Energy Economics 92 (2020) 104964

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Does renewable energy substitute LNG international trade in the energy transition?

Sarah Najm [a,b], Ken'ichi Matsumoto [c,d,*]

[a] Department of Economics, College of Business Administration, King Saud University, Riyadh 11451, Saudi Arabia
[b] Department of Economics, University of Reading, Whiteknights, Reading RG6 6AA, UK
[c] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan
[d] Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 3173–25 Showacho, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan

ARTICLE INFO

Article history:
Received 30 June 2020
Received in revised form 15 September 2020
Accepted 22 September 2020
Available online 30 September 2020

Keywords:
Energy transition
Liquified natural gas trade
Trade gravity model
Renewable energy
Free trade

ABSTRACT

Renewable energy is a vital tool for the energy transition and sustainable development goals. The global economy, however, remains heavily reliant on fossil fuels despite efforts to reduce global greenhouse gas emissions. Demand for natural gas is rising as a bridge for moving towards a low-carbon economy, but whether natural gas and renewable energy represent substitutes in the global energy mix remains underexplored. We tackle this concern by examining the impact of renewable policies on international trade in liquified natural gas (LNG) among 1359 trading partners during the period 1988–2017. We measure renewable energy policies based on the ratio of renewable energy to total energy usage in importing trading partners, which also corresponds to a proxy for energy transition policies. The analysis is conducted using a global panel dataset in a trade gravity framework by applying various econometric methods and model specifications to measure LNG trade as a dependent variable. The results show that the energy transition, measured by the share of renewable energy, has a negative impact on LNG trade. This suggests that investing in cleaner energy technologies can reduce LNG trade globally, as a channel towards reducing natural gas demand. The results are consistent with the narrative where natural gas and renewable energy represent partial substitutes at the global level. However, subgroup analysis suggests that less-developed economies and the shale revolution period seem to impede progress towards the energy transition.

1. Introduction

Renewable energy is a vital tool for the energy transition and sustainable development goals (SDGs). The global economy, however, remains heavily reliant on fossil fuels. Fossil fuels accounted for 84.7% of primary energy consumption in 2018, of which 28.2% was for natural gas (BP, 2019). Demand for natural gas has been accelerating with an annual growth rate of 2.7% in the period 2007–2017 and 5.3% in 2018 (BP, 2019). Demand for natural gas is also rising as a bridge for moving towards a low-carbon economy since it represents the least carbon-intensive fossil-fuel resource. International trade in natural gas is growing in a world of unevenly distributed resources struggling to move towards the energy transition. The share of the inter-regional pipeline natural gas trade has been historically higher than liquified natural gas (LNG) trade, but LNG is gaining grounds due to technological progress and higher demand for clean air. For instance, LNG trade accounted for 28.6% of natural gas trade in 2000 but increased to 45.7% in 2018 (BP, 2019). LNG trade is expected to dominate future natural gas trade, especially to enable the shift from regional to global markets. It represents an efficient mode of transport to reach global consumers as the costs of using inter-regional pipeline rapidly increase with distance (Alrajhi and Abdullah, 2018). Thus, it is more economically viable to trade LNG in large quantities and correspond to a broader range of global consumers.

Natural gas, however, is slowly losing its appeal as a climate change mitigation solution for at least two reasons. The first reason stems from the fact that natural gas remains a type of fossil fuel, despite being less carbon-intensive than oil and coal. Another concern is due to methane leakage associated with both natural gas international trade and domestic usage. Based on a hybrid lifecycle energy strategy analysis, Gilbert and Sovacool (2017) argue that global greenhouse gas (GHG) emissions are expected to increase due to rising energy demand and methane leakage. Excess dependence on natural gas may delay the energy transition to a low-carbon economy. Natural gas no longer represents a climate change solution, but only a bridge to the energy transition. It is essential, therefore, to examine how energy transition policies interact with natural gas output changes, whether domestically or through international trade. We contribute to this debate from the lens of LNG international trade where the role of environmental aspects remains underexplored in related literature, including Maxwell and Zhu

* Corresponding author.
E-mail addresses: snajm@ksu.edu.sa (S. Najm), kenichimatsu@nagasaki-u.ac.jp (K. Matsumoto).

https://doi.org/10.1016/j.eneco.2020.104964

(2011), Dehnavi and Yegorov (2012) and Oglend et al. (2016). What incentivises LNG patterns of trade over time? To what extent would natural gas and renewable energy represent substitutes in LNG importing countries?

This study investigates the impact of the rise in energy transition policies, measured by the share of renewable energy to total energy usage, on LNG international trade. We conduct the analysis using a global panel dataset between 1988 and 2017 in a trade gravity framework. This study provides crucial implications for the effectiveness of renewable energy policies by exploring the extent to which counterintuitive policy outcomes may occur. This tests the premise of whether the rise of environmental initiatives stimulates excess emissions in aggregate, as discussed in green paradox literature pioneered by Sinn (2008, 2012). Hence, this study contributes to multiple research fields, including LNG trade determinants, the green paradox and the rebound effect nested within. We aim to bridge between strands for a broader interpretation of the relationship between LNG international trade and the energy transition. This allows us to tackle the question of the extent to which natural gas and renewable energy correspond to complements or substitutes.

Section 2 presents a background on the role of natural gas in the energy transition and the conceptual framework of our research question. Section 3 presents an overview of related literature strands. Section 4 includes data description and econometric methods. Section 5 provides estimation results and discussion. Section 6 concludes this study and provides policy implications.

2. Background

This section sets a background from an environmental perspective on how the prospect of the natural gas industry is becoming questionable for tackling climate change and the global SDGs. The climate change community no longer views natural gas as a climate change solution (Kah, 2019, 2020). The changing dynamics in the role of natural gas is central to explain the future energy mix. The contribution of natural gas declines when predicting the future of energy mix based on the sustainable development scenario, which is a contrast to stated policy scenarios (IEA, 2019). In contrast to earlier predictions as it gained popularity in previous years, the central role of natural gas in the energy transition continues to decay among developed economies. More regulations in the European Union and the United States (US) call for reducing dependence on natural gas due to methane flaring and leakage (Kah, 2020).

