frame from 2004 to 2017, Busu (2019) reveals that renewable energy sources have a positive influence on economic growth at the EU level. Busu and Trica (2019) also examine the sustainability of the circular economy based on different environmental indicators, and its impact on EU economic growth. They find out that circular economy, proxied by resource productivity, has a positive effect on economic growth across the EU. Chen et al. (2020) examines the impact of circular economy on the economic growth in Chinese cities using quasi-natural experiment approaches and find that the growth rate of GDP of the pilot cities decreases significantly due to the restraint by the circular economy policy compared to the pilot cities of non-circular economy. George et al. (2015) undertake a circular economy analysis by utilizing a simple model with a polluting input and a recyclable input to examine the impact of the recyclable resource on economic growth. They argue that contrary to the Environmental Kuznets Curve (EKC), environmental quality cannot be maintained or improved through economic growth, and advocate for the realisation of an improved environmental quality through an increase in either the environmental self-renewal rate or the recycling ratio. They conclude that economic growth is affected by the marginal product of the recyclable input, the recycling ratio, the cost of using the environmentally polluting input, and the level of pollution associated with the utilisation of the polluting input.

3. Gross domestic product: measurement issues

Gross Domestic Product (GDP) is a measure of economic value of the goods and services produced within an economy in a specific time period. GDP encompasses consumer goods like food and clothing, capital goods like new machinery and building, production for government, and adjustments for international trade. GDP as a macroeconomic aggregate which provides monetary information about short-term production is important for understanding the business cycle and to estimate long-run growth (Landefeld, 2000). There are three alternative approaches for measuring GDP in the National Accounts. First, the production or output approach which is the sum of the output of goods and services produced less the intermediate inputs used in their production (i.e. Gross Value Added). Second, the income approach which is the sum of incomes earned by households and businesses in the production of goods and services, plus any taxes (less subsidies) on production and imports. Third, the expenditure approach which is the sum of the final expenditure by households, businesses (capital formation and inventory accumulation) and the government, plus exports, less imports of goods and services.

Ideally, the three approaches should be the same as they are quantitively valid methods of measuring GDP, but, in practice, the measured GDP arising from these approaches can be sometimes different (Bean, 2016). Of course, various components within the National Accounts offer many useful insights either for distinguishing which industries/sectors are contributing most to the growth of aggregate output or productivity (production account) or to pin down the main sources of demand growth in the economy (expenditure accounts). Nominal GDP is measured in the prices existing in each year by grossing up the product of the price of each good and the corresponding quantity at the current prices. However, real GDP is obtained by using an estimate of the price change to deflate the nominal value, with prices held constant from year to year in order to even out the effect of inflation or deflation from output trend over time. Hence, price indices are very fundamental to regulating the composition of the flow of goods and in introducing the benefits of new and improved goods into the economy (Hulten and Nakamura, 2019). Net National Product (NNP) makes an adjustment to GDP by subtracting depreciation from investment, thereby including only net investment of total output. However, GDP is still a preferred measure of country's output because of the challenge in estimating depreciation, but gross investment can be estimated quite accurately (Nordhaus, 2021).

The scope of GDP is mainly influenced by the production boundary and the asset boundary between market and non-market production. While GDP relates to goods and services priced in markets, the non-market side of the boundary is largely ignored. In other words, the important costs associated with non-market activities and negative externalities that are not produced and exchanged in the markets are excluded from GDP. For example, the electricity produced and sold by an electric utility is included in GDP but the negative impacts on global warming associated with electricity production are not properly accounted for in GDP.

The production boundary includes transactions in goods and services on current account and explains the scope of national accounting concepts like production, income, consumption, and saving. Given that all incomes fall within the stream of value added generated by production, all production must be either domestically consumed or exported abroad or invested. The asset boundary covers assets held on capital account which reflects tangible and intangible assets and the financial assets and liabilities. Moreover, the non-marketed activity often occurs within household sector such as unpaid activities, home production and other non-market activities are not captured within the National Accounts basically due to the fusion of household production with consumption goods (Coyle, 2019). Hence, the accuracy of the conventionally measured GDP and, by extension, measures of aggregate productivity that stems from components of GDP growth, has been questioned. This has been subjected to the longstanding measurement debate as GDP is not a measure of welfare and does not capture economic inequality or sustainability, mentioned earlier.

According to Sichel (2019), there are two important issues pertaining to GDP measurement. First, getting accurate price indexes for adjusting nominal output and capital such that changes in the quality and variety of goods and services are correctly captured. Second, what GDP should measure and how should economic welfare can be measured. In reality, the challenge of quality change becomes all the more intractable as standard price deflators measure the prices of products that consumers buy as opposed to the cost of attaining a given level of economic well-being (Nordhaus, 1998). The unmeasured gains from quality improvements and the fact that consumers have witnessed vast number of digitally-enabled activities due to massive growth of the internet reflect the measurement problems in GDP, which is somewhat difficult to hedonically adjust for given the lack of prices for household digital intermediation services (Coyle, 2019) (e.g. Google searches). In addition, GDP has been described as an imperfect measure of economic welfare as it only accounts for the production measure while other important factors that influence living standards such as the natural environment, leisure, inequality, mortality, morbidity and crime are not properly accounted for (Jones and Klenow, 2016). Incorporating the welfare dimension into economic measurement facilitates an appraisal of the outcomes of changes in economic policies and evaluation of the results as well as providing the scope for concepts that describe the income distribution, such as poverty and inequality (Jorgenson, 2018).

