Energy and Productivity Briefing Note

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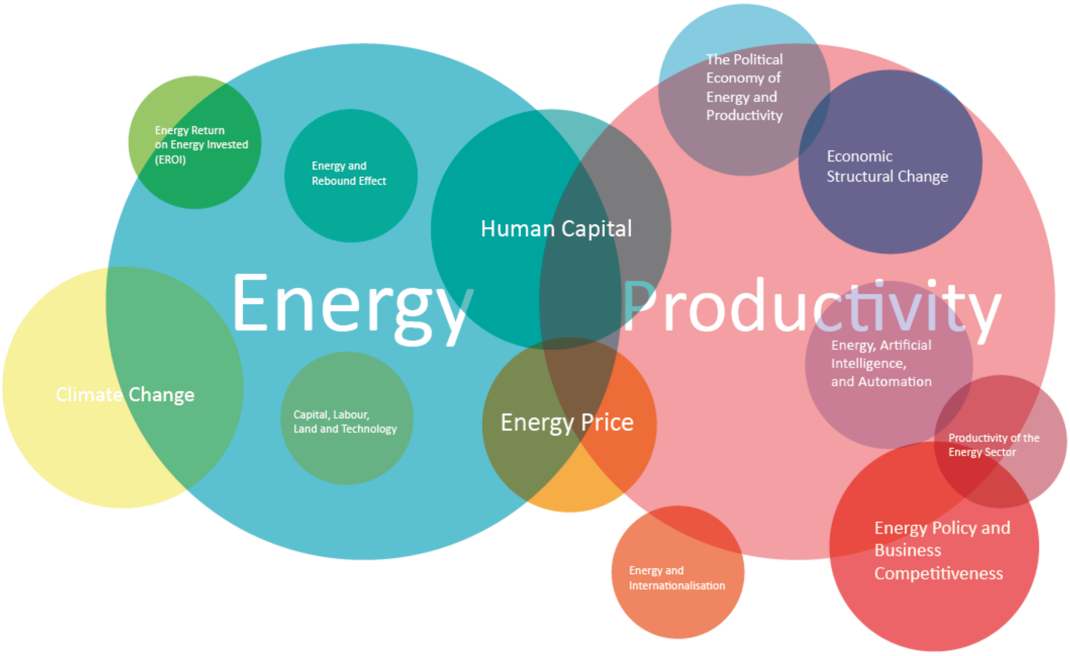

This note provides a preliminary overview of thinking on the energy-productivity nexus. Here we sketch what we consider to be the key mediating factors in the relationship between energy and productivity, and associated research questions. The aim of this note is to provoke further discussion. It is a work in progress and is not by any means definitive. We welcome challenges to the ideas and structure of this note.

Themes

1. **Productivity and the Factors of Production.**
2. **The Political Economy of Energy and Productivity.**
3. **Energy Return on Energy Invested (EROI).**
4. **The Productivity of the Energy Sector.**
5. **Economic structural change**
6. **Productivity, Energy Prices and Competitiveness.**
7. **Climate Change and Productivity.**
8. **Artificial Intelligence, Automation, and Energy.**
9. **Inequality, Productivity, and Energy.**
10. **Energy and Human Capital.**
11. **Energy and the Rebound Effect.**
12. **Energy, Trade and Globalisation.**

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Theme 1 Productivity and the Factors of Production.

The production function is an analytical framework that is widely used to explore the relationship between productivity and various aspects of the economy. In simple terms, it attempts to draw the relationship between production and the key inputs in the production process. These are typically capital, labour and technology. Other factors such as human capital and land may also be included. Production functions can be employed econometrically (growth accounting) or as a part of a modelling approach. Energy has been incorporated into production functions, but there remain questions over the best way to approach this. The production function itself has been subject to multiple critiques. Existing production function analyses come to different conclusions regarding the relationship between energy and the other factors of production.

1.1 How do various factors of production relate to energy?
1.2 How do changes in the prices of the factors of production mediate the energy-productivity relationship?
1.3 Is the production function a useful analytical device for thinking about energy and productivity?

