Energy Efficiency Measurement:

From Single to Composite Indicators

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Introduction

- Two big challenges in the 21st century: Climate Change & Energy security
- Improving energy efficiency helps to
  - Reduce energy consumption and CO2 emissions
  - Enhance energy security
  - Decrease energy cost
  - Increase business competitiveness
  - Create a positive image

Introduction

Energy efficiency is a generic term which means different things for different people/organizations.

Model 1

Model 2

Estimated New EPA MPG	
REGULAR GASOLINE	REGULAR GASOLINE
46 Combined	28 Combined
48 City / 45 Hwy	25 City / 33 Hwy

Source: http://www.fueleconomy.gov/feg/byclass.htm

Which model more ***energy efficient?***

“十三五”主要行业和部门节能指标

指　　标	单　位	2015年实际值	2020年	
			目标值	变化幅度/变化率
工业：				
单位工业增加值（规模以上）能耗				[-18%]
火电供电煤耗	克标准煤/千瓦时	315	306	-9
吨钢综合能耗	千克标准煤	572	560	-12
水泥熟料综合能耗	千克标准煤/吨	112	105	-7
电解铝液交流电耗	千瓦时/吨	13350	13200	-150
炼油综合能耗	千克标准油/吨	65	63	-2
乙烯综合能耗	千克标准煤/吨	816	790	-26
合成氨综合能耗	千克标准煤/吨	1331	1300	-31
纸及纸板综合能耗	千克标准煤/吨	530	480	-50

China’s Industrial energy efficiency targets by 2020

Introduction

- The indicator approach prevails in energy efficiency analysis
- Different types of indicators have been used in various application contexts
- The selection/development of an appropriate energy efficiency indicator is dependent on its definition

Question: how to define and measure energy efficiency at economy level?

Energy efficiency concepts

- In physics and engineering, the energy efficiency of a process, denoted by *eta*, is defined as:

$$\text{efficiency } \eta = \frac{\text{output}}{\text{input}}$$

where *output* is the amount of mechanical work (in watts) or energy released by the process (in joules), and *input* is the quantity of work or energy used as input to run the process.

In physics and engineering, It is a *dimensionless* number with a value between 0 and 1. Due to the principle of conservation of energy, energy efficiency within a closed system can never exceed 100%.

Energy efficiency concepts

- **Descriptions/concepts of energy efficiency at macro level**

“How effectively energy is being used for a given purpose” (OEE, Canada)

“A change to energy use that results in an increase in net benefits per unit of energy” (EECA, NZ)

“The ratio of the amount of energy services provided to the amount of energy consumed” (EIA, USA)

“The activity or product that can be produced with a given amount of energy” (EERA, USA)

“Energy efficiency is the first fuel of a sustainable global energy system” (IEA)

"A ratio between an output of performance, service, goods or energy, and an input of energy" (European Commission, Directive 2006/32/EC)

“A reduction in the energy used for a given service (heating, lighting, etc.) or level of activity” (World Energy Council)

Energy efficiency concepts

- It is often defined as the inverse of *energy intensity*.
- At the device/process level, there is little difference between *energy efficiency* and *energy intensity* - one is simply the inverse of the other.
- At the macro level, energy efficiency is not a meaningful concept because of *the heterogeneous nature of energy services*.
- An intensity measure can be calculated at the macro level, although its information content is limited without knowing the underlying sector details.
- At economy level, the *substitution effect* between energy and other inputs make the measurement of energy efficiency be more complicated.

Energy efficiency concepts

Examples of ***energy intensity indicators*** at various levels of aggregation of energy consumption:

Country	*Economy-wide*	E/GDP	E/capita	E($)/GDP
Sector	*Transportation*	E/passenger-km		E/tonne-km
	Industry	E/value-added		E($)/value-added
	Residential	E/household		E/(floor space)
	Commercial/Institutional	E/(floor space)		
Sub-sector	*Passenger transport*	E/passenger-km		
	Non-metallic mineral products	E/value-added		
	Educational buildings	E/(floor space)		
End-use	*Car*	E/km		
	Cement	E/tonne		
	Lighting	E/(floor space)		

Composite energy intensity (CEI) index

- The *energy-GDP ratio*, i.e. *energy use per unit of GDP*, has long been used by researchers and analysts to track changes in economy-wide energy efficiency.
- However, the changes in the energy-GDP ratio may arise from sources unrelated to energy efficiency, such as activity structure change.
- Composite energy intensity indexes (CEIs) may be used in place of, or to complement, the energy-GDP ratio for tracking energy efficiency trends.
- How to construct a composite energy intensity (CEI)?

