A Multicriteria Assessment Approach to the Energy Trilemma

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Introduction

- Providing adequate, reliable, and affordable energy, is a key for sustainable development
- Global energy demand expected to grow by 30-40% by 2040 (IEA)
- Fossil fuels' share in global energy demand is higher than 85%
  - Current policies to decrease it below 75% in 2040 are not enough to stem the rise in energy-related CO2 emissions
- Energy security concerns are on the rise
  - IEA estimates that $900 billion per year in upstream oil and gas development is needed by the 2030s to meet projected demand
- Energy efficiency is a critical tool to relieve pressure on energy supply and mitigate in part the effects of increasing prices
  - Fossil-fuel subsidies totaled $550 billion in 2013, thus holding back investment in efficiency and renewables

Towards unifying approaches

- The aforementioned aspects (environmental, security, efficiency, …) have been extensively researched as independent topics
  - Their apparent connections call for a unifying approach
  - Identification of strengths, weaknesses, and trade-offs
- Comprehensive historical data are available
  - Need for framework for organizing the data to provide insights and policy recommendations
  - Monitoring time trends, cross-sectional comparisons between countries & regions
  - Aggregate results and disaggregated assessments for each policy dimension

Energy performance benchmarks

- IAEA, IEA, UN Dept. of Economic and Social Affairs, Eurostat, European Environment Agency
  - Energy indicators of sustainable development
  - A framework, rather than an assessment
  - 7 themes, 19 sub-themes, 30 indicators
- World Economic Forum (WEF)
  - Energy Architecture Performance Index
  - Availability: 2013-2016 (data coverage up to 2013)
  - 126 countries (2016), 18 indicators
    - Three main dimensions: Economic growth and development, Environmental sustainability, Energy access and security
    - 8 sub-dimensions
- World Energy Council (WEC)
  - Energy Trilemma Index
  - Availability: 2011-2015 (data coverage up to 2013-14)
  - 130 countries (2015), 23 indicators
  - Cross-sectional contemporaneous analysis (no time effects)

WEC's energy trilemma framework

- Energy performance (75%)
  - Energy security (25%)
  - Energy equity (25%)
  - Environ. sustain. (25%)
- Contextual performance (25%)
  - Political strength (8.3%)
  - Societal strength (8.3%)
  - Economic strength (8.3%)

Motivations & fundamentals of the methodology

- Transparent aggregation process providing global and partial assessments
  - Results for each dimension of the analysis
  - Aggregate evaluation of all dimensions
- Cross-sectional and intertemporal comparisons
  - Consideration of time effects and identification of time trends
- Avoiding ambiguous data normalizations that lack transparency and distort the available information
- Flexible weighting scheme for the indicators, considering the particular characteristics of each country and the changes over time
  - Data-driven process instead of expert judgments

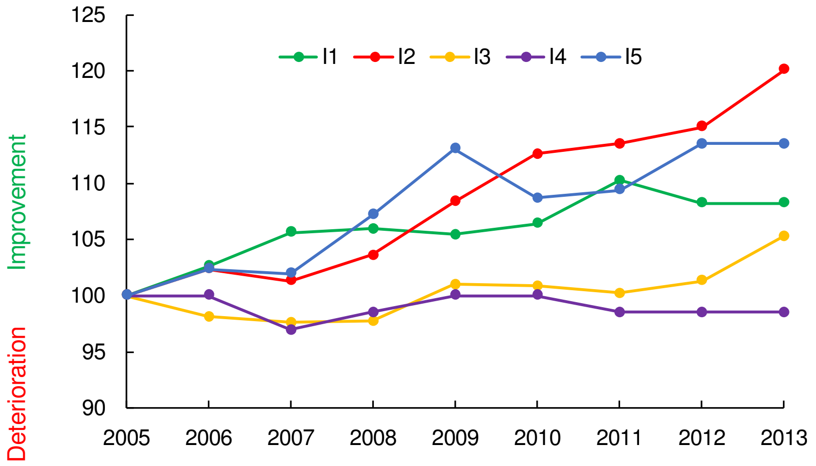
Data

- 34 OECD countries
  - ~50% of global energy use
- Time period: 2005-2013
  - Major changes in the global economic-energy environment (economic crisis, oil price volatility, policy actions - EU 2020)
- 13 indicators describing energy security, equity, and sustainability
- Data sources:
  - World Bank, OECD, EIA, Yale's EPI

