Energy for Planet Earth – 30 years on

PART TWO: ENERGY INTENSITY FORECASTS

Background

In September 1990, Scientific American published a special issue entitled ‘Energy for Planet Earth’. In this publication, Scientific American explored the sources of energy, the future for energy, made predictions on technological breakthroughs and suggested solutions for what they considered was an imminent energy crisis. Many of these predictions by Scientific American were made for 2020. Given we have reached that date, we can look back and compare the predictions with what actually happened.

In a three-part series, Frontier Economics will compare actual outcomes to 2020 with the predictions made by Scientific American. This comparison of actual versus predicted outcomes, especially where technological change is involved, can help us learn about the factors that have been determinative to the global community and provide guidance on how we can improve economic forecasts.

We focus on three areas where Scientific American made long-term forecasts:

- Primary energy demand (covered in Part One)
- Energy intensity (this paper)
- Emissions intensity (covered in Part Three).

Scientific American gets it right in Part One

In Part One we reviewed the performance of Scientific American’s long-term forecasts on primary Energy Demand.[1] We found that, overall, Scientific American’s forecast was reasonably accurate. However, Scientific American did not perform as well on the growth performance by country. Most significantly, Scientific America materially underestimated the rapid and large increase in the growth of developing nations, such as China and India. That is, countries that were relatively poor in 1990 grew more quickly than expected, and they used energy to achieve this growth.

In this second part of our three-part series, we assess the performance of Scientific American’s forecast of Energy Intensity.

Why worry about energy intensity?

Energy intensity is a measure of how much energy is required to produce a unit of output. Conventionally, the measure of output used is Gross Domestic Product (GDP). The level of

[1] Frontier Economics (2020), *Energy for Planet Earth – 30 years on (Part One)*, February, Weblink: https://www.frontier-economics.com.au/publications/energy+for+planet+earth+30+years+on+part+one

energy intensity has a bearing on environmental and economic outcomes. For a fixed energy intensity and where emissions intensity is constant, if economic activity increases, this will result in more emissions and consumption of more energy resources. Energy intensity was of interest to Scientific American because improving the economic well-being of developing countries could result in a dramatic increase in emissions if energy intensity (and emissions intensity – the subject of Part Three of this series) was not improved over time.

In Energy for Planet Earth, Amulya K. N. Reddy and José Goldemberg considered the issue of energy intensity and what this meant for environmental outcomes if developing countries improved their economic wellbeing in their article *Energy for the Developing World*.[2]

Reddy and Goldemberg predicted that developing countries would benefit from improvements in materials science and energy efficiency innovations from industrialised nations. This technological transfer would avoid the high energy intensity peaks that occurred over the course of the previous 150 years of economic development of, what arenow, developed economies (see **Figure 1**).

Finding a consistent data source

To update Reddy and Goldemberg's analysis we needed a dataset that was consistent with that used by the authors. There are many different sources of energy intensity data. Unfortunately, Reddy and Goldemberg did not provide the source of the data they used. However, it is believed that the data used by Reddy and Goldemberg most likely came from the following sources:

- Energy data - UN Energy Statistics Yearbook (UN Statistical papers, Series J. No. 30).
- GDP data - Penn World Table Mark 4 and 5[3]

