Making the Trilemma Work for Asia

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THE LANTAU GROUP
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Asia's power sector faces ever-tougher questions

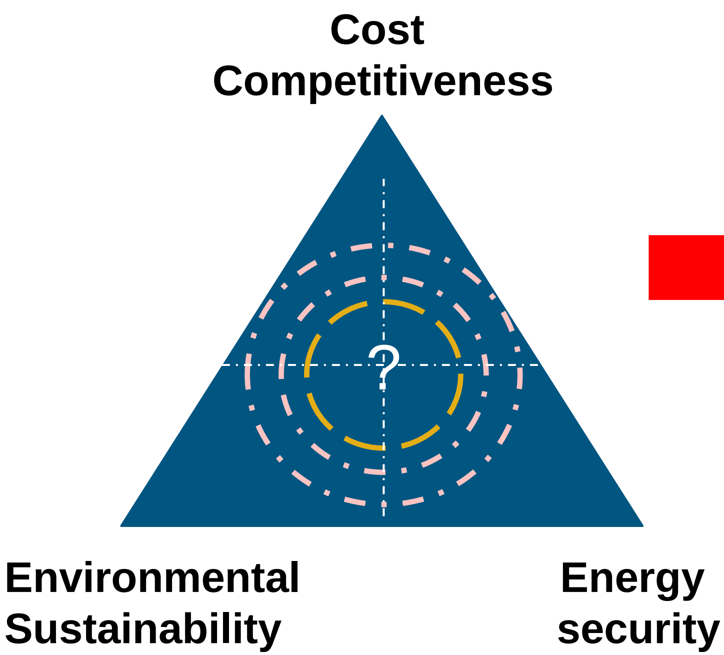
- determining the appropriate size, type, and approach to strategic infrastructure such as an LNG terminal;
- matching an LNG terminal to a value-enhancing fuel contracting strategy;
- determining how to achieve environmental improvement at lower cost;
- evaluating the value of coal-fried versus natural gas-fired generation capacity;
- determining whether to support renewable technologies that reduce exposure to volatile fuel markets but increase intermittent generation;
- evaluating fuel mix policies that would target and thus constrain choices to operate or invest in future generation even if fuel markets shift in the future as they have many times in the past;
- the impact of disruptive technology or fuel market developments; the role of markets versus regulation versus direct intervention;
- what to do about carbon and non-carbon emissions

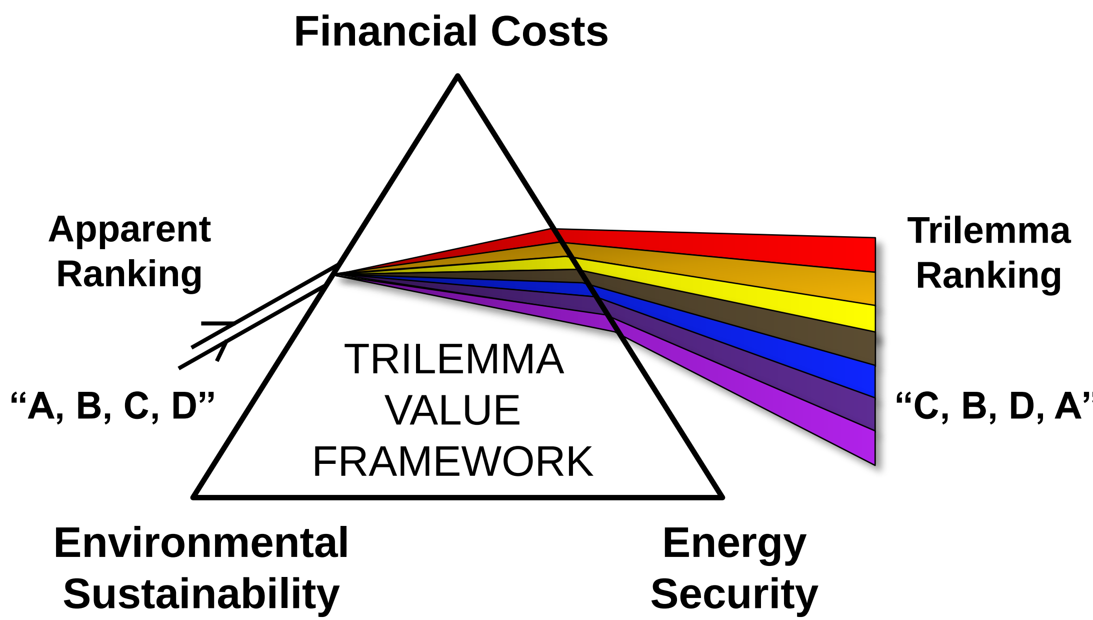
These questions are not easy! Good answers require a coherent and consistent framework

We propose a trilemma framework, but only if it is rigorously defined….