However, players in the natural gas industry do not necessarily fall within the climate change community. The natural gas landscape is more politically driven than oil markets. Suppliers vary dramatically in their location, regulations and economic structure (Griffin, 2017). The diverse nature of natural gas players has two implications. Despite that this diversity fosters energy security in times of shortage, scattered distribution in natural gas resources represent a challenge for international trade – the trade to production ratio in natural gas is far less than it is for oil (Alrajhi and Abdullah, 2018). This makes it less feasible to sustain anti-competitive practices among natural gas producers in the long run, in comparison to more homogenous oil producers (Alrajhi and Abdullah, 2018). Additionally, this diversity may impede progress made to reduce emissions from fossil fuels. It adds a growing pressure to meet carbon-reduction targets in countries abiding by climate change policies. Thus, it remains crucial to examine how the rise of renewable energy interacts with natural gas usage, whether domestically or globally.

The conceptual framework of this study is to examine the interaction between the energy transition, measured by the share of renewable energy to total energy usage, and fossil fuels measured by LNG international trade. Sinn (2008, 2012) argue that climate change demand-driven policies generate unintended consequences by increasing global emissions from fossil fuels. The rebound effect is concerned with sector-specific analysis to examine whether green initiatives stimulate more energy usage. An overarching link, therein, boils down to a similar concern: whether green initiatives generate counterintuitive outcomes by increasing emissions from fossil fuels.

3. Literature review

LNG trade dynamics remain underexplored in the academic literature, compared to oil trade-related studies (Maxwell and Zhu, 2011), especially in the energy transition debate. A prime literature gap is where studies neglect the impact of green policies on LNG trade patterns, but this ultimately concerns environmental economics, the green paradox and the rebound effect literature. That is to tackle the concern of whether environmental initiatives are counterintuitive by stimulating higher emissions. The answer to this concern conceptually links to the rebound effect from a micro viewpoint and more broadly to the green paradox. The rebound effect is where efficiency gains and the rise of cleaner energy stimulate using more fossil fuels (Berkhout et al., 2000; Marques and Fuinhas, 2012; Marques et al., 2018).

Marques et al. (2018) use an autoregressive distributed lag model to examine whether alternative energy substitutes fossil fuels in power generation during the period 1990–2014. The study finds that unlike solar and hydro energy, wind energy fails to substitute fossil-fuel power generation in various European countries. This suggests that moving towards a low-carbon economy is less straightforward than initial expectations when designing green energy policies. Quantitative analysis on the magnitude of the rebound is difficult to obtain, given the complexity of different drivers it involves, whether behavioural or economic factors (Ramos-Martin 2003). Thus, though the empirical support could be weak in micro-analysis (Berkhout et al., 2000, Greening et al., 2000), it remains conceptually essential to examine the rebound effect on various scales given counterintuitive policy outcomes it may generate. Ongoing analysis of the interaction between renewable energy policies and different types of fossil fuels represents an important step in that direction.

The green paradox, pioneered by Sinn (2008), explains imperfect climate policy design when limited to demand-side measures without due consideration to the supply side of fossil fuels. Despite empirical challenges to test the green paradox phenomena (Jensen et al., 2015), some studies explored the impact of increasing support of renewable energy on fossil-fuel production, such as Grafton et al. (2014), Di Maria et al., 2014, Lemoine (2017), Zhang et al. (2017), and Najm (2019). Other strands in the green paradox literature primarily consist of theoretical studies, including Gerlagh (2011), Hoel (2011), Smulders et al. (2012), Van der Ploeg and Withagen, 2012, and Rezai and van der Ploeg (2017). Despite the literature of inconclusive outcomes, the green paradox school of thought remains with a prime concern to examine what impedes reducing global emissions by focusing on fossil fuel industries.

Also known as carbon leakage, another aspect of the green paradox literature is with a spatial perspective as climate change policies are only binding in a sub-group of countries. The argument holds where implementing emission reduction plans stimulates freeriding outcomes from non-abating countries through international trade (Van der Werf and Di Maria, 2012; Hagem and Storrøsten, 2019).[1] Most related studies here commonly use general equilibrium models with variations of the Hotelling Rule (Hotelling 1931; He and Fu, 2011; Sinn, 2012; Van der Werf and Di Maria, 2012; Hagem and Storrøsten, 2019). For instance, Hagem and Storrøsten (2019) distinguish between spatial and intertemporal leakage in a dynamic theoretical model, where they suggest that targeting supply-side environmental policies generates welfare gains in the long run.

[1] A literature survey and policy responses to carbon leakage can be found in Zhang (2012).

Some studies explore the role of different economic costs in natural gas trade, including Maxwell and Zhu (2011), Dehnavi and Yegorov (2012) and Oglend et al. (2016). Maxwell and Zhu (2011) investigate the relationship among natural gas prices, imports and LNG transport costs using US monthly data over the period 1997–2007 in a vector autoregression framework, while Zhang et al. (2018) use both global and Asian datasets in a trade gravity framework to investigate LNG trade determinants over the period 2004–2015. However, the impact of energy transition tools on trade in natural gas across countries remains underexplored in the literature. For instance, Voudouris et al. (2011, 2014) evaluated the future scenarios for natural gas production focusing on the energy transition using the agent-based model, but without due consideration to the drivers of international trade in natural gas.

