SDG 7: how a pinch analysis can help visualise emission cuts for developing countries

Professor Dominic Foo & Professor Raymond Tan

Executive Summary

Policy makers should use the carbon emissions pinch analysis (CEPA) as a graphical technique to allow the energy-climate nexus to be analysed visually and easily. This will help decision makers achieve the emission cuts they need. We illustrate the usefulness of CEPA by applying it to the case of the Philippines as a representative developing country.

Recommendations

- CEPA should be used to visualise the energy-climate nexus in a simple format, making it easier for non-experts to use the information
- CEPA should be used to provide a 'big picture' understanding of the energy demands and sources within a country
- CEPA should be used to help countries make recommendations on which energy source they should be using, as well as if they need to incorporate Negative Emissions Technologies (NETs)

Introduction

Many countries have committed to reduce their carbon emissions under the Paris Agreement. These voluntary cuts, known as intended nationally determined contributions (INDCs), are meant to limit temperature rise to no more than 2°C by the year 2100. Above this threshold, climate change will become catastrophic. The problem is that deep emissions cuts are needed to achieve this goal; according to the Intergovernmental Panel on Climate Change (IPCC), the world's net carbon emissions need to be reduced to zero by mid-century.

Developing countries with Paris Agreement pledges face the challenge of meeting both their economic growth goals with their INDCs. Economic growth will increase energy consumption, which in turn will raise emissions unless new technologies are used. Energy technologies with very low or zero-carbon emissions already exist commercially, and are competitive under some conditions, while next-generation technologies with negative carbon emissions are still over the horizon.

The decision to actually use low, zero or negative emissions technologies requires decision makers to balance economic, environmental and societal goals, while using specialist information from scientists.

What is carbon emissions pinch analysis (CEPA)?

We developed CEPA as an energy planning tool to distribute different energy sources to different sinks (or demands), with carbon emissions limits. These sinks can be economic sectors or geographic regions. CEPA is based on pinch analysis, a technique developed in the 1970s to improve the energy efficiency of industrial plants. Pinch analysis uses thermodynamic principles to find 'targets' or energy budgets for industrial plants. These energy targets give the lowest possible energy consumption and combustion emissions for the industrial plant, and act as benchmarks that are firmly grounded in the laws of physics. Engineers can then design plant modifications to meet these targets. The basics of pinch analysis can be found in many engineering textbooks, and do not need to be described here.

How CEPA works

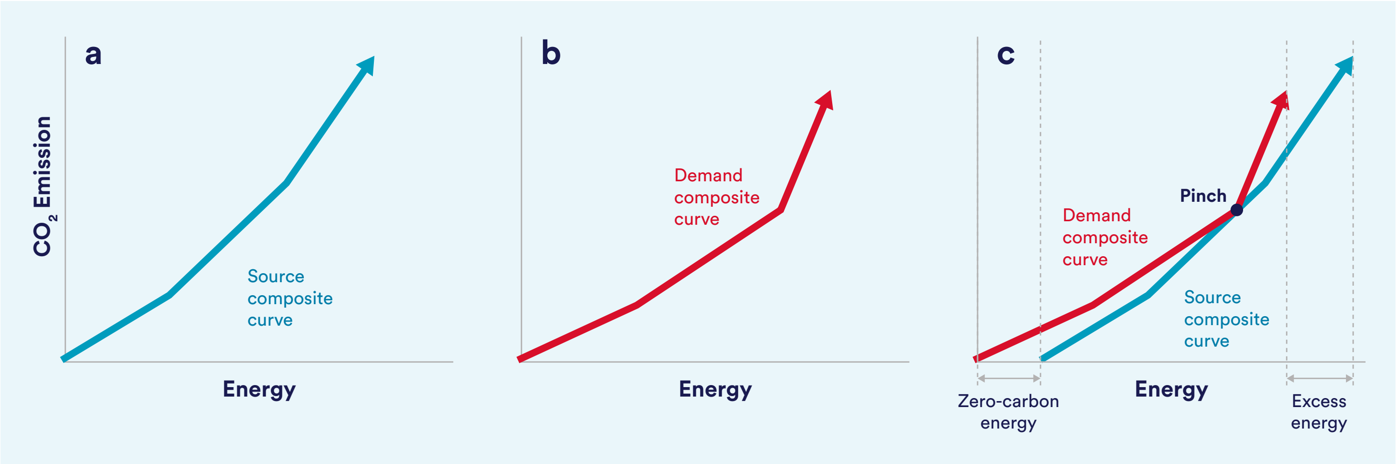
CEPA carbon intensity (emissions per unit of energy) is a measure of energy quality. Any given energy quantity or load can be tagged with a corresponding quality value. The quantity and quality of energy flows can be plotted graphically in a carbon-energy diagram.[1]