From Ambiguous Triangle

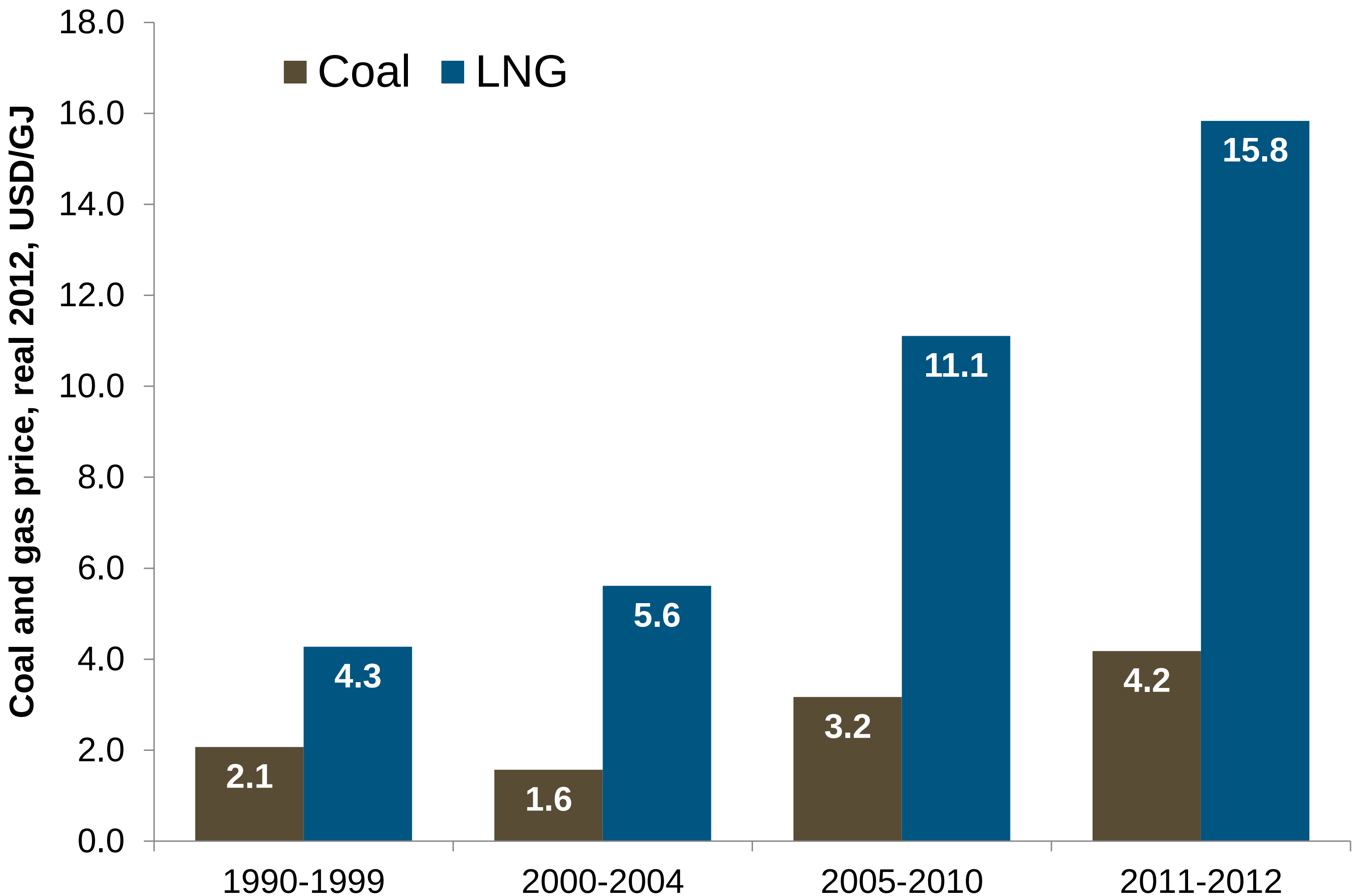
To Clarifying Prism



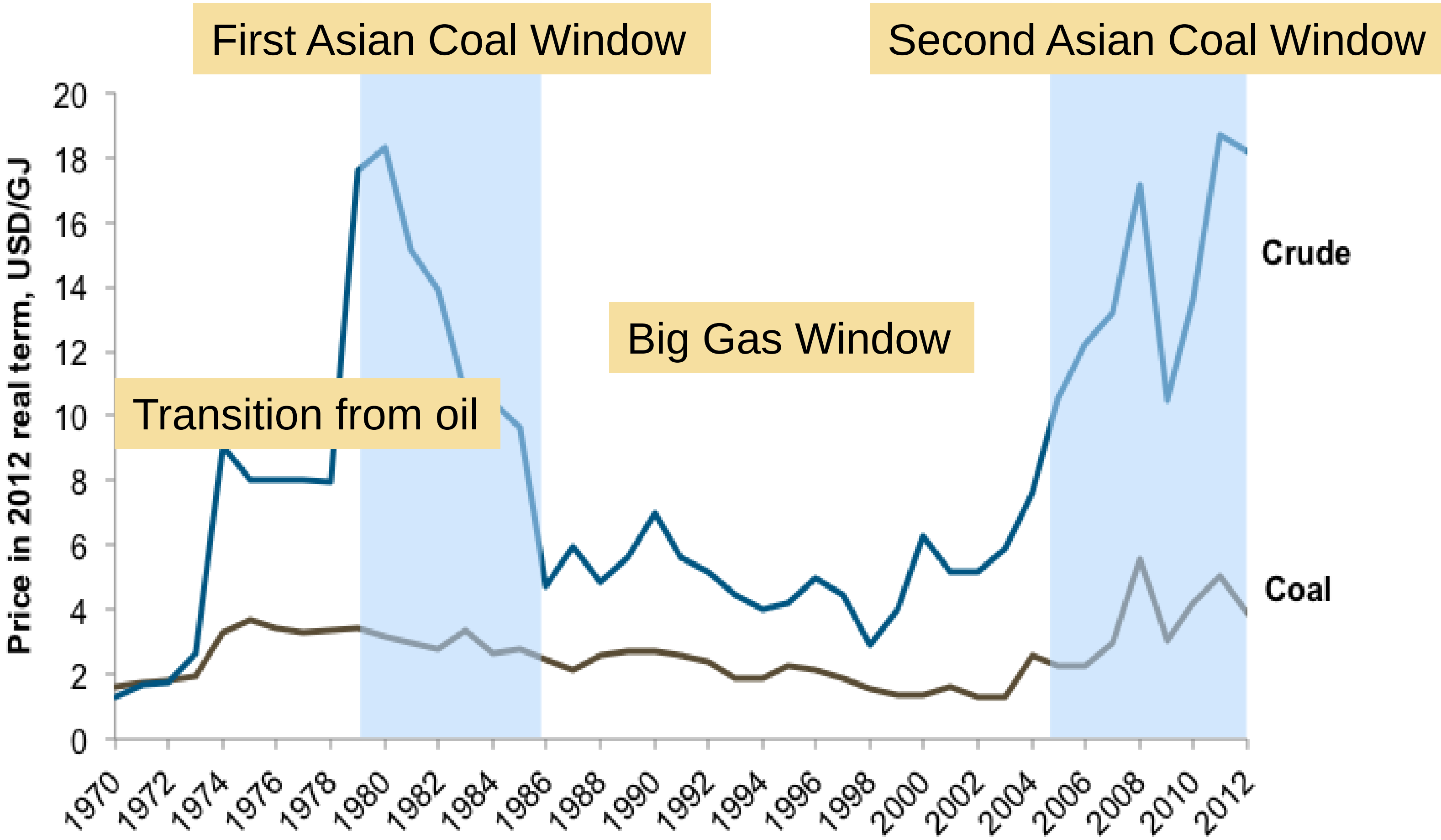


The trilemma is not a balancing act, but rather a way to decompose problems in useful ways

The challenges are tougher because coal and gas prices have grown apart by such a large extent



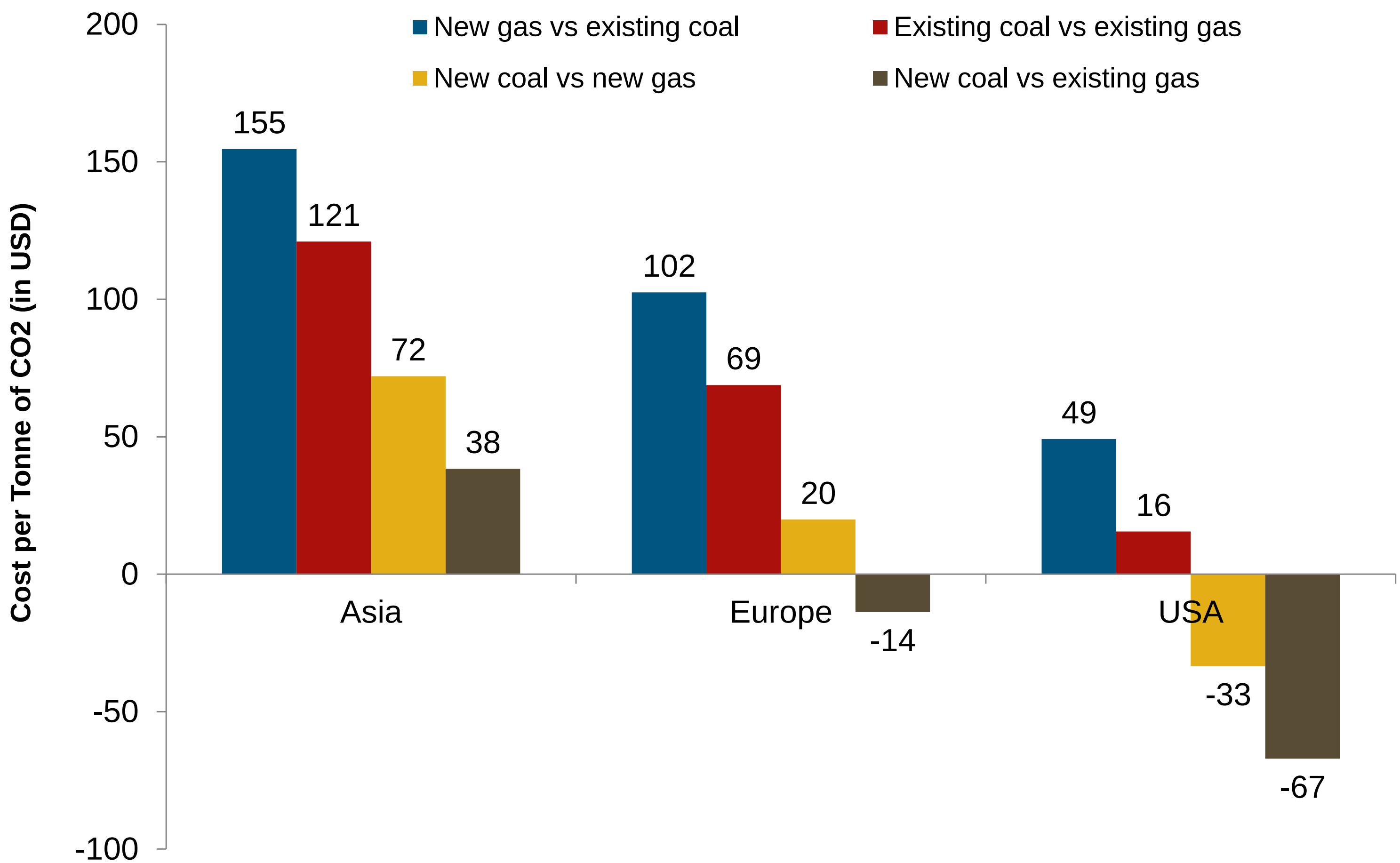
A coal window has once again opened up. Do we ignore it? At what cost?



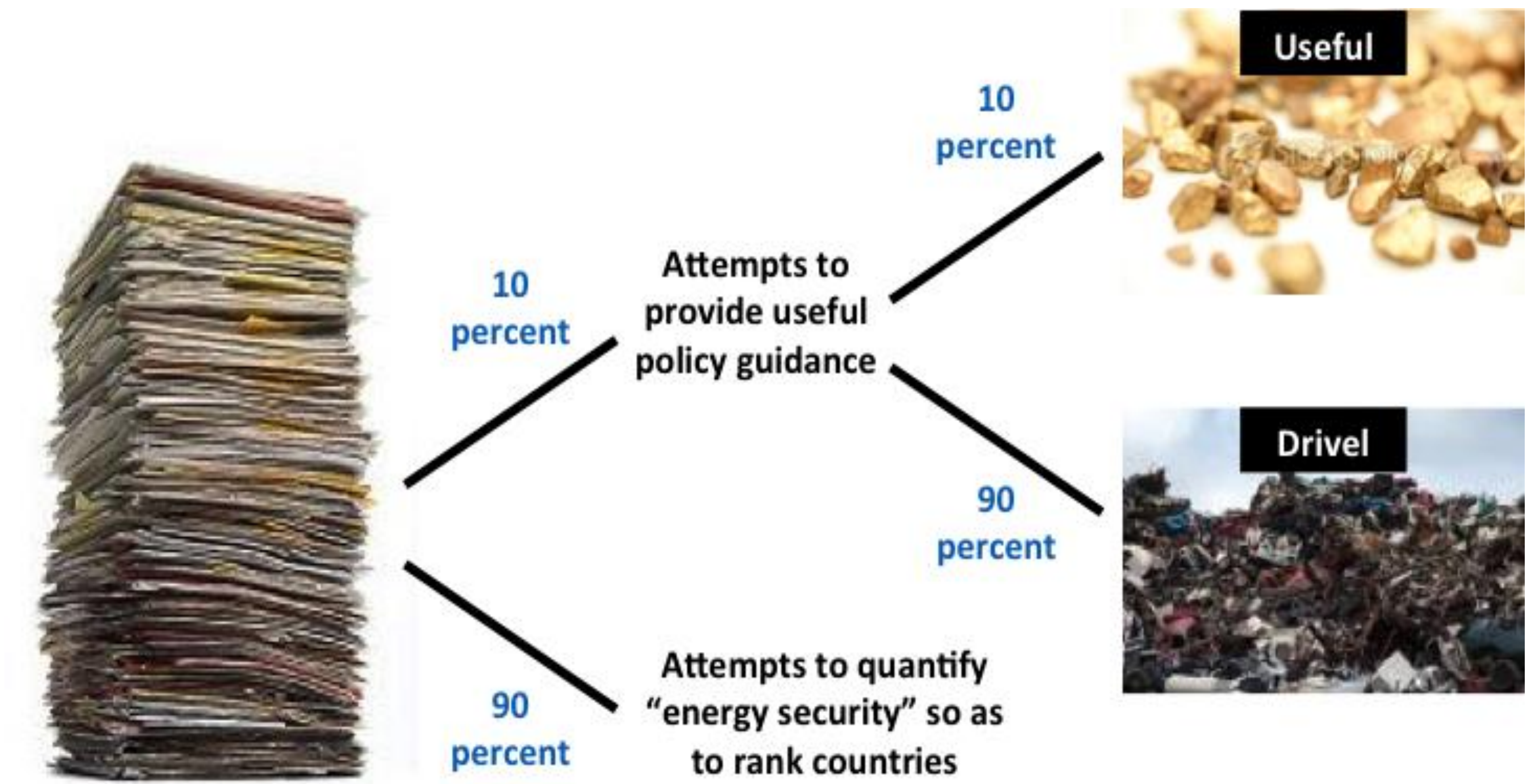
Note: Crude price: 1970 - 1987:Arab Light Crude prices ; 1988 - 2012: Brent price (historical Brent price only starts from May 1987)
Coal price: 1970 - 1982: average coal prices in the US from EIA; 1983 - 2012: Newcastle FOB price

If you had gas available from the late 1980s, you moved towards it through the 1990s and early 2000s – due mainly to the relatively low oil prices of that period

As a result the cost of switching from gas to coal for carbon or other environmental reasons is very high in Asia – higher than in the ROW



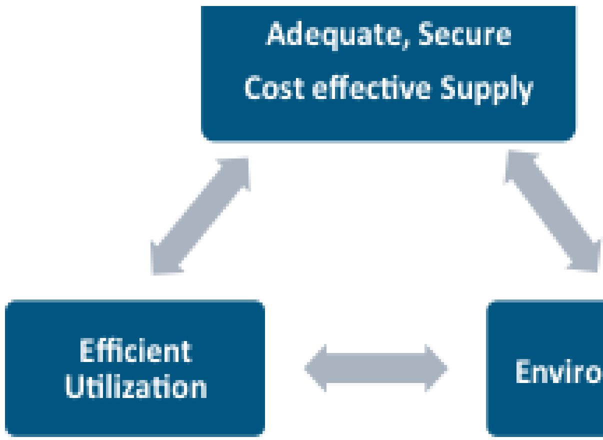
We also looked for insights in the broader energy policy literature, but found very little that was useful….

