Comparative Analysis of Operational Efficiency of Large-scale Solar Power Generation Companies

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Outline of presentation

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Introduction

- Paris Agreement entered into force in November 2016 and set goals to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels

- The COP26 summit held in UK from October to November accelerated action towards the goal of the Paris Agreement by adopting the Glasgow Climate Pact highlighting to keep warming to 1.5 degree Celsius

- As one of the renewable energy resources, solar photovoltaic (PV) has grown in an accelerating speed. The cumulative installed capacity has increased from 40 gigawatts in 2010 to over 700 gigawatts in 2020

- This study examines operational efficiency of large-scale solar PV companies over the world, which play an important role for achieving a society’s carbon neutrality while securing a regional electricity supply, using DEA-based Malmquist index

Literature

Non-DEA	
Author	Methodology
Ibarloza et al. (2018)	Economic and financial performance analysis
Guaita-Pradas and Blasco-Ruiz (2020)	NPV; WACC; CAPM and historical return analysis
Kuo (2011)	Stochastic Frontier Function OLS regression model
Zhang et al. (2016)	Panel model of direct/indirect subsidies Panel model of innovative/non-innovative subsidies
Schabek (2020)	Panel data regression model
Luts et al (2021)	Random-effect model; Fixed-effect model of panel analysis
Paun (2017)	Financial analysis
Rastogi (2020)	Clustering using machine learning approach
Zhang et al. (2015)	Threshold regression model
Tomczak (2019)	Ratios analysis; Altman model; Cluster analysis

Literature

DEA			
Author	Specific model	Input/output	Data size
Halkos (2011)	Bootstrap VRS model	3 inputs: debt to equity, assets turnover, current ratio 4 outputs: gross profit margin, operating profit profit margin, return on equity, return on	3 years 78 companies
Curtis (2020)	CRS model	1 input: total asset 2 outputs: Revenue, EBIT	1year 12 wind farms
Menegaki (2013)	CRS model; VRS model; Malmquist method	5 input: percentage of RES, final energy consumption, greenhouse gas emission, employment rate, real gross fixed capital formation 1 output: Real GDP per capita	14 years 31 European countries

Purpose of this study

- This study examines operational performance of renewable power companies by DEA-based Malmquist productivity index (MI) that can evaluate the temporal development of holistic measures of efficiency
  - Most of existing studies use conventional financial measures and ratios such as revenues and return on assets (ROA) . In addition, they adopt DEA to measure the efficiency of companies applying basic DEA models to pooled or cross-sectional data of companies, so they cannot examine the temporal development of performance measures
- This study compared efficiency of companies among different regions and different generation compositions, because the diffusion of renewable power generation is influenced by regional differences in energy policy, institutions, and support schemes of renewable power generations

Methodology

- DEA is a mathematical programming method for the holistic performance assessment of various decision-making units (DMUs). DMUs are solar PV generation companies in this study
  - Linear programming is used to solve the DEA model
- Compared to standard DEA models, super efficiency model (SEM) conducts a one-step-further comparison among all the efficient DMUs without adjusting inefficient ones
- Malmquist index is commonly used for comparing the efficiency of two different time periods with changed technology levels
  - Global Malmquist index overcomes three disadvantages of standard Malmquist index

Standard DEA and super efficiency models

Standard DEA

$$\min \quad \theta$$

$$\text{s.t.} \quad \theta x_{ki} \geq \sum_j \lambda_j X_{ji}, \; i = 1, \ldots, m,$$

$$y_{ks} \leq \sum_j \lambda_j Y_{js}, \quad s = 1, \ldots, r,$$

$$\lambda_j \geq 0, \; j = 1, \ldots, n.$$

DMU: $j \; (j = 1, 2, \ldots, n)$

Inputs: $X_{ji} \; (i = 1, 2, \ldots, m)$

Outputs: $Y_{js} \; (\mathrm{s} = 1, 2, \ldots, r)$

Super efficiency

$$\min \quad \theta_k - \varepsilon(s^+ + s^-)$$

$$\text{s.t.} \quad \sum_j \lambda_j Y_{js} - s^+ \geq Y_{ks}, \; s = 1, \ldots, r,$$