We use CEPA to plot different energy sources end to end to form a source composite curve, as shown in Figure 1a. We also plot multiple energy demands in a similar way to form a demand composite curve, as shown in Figure 1b. We can think of these composite curves as paths in the

1. The formal name for this tool is called the 'Energy Planning Pinch Diagram'.

carbon-energy diagram. Then, we put the two composite curves in the same graph, as shown in Figure 1c. Carbon constraints in the system are met if the source composite curve is entirely below and to the right of the demand composite curve. If this condition is violated, we shift the source composite curve horizontally to the right. The smallest possible horizontal shift that meets this condition is the target, which gives the minimum amount of zero-carbon energy source that the system needs for all carbon constraints to be met. Here, the term 'zero-carbon' can refer to energy sources such as renewables, whose actual carbon intensities are minuscule compared to fossil fuels. We can also see that in this scenario, the two composite curves touch each other at a junction. This junction is known as the 'pinch point'.

Figure 1. Plotting of (a) source composite curve, (b) demand composite curve, (c) carbon-energy diagram



Results and conclusions

CEPA can be used as a high-level planning and visualisation tool for decision makers. Detailed problem analysis can follow using other tools such as computer models and programs.

We take the case of the Philippines as a representative example of a developing country facing carbon-constrained growth challenges. The Philippines has enjoyed a decade of sustained economic development with GDP growing 6% per year which has resulted in increased energy demands. One worrying trend is the increasing average carbon intensity of electricity due to the reliance on coal-fired power plants for cheap electricity. In 2017, 94.3 TWh of electricity was produced along with 60.1 Mt of CO2 emissions (equivalent to 51% of the Philippines total use of fossil fuels). The entry of electric vehicles into the market put additional pressure on energy planners to meet this demand for cheap electricity. However, it is also important to meet the country's commitment to the Paris Agreement, which is to cut carbon emissions by 70% by the year 2030.

Analysts and policy makers grappling with these issues can use CEPA to explore options. In Figure 2, we can see the CEPA plot for 2017. The source composite curve represents the combined output of all the power plants in the country, and the demand composite curve gives the total demand for electricity for all end uses. Figure 2 also shows the projected business-as-usual growth of the power sector in 2030. The carbon emissions grow by the same factor as total electricity output, but the carbon emissions intensity remains fixed. Based on the INDC, to cut emissions by 70%, the demand composite curve will have a shallower slope, as shown here. We can now see that the two composite curves cross each other, indicating a violation of the carbon constraints.

One solution is to shift the source composite curve to the right, as shown in Figure 3. Here, we can see that the length of the horizontal segment of the source composite curve (the combined annual output from all zero-carbon power plants) is now 117.5 TWh, compared to 41.8 TWh in the business-as-usual scenario in Figure 2. This additional renewable energy also displaces an equivalent capacity of coal-fired power plant, as shown by the part of the source composite curve that extends to the right beyond the demand composite curve. We can estimate which of the country's coal-fired power plants need to be shut down for good, leaving just 8.5 TWh (= 169.7 – 161.2 TWh) of annual capacity in place.

In practice, high-level energy planning decisions may need modification based on various social, economic, or political factors. CEPA can still be used to consider possible options in such cases. For example, if it becomes necessary to retain 14 TWh of annual generation capacity from coal-fired power plants, the only way to meet the carbon emissions cap is to add negative emissions technologies (NETs). NETs are a different technique for removing carbon from the atmosphere. For example, the use of biomass to co-produce electricity and biochar can be NETs, if the biochar is applied to farmland like compost. This process sequesters carbon (which was originally absorbed by plants from the atmosphere via photosynthesis) into the ground in stable, solid form. Biochar's use in developing countries is limited in scale only by biomass supply and available land area. We suggest that biochar is used as a NET in the Philippines to meet the carbon emissions limit as shown in Figure 4. The last, downward-sloping segment of the source composite curve represents the production of electricity with negative carbon emissions. The combined output from all zero-carbon (renewable) power plants is reduced to 92 TWh.

Summary

To achieve a 70% reduction of GHG emissions from electricity generation, the Philippines government should reverse the trend of increased use of coal-fired power plants, and favour renewable energy sources (e.g. solar, wind, hydroelectric, biomass, geothermal, tidal and wave energy). If these measures prove insufficient, NETs will need to be used to further offset carbon emissions. Similar measures will be needed in many developing countries trying to balance economic growth with emissions cuts; CEPA can be used to help officials in energy ministries make better decisions.