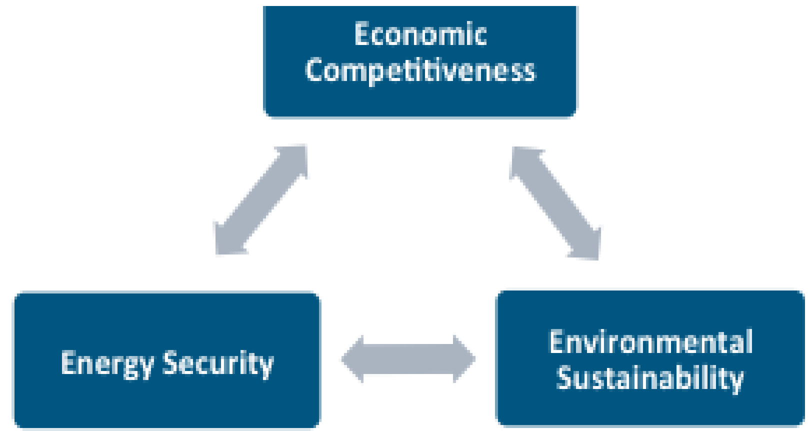


So we developed the TLG trilemma framework for analysing the “coal window” -- focusing on costs, environmental impacts and energy security

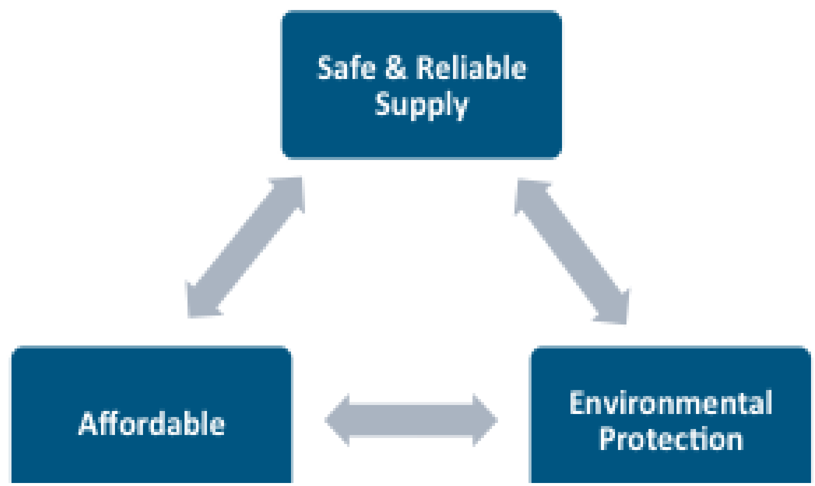
Traditional System Costs	**Environmental Impacts**	**Energy Security**
Capital Costs by technology Technology costs Cost of capital (WACC) Tax and depreciation Economic life Fuel Costs by technology O&M Costs by technology	Air resources Water resources Land resources Noise emissions Other ecosystem detriments (e.g., endangered species and climate effects) Disposal / remediation costs	Physical energy security Cost of avoiding lost load Financial energy security Responding to disruptive changes in the cost of critical inputs (e.g., fuel) Short-term (fuel switching through dispatch) Medium-term (supply chain adjustments/ re-sourcing) Long-term (capital investment) Factoring an appropriate value for risk aversion Mitigating exposure to market power Obtaining benefits of longer-term learning curve effects

The TLG trilemma differs from trilemmas adopted by many countries – which are often used to justify/explain decisions after they have been made