Considering the fact that the problem with GDP is that it does not account for quality measurement, emissions and other non-market activities, an appropriate measure of output would adjust for quality improvement, incorporate essential non-market goods and investment and, in addition, correct for negative externalities. Several adjustments to GDP have been proposed in the literature on welfare measurement. Nordhaus and Tobin (1972) introduced a measure of economic welfare (MEW) which incorporates the components of consumption of GDP such as the value of leisure and nonmarket production activity which are normally excluded in the GDP. The MEW excluded inequality and the distribution of economic welfare. Other potential adjustments include pricing positive and negative externalities and adding and subtracting these values to total output, as proposed by Weitzman (1976). There are difficulties in computing the cost of emissions and other externalities due to data not being readily available and there being a range of prices to choose from. More recently, adjustments are being made to GDP include nonmarket dimensions of welfare which transcend the historic structure of the national accounts. To account for the impact of sustainability, an adjusted measure of GDP is being undertaken by the UK Office National Statistics (ONS) to incorporate the depletion of natural resources and the degradation of the environment to GDP. This is beyond conventionally measured GDP in order to harmonise Environmental Accounts with the National Accounts (Bean, 2016). By the same token, the World Bank provides a measure of sustainability using adjusted net saving (ANS) or genuine saving per capita which adjusts for resource depletion and environmental degradation and investment in human capital (Lange, Wodon, and Carey, 2018).

3.1 Productivity growth and measurement

Productivity growth is the portion of output growth that is not explained by the growth of labour and capital inputs, and it is usually attributed to contribution of technological progress[8]. TFP growth can calculated using different methods, among which are standard growth accounting methods. Theories about growth accounting methods and applications have evolved over time with some key influential studies from Abramovitz (1956), Solow (1957), Kendrick (1961), Jorgenson and Griliches (1967), Lichtenberg et al. (1987) and Jorgenson et al. (1987). Following Lichtenberg et al. (1987), we provide a simple set-up of the growth accounting approach based on the assumption that all factors are in equilibrium. Consider a production characterized by a two-factor production function:

$$Y(t) = A(t)\ F[K(t)\ L(t)] \tag{1}$$

where Y is value added, K is stock of physical capital, L is labour input, and A is a Hicks-neutral measure of technical change[9].

Assume a Cobb-Douglas production function:

$$Y(t) = A(t)\ .\ \Pi_i^2\ X_i(t)^{\beta_i} \tag{2}$$

where $X_1(t)$ equals $K(t)$, $X_2(t)$ equals $L(t)$, β_i the output elasticity of factor i. An index of TFP is defined as

$$TFP(t) = A(t) = \ Y(t)/\Pi_i^2\ X_i(t)^{\beta_i} \tag{3}$$

Taking the log of this equation and computing time derivatives yields

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[8] TFP growth was termed "the measure of our ignorance" by Abramovitz (1956).

[9] The TFP growth framework is based on value added instead of gross output, implying that intermediate inputs have been excluded from output, so that productivity growth can occur only through value-added.

$$T\dot{F}P/TFP = \dot{A}/A = \dot{Y}/Y - \sum_i^2 \beta_i(\dot{X}/X) \quad (4)$$

Intuitively, TFP growth can be referred to as a residual i.e., output growth minus the growth of the combined factor inputs.

Jorgenson et al. (1987) discuss the growth accounting method for productivity measurement based on a model of producer behaviours, while employing the rate of productivity growth to show the possibilities of changes in substitution over time. They introduce the dual to the model of production based on a function that gives the price of output as a function of the prices of intermediate input, capital input, labour input, and time[10].

Productivity is considered a key source of economic growth and sustained improvements in trend productivity growth are very important for a country's economic welfare. However, several studies have reported a slowdown in UK and other developed economies' productivity growth since 2008. For instance, Crafts and Mills (2020) show that the current productivity slowdown – even before the impact of COVID-19 – in the UK has led to the productivity level in 2018 being 19.7 per cent below the level it would have reached, had the pre-2008 trend path prevailed. What explains this slowdown is unclear and has been labelled a "productivity puzzle". Investigation has focused on the development and deployment of ICT (see, e.g. Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000, Jorgenson et al. 2006, Corrado et al., 2007). Nicoletti and Scarpetta (2003) takes another perspective on the issue; suggesting that the stringency of product market regulation and other competition enhancing policies might be responsible for the fall in productivity.

Lately, there have been a renewed shift in the productivity discourse towards the possible effects of environmental regulation on productivity in respect to the Porter Hypothesis, particularly on manufacturing firms performance.[11] Ajayi et al. (2020) take this further by examining the impact

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[10] See Jorgenson et al. (1987) for a detailed discussion on the sectoral productivity growth based on production functions for each industrial sector, giving output as a function of intermediate input, capital input, labour input, and time.