$$\theta_k x_{ki} \geq \sum_j \lambda_j X_{ji} + s^-, \; i = 1, \ldots, m,$$

$$s^+ \geq 0, s^- \geq 0,$$

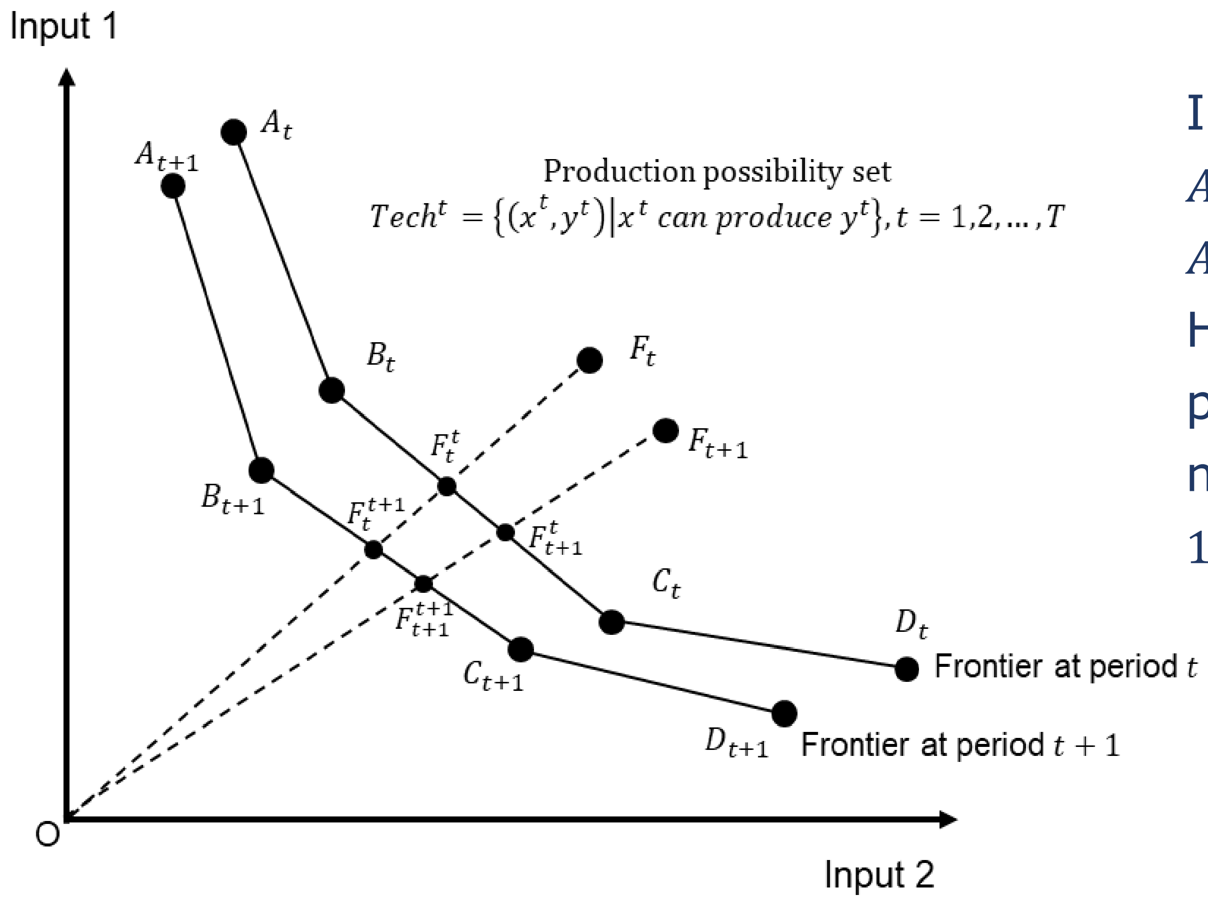
$$\lambda_j \geq 0, j = 1, \ldots, n, j \neq k.$$

DMU_k: Efficient DMU by CRS

s^+, s^-: slack variables

ε: a very small constant number

Malmquist index vs. global Malmquist index

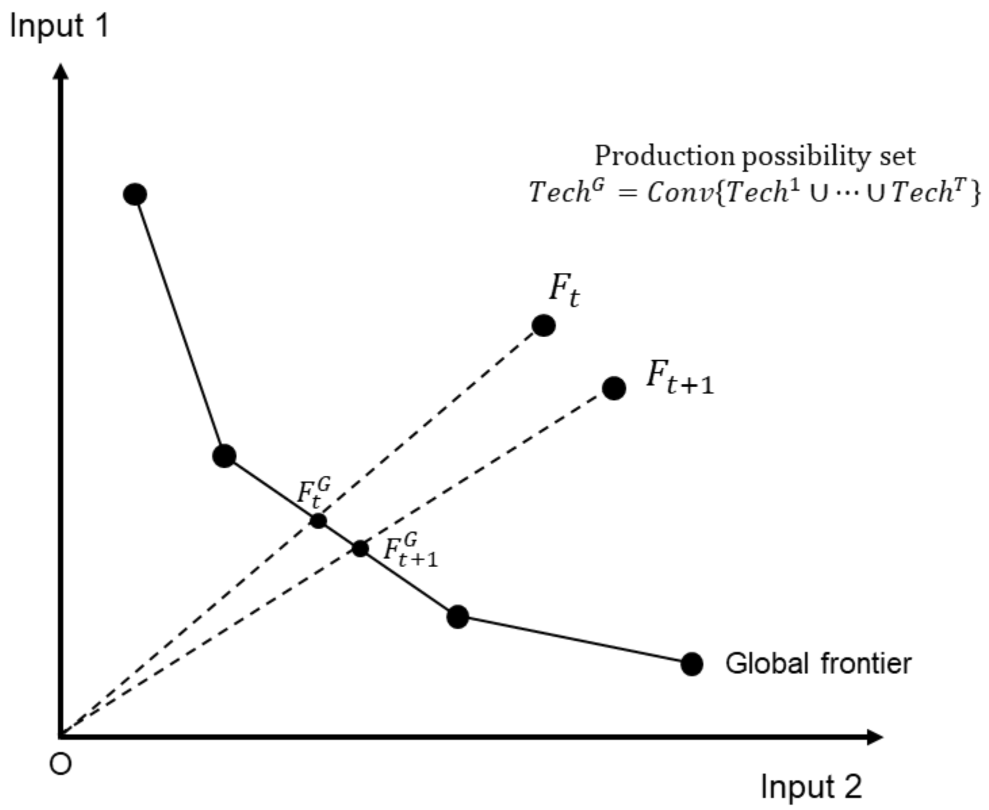


Two periods frontier and input-oriented Malmquist index

In a case of two periods with t and $t+1$, line $A_tB_tC_tD_t$ is the VRS frontier at period t and line $A_{t+1}B_{t+1}C_{t+1}D_{t+1}$ is the VRS frontier at period $t+1$. Here we define F_a^b that presents the production point placed on the frontier where observed point F_a moves on a frontier at period b ($a = t, t+1, b = t, t+1$).

$$MI = \left[\frac{\frac{OF_{t+1}^t}{OF_{t+1}}}{\frac{OF_t}{OF_t^t}} \times \frac{\frac{OF_{t+1}}{OF_{t+1}^{t+1}}}{\frac{OF_t^{t+1}}{OF_t}} \right]^{1/2}$$

Malmquist index vs. global Malmquist index



Global frontier and input-oriented GMI

In the same case, the global Malmquist index (GMI) is defined in a production possibility set $Tech^G = Conv\{Tech^1 \cup \cdots \cup Tech^T\}$, meaning that all technology frontiers including the newest one is taken into consideration.