Hong Kong

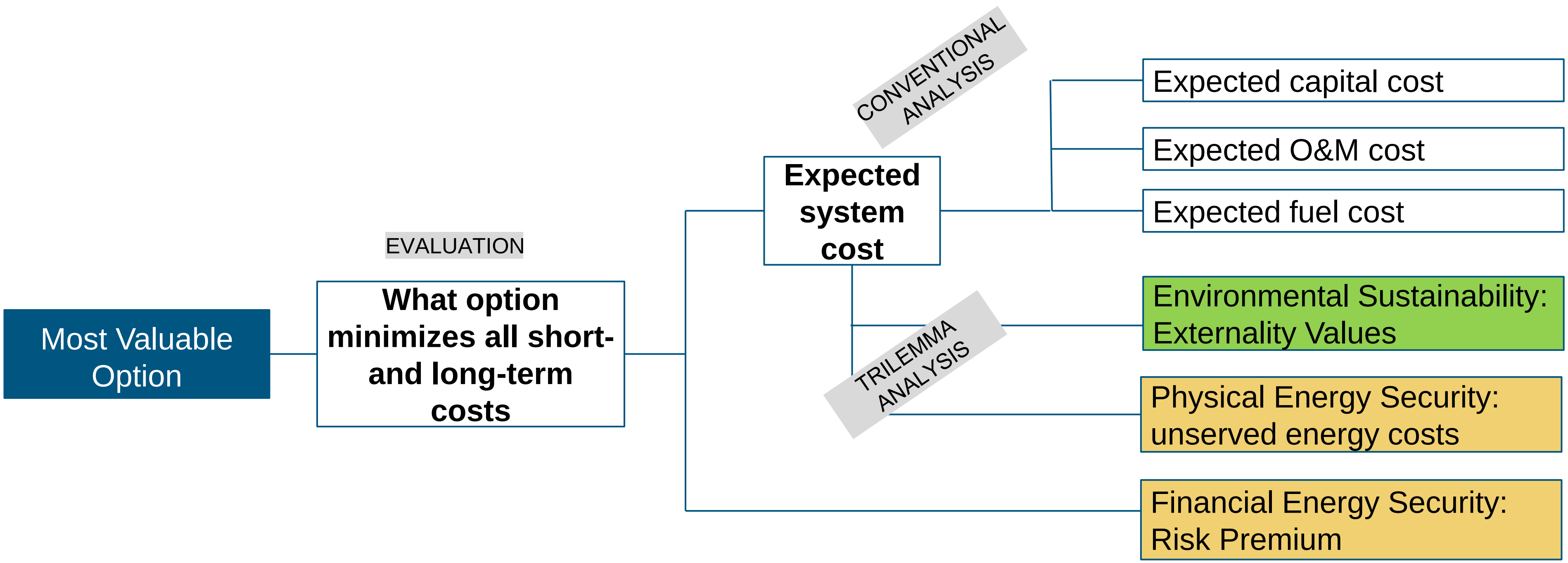


Soft
SQUIshy
Elastic

THE "SQUISHE" TRILEMMA

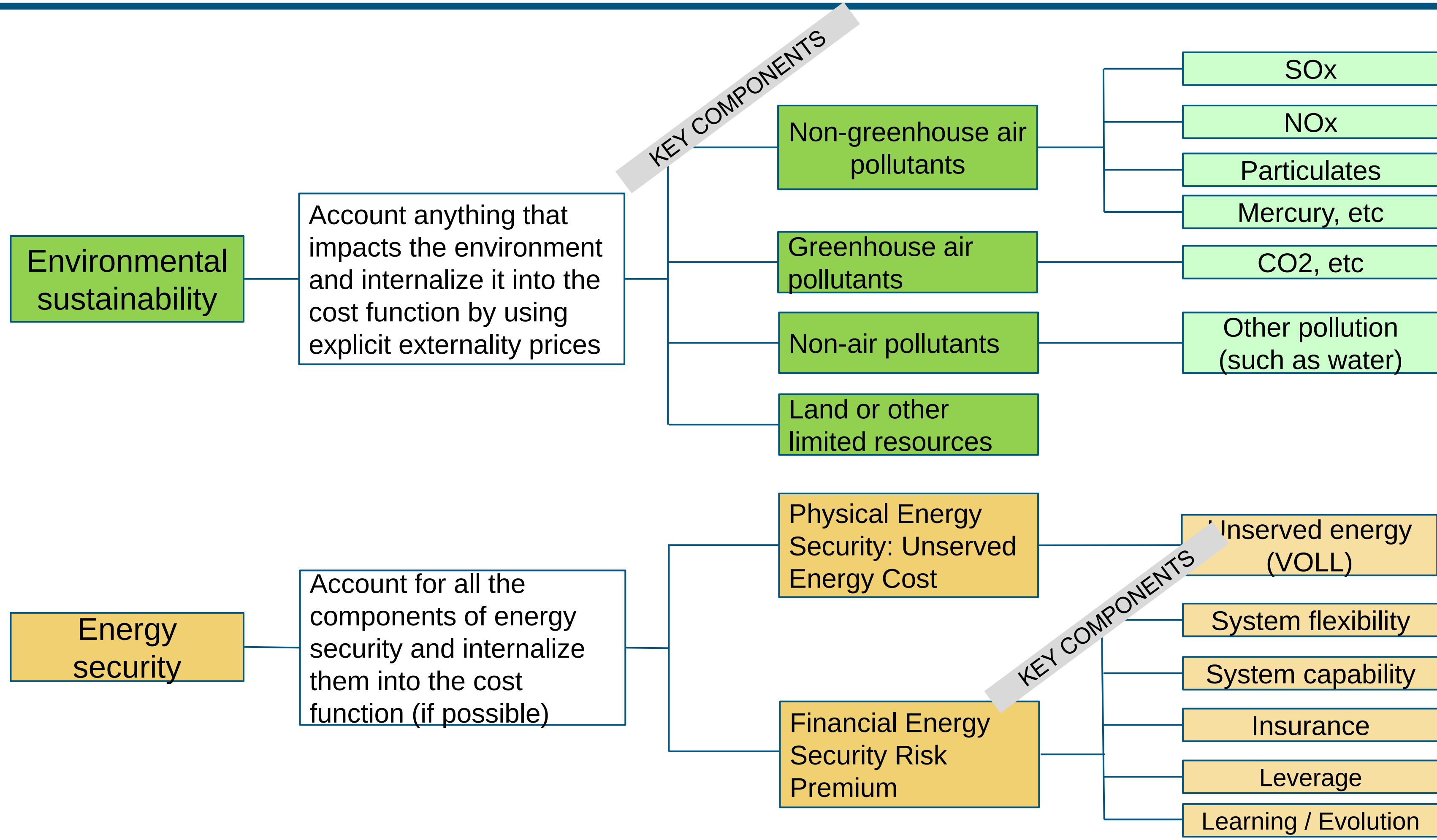
Everything to everybody

Overall TLG Trilemma structure



Mutually Exclusive / Collectively Exhaustive (MECE) factors

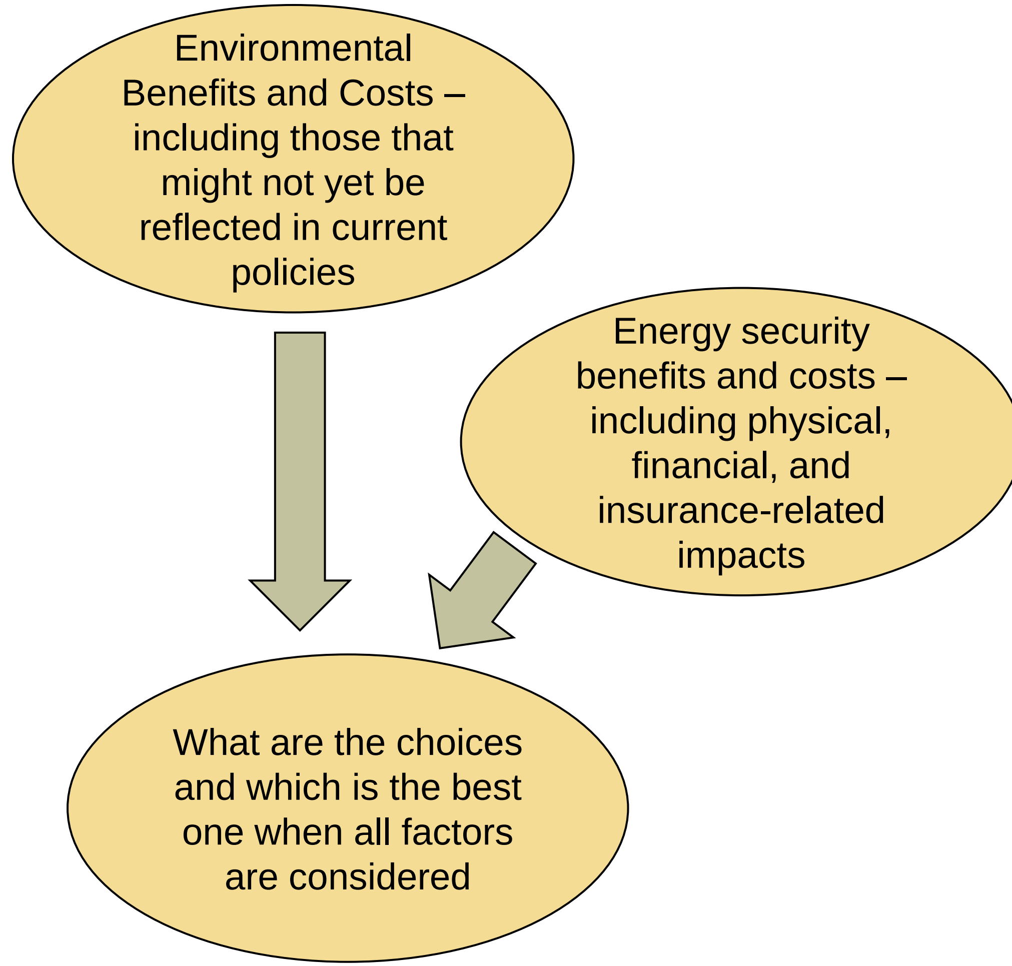
TLG trilemma: First level drill down into environmental and security factors



Must include all factors and drill down to a level where each can be quantified or qualified via direct analysis or hypothesis testing

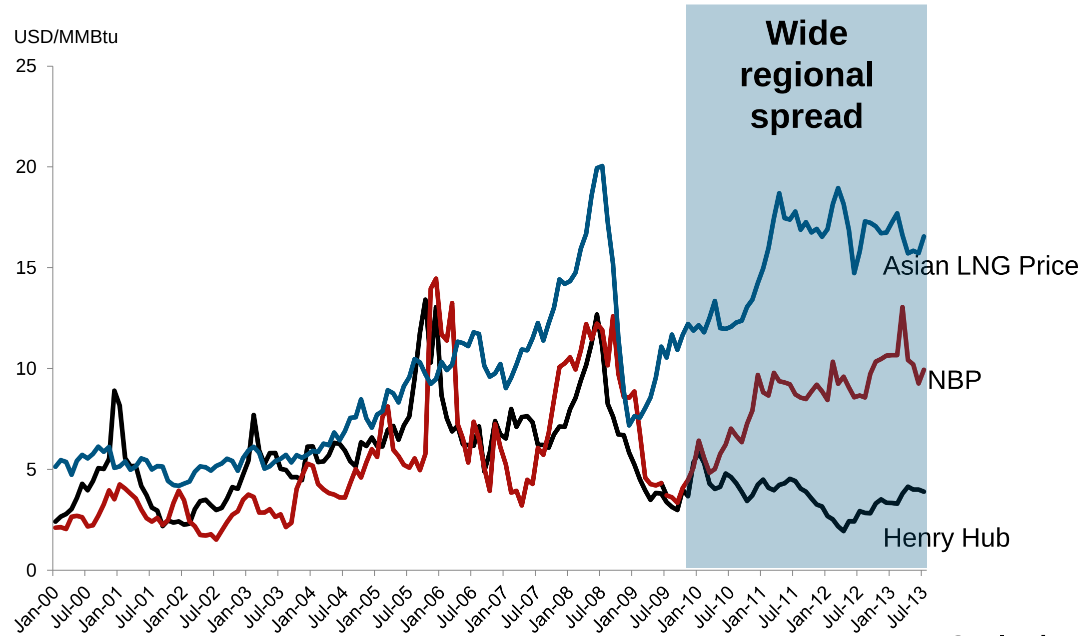
The next step is to actually evaluate options using the TLG trilemma framework

- For each decision
  - What are the costs, benefits and risks
  - How do these map to the trilemma framework
  - What values should be assigned to environmental externalities and energy security risks
  - Is there a market failure that prevents the "right" decision from being made
- The "best" decision – the one that minimises total costs across the trilemma value framework



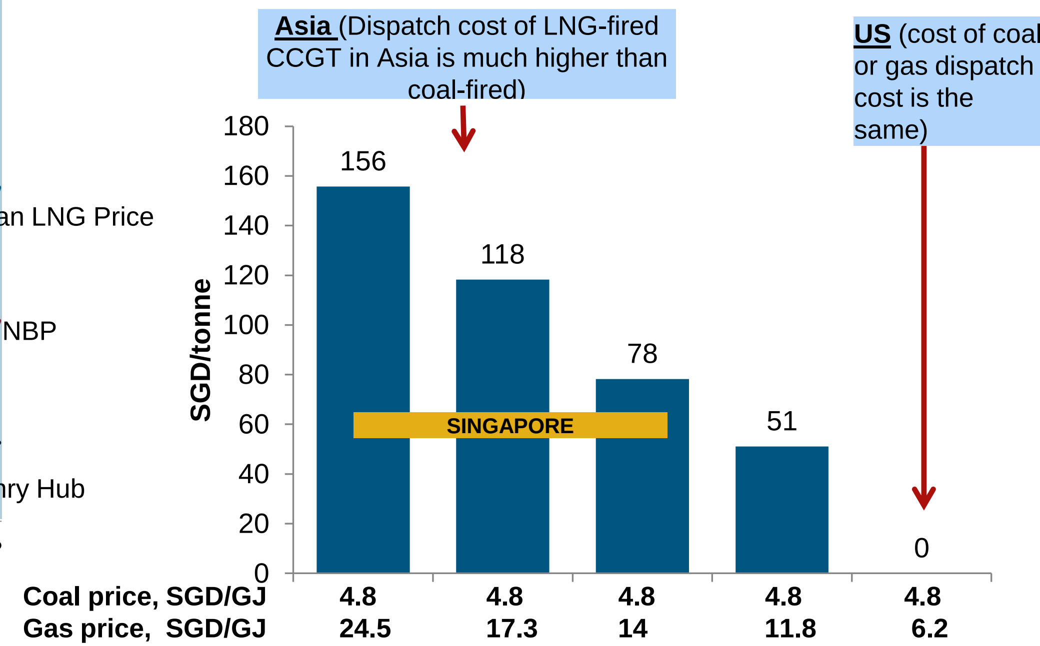
Within the environmental aspect of the trilemma, carbon is, by far, the key factor that can shift decisions – other emissions are easily mitigated using the latest AQCS compliant technologies in new installations (including coal)