Indicative references: (Robinson, 1953, Huntington, 1989, Jackson, 1996, Adenikinju, 1998, Felipe and McCombie, 2006, Wang, 2007, Ayres and Voudouris, 2014, Pablo-Romero and Sánchez-Braza, 2015, Keen et al., 2019, Sakai et al., 2019)

Theme 2 The Political Economy of Energy and Productivity.

Energy use is a function of the socio-economic system within which energy systems are embedded. Therefore an understanding of the social dynamics underpinning the economy are central to understanding energy use in the modern UK economy. Political economy analysis of energy-economy relations focuses on the historical development and current form of social and financial structures, institutions and power differentials, and the ways these interact with energy and productivity. For example, energy has been analysed in terms of class struggle, growth imperatives, financial speculation, and consumer capitalism.

2.1 How is energy use influenced by the market and other institutions of UK capitalism?
2.2 How has the evolution of the global energy system shaped UK productivity?
2.3 How does measurement of productivity in terms of value added impact energy use?

Indicative references: (Debeir et al., 1991, Jackson, 1996, Zenghelis, 2014, Malm, 2016, Foxon, 2017, Jackson, 2017, Kallis, 2017, Pirgmaier and Steinberger, 2019)

Theme 3 Energy Return on Energy Invested (EROI).

Energy Return on Energy Invested (EROI) is the ratio of delivered energy to the amount of energy input needed for its delivery. Although a simple concept, the devil, as Murphy and Hall (2010) put it, is in the detail and there remain questions around how best to operationalise EROI in economic analysis and how to fill in data gaps. EROI provides a frame for understanding both macro and micro-level changes in productivity. As EROI increases more energy is made available for production. But, estimated trends for a number of energy sources suggest that EROI is declining. At the same time, there remain questions over the EROI of wide scale renewable energy use, with some studies pointing to the potential for the energy sector to effectively cannibalise the rest of the economy.

3.1 What are the likely EROI trends for different energy sources going into the future?
3.2 Is there a robust evidence base for a historic relation between EROI and productivity growth?
3.3 Through what mechanisms, would declining EROI be linked to a slowdown in productivity growth?
3.4 Can the UK improve its national EROI and see a low carbon transition?

Indicative references: (Cleveland et al., 1984, Worrell et al., 2003, Murphy and Hall, 2010, Hall et al., 2014, Brand-Correa et al., 2017, Jarvis, 2018, Sers and Victor, 2018, Victor Court et al., 2018, Jackson, 2019b)

Theme 4 The Productivity of the Energy Sector.

The technologies and practices of the energy sector are likely to be central to the relationship between energy and productivity. To understand past, present and future energy production, we have to understand research and development (R&D) in the sector. This must also include the associated human and institutional capacity, and the financial dynamics of investment and deployment. In particular, innovation in the energy sector is relevant to the recent lively debates about the feasibility, efficiency, and energy and monetary returns of low carbon energy technologies.

4.1 Is there significant technological innovation directed at the energy sector?
4.2 Is it costly for firms to adapt new energy technologies?
4.3 Is the policy environment supportive of technologic developments in the energy sector?
4.4 Are there limits on what we can expect from energy innovation, in terms of productivity growth?

Indicative References: (Margolis and Kammen, 1999, Boyd and Pang, 2000, Fisher-Vanden et al., 2006, Wissner, 2011, Zenghelis, 2014, Foxon, 2017, Hardt et al., 2017, Sakai et al., 2019).

Theme 5 Productivity and Structural Change.

Different economic activities have different values and different energy requirements. Consequently, changes in the contribution of the economic sectors in the economy impact the overall productivity growth and energy demand. Indeed, various developed economies has witnessed a productivity slowdown which coincided with the shift to the services sector. Services are often thought to have lower energy requirements, those this depends on the boundaries of the analysis.

5.1 Is there evidence to suggest that the transition to services was a cause of the productivity slowdown? How might this relate to direct and indirect energy use?
5.2 Could future developments enable energy to increase productivity growth within the service sector?
5.3 What kind of energy services are particularly useful for the service sector?

Indicative References: (Lee and Chang, 2005, Allcott and Greenstone, 2012, Hardt et al., 2017, Jackson, 2017, Hardt et al., 2018, Jackson, 2019b)

Theme 6 Productivity, Energy Prices and Competitiveness.