Indicators - Security

Indicators	Sources
I_1: Electric power transmission and distribution losses (% of output)	WB
I_2: Simpson (Herfindahl) index of electricity production sources	WB
I_3: Net energy imports (% of energy use)	WB
I_4: Total primary energy production / Total primary energy consumption	EIA
I_5: Days of oil stocks	EIA

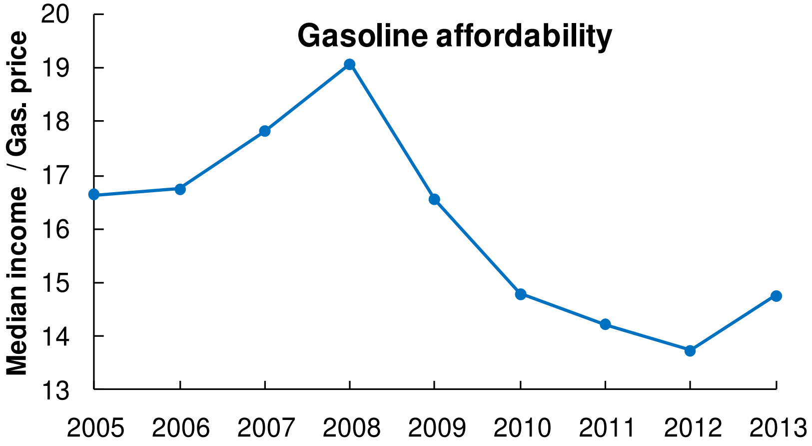
Indicators' time trends - Security



Indicators - Equity

Indicators	Sources
I_6: Number of procedures for getting electricity	Doing Bus.
I_7: Getting electricity time (days)	Doing Bus.
I_8: Cost of getting electricity cost (% of income per capita)	Doing Bus.
I_9: Gasoline affordability (median annual disposable income, 2014 thous. $ PPP / Gasoline price)	WB, OECD

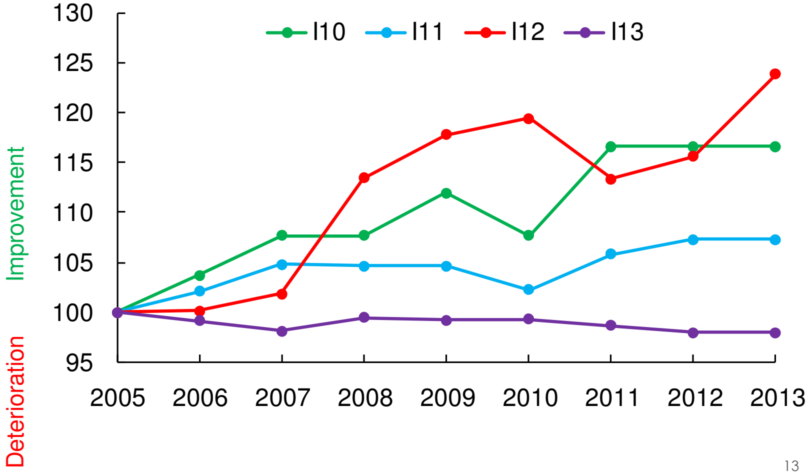
Indicators' time trends - Equity



Indicators - Sustainability

Indicators	Sources
I_{10}: CO_2 intensity (kg per 2011 PPP \$ of GDP)	WB
I_{11}: Energy intensity level of primary energy (MJ/\$2011 PPP GDP)	WB
I_{12}: Population weighted exposure to PM2.5 (µg / m^3)	Yale's EPI
I_{13}: CO_2 emissions from electricity and heat production (% of total fuel combustion)	WB