Figure 2. Planning for year 2030, based on constant energy intensity per unit GDP (with continued 6% annual growth rate; dotted lines show composite curves for year 2017)

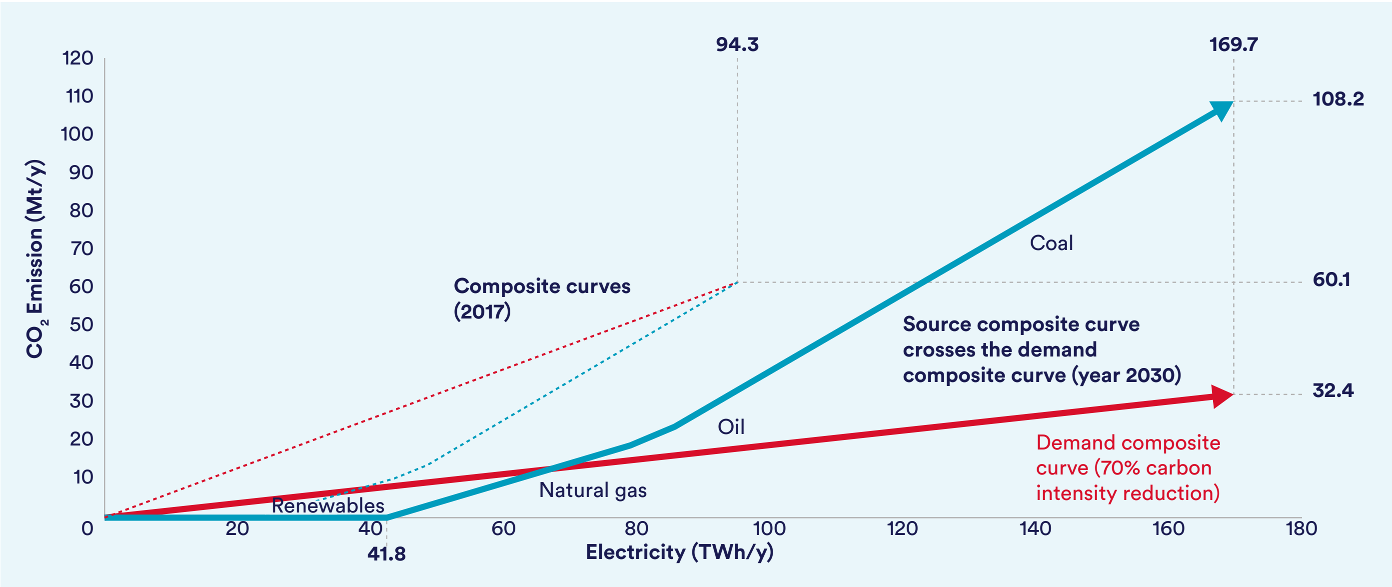


Figure 3. Carbon-energy diagram for year 2030, with 117.5 TWh from zero-carbon power plants, leaving just 8.5 TWh from coal-fired power plants