[11] See Venmans et al. (2020) for a more detailed review of recent studies on the environmental regulation and firm performance.

of decarbonisation policies on productivity in the electricity and gas sectors in the advanced countries, and confirm that a productivity slowdown does exist in the energy sector, and that the productivity puzzle appears to at least be partly due to more ambitious climate policy. This is interesting because these industries are currently at the forefront of policies to tackle climate change and this could occasion poor measured productivity performance.

However, the Office of National Statistics (ONS) is currently giving significant weight to the measurement issues often linked to the slowdown in productivity by adopting double deflation[12] as an appropriate deflator measurement. Simply put, double deflation requires that industry's gross output be deflated by the price of its output, while each input is deflated by its own price index (Oulton, 2004). Double deflation is important for gross domestic product (GDP) and industry gross value added (GVA) measures, and by extension for productivity growth. Stoneman and Francis (1994) argue that that double deflated value added was the superior concept to employ for the measurement of productivity among other alternative indicators of output growth indicators considered. The new GVA at the industry level arising from using this appropriate measurement caused large revisions to productivity growth rates in many industries and changes to the growth of whole economy GVA, thereby resulting in the size of the slowdown in productivity growth being a little smaller than previously measured (ONS, 2021), particularly for the UK manufacturing sector.

Although productivity growth was revised downward for many services industries when adjusting for double deflation, only one in four major manufacturing industries experience an upward revision in their productivity growth. While the productivity revision marginally changed for electricity and gas industries, there is a significant improvement in the productivity of telecommunications industry due the widening of the scope of Services Producer Price Index (SPPI) for Telecommunication Services, which includes broadband and mobile data.

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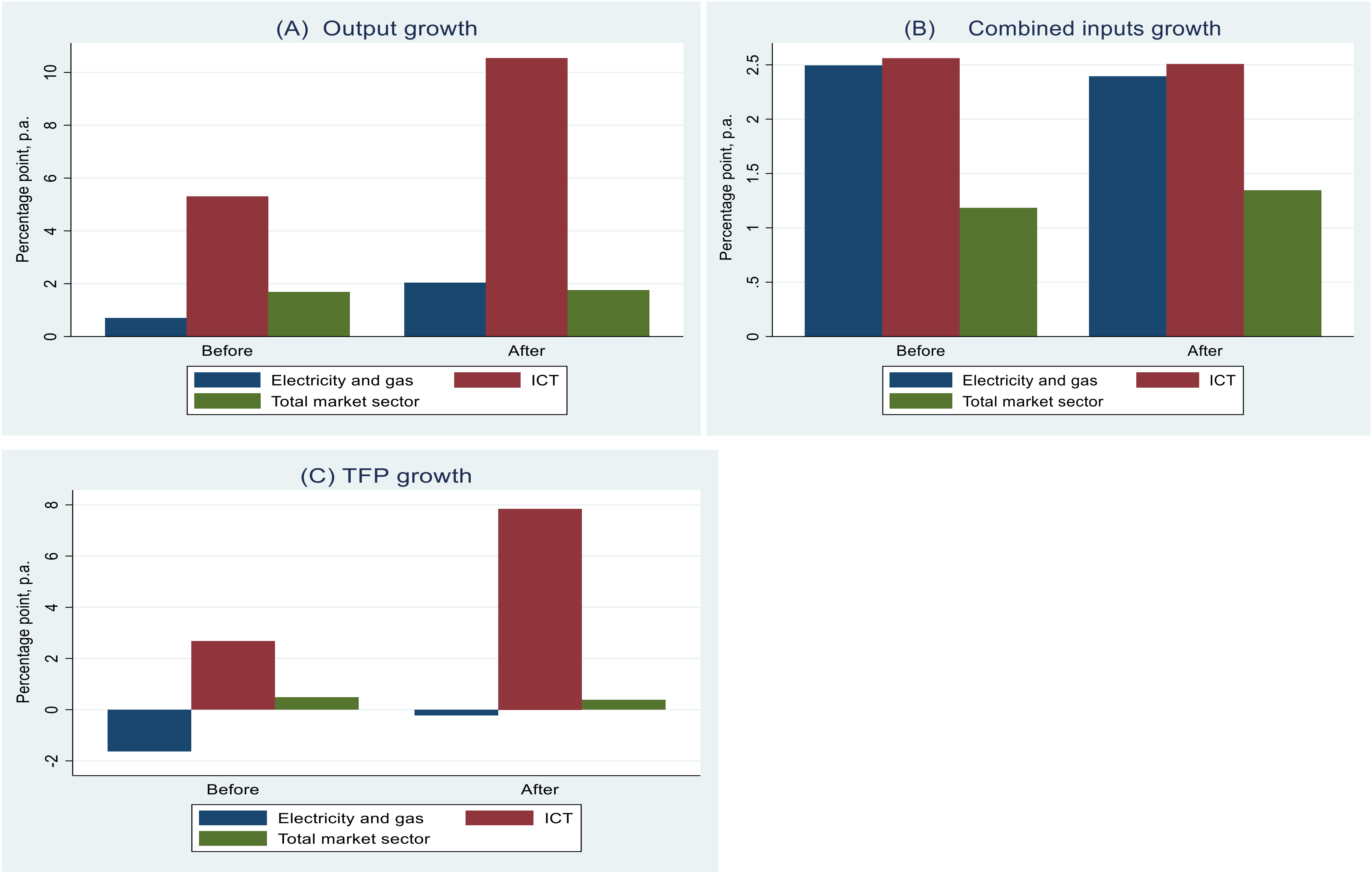
[12] Double deflation is a "method for calculating value added by industry chained volume measures, which takes separate account of the differing price and volume movements of input and outputs in an industry's production process" (ONS, 2021).