1. Bottom-up approach (e.g. ODEX)
2. Decomposition cum aggregation (DCA) approach

The DCA approach

Step 1. Use index decomposition analysis to isolate the energy intensity effects at lower levels (e.g. sub-sector level)

Step 2. Construct CEI use the energy intensity effects obtained.

- How to select an index decomposition analysis method?

  Answer: LMDI

$$E_i = \sum_{j=1}^{n_i} E_{ij} = \sum_{j=1}^{n_i} Q_i \frac{Q_{ij}}{Q_i} \frac{E_{ij}}{Q_{ij}} = \sum_{j=1}^{n_i} Q_i S_{ij} I_{ij}$$

$$\Delta E_i^{0,T} = E_i^T - E_i^0 = \Delta E_{i-act}^{0,T} + \Delta E_{i-str}^{0,T} + \Delta E_{i-int}^{0,T}$$

Alternative DCA models

- **LMDI methods**: LMDI-I, LMDI-II
- **Decomposition form:** Additive, Multiplicative
- **Indicator for decomposition：** Energy consumption level, Aggregate energy intensity
- A total of eight DCA models:

$$CEI_i^{\Delta E} = \frac{E_i^T / Q_i^T}{EH_i^T / Q_i^T} = \frac{E_i^T}{E_i^T - \Delta E_{i-int}^{0,T}}$$

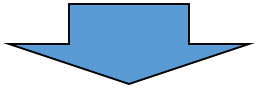
$$CEI_i^{\Delta I} = \frac{I_i^T}{IH_i^T} = \frac{I_i^T}{I_i^T - \Delta I_{i-int}^{0,T}}$$

$$CEI_i^D = D_{i-int}^{0,T} = \prod_{j=1}^{n_i} \left(\frac{I_{ij}^T}{I_{ij}^0} \right)^{w_{ij}^D}$$

$$CEI_i^R = R_{i-int}^{0,T} = \prod_{j=1}^{n_i} \left(\frac{I_{ij}^T}{I_{ij}^0} \right)^{w_{ij}^R}$$