Indicators' time trends - Sustainability



Aggregation models

- Benefit-of-the-Doubt (BoD) approach (Cherchye et al., 2007, Composite Indicators. Soc. Indic. Res 82, 111-145)
  - The weights are defined endogenously (case-specific), rather than being externally fixed, common for all cases
  - A good relative performance of a country in a particular sub-indicator may indicate that this country considers the policy dimension concerned as relatively important
- Level I: partial evaluations

$$Y_{it}^{sec} = \sum_{k \in sec} w_{ikt} I_{ikt} \qquad Y_{it}^{eq} = \sum_{k \in eq} w_{ikt} I_{ikt} \qquad Y_{it}^{sust} = \sum_{k \in sust} w_{ikt} I_{ikt}$$

  - No data normalization (the weights do not sum up to 100%)
- Level II: aggregate assessment

$$w_{it}^{sec} Y_{it}^{sec} + w_{it}^{eq} Y_{it}^{eq} + w_{it}^{sust} Y_{it}^{sust}, \qquad w_{it}^{sec} + w_{it}^{eq} + w_{it}^{sust} = 1$$

Methodology

Level I: security, equity, sustainability assessments

- For each country *i*, its partial score on sub-dimension *D* (security, equity, sustainability) in year *t*, is obtained through the solution of the following linear program

$$\begin{aligned} \max \quad & Y_{it}^{D} & \\ \text{s.t.:} \quad & Y_{jt}^{D} \leq 1 & \forall \text{ country } j \text{ \& year } t \\ & \frac{0.15}{n_D} \leq w_{ikt} I_{ikt} / Y_{it}^{D} \leq 0.35 & \forall \text{ indicator } k \in D \end{aligned}$$

where n_D the number of sub-indicators in dimension D

Methodology
Two-stage aggregation process

Level II: aggregate assessment

- Scheme 1: average of the three assessments from level I
- Scheme 2: BoD weighted average

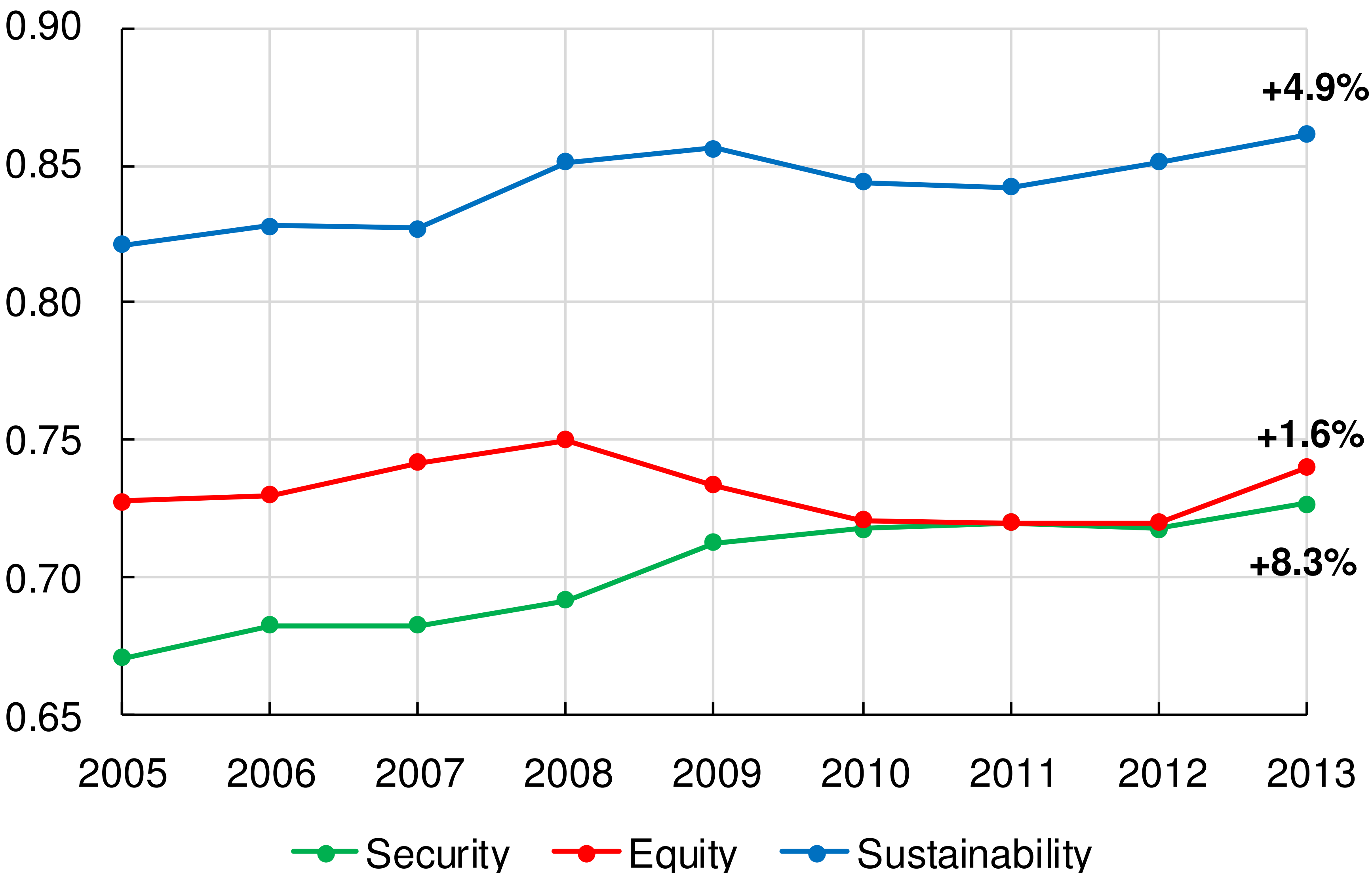
$$\max \quad w_{it}^{\text{sec}} Y_{it}^{\text{sec}} + w_{it}^{\text{eq}} Y_{it}^{\text{eq}} + w_{it}^{\text{sust}} Y_{it}^{\text{sust}}$$