Fig. 3: Growth rates of input, output and productivity in the UK, 1997-2020.



Source: Office of National Statistics (2021)

Fig. 3 shows the input growth, output growth and productivity growth per annum from 1997 and 2020 for electricity and gas sector, information and telecommunication sector, and total market sector before and after the double deflation revision. Panel A shows that output growth before and after revision. The growth rate of output in ICT sector increased by almost a factor of two, from 5.31% p.a. before the revision to 10.54% p.a. after the revision, and electricity and gas sector output grew from 0.2% p.a. to 2.04% p.a. Though, the total market sector remains largely unaffected by the revision to gross valve added. Since double deflation is mainly applied to gross value added, input growth is virtually not affected across all the sectors as reported in Panel B. Meanwhile, in Panel C, there was a marginal improvement in the TFP growth electricity and gas sector from -1.63% p.a. to -0.22% p.a. whereas telecommunication TFP experienced a significant growth from 2.68% p.a. to 7.84% p.a. due to the revision. Total market TFP fell by 0.09% p.a. due to the revision, although still contributing positively to the growth of value added of the total economy during this period. It is intriguing to observe that despite the relatively fixed level of input growth rate in electricity and gas industries, TFP growth in still negative. This is not surprising as electricity and gas industries have experienced significant changes in their regulatory environment in terms of pressure on quality of service and environmental targets. The insights drawn from this analysis of input and output growth also underscore the argument that increases in capital intensity in the energy sector in a period when physical demand for energy has been actually falling is reducing productivity.

In contrast, the foregoing reveals some mapping issues when placed side by side with UK energy data. According to DUKES (2021), double deflation figures do not match the quantity of energy used. For example, electricity demand declined over the whole period, with an average growth rate of -0.13% p.a., whereas as electricity generation plant capacity has been on the increase over the same period, growing at 0.20% p.a. Coal generation plant capacity experienced a significant collapse but was augmented by a big increase in other types of generation capacity, particularly onshore and offshore winds energy capacity. Gas demand also experienced a negative growth of -1.21% p.a. over the period. Thus, there appears to be measured value added growth which goes beyond the observed contraction in physical units.

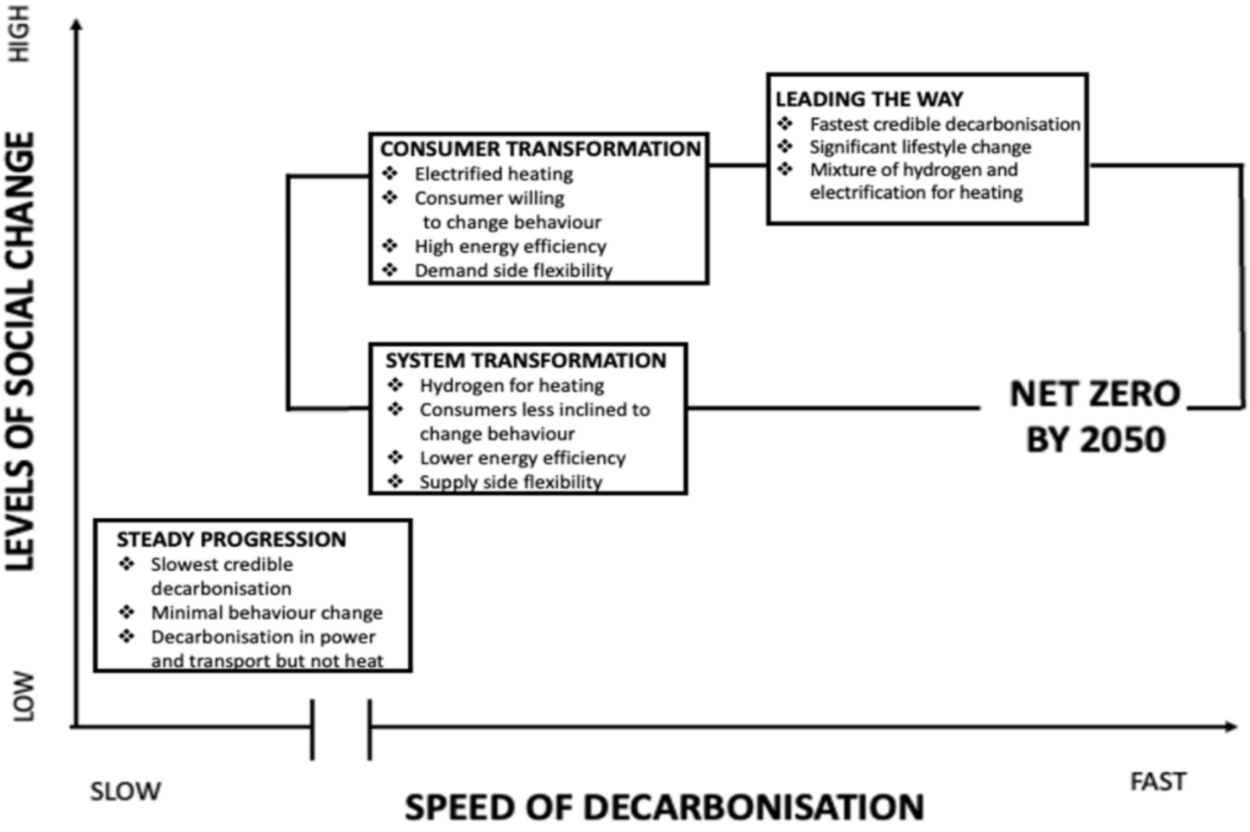
4. What are the prospects for energy sector productivity under net zero?