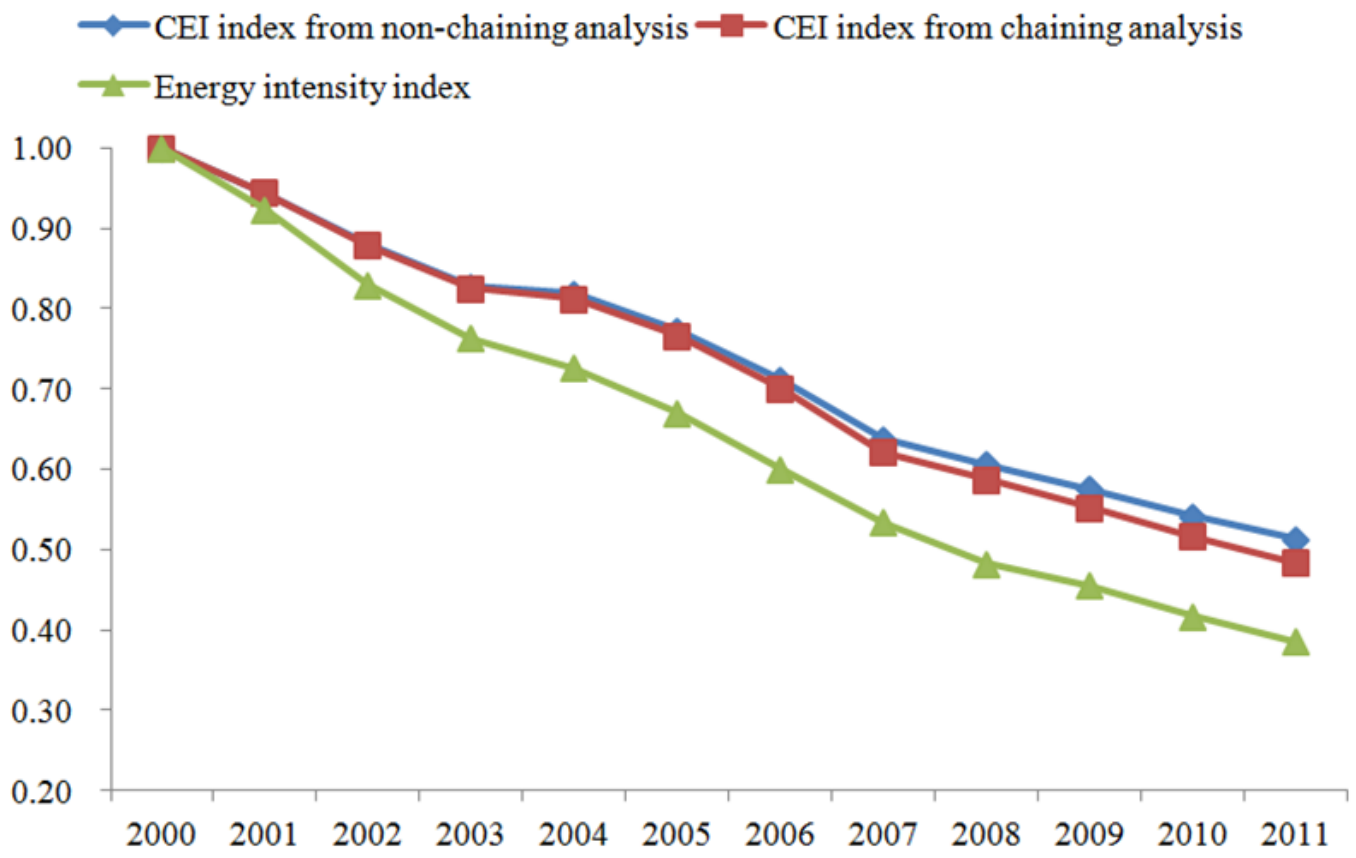
A simple example of DCA application

	Year 0				Year T			
	E_0	Q_0	S_0	I_0	E_T	Q_T	S_T	I_T
Sector 1	60	20	0.2	3.0	120	48	0.4	2.5
Sector 2	40	80	0.8	0.5	27	72	0.6	0.375
Total	100	100	1.0	1.0	147	120	1.0	1.225



	Energy consumption approach		**Energy intensity approach**	
	Additive	Multiplicative	Additive	Multiplicative
LMDI-I	0.853	0.813	0.842	0.812
LMDI-II	0.850	0.809	0.839	0.809

Application of DCA to the Manufacturing Sector in China



An observation

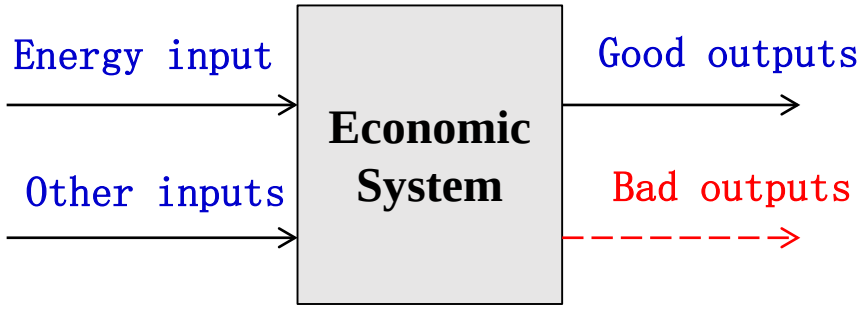
- The CEI model by multiplicative LMDI approach

$$CEI_i = D_{i-int}^{0,T} = \prod_{j=1}^{n_i} \left(\frac{I_{ij}^T}{I_{ij}^0} \right)^{w_{ij}}$$

- It is quite similar to the bottom-up approach and the tricky part lies in the determination of the weights

Another issue: How to consider the substation effect?