Another related strand explores the role of LNG trade in the climate change context, such as Gilbert and Sovacool (2017), but without analysing its link to the energy transition debate. Gilbert and Sovacool (2017) indicate that US LNG exports entail different climate damages to four Asian trading partners – China, India, Japan, and South Korea. The study finds that LNG trade between the US and China creates positive and negative effects on GHG emissions. Gilbert and Sovacool (2017) argue that global emissions are expected to increase due to rising energy demand and methane leakage.

The discussion above indicates a lack of thorough analysis in the literature on the interaction between environmental policies and LNG international trade at the global level. Climate policy is contestable where energy transition policies paradoxically generate incentives to increase emissions. The paradoxical outcome may occur whether domestically or through international trade. We contribute to this debate by analysing whether energy transition policies paradoxically amplify global emissions through the channel of LNG international trade. We account for both economic and institutional variables in the model specification. The following section provides an overview on data and methods used in this study.

4. Data and methods

This section describes the dataset, data sources, definitions of variables, and econometric methods. This study uses an unbalanced panel dataset during the annual period from 1988 to 2017, where the cross-section dimension represents pairs of countries based on the LNG trade data. The number of cross-sectional observations is 1359 global trading partners. We also use subsamples of the global dataset based on country groups and different time periods for an extended interpretation of results.

4.1. Variables and data sources

The main dependent variable we use is the bilateral trade value of LNG (*Trade_value*), but we also use the trade volume (*Trade_volume*), and the trade value and trade volume per GDP (*Trade_value_GDP* and *Trade_volume_GDP*). Using different trade specification variables allows us to account for further robustness checks of results.

The independent variables we use are as follows. We define the green energy index (*Green*) as "the ratio of renewable energy consumption to the total energy consumption" in the LNG importing country. The green energy index is a proxy for environmental incentives to trade between countries, which represents the main independent variable of interest in this study. This is to test the impact of the energy transition policies on LNG international trade. We expect the green energy index to capture a positive-sign relationship if LNG and renewable energy represent complements, but a negative sign if being substitutes over time. A positive-sign relationship is also in favour of the green paradox and the rebound effect, suggesting that green policies are counterintuitive by stimulating more global emissions. From an environmental perspective, the negative relationship is preferable since LNG remains a fossil-fuel source emitting GHGs, with methane leakage and gas flaring concerns.

The World Trade Organization (WTO) index (*WTO*) aims to capture institutional incentives to trade between countries. The index represents a dummy variable taking the value of one if both trading partners hold a WTO membership, and zero otherwise. We expect this index to have a positive outcome if reduced trade barriers by participating in the WTO generate greater incentives to trade. Nevertheless, this also suggests that freer trade is environmentally problematic by promoting trade in fossil fuels and stimulating higher global emissions. The LNG price (*Price*), also used as an independent variable, was calculated as "trade value of LNG / trade volume of LNG." Theory suggests that prices would have a negative effect on LNG trade as a price increase is expected to reduce the demand for imports. In other words, the price variable embodies a cost for LNG importing countries, despite representing economic incentives for exporting countries to gain revenues. We therefore expect this variable to be with a negative-sign coefficient when using LNG trade as dependent variables.

Other independent variables are as follows. GDP of exporters and importers (*GDP_exp* and *GDP_imp*) are used as independent variables in the traditional trade gravity model to account for economic scale. Both GDP of exporters and importers are expected to have a positive impact on trade. The distance between two trade partners (*Distance*) is also used as an independent variable following the traditional trade gravity model. In addition, degree days, including heating/cooling degree days, of importing countries (*Degree_days*) are expected to affect LNG trade, as energy demand for heating/cooling is likely to increase in colder/hotter days.

Data for the green energy index were collected from the World Bank.[2] Trade-related data was taken from the United Nations' Comtrade Database.[3] GDP series were obtained from the World Development Indicators of the World Bank.[4] The distance data between two trading partners was obtained from Mayer and Zignago (2011). The degree days data series were calculated by the annual average temperature obtained from the Climate Change Knowledge Portal of the World Bank.[5] Table 1 shows the descriptive statistics of the dependent and independent variables used in this study.

4.2. Empirical framework

The empirical framework of this study is based on the trade gravity model pioneered by Poyhonen (1963) and Tinbergen (1962). Kabir et al. (2017) provide a literature survey on both empirical and theoretical trade gravity studies. Trade gravity models are used to predict trade flows with the premise that larger economies trade more and farther countries trade less – Eq. (1).

$$Trade_{ij} = \alpha_1 \left(\frac{GDP_i^{\alpha_2} GDP_j^{\alpha_3}}{Distance_{ij}^{\alpha_4}} \right), \quad (1)$$

where: $Trade_{ij}$ is bilateral trade flow between trading partners i and j, GDP_i and GDP_j are GDP of the two trading countries i and j, $Distance_{ij}$ is the geographical distance between trading partners i and j, and α_1, α_2, α_3, and α_4 are coefficients.

By taking the logarithm, Eq. (1) can be rewritten as a linear model as Eq. (2).

$$\ln(Trade_{ij}) = C + \alpha_2 \ln(GDP_i) + \alpha_3 \ln(GDP_j) + \alpha_4 \ln(Distance_{ij}) + u_{ij} \quad (2)$$

where: C is constant and u_{ij} is an error term.

[2] The data is available at https://data.worldbank.org/indicator/eg.fec.rnew.zs.

[3] The data is available at https://comtrade.un.org/. We used the commodity code of 271,111.

[4] The data is available at http://datatopics.worldbank.org/world-development-indicators/.

[5] The data is available at https://climateknowledgeportal.worldbank.org/.

Table 1
Descriptive statistics.

