The Costs of Fuelling Economic Growth

By Robert U. Ayres , INSEAD

A study of ten large global economies shows that exergy – not human labour – is the primary driver of GDP growth. Existing production models cannot explain growth.

A new generation of smart machines could possibly **replace a large proportion of existing human occupations**, according to the **World Economic Forum**. But even before the emergence of “smart machines”, the relationship between **exergy** and production is clear to physicists, industrialists and political leaders.

However, economists have been misled – one could say mesmerised – by Philip Wicksteed’s “exhaustion theorem” from the 19th century that says, in effect, that the importance of energy in the economy of a country must be proportional to the share of energy costs in the country’s total expenditure. Built on this theorem, economic modelers from Robert Solow to William Nordhaus assume that cutting energy consumption (to reduce greenhouse gas emissions that cause climate change) won’t have a serious impact on gross domestic product (GDP). But this is far from today’s reality because the theorem is flawed.

Today, in spite of the importance of energy, the share of energy costs in the United States national accounts is only about 4 percent, while payment to workers in the form of wages and salaries account for at least 70 percent of GDP. On the impact of energy shortage on GDP, look no further than the effects of Russia's invasion of Ukraine on Germany, the world's industrial powerhouse.

Cheap Russian gas has powered Germany's industries since the 1990s. When access was cut, wholesale natural gas prices in Germany surged nearly **400 percent** in early September 2022. Energy-intensive industries such as chemicals, glass and metal producers were forced to curb output, stop production or relocate production. As a result, Germany's GDP growth in 2022 fell by over 25 percent, from 2.6 percent in 2021 to **1.9 percent** in 2022.

A significant consequence was that Germany had to fall back on coal temporarily, in spite of plans to phase out coal-fired power by 2030. Against the backdrop of the global energy and climate crises and a looming recession, it is ever more important to understand the role of energy in production, and the cost of greenhouse gas emissions on the environment, especially carbon dioxide and methane.

Redefining 'work'

My point is that the **economy depends entirely on energy** to do work – in the thermodynamic sense. "Doing work" here refers to generating electricity to produce light and perform all kinds of mechanical work. It provides heat to cook food, heat houses, smelt metal ores and produce cement for construction. Work performed by internal combustion engines also drives cars, buses, trucks, tractors, ships and airplanes.

All these economic and human activities depend on energy (exergy) inputs. Without energy, they would all stop short, never to go again, like the song "My Grandfather's Clock". A worker or a working animal without food or feed is a corpse. An engine without fuel or electric power is a pile of useless junk. Exergy – or the part of energy that is capable of performing thermodynamic work – is the unique and only "factor of production" that counts. While capital goods play a role, they too were produced by thermodynamic work done in the past.

Yet, despite the essential role of exergy in the economy, it is drastically under-represented in statistics and missing in economic models and textbooks. In economic growth theory, the Cobb-Douglas production function is commonly used to model the relationship between production output (GDP) and production inputs (or "factors"). Since Adam Smith's era in the 18th century, the widely recognised inputs are: agricultural **land, labour and capital** (tools, animals, buildings). Where is exergy?

Exergy as the new labour in production

If "labour" is another word for "doing work" and if work can be measured in terms of energy (exergy) consumption reasonably accurately, exergy would be the dominant factor to explain and predict production (GDP) output in economic models. This perspective could offer important insights on the impact of energy constraints on businesses and the economy.

In a **recent study**, my co-authors* and I set out to empirically prove this perspective. We analysed the GDP, capital, labour and exergy data of the ten largest economies that cover over **65 percent of global GDP**: Australia, Canada, China, France, Germany, India, United States, United Kingdom, Japan and Italy. We used the Cobb-Douglas production function to produce individual economic estimations for each country and an estimation for all ten countries for the period of 1960 to 2014. Two alternative sets of inputs were used to produce the estimations: the conventional one based on labour (payments to employees) and financial capital stock vs. exergy and capital (in energy units).

The results show that viewing labour as work done – by exergy consumption – explains economic growth almost perfectly. Specifically, the outputs for the two sets of inputs match only when an exogenous multiplier representing technological change (or "total factor productivity" change) is included in the first estimate using conventional inputs. But no such multiplier is needed for the second estimate. We empirically show that exergy consumption can replace labour as an input for production without an additional multiplier to account for technological change.

More importantly, our findings underpin the essential role of energy behind GDP growth and the relevance of exergy as either a substitute or complement for labour in aggregate production functions.

The wider picture: An environmental perspective

From the economic point of view, the belief held by most – including governments and institutions – is that the economy must grow. Yet, exergy and economics cannot be viewed in isolation. With the increased demand for energy to fuel growth, the singular pursuit for growth will not benefit the environment nor make society more equitable.

Industrial production, food production, economic and other systems are part of a larger environmental system that interacts and evolves. Among the global systems, food production is one of the most critical – albeit unsustainable – ones. In a typical scenario, large volumes of water, nitrate and phosphate fertilisers are applied to expansive farmlands in Brazil to grow soybeans that are sent to the US and fed to cattle together with artificial growth promoters. Alongside beef, methane and other carbon emissions are produced. The luxury of access to affordable steaks clearly comes at a cost to the environment.

At the recent World Economic Forum in Davos, there was broad consensus that climate change is an important topic and that all carbon-based fuels should be eliminated by 2050. The question is: How can the inherent tensions between economic growth and sustainability best be managed?

Invest in change

In practice, significant investments are needed to make energy and other systems more sustainable. Electrification is underway in an ambitious fashion in the motor industry, backed by governments and industry. The EU is targeting **100 percent** fully electric vehicles (EV) by 2035 and China is requiring manufacturers to produce **new energy vehicles** (NEVs) to meet credit requirements.

However, even when every vehicle is an EV, only 30 percent of the current carbon emissions will be eliminated. To eliminate all emissions, it is necessary to electrify everything, powered by renewable energy. Technologies such as turbines and photovoltaics are capable of tapping solar, wind and hydro power, but their efficiency and scale need to be improved to bring significant environmental impact. The recent breakthrough in **nuclear fusion** – often described as the "holy grail" of energy production – is another important step towards powering the world with almost unlimited clean energy instead of relying mostly on fossil fuels.

Although governments often take the lead, investing in change is not limited to governments. Business leaders have the power to make their operations more efficient and sustainable by modifying their interactions with the environment. Companies should allocate a portion of profits into creating real value for the company through research and development instead of distributing profits as dividends to shareholders or for **share buybacks**.

Exergy is intertwined with business operations, productivity and the environment. Investment in more sustainable processes and products may not be immediately profitable but will profit both the environment and businesses in the long run. When business leaders recognise this interdependency, it could lead to improved risk assessment as well as greater accountability towards the environment.

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About the research

"Exergy versus labour in aggregate production functions: estimates for ten large economies" is published in the *International Journal of Exergy*.