- CEI is still a partial indicator
- Energy needs to be accompanied with other inputs (e.g. labor) in order to generate outputs
- Total factor energy efficiency (TFEE) concept was proposed in 2006, which was followed by a number of relevant studies



The ways for deriving TFEE

- Frontier approaches are widely used
- There are two main frontier analysis techniques: Data envelopment analysis (DEA）, Stochastic frontier analysis (SFA)
- In practice, SFA has been used for developing ENERGY STAR plant Energy Performance Indicators

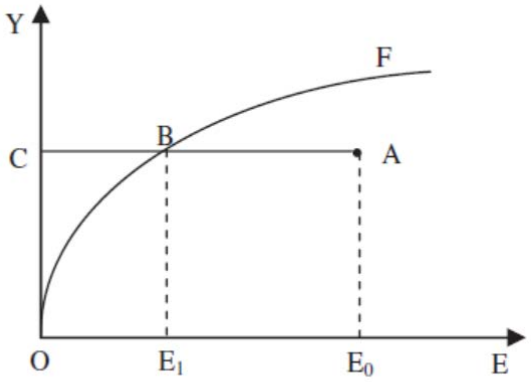


Fig. 1. A graphical illustration of EEI.

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Measuring economy-wide energy efficiency performance: A parametric frontier approach

P. Zhou [a,*], B.W. Ang [b], D.Q. Zhou [a]

Energy Efficiency
DOI 10.1007/s12053-015-9388-5

ORIGINAL ARTICLE

Measuring persistent and transient energy efficiency in the US

Massimo Filippini · Lester C. Hunt

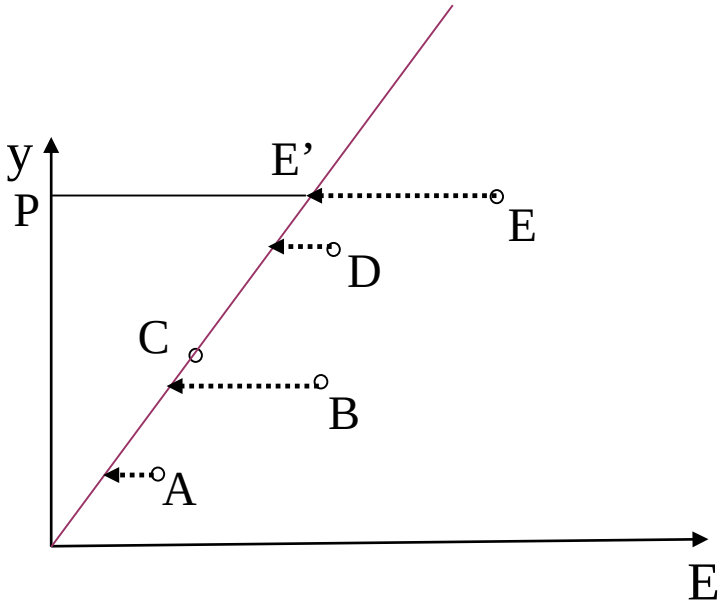
DEA methodology

- Engineering-Science definition of efficiency — "**Output-to-Input Ratio**", i.e.

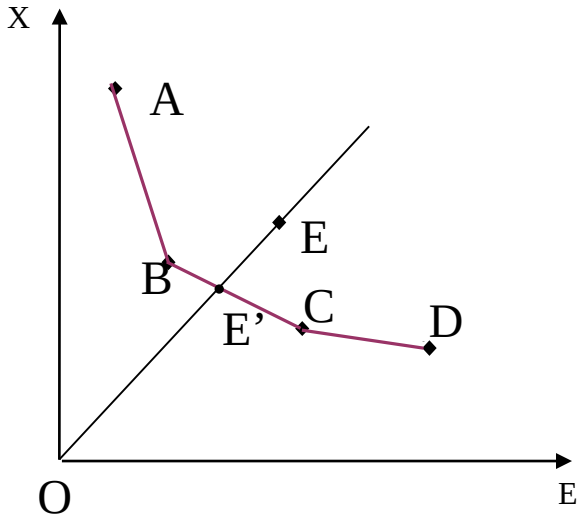
  Eff=output/input (0<=*Eff*<=1)

- In the case of multiple inputs and outputs,

Eff=[weighted sum of outputs]/[weighted sum of inputs]