In this section we consider the prospects for green growth under net zero scenarios for the electricity sector in Great Britain. We have detailed projections of electricity supply and demand from National Grid Electricity System Operator (NG ESO). This allows us to show what it would take for productivity to grow in a sector where we have net zero projections for both electricity output and for the size of inputs into the electricity sector.

4.1 Future Energy Scenarios and energy sector productivity

NG ESO is the system operator of Great Britain's electricity grid. It sets out Future Energy Scenarios (FES) as a means of identifying a spectrum of separate, credible pathways to decarbonise the UK energy system in line with the objectives of 2050 net zero target (NG ESO, 2021). FES is borne out of shaping the future of the energy system considering the imminent deadline of the net zero target in relation to the time lag inherent in undertaking the large-scale investments in green infrastructure needed to facilitate the energy transition while being cognisant of key uncertainties in term of the roles of bioenergy, carbon capture and behavioural changes in reaching net zero. Decarbonizing the energy sector could be attained via different routes, with potential trade-off associated with each pathway. There are four scenario frameworks put forward in the FES 2021; Steady Progression, Consumer Transformation, System Transformation and Leading the Way, with each one considering the amount of energy that might be needed and how it could be sourced (NG ESO, 2021).

Fig 4: The Scenario Framework



Source: Adapted from NG ESO (2021, p. 5)

All scenarios in FES 2021 have higher levels of decarbonisation of the energy system compared to the present day. However, NG ESO (2021) shows that three of these four FES scenarios can ultimately reach net zero by 2050, namely Consumer Transformation, System Transformation and Leading the Way as shown in Fig. 4. On the one hand, both Consumer Transformation and System Transformation scenarios represents two separate routes of reaching net zero by 2050, either by changing the way we use energy or changing the way in which energy is generated or supplied. On the other hand, Leading the Way scenario emphasizes a mix of increasing consumer engagement and world-leading technology investments to accelerate emission reduction trajectory. Decarbonisation is fastest in Leading the Way scenario in which the UK reaches net-zero emissions in 2047 and attaining emission reduction by 103% of 1990 levels by 2050. The speed of decarbonisation is slowest in the Steady Progression scenario, and this scenario is short of the target of net zero, in which emissions are reduced by 73% of 1990 levels in 2050.

A significant rise in energy efficiency to scale down energy demand is expected in most FES scenarios, particularly in Consumer Transformation and Leading the Way scenarios. The increasing penetration of renewable energy sources in the energy systems is an important feature of the FES and hydrogen produced mainly from electrolysis powered by renewable electricity, as opposed to natural gas, would play a key role in decarbonizing most challenging areas such as industrial process in the Leading Way scenario. Due to the high intermittency associated with renewable energy sources, energy storage constitutes a major component for the flexibility of the system while demand side response and smart energy management would be deployed to manage higher peak electricity demands of the system. Natural gas continues to be depended on for domestic heating under Steady Progression scenario, whereas the adoption of Electric Vehicle (EV) is projected to grow to replace fossil-fuel powered vehicles. FES also covers interconnection capacity with other nations, with a projection for gradual net generation interconnector flows go into the UK up until 2027.

As the UK strives for net zero by 2050, there could be some unintended consequences with regards to productivity as output goes down relative to business as usual because of energy efficiency. In addition, the increasing costs of inputs required for investment in low- carbon technologies in the face of declining measured output could exacerbate the current productivity slowdown. To provide a context on the implication of rising input growth in the face of declining output growth on productivity for electricity supply, we simulate what might happen to TFP under the NG ESO System Transformation Scenario[13] of the Future Energy Scenarios 2021 (NG ESO, 2021).

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[13] Our simulation is based on the System Transformation scenario input and output data as the scenario shows the expected changes that would happen in the supply side of the energy system. It also represents one of the three routes under the net zero agenda where full decarbonation can be realised by 2050..