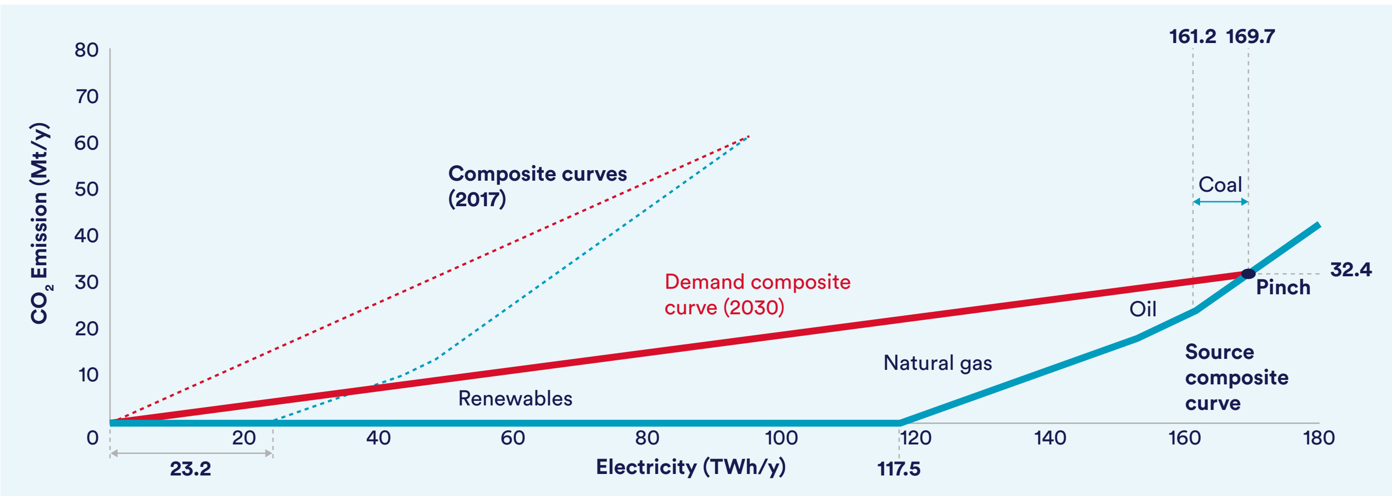
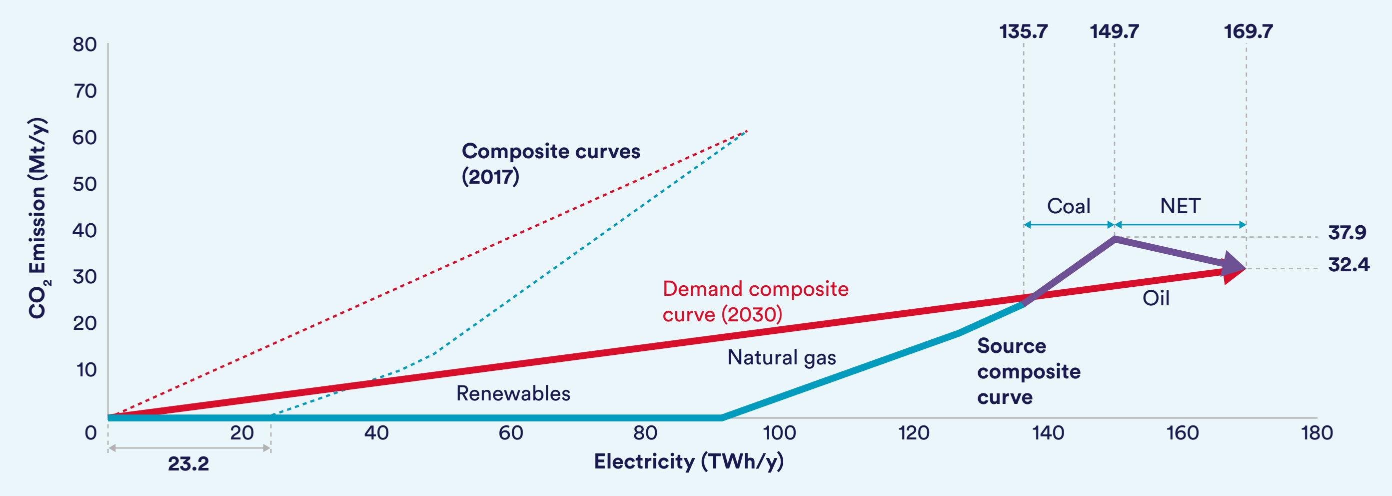


Figure 4. Carbon-energy diagram with NET implementation, with 92 TWh from zero-carbon power plants, with 14 TWh from coal-fired power plants



Implications

Policy makers should use CEPA as a decision support and communication tool, because this technique provides an intuitive view of a country's energy-climate nexus.

Climate change is a major environmental issue which can only be solved by effective decision making towards the use of technologies with low, zeroor negative carbon emissions.

Decision makers have to deal with multiple conflicting goals and stakeholder demands. Decision support tools such as CEPA can help improve the quality of real-world decisions by simplifying the visualisation of the energy-climate nexus in simple graphical form. This technique is especially valuable for being able to give 'big picture' insights, and for enabling effective visual communication. By comparison, detailed computer models can be challenging for both decision makers and their stakeholders to understand. Combined use of both approaches offers the best possible route to rational decision making towards climate stabilisation.

Resources

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Professor Dominic Foo is the Director for Centre of Excellence for Green Technologies (CEGT), University of Nottingham Malaysia. He is a Fellow of the Institution of Chemical Engineers and Fellow for the Academy of Science Malaysia. He can be contacted at **Dominic.Foo@nottingham.edu.my**

Raymond R. Tan is Professor of Chemical Engineering and University Fellow at De La Salle University, Philippines. He is also a member of the National Academy of Science and Technology of the Philippines. He can be contacted at **Raymond.Tan@dlsu.edu.ph**