This blog has been written as an introductory and educational piece on the Kaya identity. The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the IFoA.

The Kaya identity

A tool which we as actuaries can use to understand and measure how CO_2 emissions and their underlying drivers change

The Kaya identity is a useful equation for quantifying the total emissions of the greenhouse gas carbon dioxide (CO_2) from human sources. The simple equation is based on readily available information and can be used to quantify current emissions and how the relevant factors need to change relative to each other over time to reach a target level of CO_2 emissions in future. The identity has been used, and continues to be important, in the discussion of global climate policy decisions.

The Kaya identity states the total emission level of CO_2 as the product of four factors:

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

where:

F = Global CO_2 emissions from human sources
P = Global population
G = Global Gross Domestic Product (GDP)
E = Energy consumption

Background

Developed by Yoichi Kaya[1], the identity is a specific application of the I = PAT identity, which relates human impact on the environment (I) to the product of population (P), affluence (A) and technology (T). On first inspection, the Kaya identity may appear to be a frivolous equation given its construction as cancelling terms leaves you with F = F. In practice, however, it is commonly used to calculate an absolute value for global CO_2 emissions from anthropogenic activities. It is also helpful in understanding how the four factors need to change relative to each other over time to reach a target level of CO_2 emissions in future, and to understand how the four factors have changed in the past. Far from frivolous!

Whilst the Kaya identity has its limitations – that the four factors should not be considered fundamental driving forces in themselves, nor as generally independent from each other – it has been regularly adopted due to its simplicity and reliance on readily available data.

Usage in policy making

Perhaps most significantly, the Kaya identity underlies the Intergovernmental Panel on Climate Change's (IPCC) analysis of emissions scenario literature[2]. The analysis provided a basis for current assessments of greenhouse gas emissions and possible response strategies. In the context of policy-making, the Kaya identity is often expressed as:

$$\begin{aligned} &Global\ CO_2\ emissions\ from\ human\ sources \\ &\qquad = Global\ Population\ \times\ Global\ GDP\ per\ Capita \\ &\qquad \times\ Energy\ Intensity\ \times\ Carbon\ Intensity \end{aligned}$$

Comparing against the original formula:

$$F = P\ \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

where:

F = Global CO_2 emissions from human sources
P = Global population
G / P = Global GDP per capita
E / G = Energy Intensity of GDP
F / E = Carbon Intensity of Energy Supply

Global population and Global GDP per capita (typically calculated using purchasing power parity) are self-explanatory concepts where the key drivers of change are well understood by demographists and economists respectively. Energy Intensity and Carbon Intensity are more often the focus of efforts to reduce global CO_2 emissions. The key drivers of change and recent trends for these factors are summarised below:

- Energy Intensity – varies by country and region with underlying factors such as economic structure, climate, geography and energy efficiency policies. Global Energy Intensity decreased by nearly one-third between 1990 and 2015[3].
- Carbon Intensity – is driven by the prevailing form of energy generation. Measured on a total life cycle basis, renewable energy sources have a lower Carbon Intensity than fossil fuels. Global Carbon Intensity has trended downwards since 1965[4], although the trend was broadly flat between 1993 and 2018[5].

Using the Kaya identity – an example

The IPCC's latest report presents an opportunity to make use of the Kaya identity. The report states that "In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range)"[6]. Or, rephrasing and simplifying: To keep the global temperature rise limited to 1.5°C, net CO_2 emissions in 2030 need to reduce by 45% from 2010 levels, and in 2050 they need to be down to zero.

The table below uses the individual components of the Kaya identity to better understand what this reduction might mean. In this simplified analysis, we project Global Population, GDP per capita and Energy Intensity in line with available data and use this to work out the required reduction in Carbon Intensity.

		2030 vs. 2010 position	2050 vs. 2010 position
Expected			
Global population [a]	(P)	123%	140%
GDP per capita [b]	(G/P)	184%	290%
Energy Intensity [c]	(E /G)	73%	54%
IPCC required change in Global CO_2 emissions	(F)	55% (i.e. a 45% decrease from 2010 levels)	0% (i.e. a 100% decrease from 2010 levels)
Required			
Carbon Intensity	(F/E)	33%	0%

[a] Assumes global population of 7.0bn (2010), 8.6bn (2030) and 9.8bn (2050).[7]
[b] Assumes world weighted average growth rate of 3.1% p.a. between 2010 and 2030 and 2.3% p.a. between 2030 and 2050.[8]
[c] Assumes trend between 1990 and 2015 continues at c. -1.5% p.a.[3]

This analysis demonstrates the significant reduction in Carbon Intensity required to limit the increase in global average temperature to 1.5°C above pre-industrial levels. By 2030 Carbon Intensity needs to reduce by two thirds from 2010 levels, and by 2050 it needs to be down to zero.

In order for Global CO_2 emissions to be zero in 2050 the Kaya identity tells us that Carbon Intensity has to be zero as none of Global Population, GDP per capita and Energy Intensity can be zero. The result implies that all fossil fuel energy use must stop unless the emissions are captured and stored or some CO_2 is removed from the atmosphere (e.g. reforestation). Ultimately, these findings are broadly consistent with the IPCC's recent statement that:

"Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems"[9].

References

[1] Kaya (1990); Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris (mimeo)
[2] IPCC (2000); IPCC Special Report on Emissions Scenarios.
[3] EIA (2016); [Online]. Available from: https://www.eia.gov/todayinenergy/detail.php?id=27032 [accessed 1 January 2019]
[4] CO2 Scorecard (2014); [Online]. Available from: https://co2scorecard.org/home/researchitem/31 [accessed 1 January 2019]

[5] R B Jackson et al (2018); Global energy growth is outpacing decarbonisation. Environmental Research Letters.
[6] IPCC (2018); Global Warming of 1.5°C: an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, p14.
[7] United Nations, Department of Economic and Social Affairs, Population Division (2017); World Population Prospects: The 2017 Revision, custom data acquired via website. [accessed 6 January 2019]
[8] OECD (2012); Looking to 2060: Long-term global growth prospects.
[9] IPCC (2018); op. cit., p17.

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