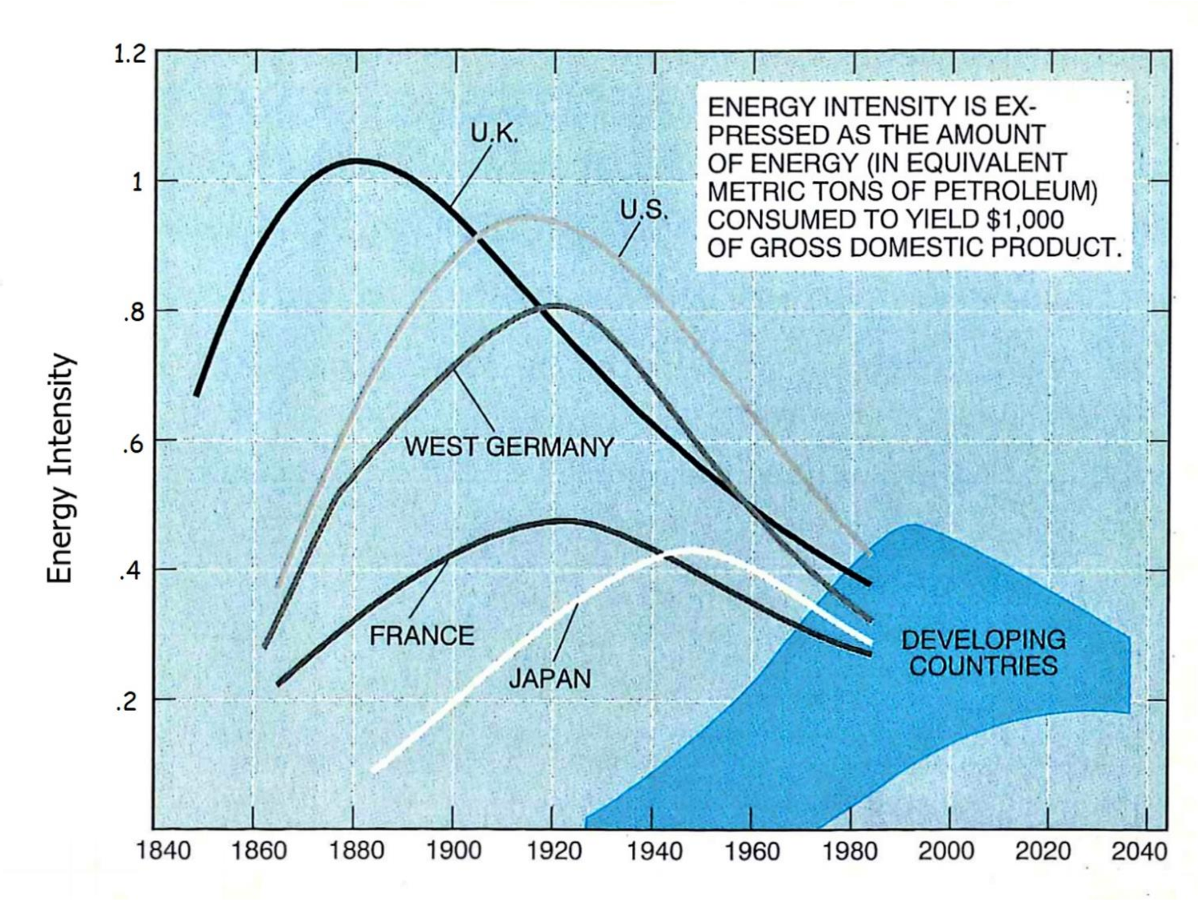
Further, the data presented in **Figure 1** appears to be derived from an article featured in the journal "Energy" by Lars J Nilsson. Nilsson examines the energy intensity trends in 31 industrial and developing countries from 1950 to 1988.[4] Sourcing data from UN Energy Statistical Papers (1986) and the Penn World Table Mark 4 and 5, Nilsson charts the energy intensities (tonnes of oil equivalent /$1000 USD 1980) from 1950 to 1988 for Japan, France, West Germany (Federal Republic of Germany - FRG), the United Kingdom and the United States. These are the same countries shown in **Figure 1**. Nilsson's equivalent figure is shown in **Figure 2**.

2 Scientific American (190), *Energy for Planet Earth*, Vol 263, Issue 3, p 63-72, September, Weblink: https://www.scientificamerican.com/article/energy-for-planet-earth/

3 National Bureau of Economics Research, Penn World Tables, Weblink: https://www.nber.org/research/data/penn-world-tables

4 Lars J. Nilsson (1993), Energy Intensity Trends in 31 Industrial and developing countries, 1950-1988, *Energy*, Vol. 18, No. 4 pp 309-322, Weblink: https://www.sciencedirect.com/science/article/abs/pii/036054429390066M

Figure 1: Profile of energy intensity of industrialised countries



Source: Scientific American 1990, Energy for Planet Earth, Special Edition 1990, p 64.