Variables	Mean	Std. Dev.	Min.	Max.	Observations
Trade_value (USD)	2.32×10^8	1.12×10^9	1	2.66×10^{10}	5134
Trade_volume (kg)	4.56×10^9	8.54×10^{10}	1	3.11×10^{12}	5020
Trade_value_per_GDP (USD/USD)	0.00028	0.0019	1.99×10^{-13}	0.066	5134
Trade_volume_per_GDP (kg/USD)	0.0052	0.12	5.99×10^{-14}	7.36	5020
GDP_exp (thousand USD)	1.86×10^9	3.98×10^9	30,332.20	1.73×10^{10}	5134
GDP_imp (thousand USD)	1.72×10^9	3.18×10^9	31,703.09	1.73×10^{10}	5134
Distance (km)	4509.49	4050.97	92.27	19,551.95	5134
Price (USD/kg)	84.18	3300.56	0.000012	228,245.60	5034
Degree_days (°C)	7.16	3.95	0.0084	33.18	5134
WTO	0.81	0.39	0	1	5134
Green (%)	16.75	24.28	0	96.84	5134

Note: The number of observations is different by variable because of data availability.

We aim to examine the effect of the energy transition on LNG trade using a trade gravity modelling framework (Eq. (2)). The econometric specification includes fixed effects to account for unobserved heterogeneity between trading partners given the diversity between them. Thus, we develop the fixed-effects model with the following specification – Eq. (3).

$$\ln(y_{kt}) = C + \beta_1 \ln(GDP\_exp_{kt}) + \beta_2 \ln(GDP\_imp_{kt}) + \beta_3 \ln(Distance_{kt}) + \beta_4 \ln(Green_{kt}) + \beta_5 X_{kt}^{-1} + \theta_k + \zeta_t + \varepsilon_{kt} \quad (3)$$

where: y_{kt} is LNG trade between trading-partner pairs k in year t, X_{kt} is a vector of the control variables (i.e., *Price*, *Degree_days*, and *WTO*), θ_k is a country pair fixed effect, ξ_t is a year fixed effect, ε_{kt} is an error term, and β_1, β_2, β_3, β_4 and β_5 are coefficients.

$Green_{kt}$ (the ratio of renewable energy in the importer side of trading-partner pairs k in year t) represents the main independent variable as a tool for the energy transition. The country pair fixed effect captures unobserved factors, such as the relationships between the two countries. In contrast, the year fixed effect captures the factors that affect trade equally across the pairs in each year, such as global economic conditions.

We use four specifications for the trade variable y: trade values, trade amount, trade values per GDP of importing countries, and trade amount per GDP of importing countries. This is expected to provide a more robust interpretation of the overall analysis. We use the logarithm of the values for all variables except for *WTO*.

5. Results and discussion

This section includes estimation results and discussion. We start by a discussion of fixed-effects ordinary least squares (OLS) estimation results with various model specifications, followed by the generalised least square (GLS) estimation results for further robustness checks in section 5.1. In addition, we conducted fixed-effects OLS estimations by dividing the dataset into subsamples based on country groups and time periods for further interpretation of the impact of energy transition policies on LNG international trade – section 5.2.

5.1. Main estimation results: global dataset

5.1.1. Fixed-effects OLS estimations

Table 2 shows the results of the panel data regression models. The dependent variable represents the value of LNG trade – the main dependent variable. Note that all models include two fixed effects (i.e., cross-section and time). Model 1 only uses the green energy index (a proxy for the energy transition) as an independent variable, whereas Model 3 uses the GDP variables for a trade gravity specification. Model 4 uses all the independent variables. Model 2 shows the trade gravity specification without the green energy index.[6]

Table 2
Effects of green energy index on the value of LNG trade.

	Model 1	Model 2	Model 3	Model 4
ln(*GDP_exp*)	–	0.560	−0.704	0.00110
		(0.472)	(0.866)	(0.874)
ln(*GDP_imp*)	–	0.794	0.703	0.484
		(0.517)	(0.565)	(0.588)
ln(*Green*×1000)	−0.436*	–	−0.534*	−0.485*
	(0.198)		(0.222)	(0.223)
ln(*Price*)	–	–	–	−0.0293
				(0.0517)
ln(*Degree_days*)	–	–	–	0.167
				(0.395)
WTO	–	–	–	0.681
				(0.513)
Constant	16.409**	−11.593	17.414	6.895
	(1.777)	(12.910)	(18.562)	(19.004)
Observations	4168	5134	4168	4076
R-squared	0.036	0.068	0.038	0.042
Number of cross sections	1184	1359	1184	1165

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

Model 1 shows that the green energy index is negative and statistically significant to the value of LNG trade at the 5% level, meaning that the energy transition or the percentage of renewable energy in LNG importing countries reduces the value of LNG trade. The coefficient outcome remains negative and statistically significant across the rest of specifications, although with a variant size of magnitude: −0.436 (Model 1), −0.534 (Model 3) and − 0.485 (Model 4).

We also use the volume of LNG trade as a dependent variable consistent with model specifications in Table 2. Table 3 depicts the results. Model 5 in Table 3 shows that the green energy index is negative and statistically significant at the 1% level. By including GDP of exporters and importers (Model 7), and other independent variables (Model 8), together with the green energy index, the green energy index remains negative and statistically significant at the 5% level. The coefficient of the green energy index was slightly lower for the trade volume compared to the trade value model when including all independent variables.

The results suggest that energy transition tools, by increasing the share of renewable energy, reduce the volume of LNG trade. This provides two implications at least. Renewable energy and natural gas represent partial substitutes based on the results of this study. This is reasonable as renewable energy can substitute natural gas for electricity usage, but without being perfect substitutes given the size of the magnitudes being less than one in most cases. The results are partly consistent with Marques et al. (2018) finding that solar and hydro energy substitute fossil fuels in power generation during the period 1990–2014.

[6] See Table A1 in the appendix for the general trade gravity estimations.

Table 3
Effects of green energy index on the volume of LNG trade.