$$GMI = \frac{\frac{OF_{t+1}^G}{OF_{t+1}}}{\frac{OF_t^G}{OF_t}}.$$

Solve the problems of standard Malmquist index

- Non-circularity
- Infeasibility
- Multiple measures of productivity change

Data and empirical results

Inputs: Total assets, Total operating expenses, Capital expenditures

Outputs: Total revenue, EBITA, Total enterprise values

Company Name	Group	Country/ Region	Total assets	Total operating expenses	Capital expenditures	Total revenue	EBITDA	Total enterprise values
China Longyuan Power Group Corporation Limited	1	China	20,427	2,197	2,090	3,371	2,037	16,528
Engie Brasil Energia S.A.	1	Brazil	5,754	1,267	346	2,232	1,176	9,931
Tunghsu Azure Renewable Energy Co.,Ltd.	1	China	2,355	493	155	539	64	1,051
Kong Sun Holdings Limited	1	China	1,542	105	98	144	70	818
Zhongmin Energy Co., Ltd.	1	China	696	150	56	159	39	909
Ning Xia Yin Xing Energy Co.,Ltd	1	China	1,333	151	68	195	107	1,245
Group 1 Avg.			5,351	727	469	1,107	582	5,080
Brookfield Renewable Partners L.P.	2	Canada	29,295	1,724	373	2,449	1,532	18,352
Northland Power Inc.	2	Canada	5,650	511	686	837	536	6,174
Innergex Renewable Energy Inc.	2	Canada	3,247	164	254	270	196	3,065
Boralex Inc.	2	Canada	2,350	210	132	275	166	2,142
Ormat Technologies, Inc.	2	USA	2,630	459	228	614	274	2,948
Group 2 Avg.			8,634	613	335	889	541	6,536
EDP Renováveis, S.A.	3	Spain	18,619	1,155	1,133	1,617	1,083	11,799
Terna Energy Societe Anonyme Commercial Technical Company	3	Greece	1,709	164	163	250	140	965
Falck Renewables S.p.A.	3	Italy	1,898	249	91	351	178	1,412
Voltalia SA	3	France	905	92	151	120	48	660
Albioma	3	France	1,642	373	112	481	168	1,481
Group 3 Avg.			4,955	407	330	564	323	3,263
GCL New Energy Holdings Limited	4	HongKong	4,360	243	692	423	286	2,573
Kenya Electricity Generating Company PLC	4	Kenya	3,108	214	271	315	180	941
Concord New Energy Group Limited	4	HongKong	1,932	210	225	269	90	820
Enlight Renewable Energy Ltd	4	Israel	612	29	81	40	14	501
Group 4 Avg.			2,503	174	317	262	142	1,209
Total Average			5,503	508	370	748	419	4,216

Companies: 20 listed global large-scale solar power generation companies from different countries and regions
Periods: 2011-2020

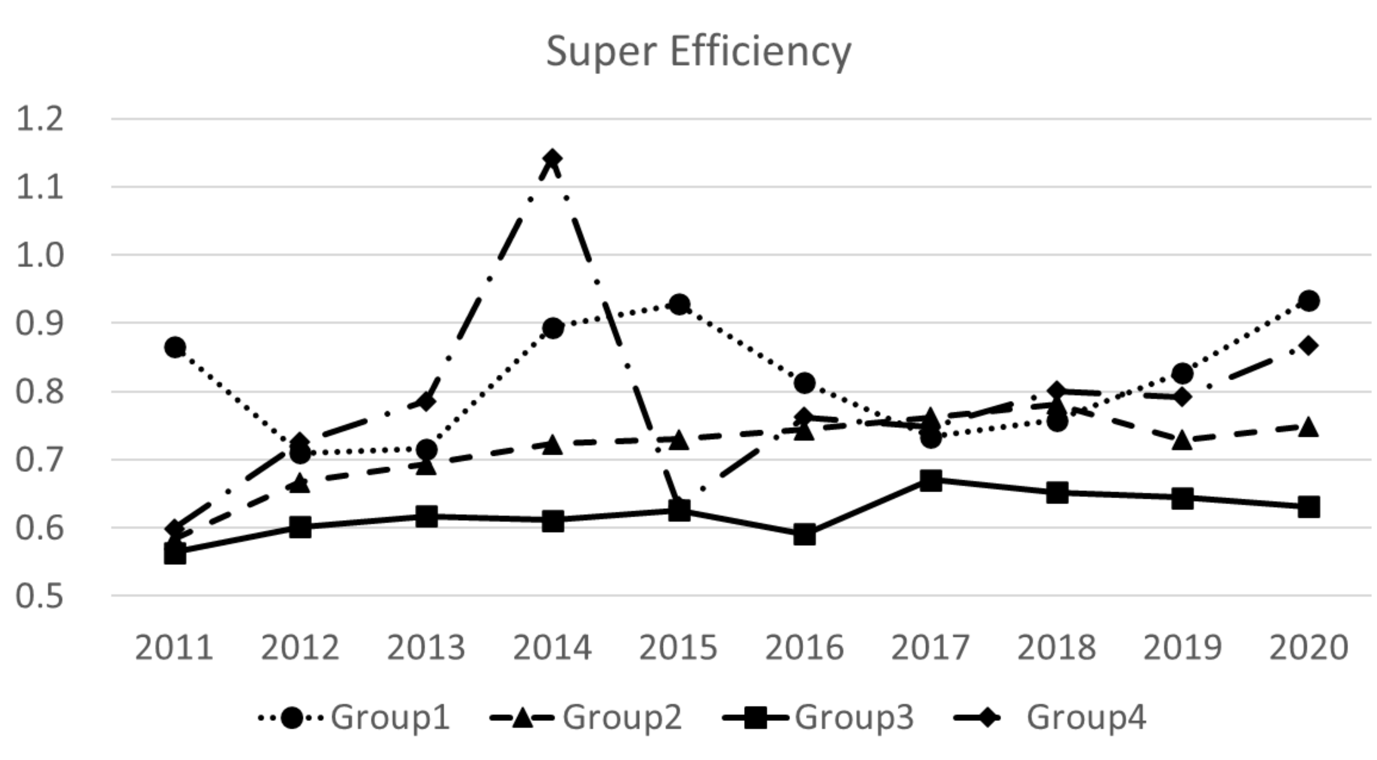
Group 1: Business Area covers only one country