Natural gas prices in US, Europe and Asia



Source: ICE, Bloomberg and TLG analysis

Implied CO2 Price for gas to be more competitive than coal

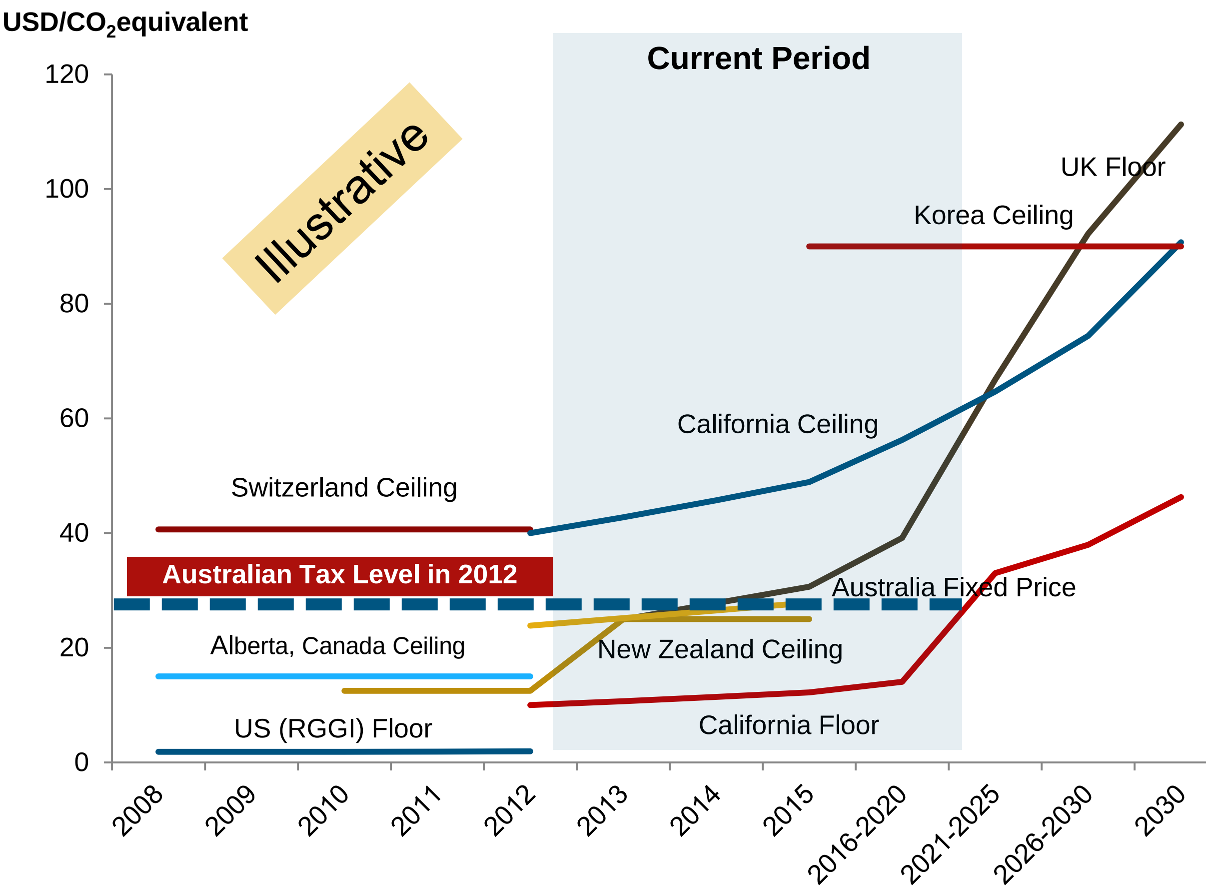


Source: TLG analysis

Concerns about local air quality are readily addressed using AQCS compliant technology – even for coal (though this is not well understood). But carbon emissions remain

After canvassing global experience, we adopt USD 24/tonne CO_2e for analysis

Carbon price cap and floors in various countries (US$/$CO_2$e tonne)



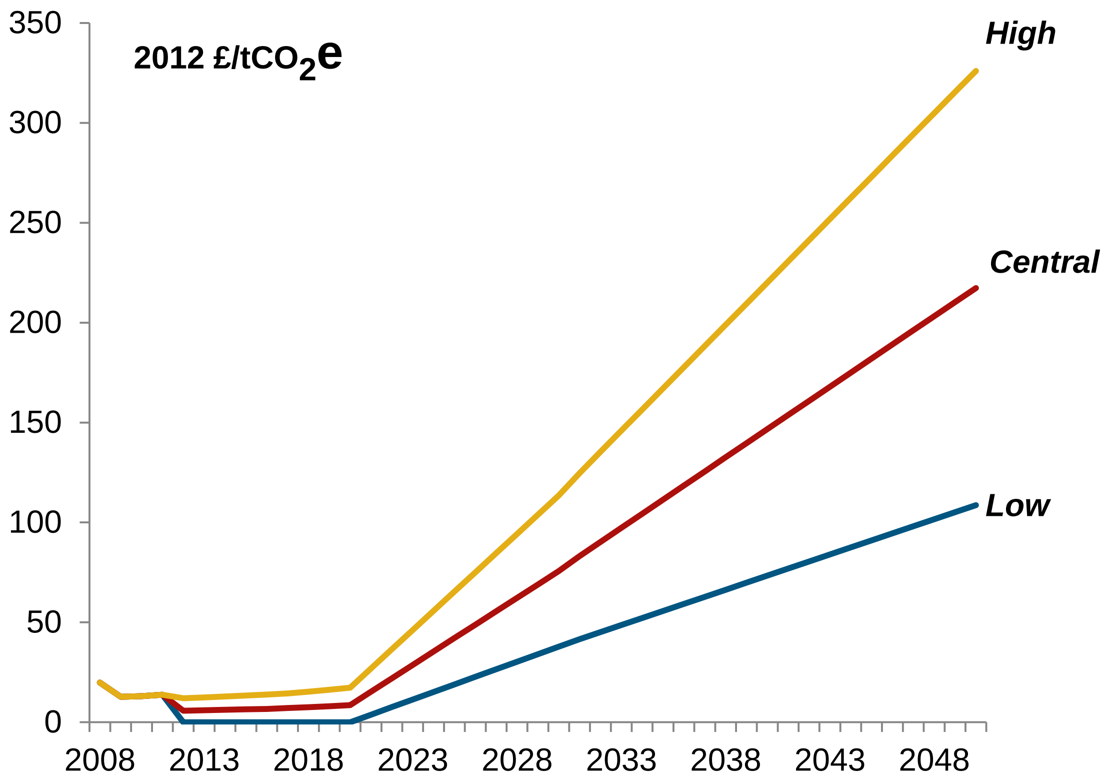
Per tonne of CO_2 equivalent	2013/2014 Local currency	2013/2014 USD
United Kingdom	GBP 15.7	24.9
California Cap	USD 40	
California Floor	USD 10	
California average	USD 25	25.0
Australia	AUD 25	25.9
New Zealand	NZD 25	20.3
Average		24

Source: TLG Research

- Based on these various values, we adopt a representative price of $24/tonne as aligning broadly with studies and longer-term expectations
- We also test the value required to cause switching from coal to gas in Asia – this value currently ranges around $67/tonne or higher depending on relative coal and gas costs.

We also analysed alternative scenarios, including much higher carbon values

UK DECC carbon prices and sensitivities 2008-2050 for appraisal

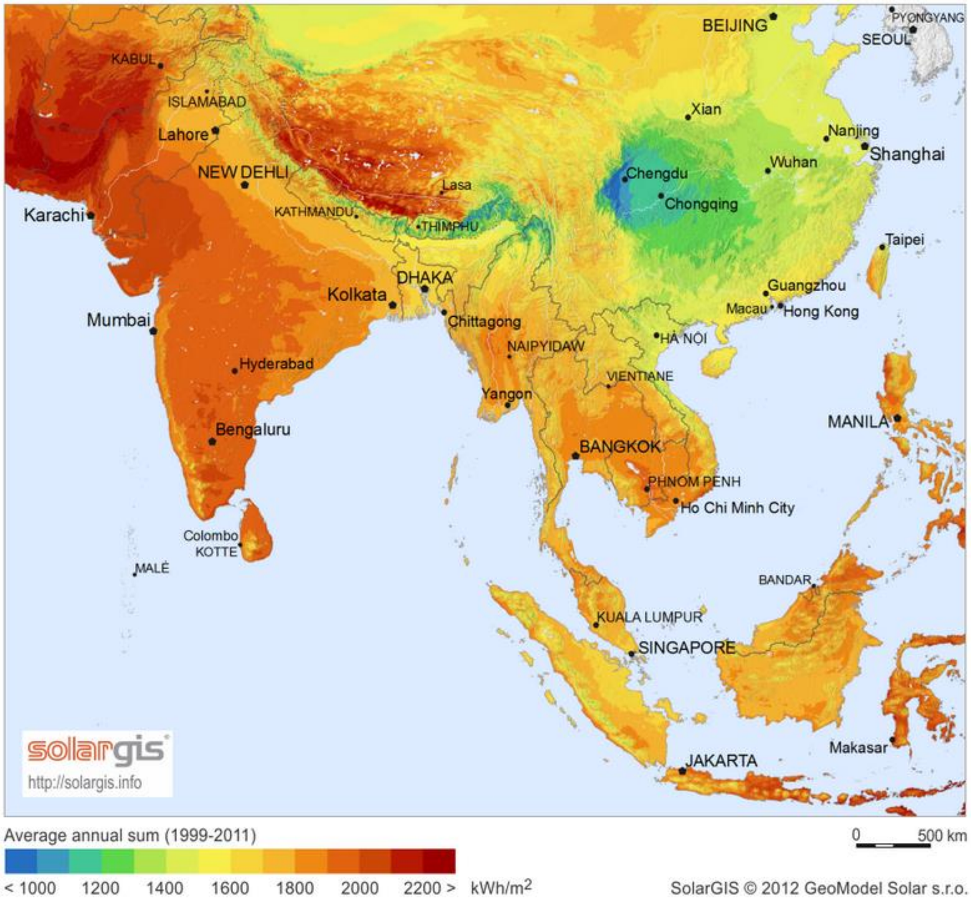


For example:

- UK Department of Energy & Climate Change (DECC) has provided three scenarios of carbon dioxide prices and recommended project planners to use these forecast to appraise their new project.
- Use is voluntary, but intended to be indicative of what risk an investment might face as GHG emissions eventually must be reduced