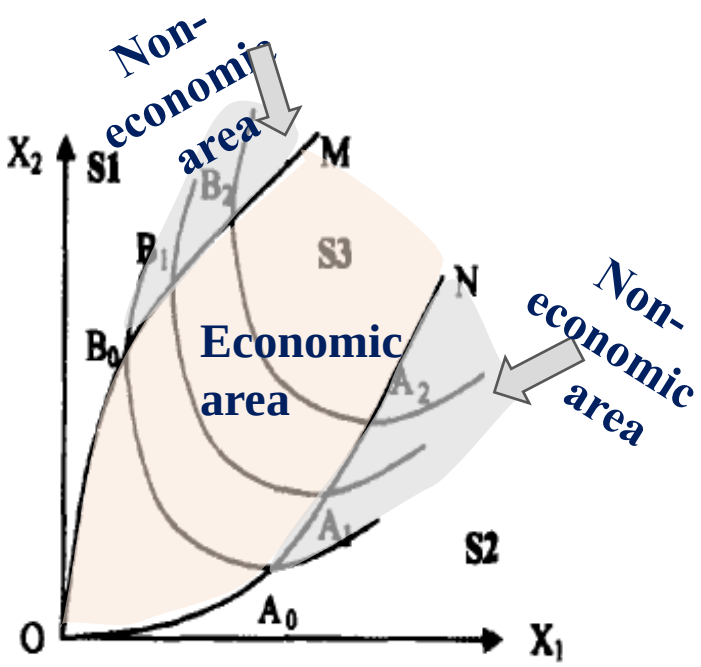
I. One input/one output case



II. Two inputs case

What is congestion?