Group 2: Business Area covers more than one country and office is in north America

Group 3: Business Area covers more than one country and office is in Europe

Group 4: Business Area covers more than one country and office is in the other countries/regions

Super efficiency



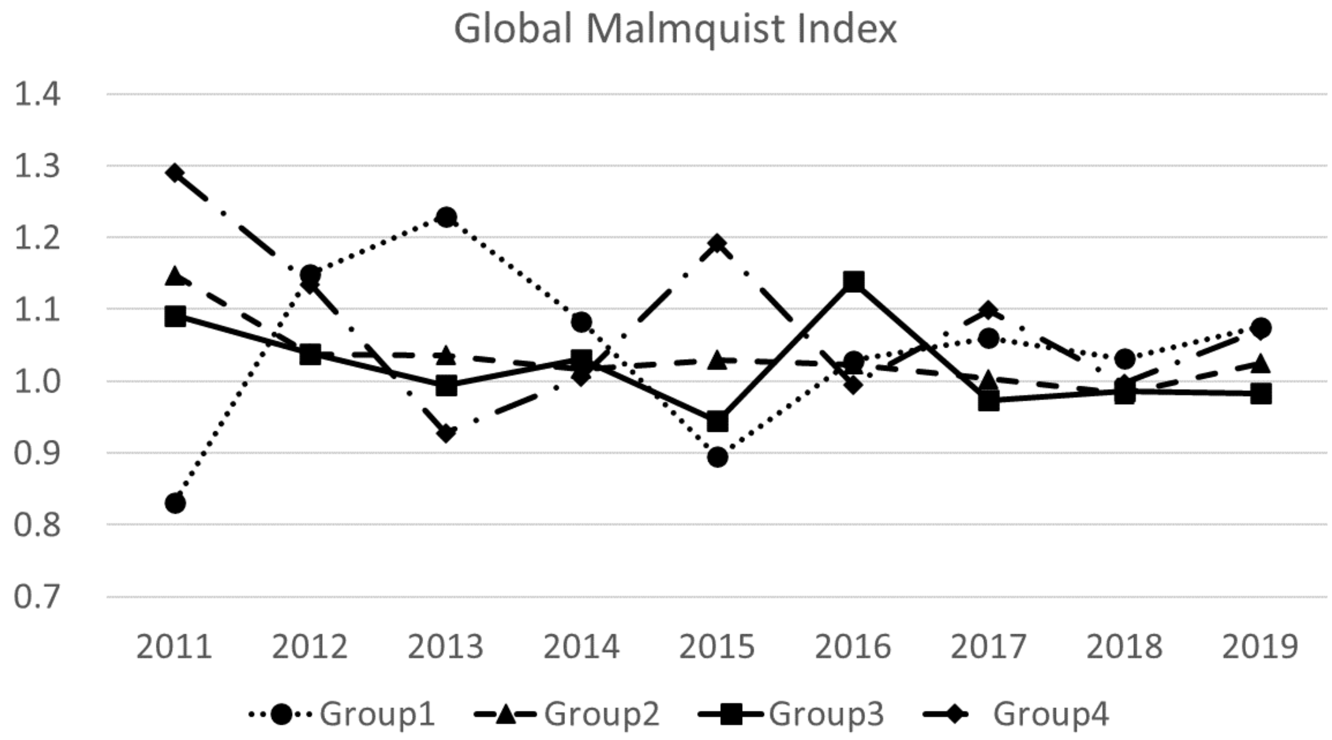
Summary of super efficiency results

Group	1	2	3	4
Avg.	**0.818**	0.716	0.621	0.785
S.D.	0.299	0.129	0.077	**0.396**
Min.	0.133	0.520	0.327	0.308
Max.	1.604	1.056	0.745	2.873
Count	60	50	50	40

Kruskal-Wallis rank sum test

Source	d.f.	Chi-sq	p-value
Groups	3	19.85	0.0002

Global Malmquist index



Summary of GMI

Group	1	2	3	4
Avg.	1.043	1.033	1.020	1.079
S.D.	0.259	0.109	0.098	0.274
Min.	0.214	0.703	0.886	0.401
Max.	2.119	1.287	1.325	2.068
Count	54	45	45	36