It is important to note that Nilsson's energy intensity figure covers the 38-year period from 1950 to 1988 whereas Reddy and Goldemberg's figure covers the period from 1840 to 1985. It is clear by comparing these two figures that Reddy and Goldemberg have stylised their series to more effectively convey the overall trends in energy intensity, whereas Nilsson has plotted actual energy intensities, which is more difficult to interpret than the stylised version of Reddy and Goldemberg.

What has happened since 1990?

The International Energy Agency (IEA) produces energy intensity data, which was in the form of energy use (kg of oil equivalent) per $1000 GDP (constant 2011 PPP).[5] This data was then adjusted to be in the same terms as the data used in the Scientific American's article. Specifically, energy was converted to Tonnes of Oil Equivalent (TOE) and the GDP series was rebased to 1990. The results of this data analysis is presented in **Figure 3** for the period from 1990 to 2015 (the latest data available at the time of writing this note).

5 IEA Statistics - (http://www.iea.org/stats/index.asp)

Figure 2: Nilsson's energy intensity figure

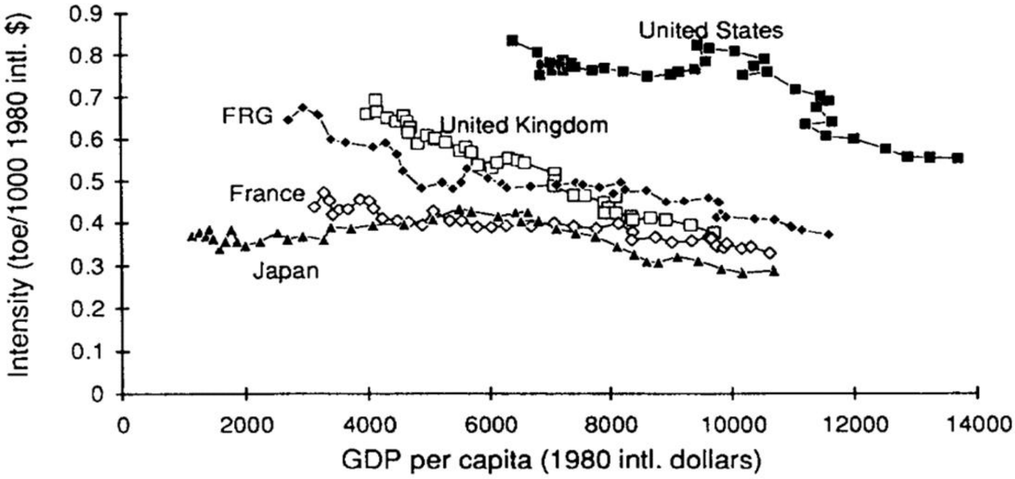
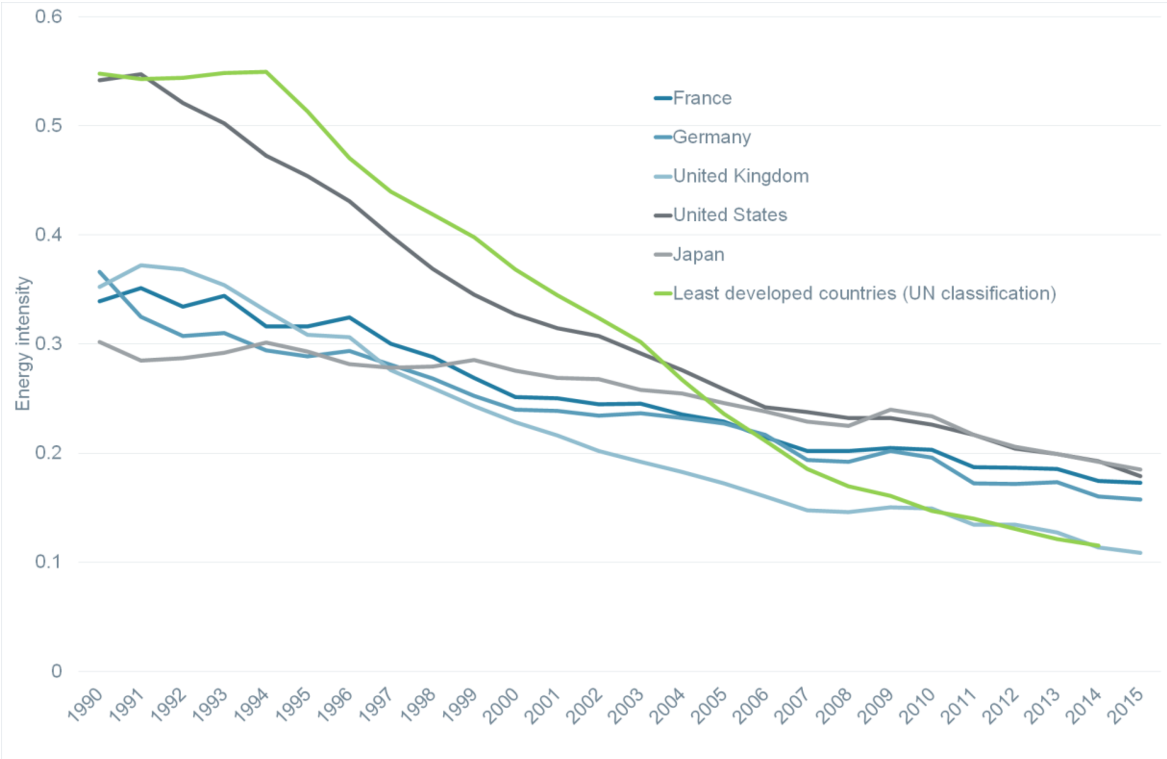