$$\text{s.t.:} \quad w_{it}^{\text{sec}} Y_{jt}^{\text{sec}} + w_{it}^{\text{eq}} Y_{jt}^{\text{eq}} + w_{it}^{\text{sust}} Y_{jt}^{\text{sust}} \leq 1 \qquad \forall \text{ country } j \text{ \& year } t$$

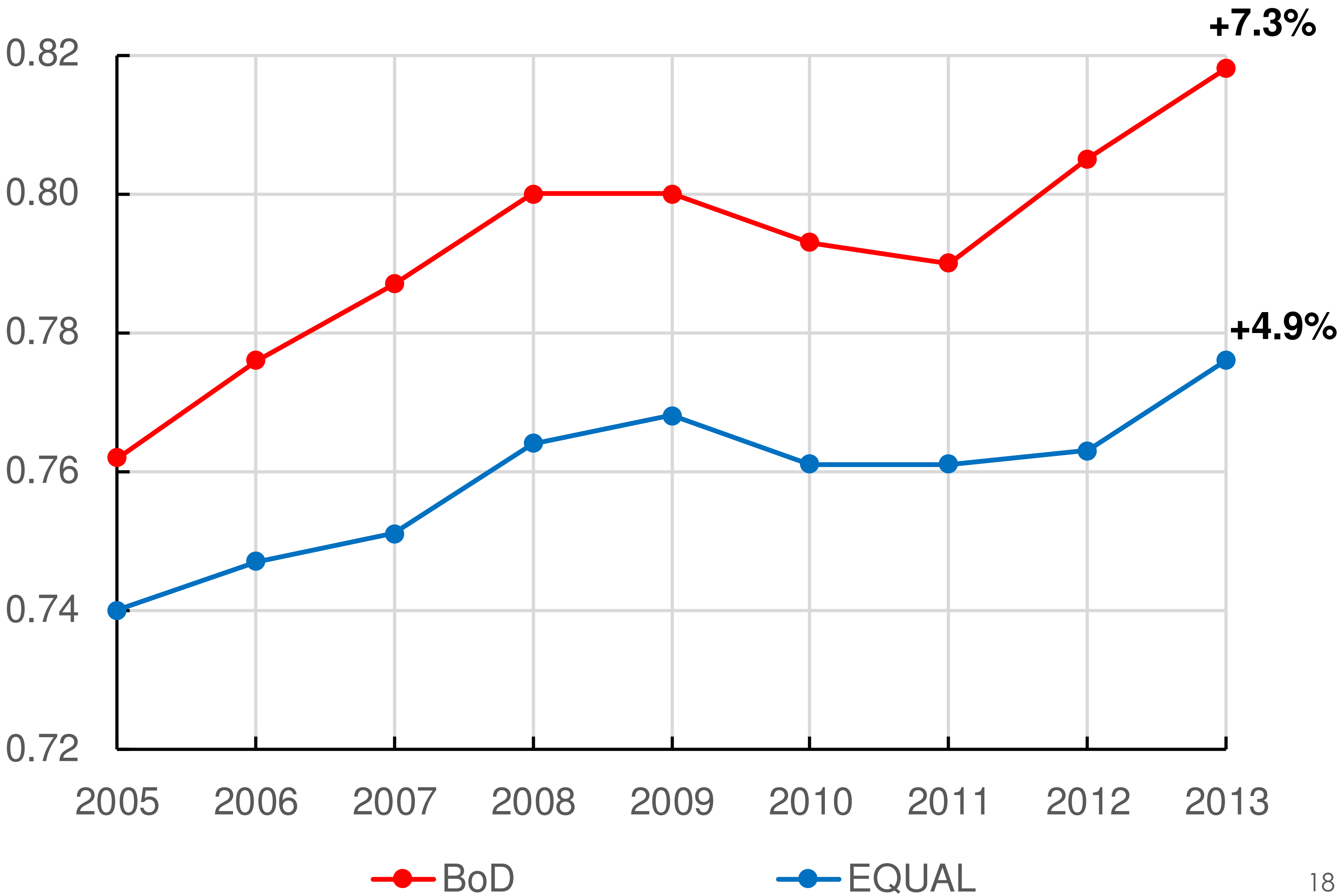
$$0.05 \leq \frac{w_{it}^{D} Y_{it}^{D}}{w_{it}^{\text{sec}} Y_{it}^{\text{sec}} + w_{it}^{\text{eq}} Y_{it}^{\text{eq}} + w_{it}^{\text{sust}} Y_{it}^{\text{sust}}} \leq 0.5 \qquad \forall D \in \{\text{sec., eq., sust.}\}$$