	Model 5	Model 6	Model 7	Model 8
ln(*GDP_exp*)	–	2.747**	3.943**	0.157
		(0.703)	(1.295)	(0.876)
ln(*GDP_imp*)	–	1.058	0.448	0.261
		(0.778)	(0.862)	(0.613)
ln(*Green*×1000)	−1.259**	–	−0.751*	−0.466*
	(0.309)		(0.326)	(0.223)
ln(*Price*)	–	–	–	−1.029**
				(0.0517)
ln(*Degree_days*)	–	–	–	0.162
				(0.396)
WTO	–	–	–	0.723
				(0.512)
Constant	24.610**	−56.988**	−63.579*	8.023
	(2.825)	(20.714)	(29.081)	(19.085)
Observations	4168	5134	4168	4076
R-squared	0.041	0.055	0.051	0.429
Number of cross sections	1184	1359	1184	1165

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

Table 5
Effects of green energy index on the volume of LNG trade per GDP.

	Model 13	Model 14	Model 15	Model 16
ln(*GDP_exp*)	–	1.763**	2.273*	0.0205
		(0.587)	(1.138)	(0.874)
ln(*GDP_imp*)	–	−0.231	−0.760	−0.494
		(0.762)	(0.888)	(0.588)
ln(*Green*×1000)	−0.916**	–	−0.624*	−0.489*
	(0.290)		(0.314)	(0.223)
ln(*Price*)	–	–	–	−1.039**
				(0.0518)
ln(*Degree_days*)	–	–	–	0.166
				(0.394)
WTO	–	–	–	0.678
				(0.513)
Constant	−3.032	−37.430*	−34.501	−0.728
	(2.615)	(18.248)	(26.297)	(18.958)
Observations	4071	5020	4071	4071
R-squared	0.095	0.099	0.098	0.447
Number of cross sections	1165	1341	1165	1165

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

The outcome is also consistent with partial evidence against a paradoxical impact of green energy since it has a negative effect on LNG as a type of fossil fuel.

The LNG price variable has a negative and statistically significant coefficient at the 1% level for the model with the volume of LNG trade as the dependent variable (Model 8 in Table 3). At the same time, it shows insignificant in the model with the value of the trade as the dependent variable (Model 4 in Table 2). It is expected that the trade volume is negatively affected by the increase in price. The trade value can be decomposed as "price × trade volume." Although the trade volume is negatively affected by price, the price increases simultaneously, which justifies the insignificant coefficient of the LNG price for the model with the value of LNG trade.

The results also indicate that the GDP coefficients of exporting and importing countries were mostly insignificant, particularly with the model that includes all the variables. The counterintuitive insignificant relationship may stem from three reasons. Firstly, the result can be due to the nature of long-term LNG trade contracts where trade may be persistent in responding to short-run economic conditions. Secondly, the outcome can be explained by the low elasticity of demand in the short run. Thirdly, econometric misspecification is another possible reason for the insignificant outcome. This will be tackled for in section 5.1.2 by using a GLS estimator.

Table 4
Effects of green energy index on the value of LNG trade per GDP.

	Model 9	Model 10	Model 11	Model 12
ln(*GDP_exp*)	–	0.560	−0.704	0.00110
		(0.472)	(0.866)	(0.874)
ln(*GDP_imp*)	–	−0.206	−0.297	−0.516
		(0.517)	(0.565)	(0.588)
ln(*Green*×1000)	−0.445*	–	−0.534*	−0.485*
	(0.197)		(0.222)	(0.223)
ln(*Price*)	–	–	–	−0.0293
				(0.0517)
ln(*Degree_days*)	–	–	–	0.167
				(0.395)
WTO	–	–	–	0.681
				(0.513)
Constant	−9.320**	−18.500	10.506	−0.0127
	(1.761)	(12.910)	(18.56)2	(19.003)
Observations	4168	5134	4168	4076
R-squared	0.027	0.047	0.028	0.029
Number of cross sections	1184	1359	1184	1165

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

The results are also robust when re-specifying the model. Tables 4 and 5 show the regression results with the value of LNG trade per GDP and the volume of LNG trade per GDP, respectively, as a dependent variable. The independent variables remain consistent with the previous specifications. Overall, the results are similar to the previous results shown in Tables 2 and 3. The green energy index has a negative and statistically significant effect on both the value and volume of LNG trade per GDP (at the 1–5% levels).

The results of the remaining independent variables are consistent with the previous estimation outcome. For example, the LNG price negatively affects the trade volume per GDP but does not affect the trade value per GDP. The results suggest that the effect of the energy transition on LNG trade is robust. We conduct further robustness checks by applying a GLS estimation in the next section.

5.1.2. Fixed-effects GLS estimations

We re-estimate the four models used in the previous section by applying a GLS estimation to tackle heteroscedasticity and serial correlation concerns. This provides additional robustness checks for the estimation results. Table 6 shows the GLS estimation results with all

Table 6
Fixed-effects GLS estimation results.

	Trade value	Trade volume	Trade value per GDP	Trade volume per GDP
ln(*GDP_exp*)	0.166	0.279*	0.166	0.209
	(0.129)	(0.134)	(0.129)	(0.132)
ln(*GDP_imp*)	0.480**	0.432**	−0.520**	−0.497**
	(0.107)	(0.114)	(0.107)	(0.108)
ln(*Green*×1000)	−0.443**	−0.451**	−0.443**	−0.446**
	(0.0405)	(0.0426)	(0.0405)	(0.0425)
ln(*Price*)	−0.0246**	−1.027**	−0.0246**	−1.036**
	(0.00700)	(0.00772)	(0.00700)	(0.00495)
ln(*Distance*)	−1.000	−0.211	−0.828	−0.969
	(2363.939)	(0.673)	(0.668)	(0.674)
ln(*Degree_days*)	0.132**	0.138**	0.132**	0.126**
	(0.0472)	(0.0469)	(0.0472)	(0.0478)
WTO	0.775**	0.810**	0.775**	0.788**
	(0.110)	(0.117)	(0.110)	(0.115)
Observations	3585	3585	3585	3580
Number of cross sections	674	674	674	674

Note: Standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

independent variables. In these estimations, both country pair and year fixed effects are included as with the previous estimates. The main independent variable of the green energy index remains negative and statistically significant at the 1% level for all the specifications. This provides further robust interpretation for the impact of the energy transition on LNG trade.