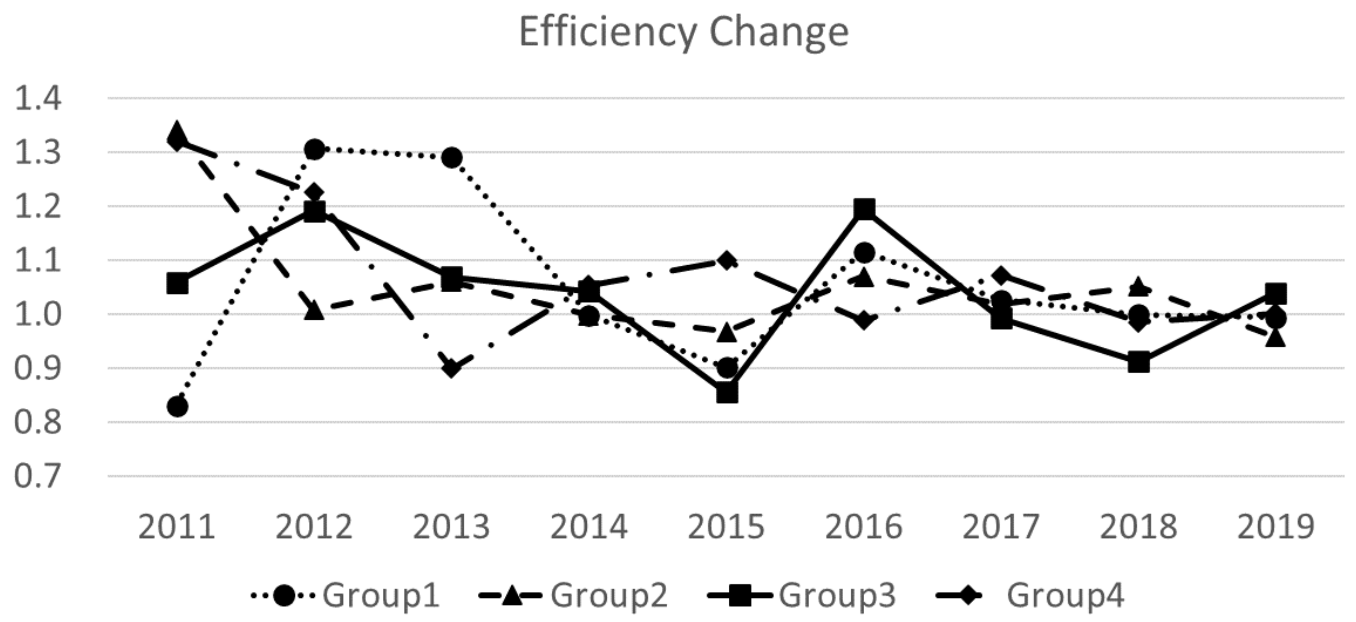
Kruskal-Wallis rank sum test

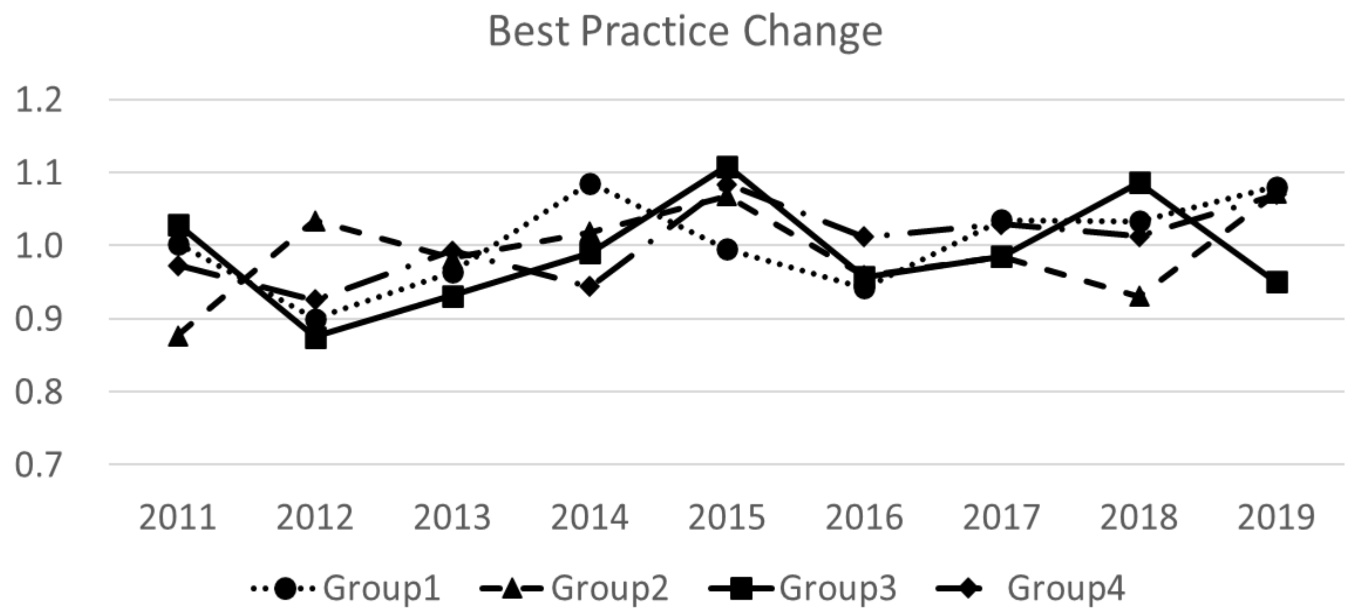
Source	d.f.	Chi-sq	p-value
Groups	3	1.76	0.6245

Decomposition of GMI

$$GMI^{t,t+1}(X^t,Y^t,X^{t+1},Y^{t+1})$$
$$= \frac{DF^G(x^{t+1},y^{t+1})}{DF^G(x^t,y^t)}$$
$$= \frac{DF^{t+1}(x^{t+1},y^{t+1})}{DF^t(x^t,y^t)} \times \left\{\frac{DF^G(x^{t+1},y^{t+1})/DF^{t+1}(x^{t+1},y^{t+1})}{DF^G(x^t,y^t)/DF^t(x^t,y^t)}\right\}$$
$$= \frac{TE^{t+1}}{TE^t} \times \left\{\frac{BPG^{t+1}}{BPG^t}\right\}$$
$$= TEC^{t,t+1} \times BPC^{t,t+1},$$