The System Transformation Scenario meets Net Zero in 2050. The scenario provides information on the total output of electricity (in TWh), total input of electricity capacity (in GW) and total fossil fuel capacity (in GW) in each year from 2020 to 2050. In addition, we also have information on the value added in the electricity sector from the ONS[14] and specifically on fuel costs from DUKES[15] for 2020. This gives us 2020 electricity revenue (£37,420m) which is divided between value added (£23,106m) and bought in materials and services (£14,314m). Of the bought in materials and services the fuel costs are estimated to be £6,330m. This cost might be saved by switching to zero fuel cost technologies. Next we divide the value added between capital and labour inputs using the KLEMS 2016 values for capital and labour contributions to value added. These divide value added: 69% to capital and 31% to labour. This gives starting values for capital, labour and fuel inputs in 2020. We can now simulate TFP under various assumptions from 2020 to 2050. We report the summary information and results for the three decades to 2050 in Table 1 (with the full annual results simulated in the Appendix, Table A1).

We start with observing from Rows 1 and 2 that decadal electricity output (in TWh) is expected to grow slowly to 2030 and faster in the 2030s and 2040s. Electrification of transport and heating speeds up rapidly in 2030s, raising gross output and value added. Rows 3 and 4 show that decadal capacity (in GW) grows rapidly throughout the entire period and most rapidly in the 2020s. Rows 5 and 6 suggest that fossil fuel use (as measured by fossil fuel GW capacity) will decline eventually, speeding up into the 2040s.

A simple measure of TFP would be subtract raw TWh output growth (Row 2) from raw GW input growth (Row 6). This shows the basic point that rapid increase in electrical capacity combined with slow growth of electrical output leads to negative TFP in the 2020s. However there is only low positive TFP growth in the 2030s and 2040s.

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[14] ONS (2021), GDP output approach-low level aggregates. Date superseded: 22 December,2021. https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/ukgdpolowlevelaggregates/current. See worksheet 2a (GVA in pounds millions, chained volume measures, UK, seasonally adjusted). SUT114: 35.1 (Electric power generation, transmission and distribution).

[15] DUKES (2021), Table 1.4.

TWh output denotes total generation by technology i.e., biomass, nuclear, fossil fuels, nuclear, wind, solar etc, and input is installed electricity generation capacity, plus storage and interconnection.

The computed TFP is a single-input measure given that capital i.e., installed capacity is the only measure of input we have got. In principle, this is an upper end of TFP (positive or negative) as we are not considering fuel and it is indicative of a case whereby as capital goes up and other factors go down, capital becomes the dominant input. There will be benefit to TFP if we are substituting capital for other factor inputs, which we simulate below.

We then offer two alternative measures of input growth to show the impact of fuel cost savings on input growth and TFP.

First, we start with our initial measures of capital, labour and fuel inputs in 2020 (£23,136m + £6,630m) and grow the first part in line with total GWs (as before) and the second part in line with total fossil fuel GWs, we end of with a new input growth rate (Row 8), which is lower than the raw GW growth rate (Row 4).[16] When we subtract this new growth rate from the raw TWh growth rate (Row 2) TFP increases but is still negative in the 2020s.

Second, we consider that only the capital input (£15,943m in 2020) now grows in line with raw GW growth and both labour and fuel inputs (£7,163m + £6,330m in 2020) fall in line with the decline in fossil fuel GW capacity. This suggests that previous adjustment was not generous enough to the benefits of declining fossil fuel use, though we do this at the risk of exaggerating the impact of declining fossil fuel use on labour inputs. Making this adjustment we see that total inputs grow much more slowly than previously (Row 9 vs Rows 8 and 4)). However, while this does lead to historically quite rapid productivity growth in the 2030s and 2040s, we still see productivity regress in the electricity sector in the 2020s.

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[16] It is worth saying we rather generously suggest all fuel costs will drop to zero as fossil fuel GWs drop to zero in 2050, which flatters TFP growth, as some of the current fuel cost is ‘electricity’ cost (DUKES, 2021, Table 1.4).

Several conclusions can be drawn from this simulation. First, the 2020s are a challenging decade for productivity growth in the electricity sector due to the combination of high input and low output growth. Second, the 2030s and 2040s look more promising as electrification increases (raising output growth) and fossil fuel (and labour) inputs decline. This is in addition to the unmeasured environmental benefits of decarbonisation. Third, this analysis suggests that the natural gas supply sector and new low carbon sectors (such as hydrogen) face their own productivity challenges. In natural gas, output may continue to decline, but the open question is can inputs be reduced as quickly as output to maintain TFP? In new sectors, to what extent will input growth have to lead, output growth, thus delaying positive TFP growth? Fourth, we have abstracted from what might happen to capital costs generation technologies and to the relative value of gross electrical output. ‘Cheaper’ capital and ‘more valuable’ output might increase the real growth of value added in the electricity sector, relative to real input growth, improving TFP growth. Double deflation of value added and combined inputs, might give rise to different measured TFP growth relative to our results which focus on underlying physical quantities.