Fig. 2. Energy intensities (toe/1000 int. dollars) vs GDP per capita from 1950 to 1988 for Japan, France, FRG, the U.K., and the U.S.

Source: see Footnote 4

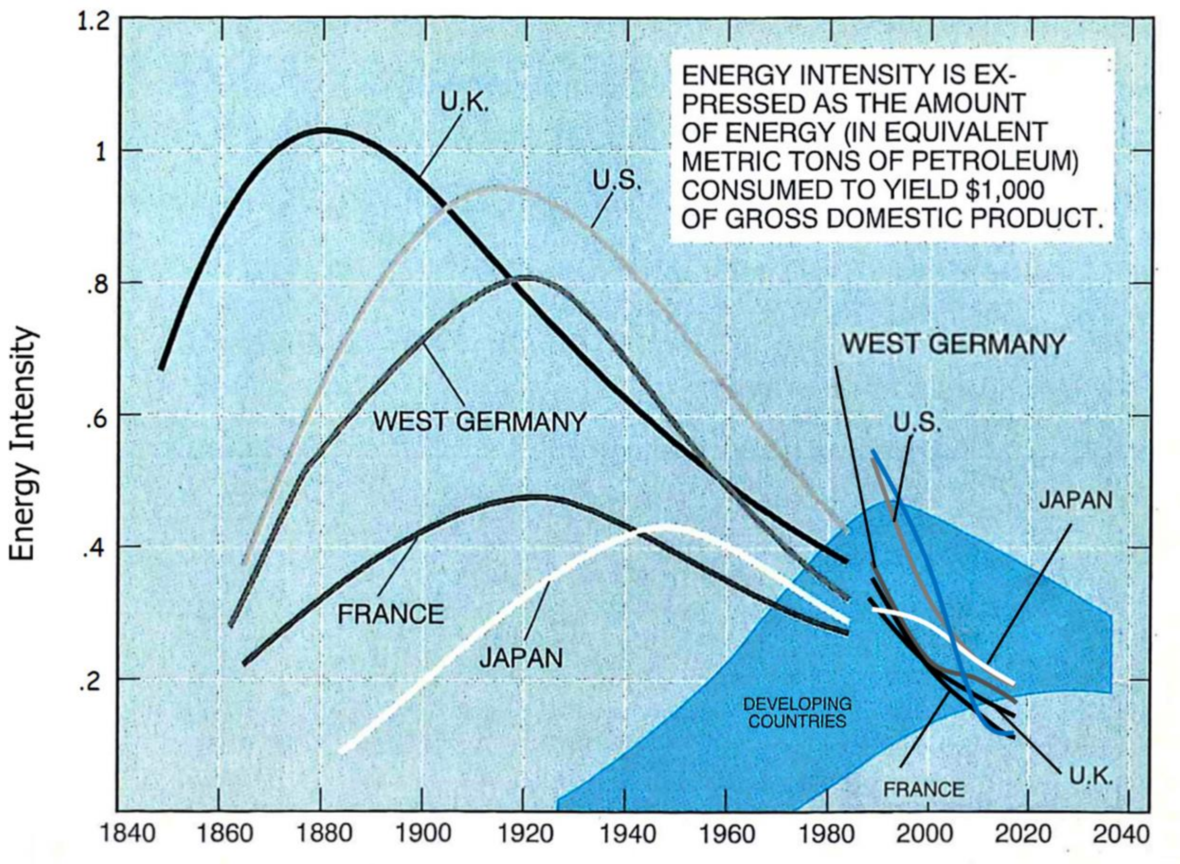
Figure 3: Energy intensity from 1990 to 2015