Congestion lies in the non-economic area of production

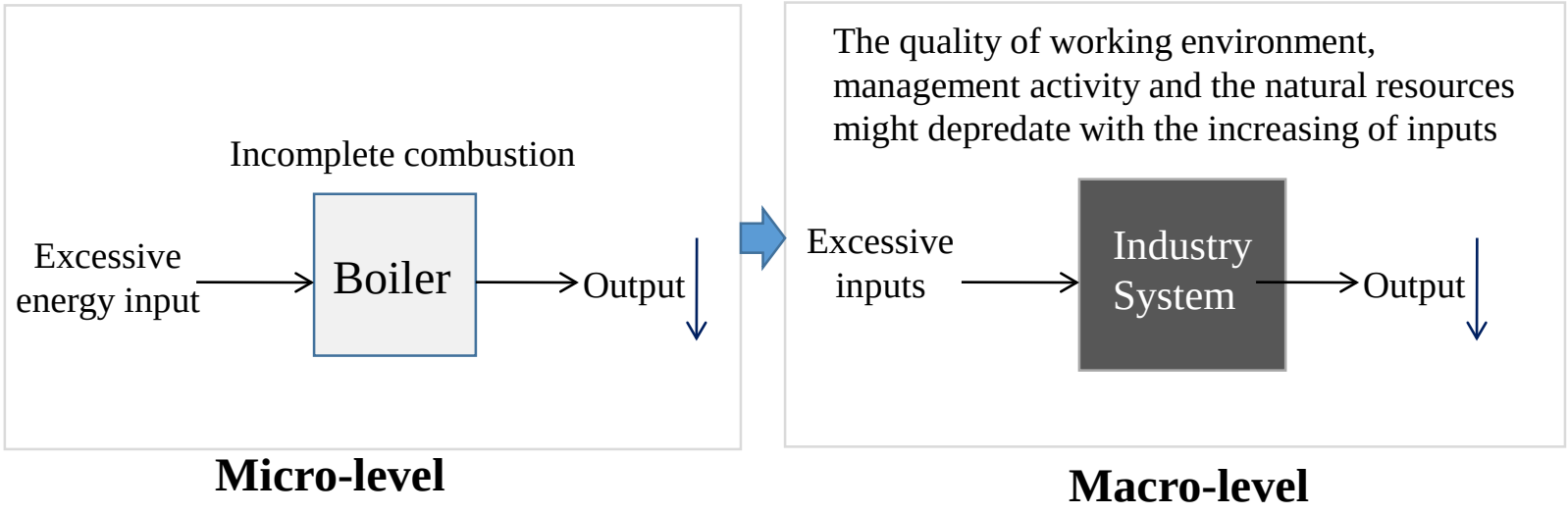


Frontier and ridge lines

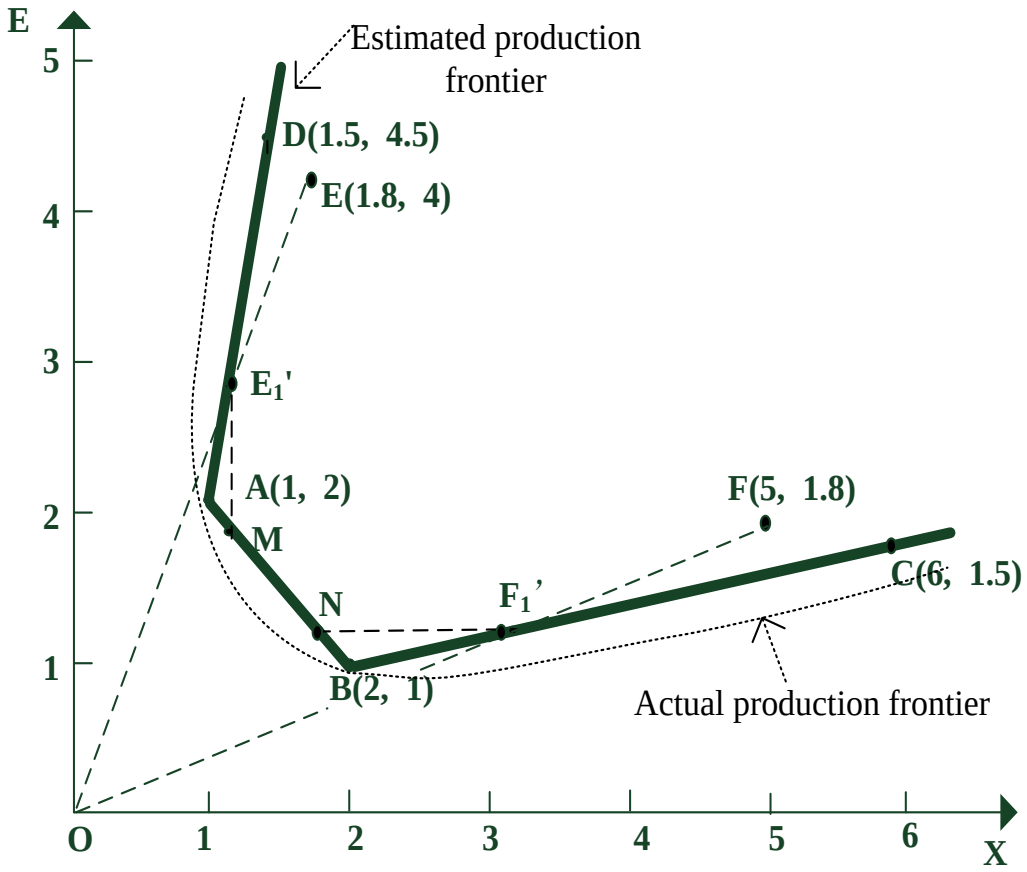
- Nobel Prize laureate ***D McFadden (1978)*** first introduce congestion into production area
- When the marginal output of certain input becomes negative, the production technology is congested.
- In the isoquants, congestion occurs in the back-bending area where the increase of some particular input is at the cost of other input's increase.

Congestion in production

- It might be difficult to observe a decline in output especially at macro level
  - The negative marginal output of one input is usually offset by the positive marginal output of other input, but it could occur because of the existence of limited factors.
  - The quality of these factors are usually not accounted for in economic analysis because they are difficult to control.