In line with theory and the above fixed-effects OLS estimations (Tables 2–5), the LNG price coefficient shows negative and statistically significant for the trade volume. However, unlike the previous outcomes, it has a negative and statistically significant impact on the trade value, although the magnitudes are much smaller in absolute term than the volume-related variables.

The variable of GDP of importers has a positive and statistically significant outcome for the models with the trade value and trade volume as dependent variables. This is consistent with the theoretical prediction of trade gravity models, despite deviating from the OLS estimation results. This is partly because the GLS is more robust than the OLS estimator to tackle misspecifications, even if clustered robust standard errors were used. However, the GDP of exporters is only positive and statistically significant for the model with the trade volume as a dependent variable. LNG trade depends on the economic situation of the importing country, where greater economic activity stimulates more energy usage. The growth process increases energy demand, especially for industrialisation purposes and a higher standard of living. In contrast, from the exporters' perspective, LNG exports depend on the availability of resources and foreign demand, rather than the economic situation in the exporting country.

The dummy variable for the WTO has a positive and statistically significant outcome in all models. This result provides crucial implications for the climate change community to analyse the role of trade institutions in amplifying global emissions through the channel of LNG trade. Thus, imposing carbon border tariffs is vital to tackle this concern.

5.2. Subsample estimation results

We extend the discussion by subdividing the dataset into two dimensions. The first subsample classifies country groups based on the level of economic development by distinguishing between the Organization for Economic Co-operation and Development (OECD) and non-OECD importers. The second division is for time periods based on different decades within the sample: 1988–1997, 1998–2007 and 2008–2017. Extending the analysis into this direction provides critical insights into the geographical spread and time series of energy transition paths. This is to test the extent to which different subsample results are consistent with the substitution effect that we found at the global level.

Tables 7 and 8 show the results for different country groups and different time periods, respectively. Note that the estimations are based on the four LNG trade specifications and all the independent variables. The estimation results focus on the green energy index output given the scope of our discussion, but full estimation results are available upon request.

The country-group results (Table 7) show that the green energy index is negative and statistically significant in all specifications of LNG trade at the 5% level for the OECD-importer group, while insignificant for the non-OECD-importer group. The coefficients for the OECD-importer group are larger in magnitude compared to full sample outcomes, which shows a high substitution effect between renewable energy and LNG trade in the OECD economies. The results provide two implications. First, the results indicate higher environmental awareness and greater climate change mitigation efforts in OECD economies, given the large magnitude of the coefficients. Environmental initiatives entail decarbonisation progress and stricter regulations, as the energy structure seems to be in favour of renewable energy over fossil fuels here, compared to non-OECD countries. This explains the dramatic decrease in LNG trade in response to a higher share of renewable energy among the OECD importing countries based on the results of this study.

In contrast to OECD trading partners, less-developed economies seem to lack a structural relationship between renewable energy policies and LNG trade based on the insignificant outcome of results. This feeds into the discussion of section 2, where we mentioned the diverse nature of players in the natural gas market which creates coordination issues. This makes it more challenging to implement sustainable energy

Table 7
Fixed-effects estimation results by country group (OECD and non-OECD).

		OECD	Non-OECD
Trade value	ln(*Green*×1000)	−0.616*	0.0510
		(0.289)	(0.349)
	Observations	1965	2111
	R-squared	0.059	0.047
	Number of cross-sections	475	703
Trade volume	ln(*Green*×1000)	−0.619*	0.125
		(0.287)	(0.357)
	Observations	1965	2111
	R-squared	0.42	0.46
	Number of cross-sections	475	703
Trade value per GDP	ln(*Green*×1000)	−0.616*	0.0510
		(0.289)	(0.349)
	Observations	1965	2111
	R-squared	0.053	0.029
	Number of cross-sections	475	703
Trade volume per GDP	ln(*Green*×1000)	−0.619*	0.0511
		(0.287)	(0.349)
	Observations	1965	2106
	R-squared	0.43	0.49
	Number of cross-sections	475	703

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$; all independent variables are included in the estimations.

Table 8
Fixed-effects estimation results by time period.

		1988–1997	1998–2007	2008–2017
Trade value	ln(*Green*×1000)	−1.038	−2.615**	0.466
		(1.039)	(0.903)	(0.285)
	Observations	480	1446	2150
	R-squared	0.076	0.062	0.044
	Number of cross-sections	235	624	808
Trade volume	ln(*Green*×1000)	−1.039	−2.605**	0.495
		(1.039)	(0.901)	(0.288)
	Observations	480	1446	2150
	R-squared	0.53	0.45	0.18
	Number of cross-sections	235	624	808
Trade value per GDP	ln(*Green*×1000)	−1.038	−2.615**	0.466
		(1.039)	(0.903)	(0.285)
	Observations	480	1446	2150
	R-squared	0.070	0.052	0.039
	Number of cross-sections	235	624	808
Trade volume per GDP	ln(*Green*×1000)	−1.039	−2.605**	0.473
		(1.039)	(0.901)	(0.285)
	Observations	480	1446	2145
	R-squared	0.54	0.46	0.19
	Number of cross-sections	235	624	808

Note: Clustered robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$; all independent variables are included in the estimations.

policies and carbon-reduction targets globally. In addition, this is consistent with the narrative that increasing LNG trade is not necessarily viewed as a bridge towards the energy transition in non-OECD importing countries. Instead, it seems to stem from increasing energy demand for meeting development plans in emerging markets, such as China. Thus, it comes as no surprise that the results lack evidence for a substitution effect between renewable energy and LNG trade in non-OECD economies.