As a commodity with a fundamental role in production, we would expect changes in energy prices to be linked to investment and consumption decisions. Energy prices have been linked to recessions, yet little is known about the dynamics of this interaction. Additionally, there is a question over the precise relation between physical characteristics of energy and its price. For example, it has been suggested that there is an inverse and non-linear relationship between price and EROI. Conversely, others place more emphasis on geo-political factors.

Understanding the determinants of energy price is important for a number of reasons, not least because of their potential impact on competitiveness. For example, there has recently been a debate about the impact of relatively higher energy costs in the UK in certain strategic energy-intensive industries like steel. The argument is whether high energy prices erode the attractiveness of the UK business market and its international competitiveness. This was fuelled by the observation that the average electricity price for steel producers in 2018 was approximately £65 per megawatt hour, compared with £43 and £31 in Germany and France respectively.

6.1 What determines energy prices?
6.2 How strong is the evidence that increased energy prices have historically been linked to slowdowns in productivity growth?
6.3 What is the likely future for renewable and fossil energy prices?
6.4 Do high energy prices exacerbate or drive economic cycles?
6.5 What is the relation between energy prices and the energy intensity of production?
6.6 How do energy policy regimes impact investment and profitability?

Indicative References: (Berndt and Wood, 1986, Jorgenson, 1982, Griliches, 1988, Park and Ratti, 2008, Coccia, 2010, Murphy and Hall, 2011, Ratti et al., 2011, Grubb and Drummon, 2018, Hallet, 2018, UK Committee on Climate Change, 2019, Jackson, 2019c, Gotzens et al., 2018)

Theme 7 Climate Change and Productivity.

The UK government has recently committed to deepening low-carbon transitions which drives significant transformational change (for example promised zero-carbon energy by 2050). This raises a number of issues that cut across the other themes in this note. Not addressed elsewhere however issues of stranded assets and climate-economy feedbacks. The former refers to fossil fuel reserves, and infrastructure that fails to make the economic returns desired by its investors because of the transition to a low carbon economy. The latter refers to the potential for the impacts of climate change (e.g. increases in extreme weather events) to impact UK productivity.

7.1 How likely is substantial fossil fuel asset stranding (assuming a rapid transition to low carbon technologies)?
7.2 How might stranding of fossil fuel assets impact UK productivity?
7.3 Through what channels might climate change impact UK productivity?
7.4 What magnitude of effects might different levels of warming have on UK productivity?

Indicative References: (Meinshausen et al., 2009, Deryugina and Hsiang, 2014, Hsiang and Jina, 2014, IPCC, 2018, Rezai et al., 2018, Carbon Tracker, 2019, Jackson, 2019a, UK Committee on Climate Change, 2019)

Theme 8 Artificial Intelligence, Automation, and Energy.

Artificial Intelligence (AI) and automation are often thought as being the key productivity breakthroughs of this century. AI and machine learning are expected to be applied to energy supply and to contribute to the consistency of renewable energy by predicting and managing fluctuations of supply and storage. Intelligent energy systems are also expected to influence consumer behaviour towards energy (for example timely adjustments in energy demand based on real time variations in energy prices). At the same time we must be aware that AI may itself be very energy intensive, and automation commonly works by replacing a labourer with a non-human energy source. Consequently it is possible that extensive uptake of AI and further uptake of automation will improve productivity by increasing energy use.

8.1 How might changes in consumption and/or working patterns in response to AI, impact energy use?
8.2 How might the adoption of AI/automation across the economy affect direct and indirect energy use in the UK economy?

Indicative references: (Edenhofer and Jaeger, 1998, Ramchurn et al., 2012, Mavromatidis et al., 2013, Brynjolfsson et al., 2018, Strubell et al., 2019)

Theme 9 Inequality, Productivity, and Energy.