Technical efficiency change	Best practice gap change





Correlation analysis

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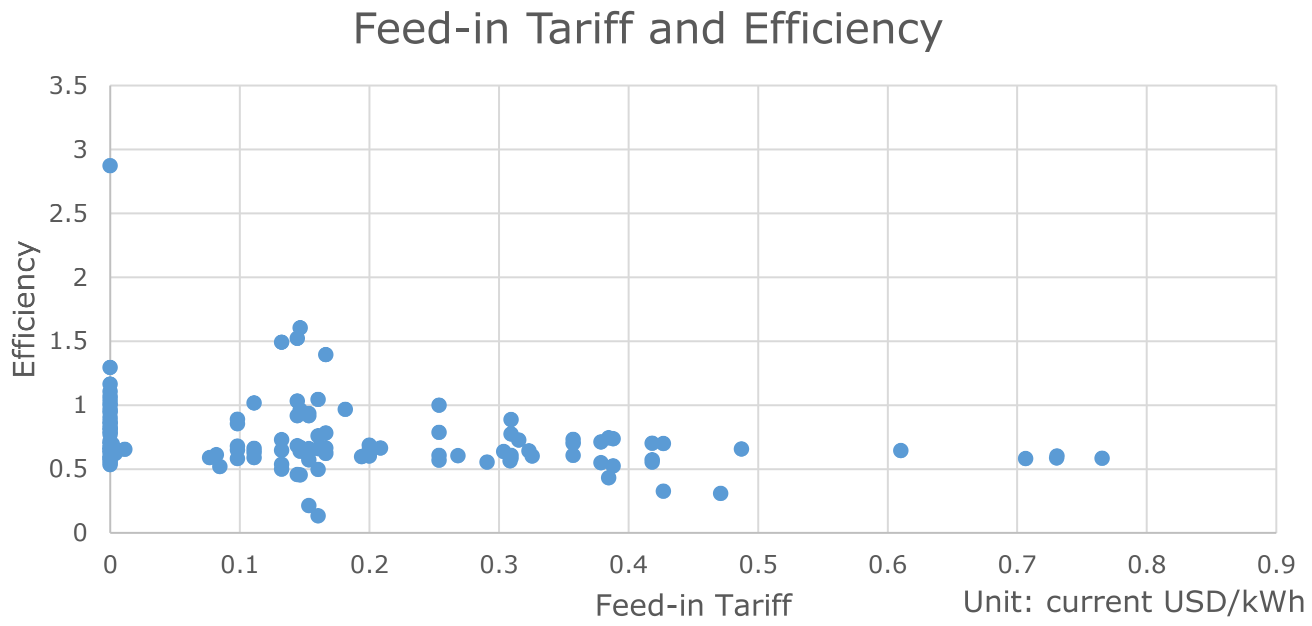
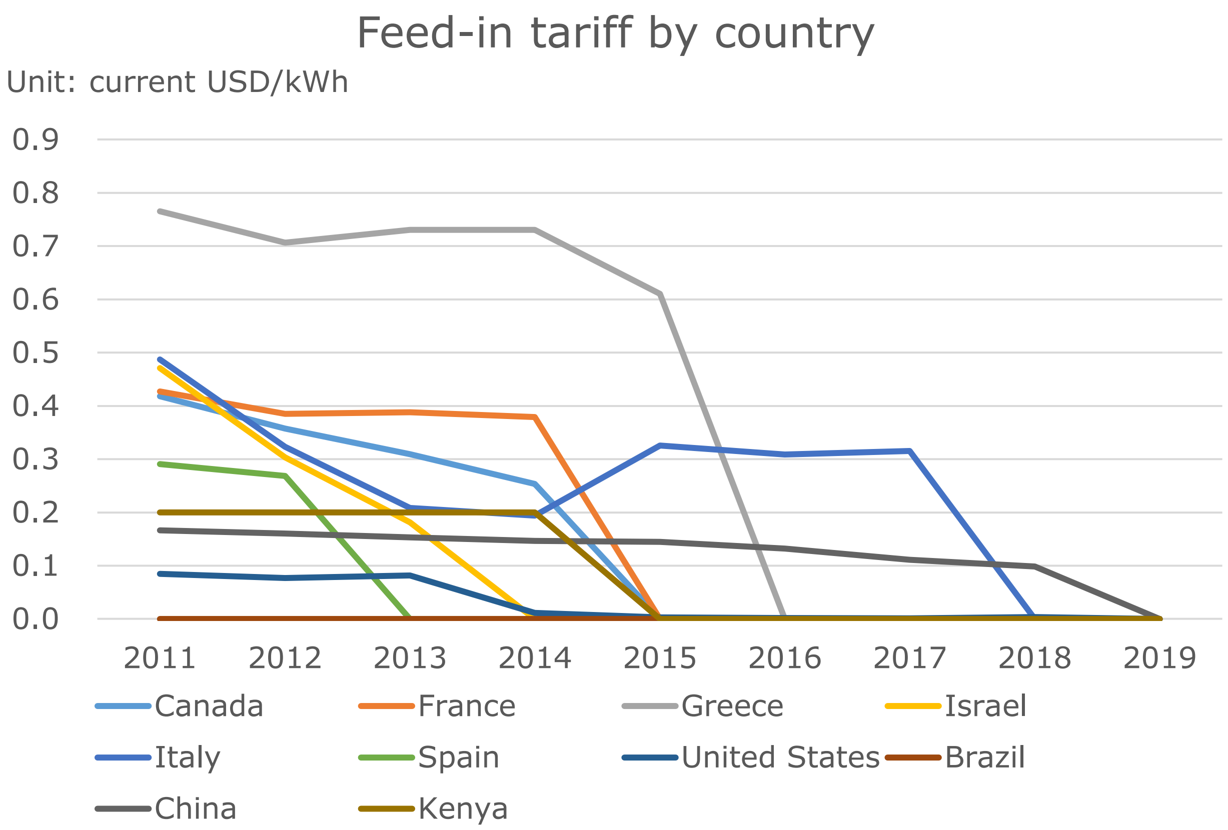
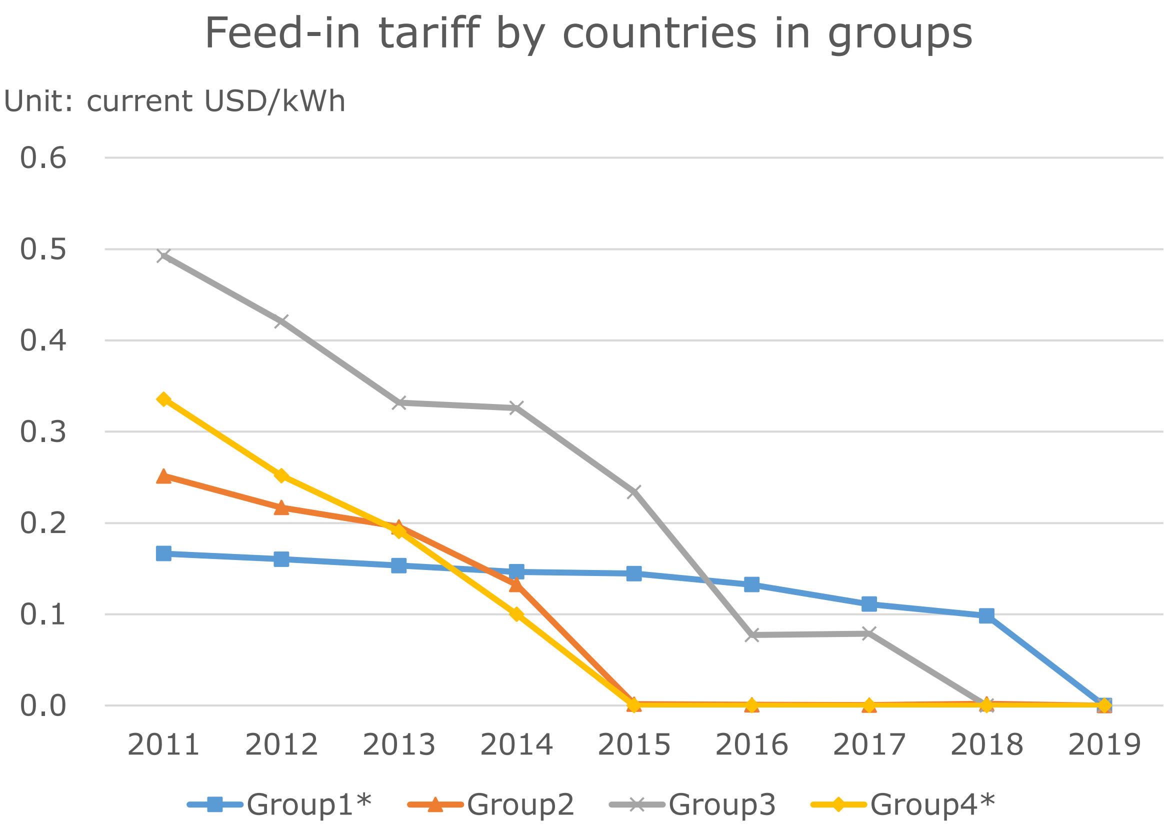
Pearson Correlation Analysis