Source: IEA

This updated energy intensity data is overlaid on to Scientific American's original figure to create an updated series of energy intensity from 1840 to 2015 for the countries that were presented in the 1990 Special Report in addition to a series developing countries (the blue line). This data is presented in **Figure 4**.

Figure 4: Updated Scientific American energy intensity trends



Source: Scientific American, IEA and Frontier Economics analysis

While there are some obvious discontinuities between Reddy and Goldemberg's stylised series and the updated IEA series, they broadly match up, especially for the UK, France, Japan and West Germany. The IEA series starts higher in the IEA series than Reddy and Goldemberg's stylised series, but comes back on the stylised trend by 2000.

There are a few important observations to make from this updated energy intensity series:

- The energy intensity of the countries listed by Reddy and Goldemberg (the UK, France, West Germany, Japan and the US) continued to fall over the 25 years from 1990.
- Reddy and Goldemberg's prediction that developing countries would take advantage of the technology of developed countries to avoid high energy intensity was precisely what happened. In fact, developing country energy intensity matched that of the best of the countries in the original 1990 series (see **Figure 3**),

- If anything, Reddy and Goldemberg *underestimated* the ability of developing countries, and the other countries listed, to improve energy intensity. All countries in the original Scientific American article and the developing countries bettered even the lower forecasted energy intensities by 2020. This trend can likely be explained by the adoption of modern technologies and materials from developed countries. Given developing countries did not have an abundance of less efficient legacy technologies to begin with, their capital stocks became quickly dominated by newer, more efficient technologies.

Shuping Li *et al* 2021 investigated the sources of energy intensity changes from 2001 to 2017 across different economic regions using IEA World Energy Balances data.[6] The results of their analysis is shown in **Figure 5**.

The drivers of changes in energy consumption are divided into factors: energy structure (the share of coal, oil, natural gas, biomass, hydro and others), energy intensity (energy consumption per GDP), population growth and GDP per capita. The length of each bar indicates the percentage contribution of each factor to the increasing or decreasing energy consumption. The dots show the average annual percentage changes in energy consumption.[7]

In all regions, growth in energy consumption due to economic and population growth has been mitigated by improvements in energy efficiency and decline in the use of oil and coal as energy sources, supported by moderate growth in the use of renewables (shown in yellow as "others"). In some regions these mitigates have been overwhelmed by growth in population and GDP, which has led to overall growth in energy demand. This is particularly the case through the rapidly growing Asian regions.