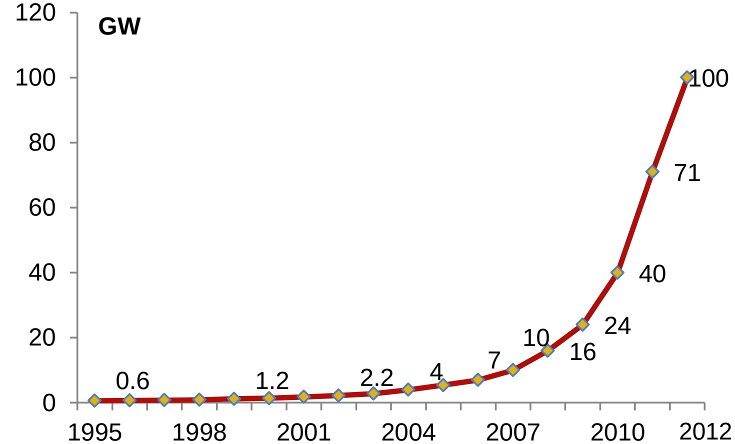
We apply the trilemma to an example Solar PV project in an above average irradiance region within Asia

Southeast Asia Solar Irradiance Map kWh/m²

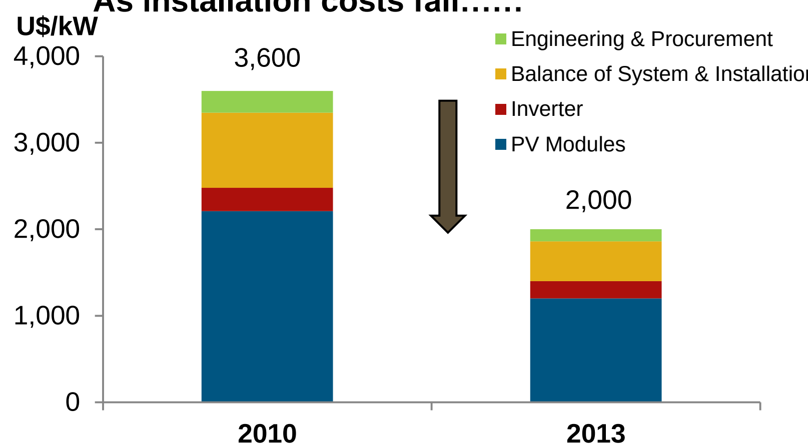


Source: SolarGIS

Solar installed capacity has exploded 1995-2012

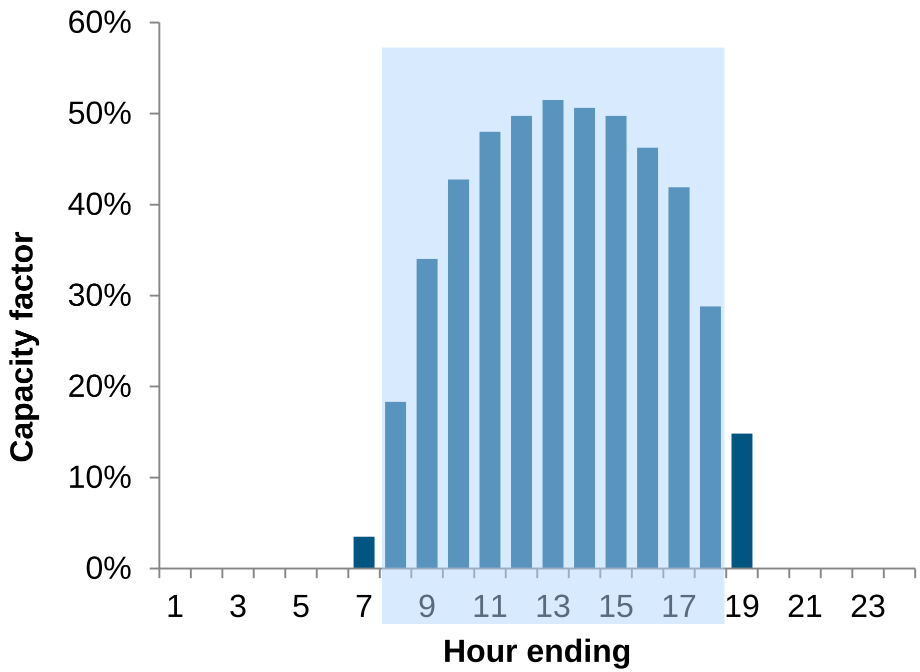


As installation costs fall……



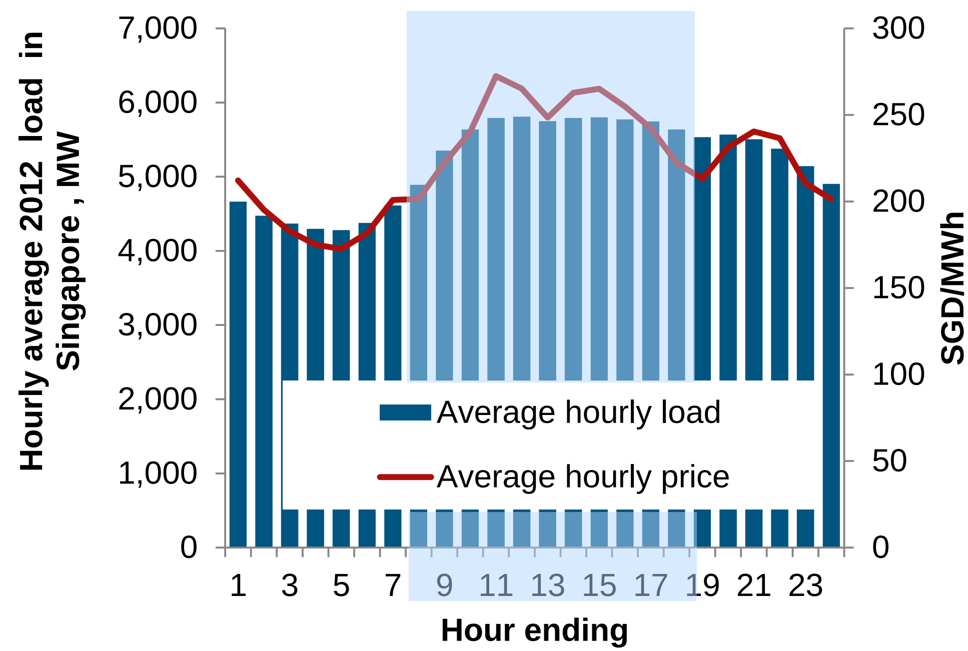
PV solar displaces LNG in those countries where LNG is the marginal fuel – creating a significant “fuel displacement” savings credit

Average hourly solar PV generation profile



Source: Calculated and adjusted based on hourly generation data from National Renewable Energy Laboratory (NREL)’s Solar Advisor Model

Typical load profile and electricity prices (Singapore)

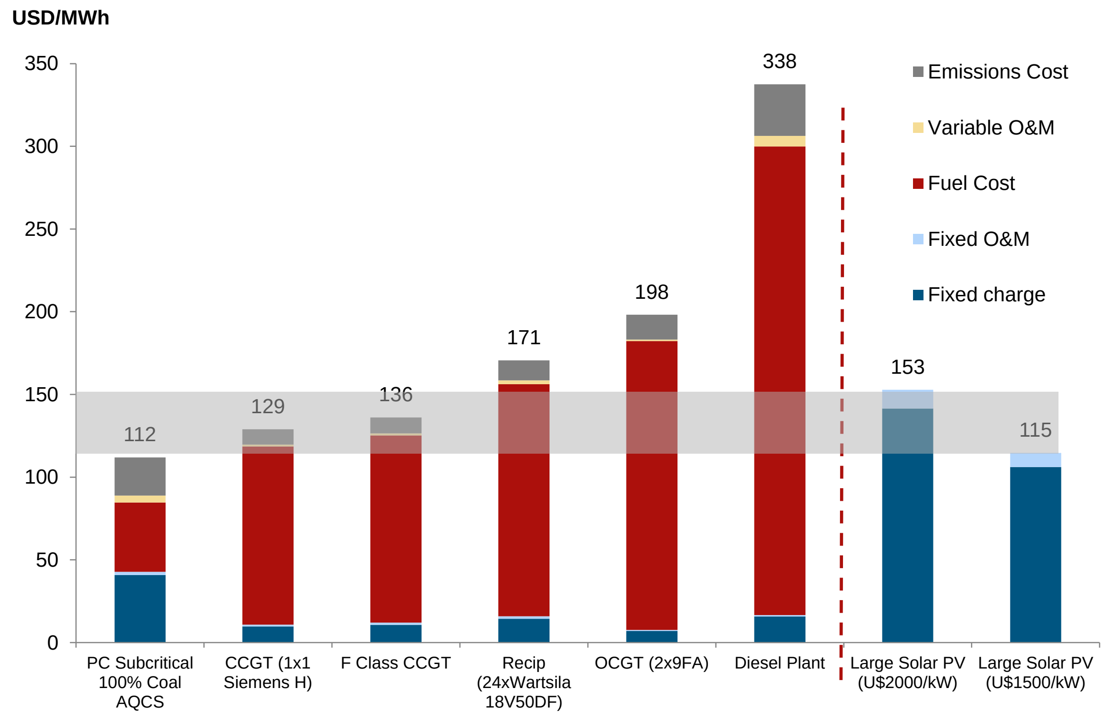


Source: Calculated based on half-hourly load and price data from Singapore Energy Market Company (EMC) website

Given the range of solar pv installation costs, together with carbon and other emissions "penalties", solar appears to be competitive with CCGT technology

Cost components of leveled cost of different technologies

With carbon cost = $24/tonne



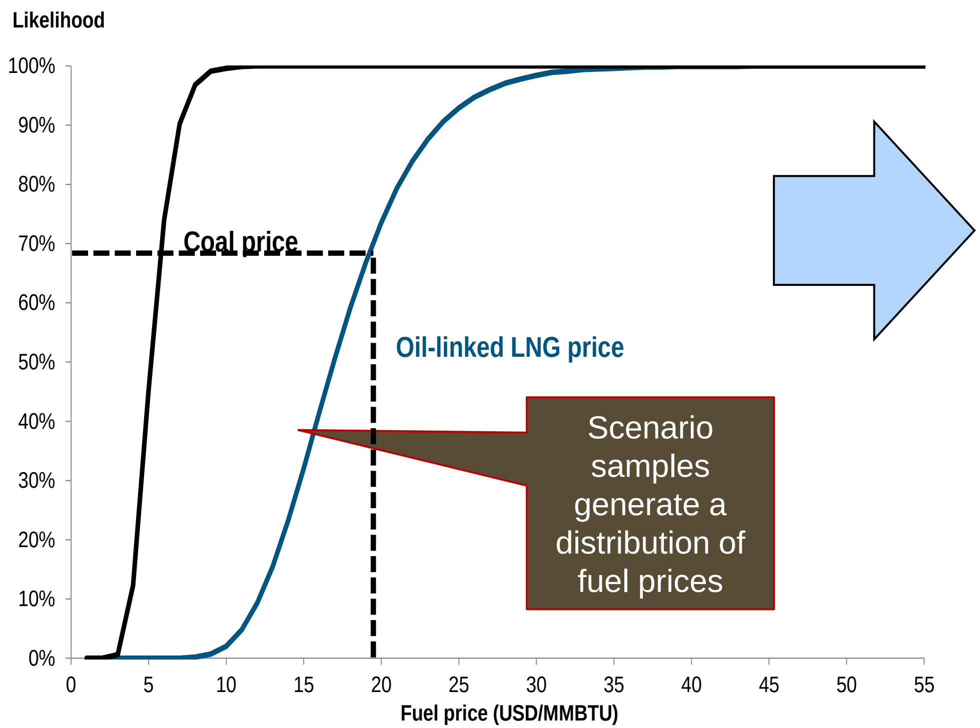
Note:

- CCGT: Combined Cycle Gas Turbine
- O&M: Operating and Maintenance
- AQCS: Air Quality Control System
- OCGT: Open Cycle Gas Turbine
- Fuel cost include supply cost of fossil fuels, such as coal, gas and oil

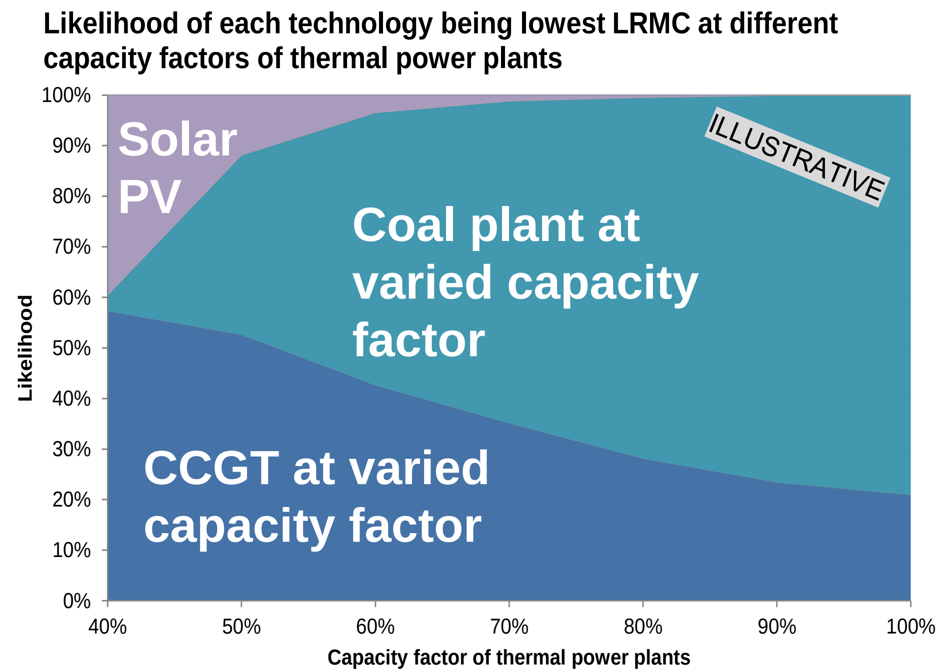
Economic damage associated with various air emissions are incorporated based on international standards and benchmark estimates

Given risk and uncertainty, we simulate the least cost generation portfolio –

Cumulative frequency distribution of fuel prices, 2014



At a reasonable CO2 externality cost, Solar PV is an efficient part of the fuel mix relative to mid-merit CCGT and begins to compete with baseload coal, given fuel cost uncertainty



Note: Using historical coal and daily oil spot and forward prices (2007-2012) to characterize the short-term and long-term volatility of the fuel prices, we use our in-house model to project the "optimal" capacity fuel mix for 1000 scenarios.

Source: TLG analysis

Solar PV is economic in many scenarios, though not overwhelmingly so

We need approaches to deal systematically with differences in energy security dimensions

Physical Energy Security

Easily Stored or Accessed

HIGH

STORABLE LIQUID and solid FUELS (OIL and Coal)

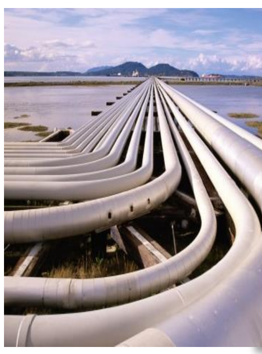
Oil and coal is secure – physically, with market access and high storability and many sources of supply.

LARGE STORAGE HYDRO POWER

High physical and financial energy security. Provided the reservoir has sufficient storage and hydro-variability is not a major issue.

MEDIUM

LOW



DEPLETING NATURAL GAS RESERVE

If gas supply infrastructure is not developed or if the gas resource is at risk, then physical energy security is an issue. Financial energy security depends on price linkage formula, which is often linked to oil in Asia

ON SHORE WIND

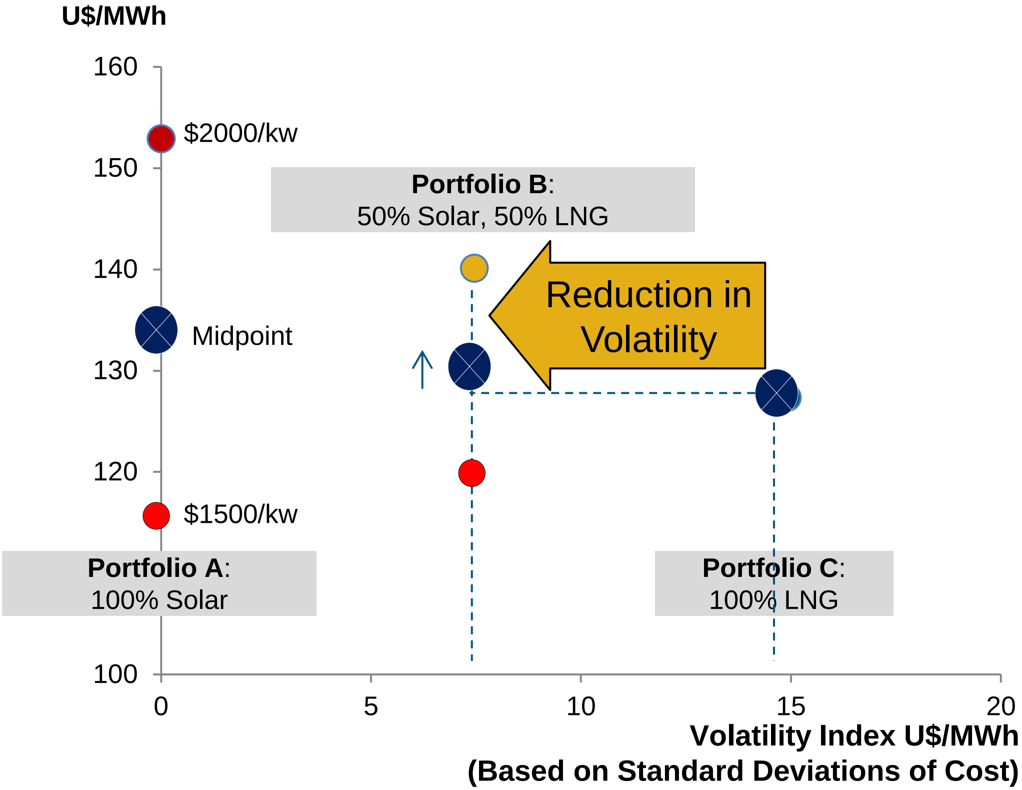
High intermittency, but costs are mostly predictable once built – no linkage to volatile oil markets, for example

Financial Energy Security

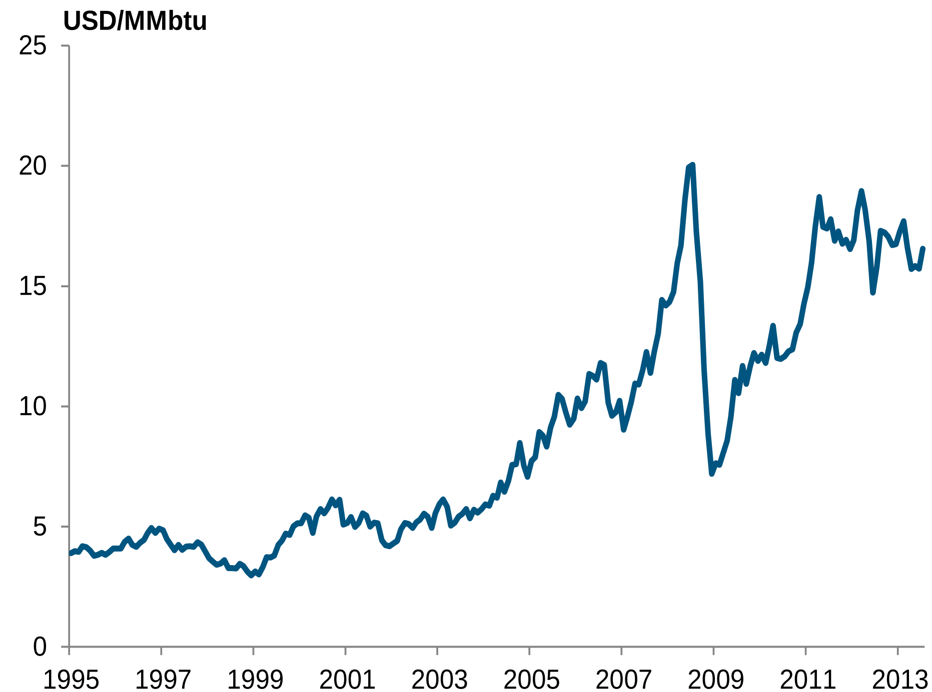
High Fixed Costs / Low Variable Costs

Risk aversion is one important aspect of energy security

Mean *levelised Cost of Energy*



Asia LNG Price (slope at 13.85) 1995- Current



Note: Fuel price input is based on Asia LNG prices for the past 12 months
Source: TLG Analysis