Correlation between efficiencies	Rho (correlation)	P value	Null hypothesis: the correlation is 0 (significance level of 0.01)
Solar energy capacity	0.102	0.1856	Do not reject
Feed-in tariff	-0.2189	0.0051	Reject
Environment related tax revenue	-0.1177	0.1614	Do not reject



Feed-in Tariff





Group 4 does not include Hong Kong

Source: stats.oecd.org

Renewable energy policies and measures

China

Feed-in Tariff		
Date	Department	Content
2011.7	Development and Reform Commission	Set price: 1.15CNY/kWh
2013.9	Development and Reform Commission	Set price: 0.9, 0.95, 1CNY/kWh
2016.1	Development and Reform Commission	Set price: 0.8, 0.88, 0.98CNY/kWh
2018.5	Development and Reform Commission	Set price: 0.5, 0.6, 0.7CNY/kWh
2019.4	Development and Reform Commission	Set price: 0.4, 0.45, 0.55CNY/kWh
2021	Development and Reform Commission	Set price: Par price (cancelled FiT)
	Local government	Subsidies: Per unit of capacity built/ Per unit of energy generated

Source: TU Qiang, et al.(2020). *The evolution and evaluation of China's renewable energy policies and their implications for the future*

Renewable energy policies and measures

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China

Renewable Energy Power Consumption Promotion Policy		
Date	Department	Content
2015.3	State council	Established an electricity market mechanism to facilitate the grid connection of renewable energy
2017.11	National energy administration	Establish an incentive mechanism for renewable energy power consumption in electricity market

Quota obligation based on RPS and TGC

In 2017.1 China started RPS and TGC to allow trading of green certificates which is a commodity providing electricity generated using renewable sources.

RPS: renewable portfolio standard, TGC: tradable green certificates

Source: TU Qiang, et al.(2020). *The evolution and evaluation of China's renewable energy policies and their implications for the future*

Renewable energy policies and measures

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USA

Policies	Date	Content
Federal tax credits	2005	30% investment tax credit (ITC) for residential, commercial and utility-scale solar installations
	2015	Extension of ITC and lifting the US ban on crude oil exports
	2020~	ITC fall to 26% in 2020 and 22% in 2021. After 2021, residential tax credits fall to zero, commercial and utility-scale fall to 10%
Public Utility Regulatory Policies Act	1978	Establish a marketplace for non-utility power producers according to e Public Utility Regulatory Policies Act (PURPA)
	2005	Applied a waiver to the purchase obligations under PURPA in most states and founded several regional electricity markets
	2016	Review of PURPA
Renewable portfolio standards (RPS)		Twenty-nine states plus the District of Columbia currently have RPS policies in place (eight states have voluntary targets). Most states administer their RPS targets on the basis of a percentage of retail electricity sales
	2019	Significant changes to strengthen RPS programs in several states to achieve 100% carbon-free electricity in 2040-2050