Table 1: Decadal Electricity Sector TFP Simulation

Year	Row	2021-2030	2031-2040	2041-2050
Output (TWh)	1	298.71	393.83	563.44
Raw Output growth (% p.a.)	2	0.56	4.30	2.56
Input (GW)	3	122.79	201.14	267.33
Raw Input growth (% p.a.)	4	6.09	4.13	2.14
Fossil fuel (GW)	5	39.73	26.32	4.11
Fossil fuel growth (% p.a.)	6	0.41	-8.71	-36.94
Raw TFP growth (% p.a.)	7	**-5.53**	**0.17**	**0.42**
Input growth with weighted fuel saving (% p.a.)	8	5.07	3.04	1.73
Input growth with weighted fuel and labour saving (% p.a.)	9	3.80	1.30	0.93
TFP growth (with weighted fuel input saving) (% p.a.)	10	**-4.51**	**1.26**	**0.83**
TFP growth (with weighted fuel and labour saving) (% p.a.)	11	**-3.24**	**3.00**	**1.63**

5. Concluding thoughts

Green growth and a green industrial revolution are popular concepts. This paper has shown that they are difficult to pin down theoretically and in terms of measurement. Green growth is somewhat of an oxymoron, certainly in terms of conventional measurement. Advanced economies that minimise environmental impact will struggle to grow under conventional measures of GDP. Adjustments to GDP measurement might make a difference but it is difficult to imagine that that difference will be large, as we demonstrate in related papers (see Ajayi et al., 2021 and Ajayi and Pollitt, 2022, on electricity and gas network sectors).

Even when we look at an energy sector where total demand is expected to grow under net zero, namely, electricity, the challenge of raising TFP in a net zero world is clear. Capital input is expected to rise faster than output, for at least in the 2020s. Falling fuel costs could offset some of this, but overall inputs are expected to rise. Only a substantial and potentially GDP related rise in energy demand could offset this. For TFP to stay constant real output prices must rise faster than real input prices but this looks potentially challenging. The sharp rise in the share of fossil fuel in electricity sector costs which has been experienced since mid-2021 following the recovery of demand from the COVID-19 pandemic and the 2022 Russian invasion of Ukraine will mean that the switch away from fossil fuels will reduce the weighted rise in inputs, potentially increasing TFP growth (though demand will also be reduced).

Fundamentally, if net zero requires higher physical inputs and reduces physical output, it will be challenging to raise measured productivity. The only route to higher productivity in energy sectors will be a relative increase in the real value of unit output, and this will probably mean higher actual general inflation adjusted unit prices. Higher headline energy prices (relative to 2020), if caused, by net zero policy may be difficult to implement politically.

Our analysis implies we are going to need more careful measurement of the quality of output and non-price factors, as we are implementing net zero policies because of them. Making sure that measured productivity accurately reflects progress towards net zero goals is going to be important given the potential for current measures of productivity to misrepresent the overall welfare impact of net zero policies. Pursuing and measuring the circular economy and the extent to which we are actually re-cycling material and reaching true environmental sustainability looks more necessary. Lower cost low carbon technologies will be beneficial and can relatively reduce the inputs required across the economy to meet net zero, improving currently measured productivity.