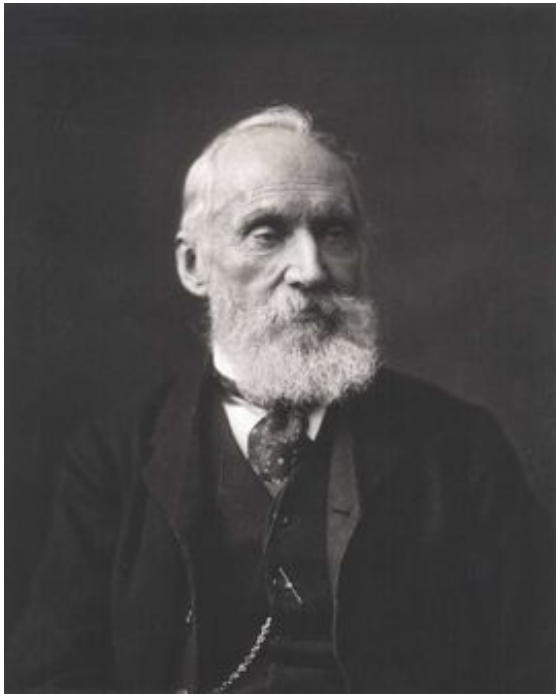


TFEE with congestion: Graphical illustration



Concluding remarks

When you can measure what you are speaking about, and express it in numbers, you know something about it; when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.



Lord Kelvin

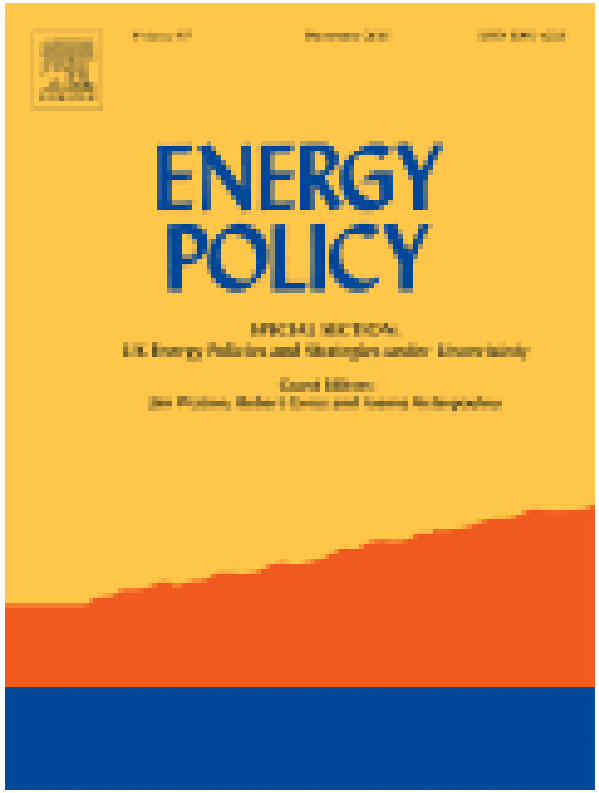
Concluding remarks

- Indicators are simple but particularly useful in quantifying energy efficiency progress
- Energy intensity indicators prevail in many application contexts
- At macro level, aggregate energy intensity (e.g. energy consumption per unit of GDP is not a good proxy for tracking energy efficiency performance
- Need to isolate out the non-efficiency effects and consider the substitution effect
- Further work is required to consolidate different methods and produce a unified framework for measuring economy-wide energy efficiency performance

Some relevant work

- Total-factor energy efficiency with congestion. ***Annals of Operations Research***, 2017.
- Does there exist energy congestion? Empirical evidence from Chinese industrial sectors. ***Energy Efficiency***, 2015.
- Measuring energy congestion in Chinese industrial sectors: A slacks-based DEA approach. ***Computational Economics***, 2015.
- Index decomposition analysis for tracking energy efficiency trends. In: ***Handbook of Environmental Economics in Asia*** , S Managi (ed.). John Wiley, 2014.
- Scenario-based energy efficiency and productivity in China: A non-radial directional distance function analysis. ***Energy Economics*** 40 (2013), 795-803.
- Energy and CO2 emission performance in electricity generation: A non-radial directional distance function approach. ***European Journal of Operational Research*** 221 (2012), 625-635.
- Linear programming models for measuring economy-wide energy efficiency performance. ***Energy Policy*** 36 (2008)， 2901-2906.

Finally, about Energy Policy



Impact factor: 4.880
5 Year impact factor: 5.458

Editorial Policy has some changes since 2015

Source: *Energy Policy's New Editorial Leadership*, Volume 85, October 2015.

Thank you!

Welcome to visit my group at China University of Petroleum, Qingdao.