Risk aversion

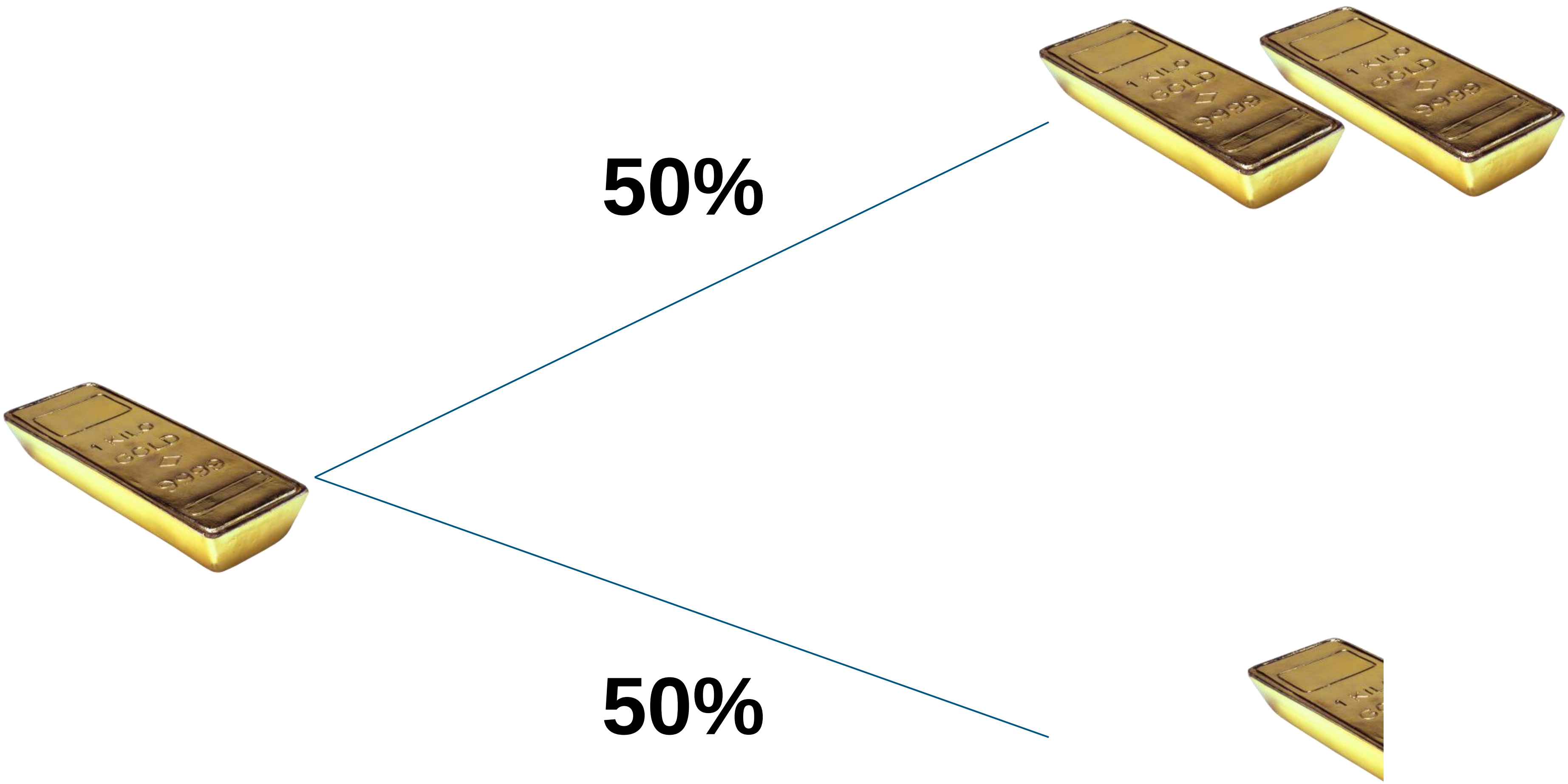
- *Several years ago, we worked for three companies who were partners in a joint venture to assist them in making decisions about that venture. Because in this decision risk tolerance was an issue, we began by assuming that their risk preferences were exponential and then assessed the risk tolerances by interviewing top executives in each company. We assessed the exponential risk tolerances by the usual simple procedure: We found the sum of money such that the executives were indifferent as a company investment to a 50-50 chance of winning that sum and losing half of that sum. The result is a close approximation to the exponential risk tolerance. We also reviewed the annual reports to obtain the net sales, net income, and equity of the three companies*

Ronald Howard, Decision Analysis: Practice and Promise was published in Management Science, Vol. 34, No. 6. (Jun., 1988), pp. 679-695.

A proxy for the exponential risk preference function

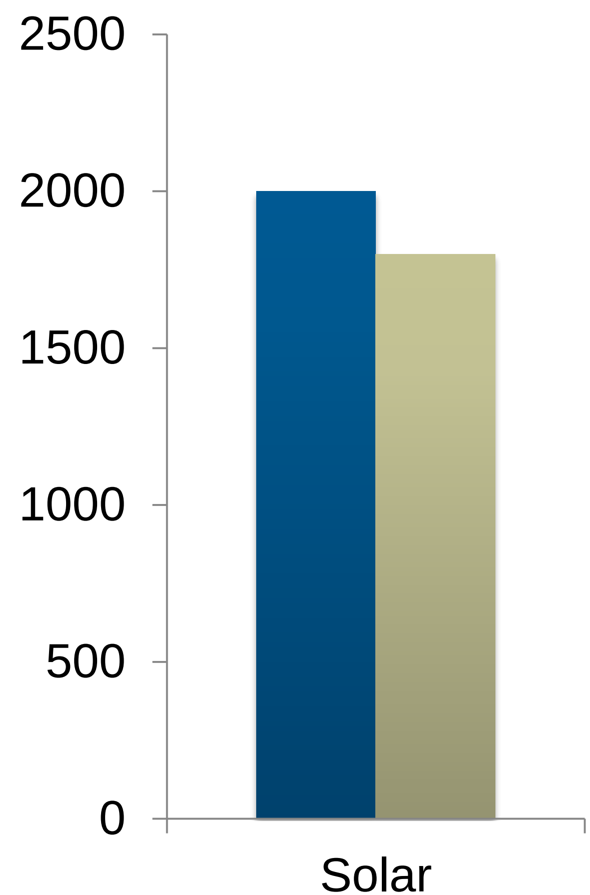
What is the most you would put at risk?

If what you might get back is:



LNG prices have had a high variance

- Based on the proxy test, a crucial point on an exponential risk tolerance function for a country is assumed to be 6.5% of annual GDP
  - (this is an area of ongoing research)
- We can therefore calibrate fuel cost exposure relative to GDP (as a proxy for ability to pay)
- We note that, since 2007, the standard deviation of Brent crude prices has been about 25%, which we can use to simulate exposure
- Under a range of assumptions where a country has significant LNG cost exposure, a solar PV project contributes a material potential benefit
- That benefit ranged from 5 to 15 percent of the capital cost of the solar project our hypothetical exercise
- For illustration, we therefore adjust the comparable value of the solar project to be 90% of its capital cost when comparing solar to LNG-fired options



When these adjustments are made (at least in this example), solar moves strongly into the money from a societal perspective

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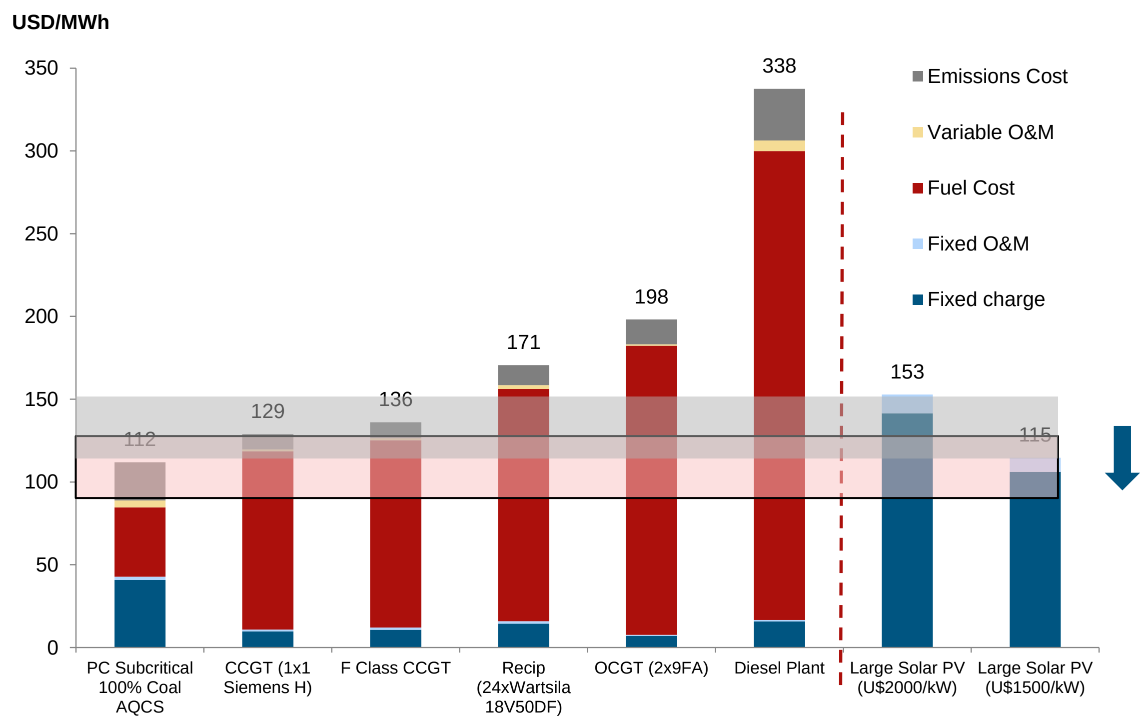

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SOLAR PV

Economic damage associated with various air emissions are incorporated based on international standards and benchmark estimates

What next?

- Analysis based evaluation is actually pretty insightful !
- There is room for more creative thinking about power options in Asia
- Coal is a sensible “green” solution if packaged with money and investments in offsets, credits or other green initiatives
- Combining coal and solar reduces exposure to global fuel costs
- The risk aversion estimates are greatest the more you are expose to LNG costs – they shrink rapidly if you already have a diverse portfolio of fuel market exposure