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Appendix

Table A1: Annual Simulation, based on System Transformation Scenario

Year	Row	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Output (TWh)	1	297.0319	297.713	294.5353	293.2507	292.6536	292.8638	294.7061	297.7061	302.1282	307.5425	313.9614	322.2025	333.3886	344.9124	358.325	382.3482	396.4466	422.9629	441.3624	458.3162	478.0303	494.6648	510.9877	525.9975	544.2588	559.7096	578.7261	591.4046	603.9516	609.3225	615.3762
Output growth (%)	2		0.229297	-1.06737	-0.43615	-0.20359	0.0718	0.629063	1.017967	1.485404	1.792047	2.087169	2.624883	3.471737	3.456587	3.888692	6.704309	3.68731	6.688491	4.350158	3.841226	4.30142	3.479803	3.299787	2.937413	3.471756	2.838855	3.397575	2.190765	2.121551	0.8893	0.993507
Input (GW)	3	87.14857	94.88337	99.76942	104.935	110.4952	118.0637	121.8051	134.12	138.4511	148.2679	157.0776	159.6461	166.7382	176.1642	189.9636	201.8198	207.9741	219.0052	224.4011	230.5292	235.1213	239.8293	247.7608	254.5127	259.0818	264.3271	271.1887	275.7213	283.2875	287.1248	290.5074
Input growth (%)	4		8.875422	5.149538	5.177519	5.298656	6.849665	3.168984	10.11031	3.229267	7.090481	5.941736	1.635199	4.442356	5.65315	7.83328	6.241291	3.049422	5.304085	2.463826	2.730839	1.992016	2.002345	3.30716	2.725173	1.795216	2.024585	2.59588	1.671357	2.744153	1.354555	1.178087
Fossil fuel (GW)	5	35.61716	36.40446	36.75046	39.66824	40.97669	42.07559	42.3341	42.28228	39.89953	40.11166	36.774	34.89006	34.80909	34.47023	33.93874	30.37117	25.22405	21.08188	18.71224	15.29575	14.40732	11.18552	9.72879	5.95317	5.457851	4.299161	2.954961	0.735597	0.490913	0.2921	0.04219
Fossil fuel (%)	6		2.210454	0.950441	7.939446	3.298487	2.681759	0.614389	-0.1224	-5.63534	0.531665	-8.32093	-5.12301	-0.23207	-0.9735	-1.54188	-10.5118	-16.9474	-16.4215	-11.2402	-18.2581	-5.80833	-22.3622	-13.0234	-38.8087	-8.32026	-21.2298	-31.2666	-75.1064	-33.2633	-40.4986	-85.5563
Raw TFP growth	**7**		**-8.64612**	**-6.21691**	**-5.61367**	**-5.50225**	**-6.77787**	**-2.53992**	**-9.09234**	**-1.74386**	**-5.29843**	**-3.85457**	**0.989684**	**-0.97062**	**-2.19656**	**-3.94459**	**0.463018**	**0.637888**	**1.384406**	**1.886332**	**1.110387**	**2.309404**	**1.477458**	**-0.00737**	**0.21224**	**1.67654**	**0.81427**	**0.801695**	**0.519407**	**-0.6226**	**-0.46526**	**-0.18458**
		0.689374																														
Simulated changes in Inputs																																
Bought-in Input (£m)		14314																														
of which fuel cost (£m)		6330	6469.922	6531.415	7049.973	7282.515	7477.815	7523.758	7514.549	7091.078	7128.779	6535.598	6200.779	6186.389	6126.164	6031.706	5397.666	4482.903	3746.742	3325.602	2718.411	2560.517	1987.929	1729.033	1058.017	969.9875	764.0613	525.1656	130.7328	87.2467	51.91299	7.498148
of which non-fuel cost (£m)		7984																														
Capital input (at Total GW growth)		15943.14	17358.16	18252.03	19197.03	20214.21	21598.82	22283.28	24536.19	25328.53	27124.44	28736.11	29206	30503.43	32227.84	34752.33	36921.33	38047.22	40065.27	41052.41	42173.49	43013.59	43874.87	45325.88	46561.09	47396.96	48356.55	49611.83	50441.02	51825.2	52527.2	53146.02
Labour input (at Total GW growth)		7162.86	7798.594	8200.186	8624.752	9081.748	9703.817	10011.33	11023.51	11379.48	12186.34	12910.42	13121.54	13704.44	14479.17	15613.37	16587.84	17093.68	18000.34	18443.84	18947.51	19324.95	19711.9	20363.8	20918.75	21294.29	21725.41	22289.37	22661.91	23283.79	23599.18	23877.2
Labour input (at Fossil Fuel GW growth)		7162.86	7321.192	7390.775	7977.562	8240.701	8461.697	8513.684	8503.264	8024.075	8066.737	7395.509	7016.636	7000.353	6932.205	6825.319	6107.856	5072.734	4239.714	3763.163	3076.082	2897.413	2249.487	1956.528	1197.224	1097.612	864.5915	594.2634	147.9337	98.72605	58.74336	8.484705
Capital input + labour input + fuel input (with fuel saving)		29436	31626.68	32983.63	34871.75	36578.48	38780.45	39818.37	43074.24	43799.09	46439.57	48182.13	48528.31	50394.26	52833.18	56397.41	58906.84	59623.8	61812.36	62821.85	63839.41	64899.05	65574.7	67418.72	68537.86	69661.24	70846.02	72426.37	73233.66	75196.23	76178.29	77030.71
Capital input + labour input + fuel input (with fuel and labour saving)		29436	31149.27	32174.22	34224.56	35737.43	37538.33	38320.72	40554	40443.68	42319.96	42667.21	42423.41	43690.18	45286.21	47609.36	48426.85	47602.85	48051.73	48141.18	47967.98	48471.52	48112.28	49011.44	48816.33	49464.56	49985.21	50731.26	50719.69	52011.17	52637.86	53162
Revenue (£m)		37420																														
Value Added		23106																														
Input growth adjusting for fuel	8		7.442169	4.290522	5.724436	4.894285	6.019865	2.676396	8.176816	1.682785	6.028608	3.752323	0.718491	3.845074	4.839664	6.746202	4.449547	1.217104	3.670614	1.63316	1.619748	1.659862	1.041069	2.812092	1.659987	1.639064	1.700783	2.23068	1.11464	2.679875	1.305995	1.118981
Input growth adjusting for fuel and labour	9		5.820337	3.290419	6.37264	4.42041	5.039258	2.084253	5.82786	-0.27203	4.639233	0.820546	-0.5714	2.985996	3.653069	5.129934	1.717079	-1.70153	0.942962	0.186146	-0.35977	1.049741	-0.74112	1.868873	-0.39809	1.327896	1.052561	1.492551	-0.02281	2.546319	1.204904	0.995753
TFP growth with fuel saving	10		-7.21287	-5.35789	-6.16059	-5.09787	-5.94807	-2.04733	-7.15885	-0.19738	-4.23656	-1.66515	1.906392	-0.37334	-1.38308	-2.85751	2.254761	2.470206	3.017877	2.716997	2.221477	2.641559	2.438734	0.487696	1.277426	1.832692	1.138072	1.166895	1.076125	-0.55832	-0.4167	-0.12547
TFP growth with fuel and labour saving	11		-5.59104	-4.35779	-6.80879	-4.624	-4.96746	-1.45519	-4.80989	1.757435	-2.84719	1.266623	3.196281	0.485742	-0.19648	-1.24124	4.98723	5.38884	5.745529	4.164011	4.200994	3.251679	4.220927	1.430915	3.335506	2.14386	1.786294	1.905024	2.213574	-0.42477	-0.3156	-0.00225

Simulated, based on NG ESO (2021)