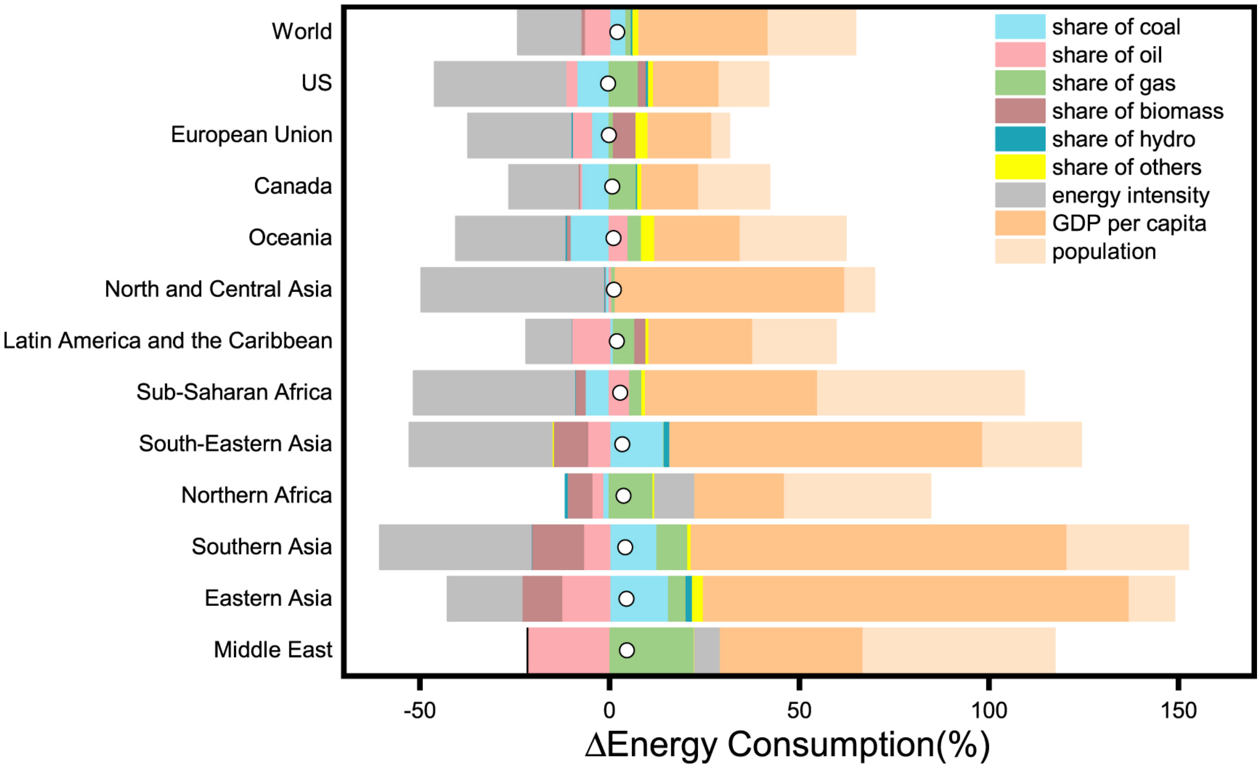
Electricity generation using fossil fuels is a major user of energy and thus a material determinant of energy intensity. Over the 30 years from 1990, the thermal efficiency of power generators has steadily improved, meaning that less primary energy is needed to produce a unit of electricity. By way of example, consider the change in thermal efficiency of generators in Europe since 1990 as shown by the European Environment Agency.[8] The thermal efficiency of conventional thermal power plants in the EU has increased from 42.2% in 1990 to almost 50% in 2016. This improvement in average thermal efficiency has resulted from the commissioning of new, higher efficiency generators and decommissioning of older, less efficient generators.

6 Shuping, Li, Jing Meng, Heran Zheng, Ning Zhang, Jingwen Huo, Yuan Li and Dabo Guan (2021), "The driving forces behind the change in energy consumption in developing countries", Environmental Research Letters 16. Wewblink: https://iopscience.iop.org/article/10.1088/1748-9326/abde05/pdf

7 *ibid*, Figure 1.