The subsample results by time period (Table 8) show that the green energy index is negative and statistically significant during the period 1998–2007, while insignificant during 1988–1997 and 2008–2017. This suggests that the substitution relationship is mainly observed in the 2000s, following rising environmental concerns in many developed economies and the increasing debates of climate change policies, including the Kyoto Protocol adopted in 1997. This is also coupled with the economic incentive to switch from fossil-fuel resources to renewable energy and reduce dependence on volatile oil markets. However, the rising political will supporting fossil-fuel industries may have slowed the progress of decarbonisation policies. For instance, the third subsample period coincides with the shale revolution in2008 and commercialising non-conventional fossil-fuel resources led by the US (US Department of Energy, 2017). This seems to have influenced decarbonisation progress and the substitution effect witnessed in the previous period.

6. Conclusion and policy implications

The share of natural gas is rapidly increasing in the total energy mix as the least emission-intensive fossil-fuel resource. Nevertheless, this is associated with growing environmental threats due to gas flaring and methane leakage. Thus, it remains essential to explore the interaction between the energy transition and LNG trade, given the various types of natural gas producers of different climate policy strictness. This study examined the effect of the energy transition, measured by the share of renewable energy, on LNG international trade. The analysis used trade gravity panel models from 1988 to 2017 by applying fixed-effects methods to account for unobserved heterogeneity between trading partners. We also used various forms of dependent and independent variables, different estimation methods, and subsamples (country groups and periods) to ensure better interpretation of results.

The results indicate that the green energy index reduces the LNG trade – this finding is robust across various specifications. We conclude that renewable energy and LNG trade represent partial substitutes when we examine the relationship at the global level. We obtained additional insights across different country groups and time periods based on subsample estimations. The rise of energy transition policies appears to dramatically reduce LNG trade in OECD economies, in contrast to an insignificant outcome for non-OECD importers. Thus, policymakers should consider the nature of economic structure among trading partners when designing energy regulations and carbon-reduction targets, as less-developed economies fall behind in the energy transition. The results also imply that the rising political will supporting shale resources seem to impede decarbonisation progress achieved in previous decades. Policymakers need to ensure coordination between conventional and non-conventional fossil-fuel industries when analysing carbon-reduction targets.

This study suggests that supporting renewable energy contributes to reducing the share of natural gas in LNG importing countries, providing partial evidence against carbon leakage and the green paradox phenomena. However, other trade incentives, including WTO membership, seem to increase LNG trade between countries. This is a critical finding for climate change policymakers, as it may delay the process of the energy transition. Further coordination between trade agreements and environmental initiatives is required to avoid amplified global emissions, such as increasing carbon border tariffs. Future work is encouraged to dig deeper to examine the impact of other trade aspects and regional agreements on LNG trade. It also remains important to analyse the impact of the energy transition on trade in other types of fossil fuels and across different economic sectors.

Acknowledgements

This study was supported by Integrated Research Program for Advancing Climate Models Grant Number JPMXD0717935457 from the Ministry of Education, Culture, Sports, Science and Technology, Japan and JSPS KAKENHI Grant Numbers JP18K11754 and JP18K11800. We thank the Research Center at the College of Business Administration and the Deanship of Scientific Research at King Saud University for their encouragement. We also would like to thank two anonymous reviewers for their constructive comments and suggestions. Any mistakes are ours.

Appendix A. Appendix

Table A1 shows the general trade gravity model for LNG trade. The dependent variable is the trade value. Model A1 is pooled OLS estimation, while Models A2 and A3 are single and double fixed-effects estimations, respectively. With the pooled OLS estimation, the distance variable was positive and statistically significant, which is counterintuitive for trade gravity models. However, this is expected in the case of LNG trade, since it involves high fixed costs and lower variable costs, providing greater incentive to trade more with distance. With the single fixed-effects model, both GDP of exporters and importers are positive and statistically significant. However, the variables are insignificant in the double fixed-effects model. Thus, the effect of GDP on the trade value may be related to the year fixed effect.

Table A1
General trade gravity model for LNG trade.

	Model A1	Model A2	Model A3
ln(*GDP_exp*)	0.0102	0.952*	0.560
	(0.0650)	(0.409)	(0.472)
ln(*GDP_imp*)	0.451**	1.135**	0.794
	(0.0579)	(0.439)	(0.517)
ln(*Distance*)	0.699**	–	–
	(0.112)		
Constant	−2.765	−27.956**	−11.592
	(1.552)	(7.379)	(12.910)
Fixed effect	–	Cross-section	Cross-section and year
Observations	5134	5134	5134
R-squared		0.033	0.068
Number of cross-sections	1359	1359	1359

Note: Robust standard errors in parentheses; ** $p < 0.01$, * $p < 0.05$.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2020.104964.

References

Alrajhi, A., Abdullah, M., 2018. Energy Economics. King Saud University Press, Riyadh, Saudi Arabia (in Arabic).

Berkhout, P.H.G., Muskens, J.C., Velthuijsen, W., J., 2000. Defining the rebound effect. Energy Policy 28, 425–432.

BP, 2019. BP statistical review of world energy 2019. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed: July 20, 2020).

Dehnavi, J., Yegorov, Y., 2012. Is LNG Arbitrage Possible in Natural Gas Market? *USAEE-IAEE Working Paper*. USAEE-IAEE Working Paper, 2110234.

Di Maria, C., Lange, I., Van der Werf, E., 2014. Should we be worried about the green paradox? Announcement effects of the acid rain program. Eur. Econ. Rev. 69, 143–162.

Gerlagh, R., 2011. Too much oil. CESifo Econ. Stud. 57, 79–102.