$$w_{it}^{\text{sec}} + w_{it}^{\text{eq}} + w_{it}^{\text{sust}} = 1$$

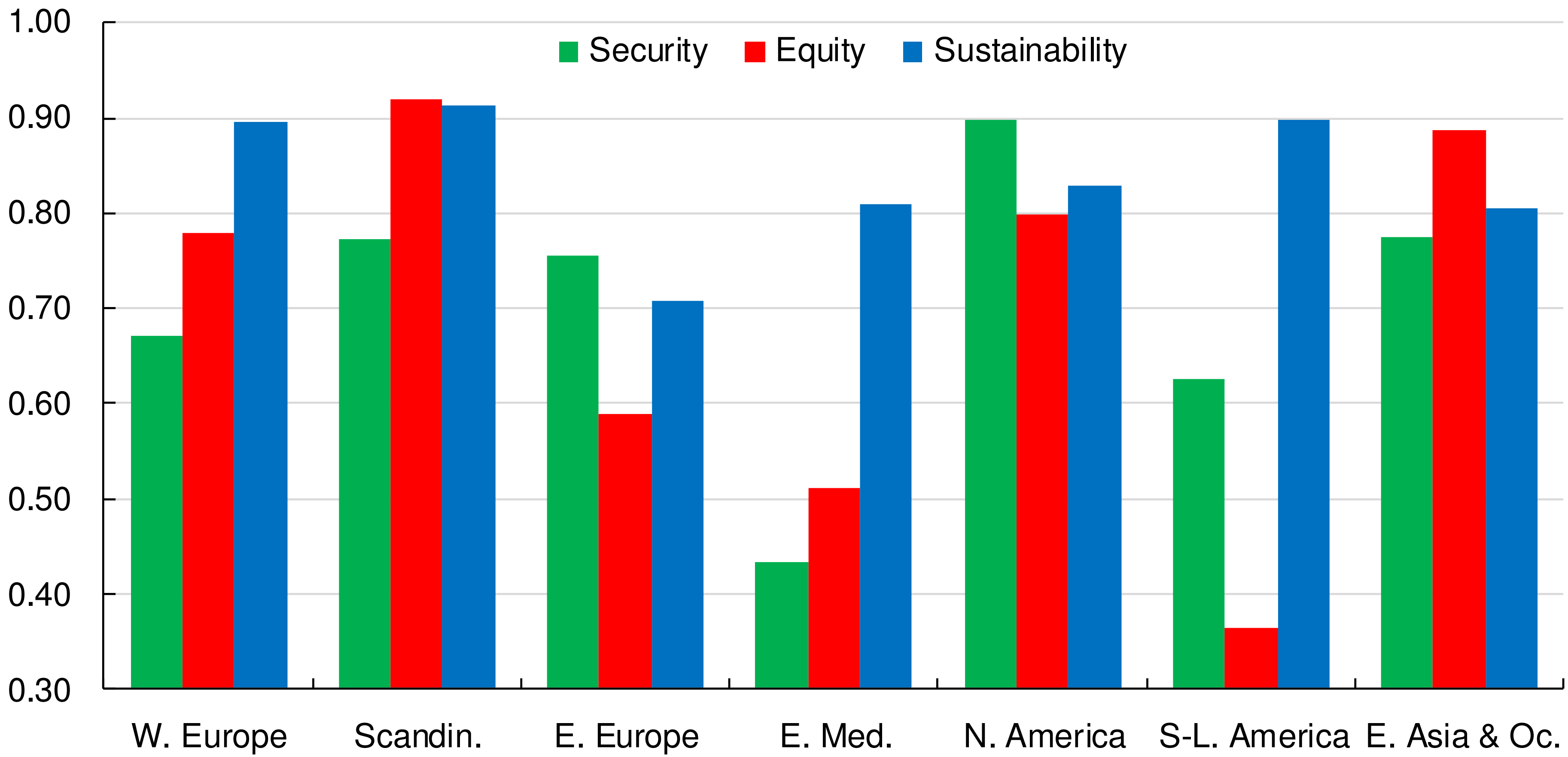
Dimensions' averages over time



Aggregate averages over time



Regional averages



Top and bottom countries

	BoD	EQUAL	Sec.	Eq.	Sust.
CHE	0.986	0.951	0.867	0.994	0.993
NOR	0.965	0.935	0.904	0.921	0.980
SWE	0.955	0.925	0.853	0.962	0.960
DNK	0.932	0.916	0.968	0.899	0.880
FIN	0.918	0.899	0.969	0.871	0.855
POL	0.667	0.616	0.699	0.488	0.661
EST	0.616	0.573	0.505	0.641	0.572
ISR	0.553	0.521	0.098	0.713	0.753
MEX	0.538	0.544	0.625	0.144	0.864
TUR	0.412	0.507	0.569	0.090	0.861