In this theme we are interested in the various ways that inequalities mediate the energy-productivity relation, particularly through the role of energy in supporting sustainable livelihoods. Productivity growth in production of energy itself has the potential to reduce inequality in terms of access to energy and other goods by making production cheaper. Likewise, increases in the productivity of either capital or labour that come via energy have the potential to reduce inequalities of consumption by making general goods cheaper and more accessible. However, this is to a large extent dependent on the other ways that socio-economic systems generate inequality. Research suggests, for example, that income, gender and geography influence the ability of different groups to use energy productively both at home and in the market.

9.1 What are the key factors that mediate the relationship between inequality, energy, and productivity?
9.2 Through what mechanisms might the distribution of income impact the energy-productivity relationship?
9.3 Through what mechanisms might the other inequalities impact the energy-productivity relationship?

Indicative References: (Greenwood, 1999, Clancy et al., 2003, Casillas and Kammen, 2010, Duro et al., 2010, Druckman et al., 2012, Campbell et al., 2014, Galvin and Sunikka-Blank, 2018, Pueyo and Maestre, 2019)

Theme 10 Energy and Human Capital.

Human capital is central to many growth and productivity theories. Human capital is generally defined as the quality of labour in terms of knowledge, skills and creativity. It has been argued that development of human capital (through specialisation, skills, and technical competencies) enables more efficient use of energy and leads to innovation which allows access to new sources of energy. Linked to this is the argument that energy provides the basis for learning. Improvements in energy efficiency within schools, for instance, have been posited as a key driver of human capital.

10.1 Through what mechanisms might energy use impact the formation of human capital?
10.2 Through what mechanisms might human capital impact energy use?

Indicative References: (Sardianou, 2008, Campbell et al., 2014, Pablo-Romero and Sánchez-Braza, 2015, Fang and Chang, 2016, Mair, 2018, Shahbaz et al., 2019)

Theme 11 Energy and the Rebound Effect.

In his 1865 book *The Coal Question* William Stanley Jevons argued that technological progress could increase efficiency of a resource yet simultaneously increase its use. He illustrated this with the example of coal, but the same observation has now been made with respect to a wide range of energy sources, referred to as the rebound effect. Rebound can occur at all stages of economic activity, and in both consumption and production. At the macro-scale it is typically argued that energy efficiency gains drive increases in economic activity (potentially via productivity gains) and this growth requires further energy use. This has implications for the low carbon transition. Although in some national cases, there have been reductions in fossil fuel use, this is not reflected at the global scale. Some analyses argue that even at the national scale renewables have had limited success in replacing fossil fuels.

11.1 Can the UK economy escape the fossil fuel rebound effect in the long run?

11.2 Can the UK economy influence global trends in fossil energy use?

11.3 How might productivity growth influence the rebound effect?

Indicative References: (Dimitropoulos, 2007, Sorrell, 2010, Sorrell, 2014, Marques et al., 2018, Mair, 2018, Semieniuk, 2018, Jackson et al., 2019, Sakai et al., 2019, Brockway et al., 2019)

Theme 12 Energy, Trade and Globalisation.

Energy trade and Foreign Direct Investment (FDI) are major factors in shaping the industrial structure of countries, its competitive advantage and consequently, in affecting energy demand and supply. Technological progress in energy is not only the result of domestic innovation that drives productivity gains but also foreign technology spillovers and knowledge diffusion. In addition, energy intensity of the UK economy has fallen in recent decades, largely due to structural changes in the economy. However, at the same time the UK has become more dependent on energy extracted overseas.

12.1 Can trade and foreign investment have specific energy productivity gains and energy-specific knowledge spillovers?

12.2 How dependent is UK productivity on fossil fuel infrastructure overseas?

Indicative References: (Mielnik and Goldemberg, 2002, Bosetti et al., 2008, Lee, 2013, Wan et al., 2015, Hardt et al., 2017, Owen et al., 2017, Hardt et al., 2018)