Gilbert, A.Q., Sovacool, B.K., 2017. US liquefied natural gas (LNG) exports: boom or bust for the global climate? Energy 141, 1671–1680.
Grafton, R.Q., Kompas, T., Long, N.V., TO, H, 2014. US biofuels subsidies and CO_2 emissions: an empirical test for a weak and a strong green paradox. Energy Policy 68, 550–555.
Greening, L., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption — the rebound effect — a survey. Energy Policy 28, 389–401.
Griffin, P. (Ed.), 2017. Liquefied Natural Gas: The Law and Business of LNG. Globe Law & Business, London.
Hagem, C., Storrøsten, H.B., 2019. Supply- versus demand-side policies in the presence of carbon leakage and the green paradox. Scand. J. Econ. 121, 379–406.
He, J., Fu, J., 2011. Is pollution haven hypothesis valid for China's manufacture sectors? An empirical analysis based on carbon embodied in trade. *Cahiers de recherche*, 11–12. Departement d'Economique de l'École de gestion à l'Université de, Sherbrooke.
Hoel, M., 2011. The green paradox and greenhouse gas reducing investments. Int. Rev. Environ. Resour. Econ. 5, 353–379.
Hotelling, H., 1931. The economics of exhaustible resources. J. Polit. Econ. 39, 137–175.
IEA (International Energy Agency), 2019. World Energy Outlook 2019. International Energy Agency, Paris.
Jensen, S., Mohlin, K., Pittel, K., Sterner, T., 2015. An introduction to the green paradox: the unintended consequences of climate policies. Rev. Environ. Econ. Policy 9, 246–265.
Kabir, M., Salim, R., Al-Mawali, N., 2017. The gravity model and trade flows: recent developments in econometric modelling and empirical evidence. Econ. Anal. Policy 56, 60–71.
Kah, M., 2019. The future of hydrocarbons: changing demand and subsequent impacts "projections for oil and natural gas demand". 1st IAEE Middle East Symposium. International Association for Energy Economics.
Kah, M., 2020. Columbia global energy dialogue: natural gas flaring workshop summary. https://energypolicy.columbia.edu/research/global-energy-dialogue/columbia-global-energy-dialogue-natural-gas-flaring-workshop-summary (accessed: May 20, 2020).
Lemoine, D., 2017. Green expectations: current effects of anticipated carbon pricing. Rev. Econ. Stat. 99, 499–513.
Marques, A.C., Fuinhas, J.A., 2012. Are public policies towards renewables successful? Evidence from European countries. Renew. Energy 44, 109–118.
Marques, A.C., Fuinhas, J.A., Pereira, D.A., 2018. Have fossil-fuels been substituted by renewables? An empirical assessment for 10 European countries. Energy Policy 116, 257–265.
Maxwell, D., Zhu, Z., 2011. Natural gas prices, LNG transport costs, and the dynamics of LNG imports. Energy Econ. 33, 217–226.
Mayer, T., Zignago, S., 2011. Notes on CEPII's distances measures: The GeoDist database. *CEPII Working Paper*, 2011–25.
Najm, S., 2019. The green paradox and budgetary institutions. Energy Policy 133, 110846.
Oglend, A., Kleppe, T.S., Osmundsen, P., 2016. Trade with endogenous transportation costs: the case of liquefied natural gas. Energy Econ. 59, 138–148.
Poyhonen, P., 1963. A tentative model for the volume of trade between countries. Weltwirtschaftliches Arch. 90, 93–100.
Ramos-Martin, J., 2003. Empiricism in ecological economics: a perspective from complex systems theory. Ecol. Econ. 46, 387–398.
Rezai, A., Van Der Ploeg, F., 2017. Second-best renewable subsidies to de-carbonise the economy: commitment and the green paradox. Environ. Resour. Econ. 66, 409–434.
Sinn, H.-W., 2008. Public policies against global warming: a supply side approach. Int. Tax Public Financ. 15, 360–394.
Sinn, H.-W., 2012. The Green Paradox: A Supply-Side Approach to Global Warming. MIT Press, Cambridge.
Smulders, S., Tsur, Y., Zemel, A., 2012. Announcing climate policy: can a green paradox arise without scarcity? J. Environ. Econ. Manag. 64, 364–376.
Tinbergen, J., 1962. Shaping the World Economy: Suggestions for an International Economic Policy. Twentieth Century Fund, New York.
US Department Of Energy, 2017. Oil Shale and Other Unconventional Fuels Activities. https://www.energy.gov/fe/services/petroleum-reserves/naval-petroleum-reserves/oil-shale-and-other-unconventional-fuels (accessed: September 12, 2020).
Van der Ploeg, F., Withagen, C., 2012. Is there really a green paradox? J. Environ. Econ. Manag. 64, 342–363.
Van der Werf, E., Di Maria, C., 2012. Imperfect environmental policy and polluting emissions: the green paradox and beyond. Int. Rev. Environ. Resour. Econ. 6, 153–194.
Voudouris, V., Matsumoto, K., Sedgwick, J., Rigby, R., Stasinopoulos, D., 2011. Exploring the production of natural gas using ACEGES. CIBS Working Papers Series 23.
Voudouris, V., Matsumoto, K., Sedgwick, J., Rigby, R., Stasinopoulos, D., Jefferson, M., 2014. Exploring the production of natural gas through the lenses of the ACEGES model. Energy Policy 64, 124–133.
Zhang, Z., 2012. Competitiveness and leakage concerns and border carbon adjustments. Int. Rev. Environ. Resour. Econ. 6, 225–287.
Zhang, H.-Y., Xi, W.-W., Ji, Q., Zhang, Q., 2018. Exploring the driving factors of global LNG trade flows using gravity modelling. J. Clean. Prod. 172, 508–515.
Zhang, K., Zhang, Z.-Y., Liang, Q.-M., 2017. An empirical analysis of the green paradox in China: from the perspective of fiscal decentralisation. Energy Policy 103, 203–211.