Source: IEA (2019), *ENERGY POLICIES OF IEA COUNTRIES United States 2019 Review*

Renewable energy policies and measures

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USA

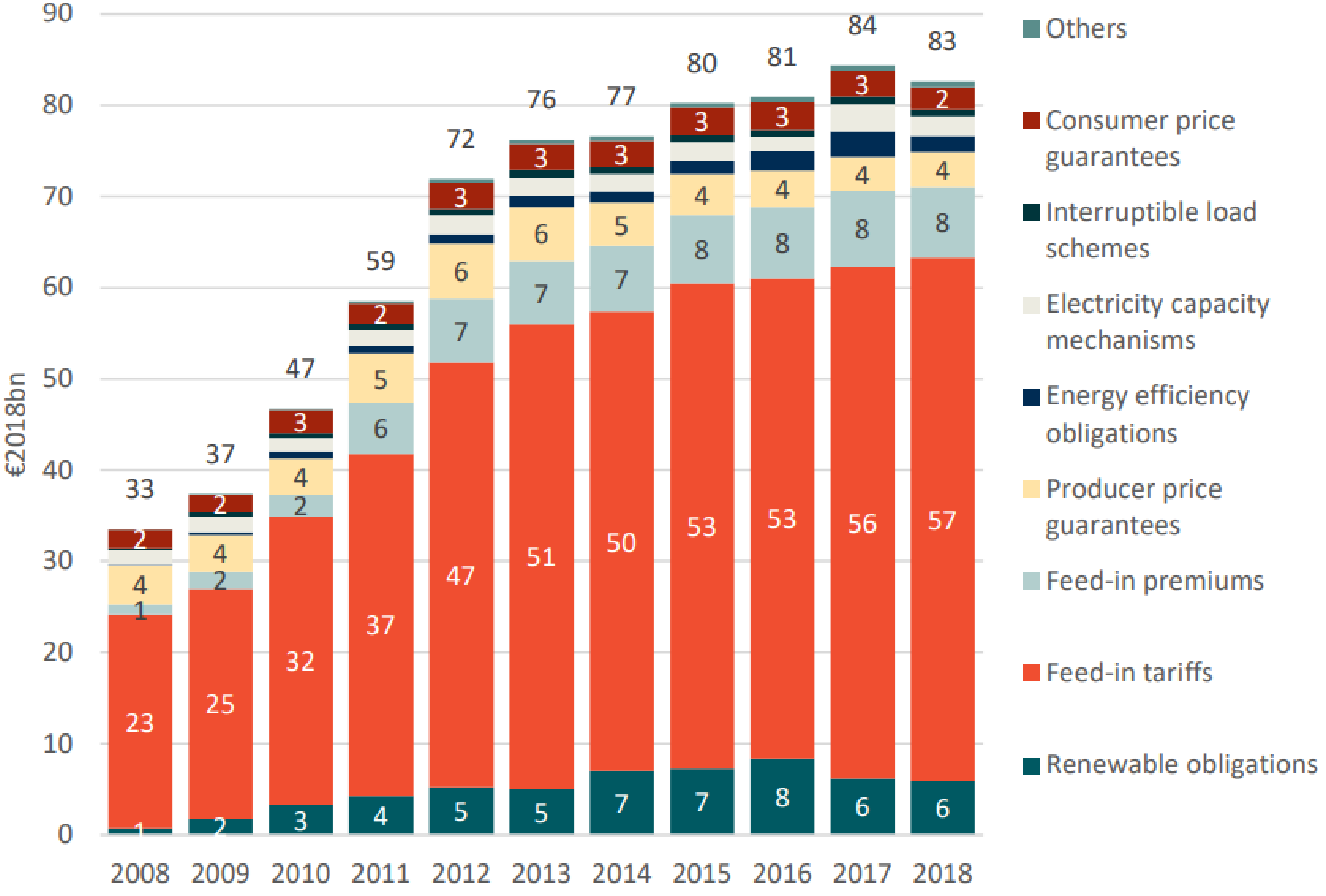
Policies	Date	Content
Trade policy	2018.1	Imposition of import tariffs on imported crystalline-silicon solar PV cells and panels. The tariffs will be in effect for four years. They were set at 30% in the first year, falling by 5% each subsequent year.
	2018.3	imposed a 25% tariff on imported steel and a 10% tariff on imported aluminum.
Net metering		A number of US states have net metering laws in place, which permit residential and commercial customers who generate their own renewable power to sell surplus electricity back to the grid
Grid upgrades		Multiple grid-upgrading projects are completed in different states to improve the balance of real-time supply and demand

Source: IEA (2019), *ENERGY POLICIES OF IEA COUNTRIES United States 2019 Review*

Renewable energy policies and measures

Europe

Figure 2-16 Income and price supports in the EU27 by type (€2018bn, 2008-2018)[11]



Source: European Commission (2021), *Final report Study on energy subsidies and other government interventions in the European Union*

Conclusions

1. Group1 (power producing companies focusing on one country/region) is operating more efficiently in comparison to those that are doing business in different areas
2. The values of GMI of all four groups have average index higher than 1, thereby the operational efficiency of them has grown over the 10 years of the study period
3. The large improvement of catch-up effects results from high peak of efficiency improvement of group 1 in 2012 and 2013. This is probably due to an efficient management that adopts single country/region business environment and institutional changes to cope with avoids management costs for adaptations
4. The companies' catch-up effects has improved significantly but with rather volatile way, compared with the total technological progress
5. Feed-in tariff is affecting efficiency in a reverse way, higher efficiency accompanies lower feed-in tariff
6. Market maturity of the country/resion that a company locates in may also affect operational efficiency of the company on account of different level of subsidies

Future extensions

1. The same method can be applied to different sources of renewable energy
2. Regression analysis can be used to analyze what factors influence the level of efficiency
3. Detailed research can be conducted on various renewable energy policies and support schemes adopted in different countries

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Thank You