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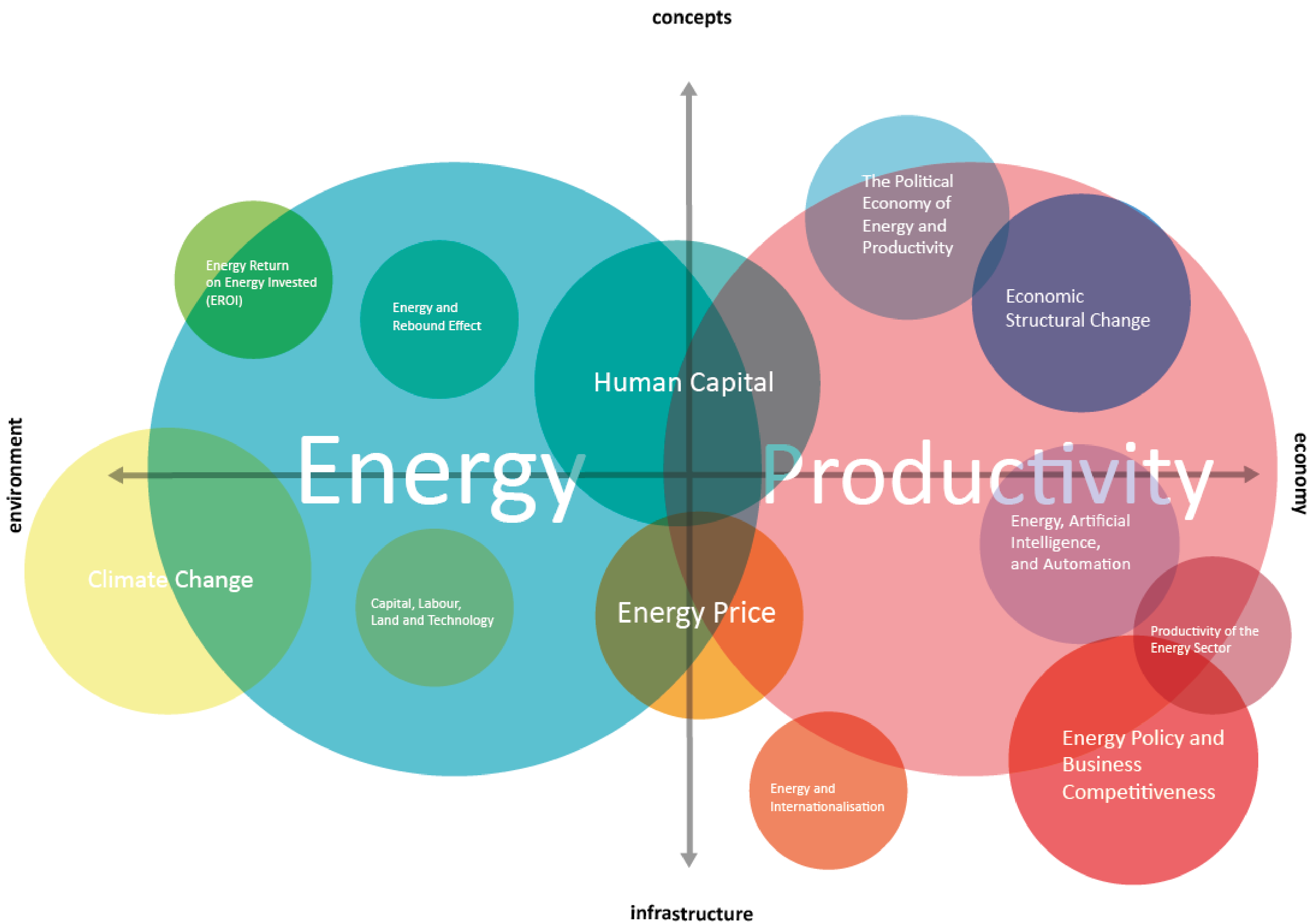
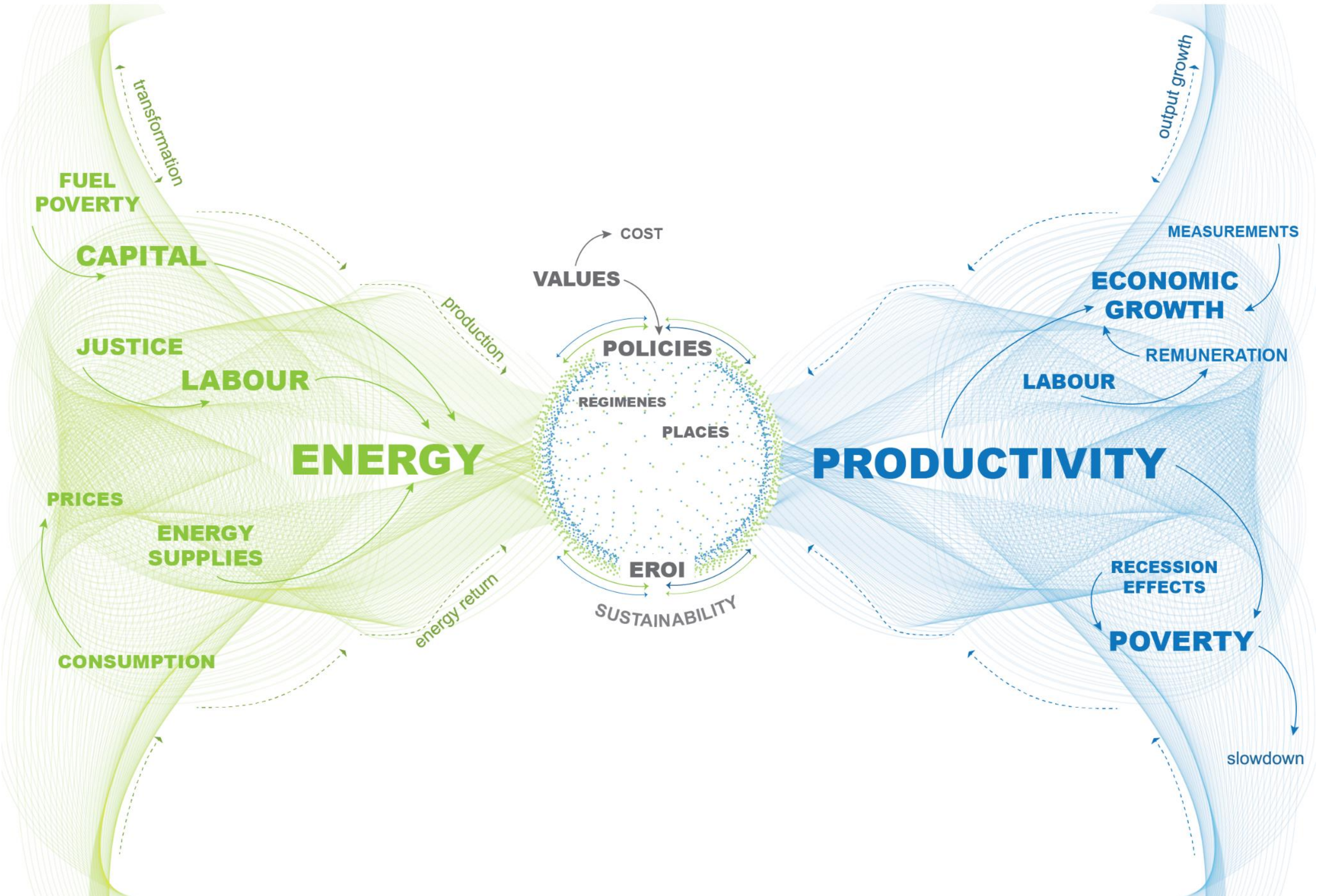

concepts
infrastructure
environment
economy
Energy
Productivity
Energy Return
on Energy Invested
(EROI)
Energy and
Rebound Effect
Human Capital
The Political
Economy of
Energy and
Productivity
Economic
Structural Change
Climate Change
Capital, Labour,
Land and Technology
Energy Price
Energy, Artificial
Intelligence,
and Automation
Productivity of the
Energy Sector
Energy and
Internationalisation
Energy Policy and
Business
Competitiveness



transformation
FUEL POVERTY
CAPITAL
production
JUSTICE
LABOUR
ENERGY
PRICES
ENERGY SUPPLIES
energy return
CONSUMPTION
COST
VALUES
POLICIES
REGIMENES
PLACES
EROI
SUSTAINABILITY
output growth
MEASUREMENTS
ECONOMIC GROWTH
REMUNERATION
LABOUR
PRODUCTIVITY
RECESSION EFFECTS
POVERTY
slowdown