8 European Environment Agency, Weblink: https://www.eea.europa.eu/data-and-maps/indicators/efficiency-of-conventional-thermal-electricity-generation-4/assessment-2

Figure 5: Changes in energy consumption 2001-2017 – by region



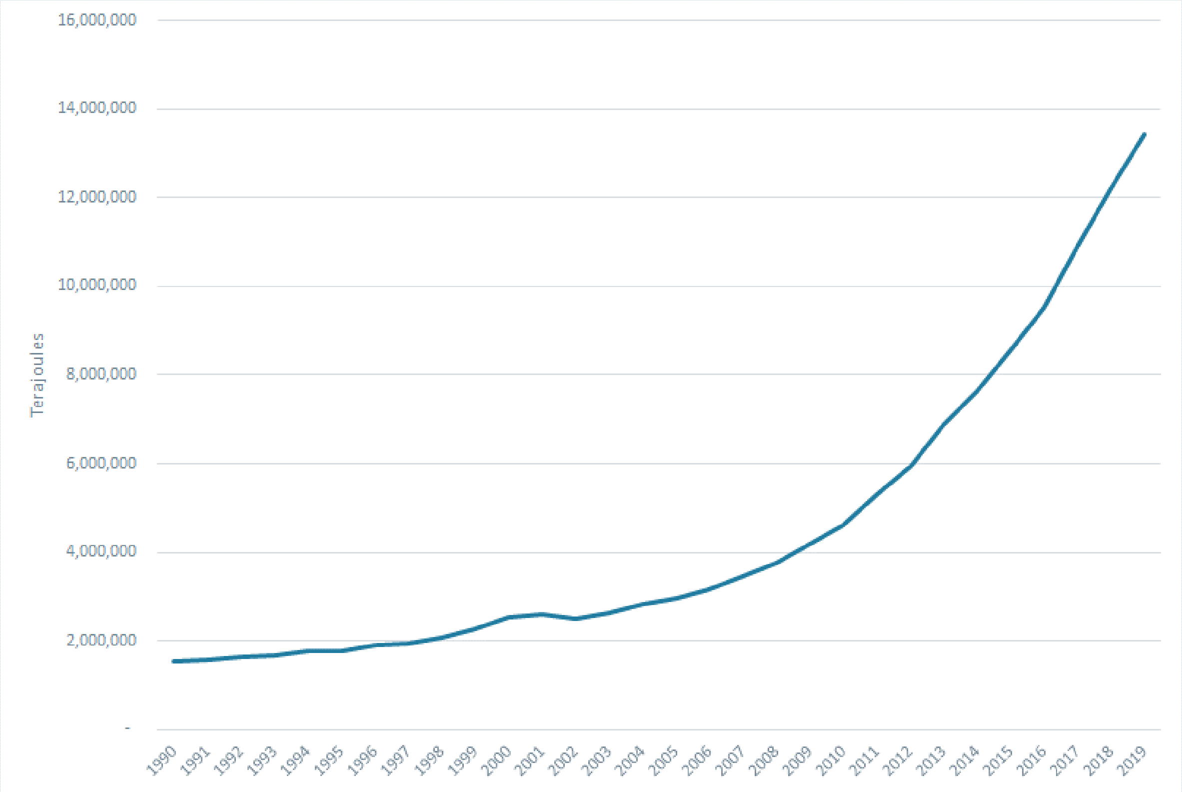
Source: See footnote 6

Another possible source of the improvement in energy intensity is the rapid uptake of renewable energy over the past 30 years (see **Figure 6**). The IEA report in their global total energy supply data that non hydro renewable energy supply has grown by nearly 800% in the past 30 years compared to the growth in coal (75%), oil (38%) and natural gas (102%) over the same period.[9]

In spite of this rapid growth in the supply of non-hydro renewable energy, it is has made very little difference to the improvement in energy intensity. While the share of renewables has been growing, the growth in fossil fuel has outstripped renewables every year in the series (see **Figure 7**). For example, over the most recent 10 years of the series (2010 to 2019), fossil fuel supply has outgrown non-hydro renewable supply by nearly six times. To replace existing supplies of fossil fuel at current demands, non-hydro renewable supplies would have to increase by 55 times current supply levels.