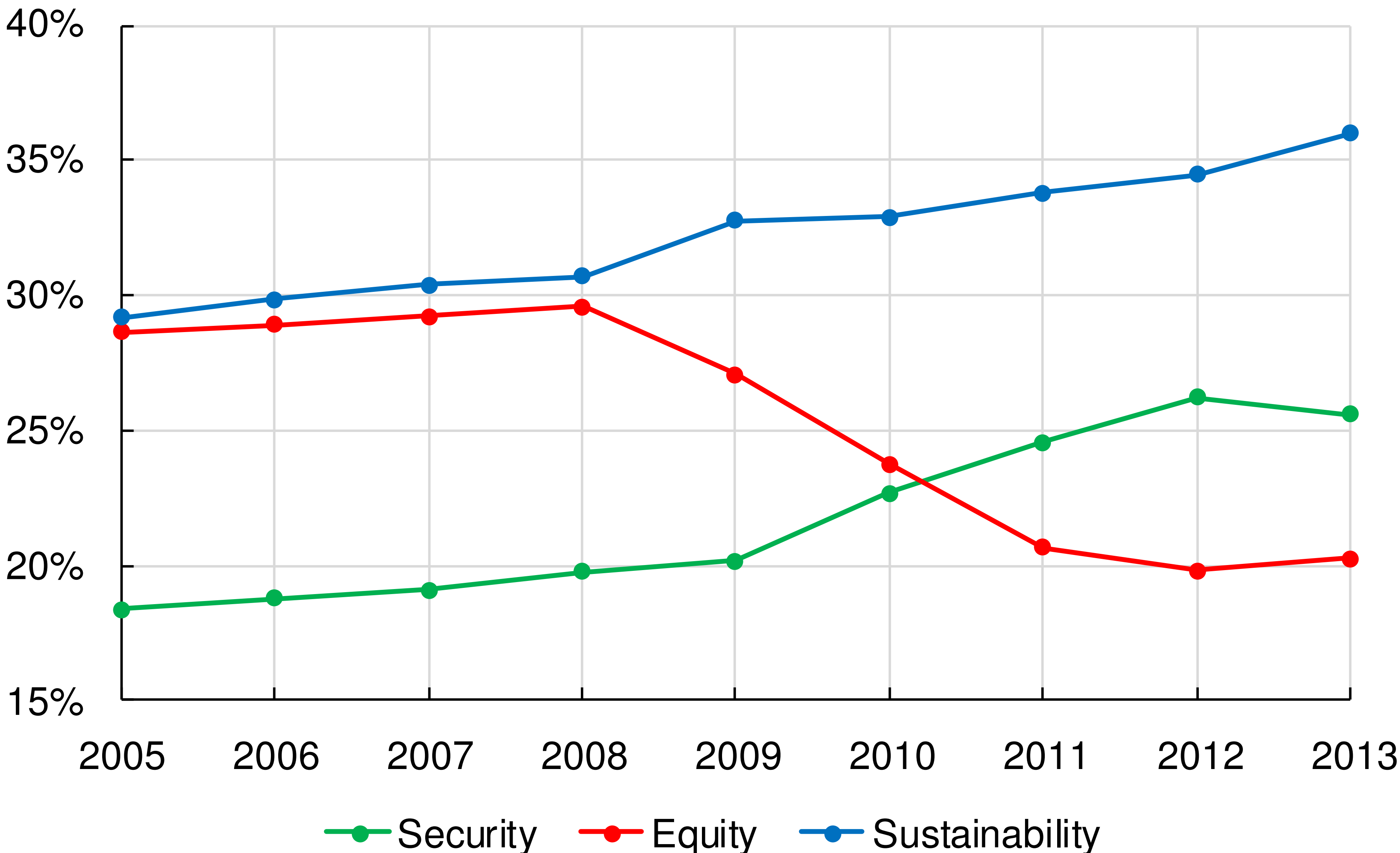
Correlations

Pearson's ρ below the diagonal, Kendall's τ above the diagonal

	Sec.	Eq.	Sust.	EQUAL	BoD
Sec.		0.25	0.04	0.63	0.60
Eq.	0.17		0.16	0.56	0.55
Sust.	0.06	0.14		0.29	0.31
EQUAL	0.72	0.73	0.43		0.90
BoD	0.63	0.76	0.37	0.94	

	WEC							
	Pearson's ρ				Kendall's τ			
	Sec.	Eq.	Sust.	Overall	Sec.	Eq.	Sust.	Overall
Sec.	0.75				0.58			
Eq.		0.70				0.42		
Sust.			0.69				0.49	
Equal				0.79				0.60
BoD				0.79				0.63

The relative weights of the dimensions



Conclusions & future research

- A data-driven methodology for assessing the energy trilemma issue
  - Supplement to existing judgmental benchmarking systems
- Over the years, improvements have been achieved in security and sustainability
  - Affordability and equity issues require further actions
- Despite the improvements in energy security, its current and historical levels are lower than the other dimensions
  - Strengthening energy security remains a challenge
- Future directions
  - Extension to a global context with a refined set of indicators
  - Examination of the countries' economic status and underline structure
  - Consideration of energy and climate change policies