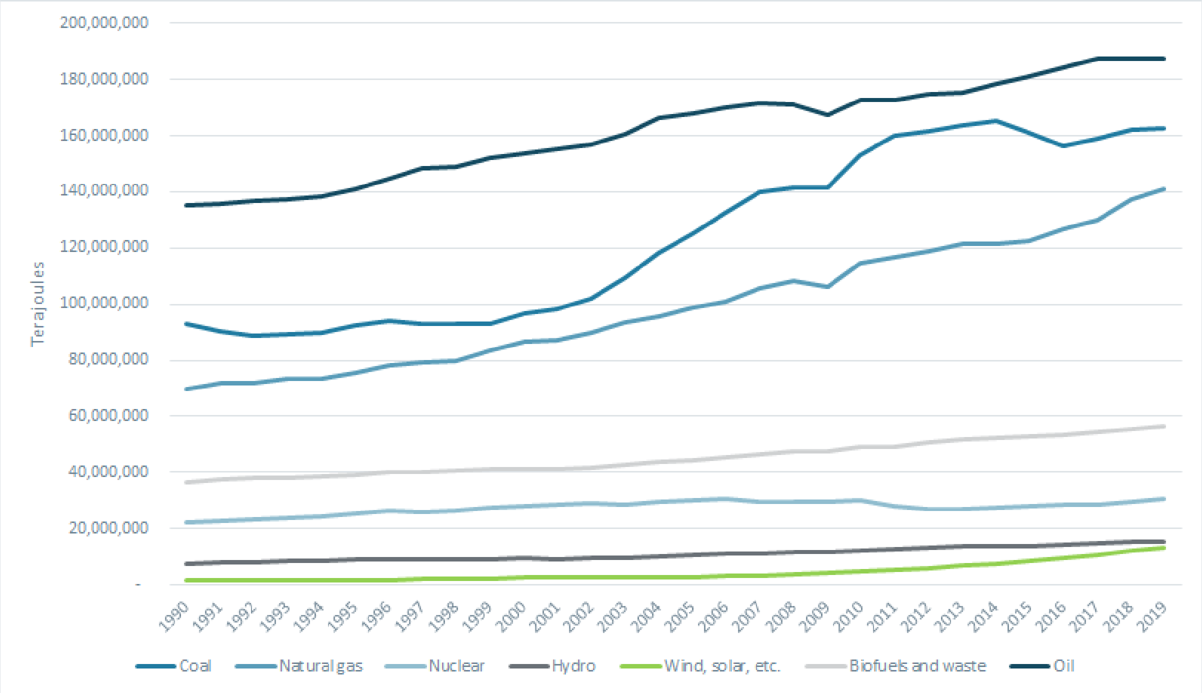
[9] International Energy Agency, Data and Statistics, Weblink: https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource

Figure 6: Growth in global (non-hydro) renewable energy (1990 to 2019)



Source: See Footnote 9

Figure 7: Global energy supply by source (1990 to 2019)



Source: See Footnote 9

Scientific American gets it right again

While Scientific American's original historical depiction of energy intensity was stylised, it did accurately convey the historic profile of energy intensity – rising as countries develop, and then falling as economies mature. Given the size of the populations in developing countries in 1990, there was a genuine concern about the impact on energy demand (and resulting environmental problems) if these countries followed the same energy intensity profile as developed countries.

However, Reddy and Goldemberg predicted that developing countries would benefit from improvements in materials science and energy efficiency innovations from developed nations and this technological transfer would avoid the high energy intensity peaks that occurred over the course of the previous 150 years of economic development of, now, developed economies. Reddy and Goldemberg appear to have been correct. The energy intensity of developing countries, while starting on the higher side of developed countries in 1990, quickly fell as they adopted the latest technologies. Indeed, by 2015, developing countries had lower energy intensity than the developed countries originally analysed by Reddy and Goldemberg. In fact, by 2015, developing countries exceeded the most ambitious energy intensity decline forecast by Reddy and Goldemberg.

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